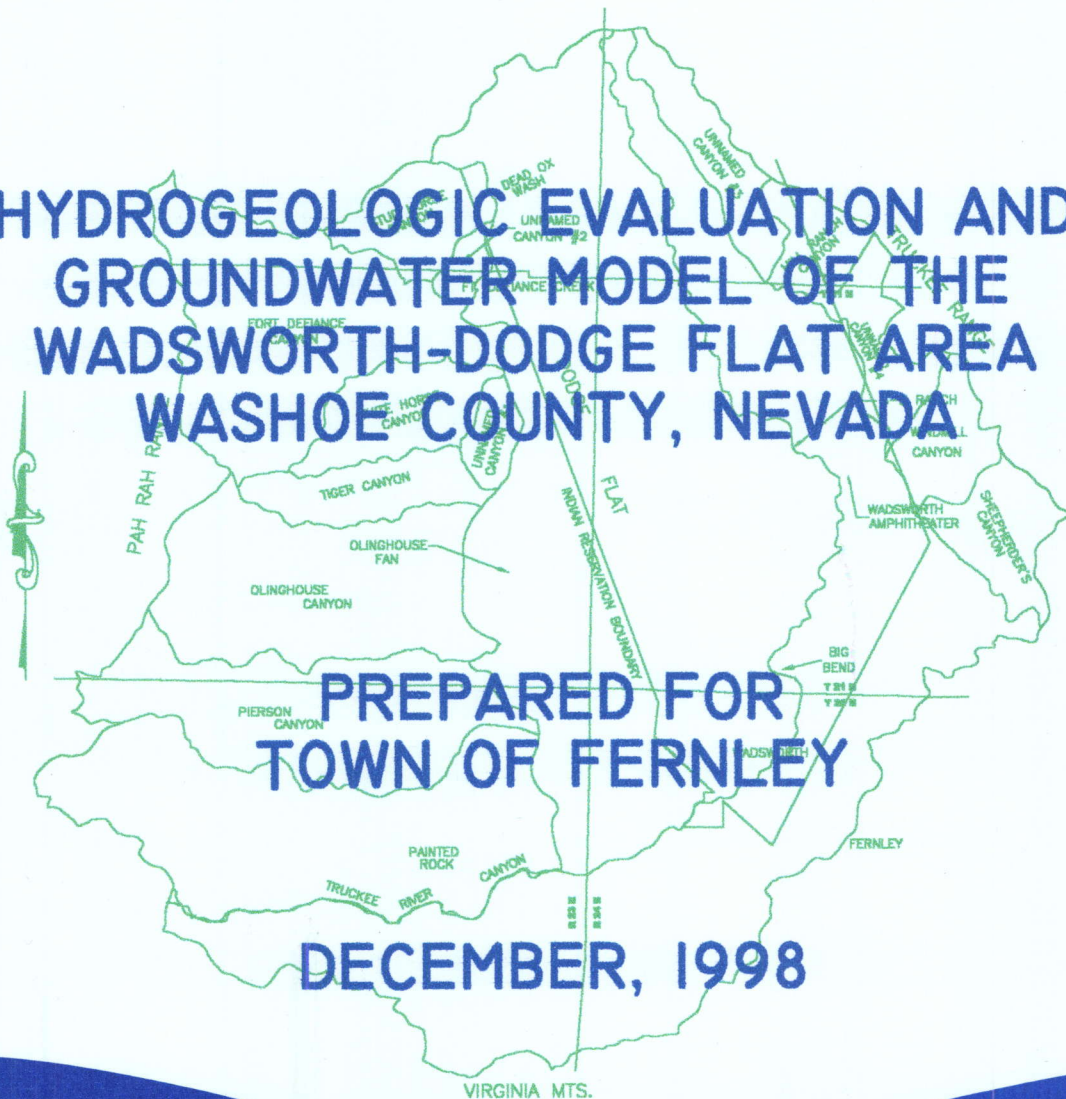


3725-00043



WATERRESOURCE
consulting engineers, inc.

**HYDROGEOLOGIC EVALUATION AND
GROUNDWATER MODEL OF THE
WADSWORTH-DODGE FLAT AREA
WASHOE COUNTY, NEVADA**



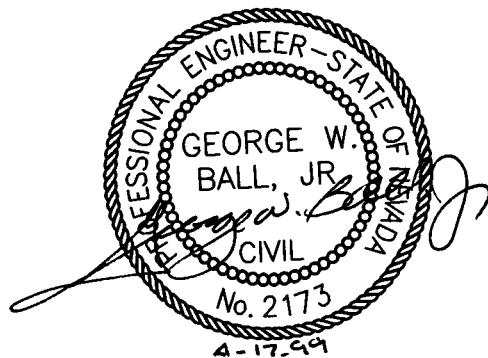
**PREPARED FOR
TOWN OF FERNLEY**

DECEMBER, 1998

**HYDROGEOLOGICAL EVALUATION AND
GROUNDWATER MODELING OF THE
WADSWORTH-DODGE FLAT AREA,
WASHOE COUNTY, NEVADA**

**Prepared for:
TOWN OF FERNLEY**

**By:
Terry Katzer,
Joseph F. Leising,
Kay Brothers,
and
George W. Ball, Jr., P.E.**



December 1998

**Wateresource Consulting Engineers, Inc.
Reno, Nevada**

TABLE OF CONTENTS

<u>SECTION/TITLE</u>	<u>PAGE</u>
1.0 EXECUTIVE SUMMARY	1-1
2.0 INTRODUCTION	2-1
2.1 Acknowledgements	2-1
2.2 Location	2-1
2.3 Purpose and Scope	2-4
2.4 Previous Investigations	3-1
3.0 PHYSIOGRAPHIC SETTING	4-1
4.0 HYDROGEOLOGIC SETTING	4-1
4.1 Data Sources	4-5
4.2 Hydrostratigraphic Units	4-7
4.3 Tertiary-Quaternary Geologic Summary	4-9
4.4 Dodge Flat - Olinghouse Fan Stratigraphy	4-9
4.4.1 Pre-Lahontan Sediments	4-11
4.4.2 Lake Lahontan and Equivalent Sediments	5-1
5.0 GROUNDWATER FLOW SYSTEM	5-1
5.1 Dodge Flat	5-1
5.1.1 Groundwater Source	5-5
5.1.2 Groundwater Movement	5-5
5.1.2.1 Hydraulic Properties	5-7
5.1.2.2 System Yield	5-7
5.1.2.3 Storage	5-8
5.1.2.4 Recharge	5-10
5.2 Truckee River Flood-Plain Aquifer	5-11
5.2.1 Groundwater Sources	5-11
5.2.1.1 Derby-Wadsworth Reach	5-12
5.2.1.2 Wadsworth-Nixon Reach	5-13
5.2.1.3 Groundwater Solute Input	5-14
5.2.1.4 Conclusion	5-15
5.2.2 Groundwater Movement	5-16
5.2.2.1 Hydraulic Properties	5-20
5.2.2.2 System Yield	5-20
5.2.2.3 Storage	5-20
5.2.2.4 Recharge	5-20

5.3	Discharge from Dodge Flat and the Truckee River Aquifer	5-22
5.3.1	Predevelopment Conditions	5-22
5.3.2	Present Condition and Pumpage	5-23
5.3.2.1	Pumpage	5-23
5.3.2.2	Irrigation	5-23
5.3.2.3	Mining	5-24
5.3.2.4	Summary	6-1
6.0	SURFACE-WATER RESOURCES	6-1
6.1	Truckee River	6-1
6.2	Mountain Front Runoff	7-1
7.0	WATER RESOURCES BUDGET	7-1
7.1	Dodge Flat	7-2
7.2	Truckee River Flood Plain Aquifer	7-2
7.2.1	Sources and Losses	7-5
7.2.2	Water Balance	8-1
8.0	WATER QUALITY	8-1
8.1	Determination of Possible Solute Sources	8-1
8.1.1	Descriptive Geochemistry	8-1
8.1.1.1	Solute Contours	8-21
8.1.1.2	Trilinear Diagrams	8-21
8.1.1.3	Olinghouse Fan Water Sources	8-24
8.1.2	Sources of Ions to Dodge Flat Groundwater	8-26
8.2	Truckee River Solute Mass Balances	8-26
8.3	Conclusion	9-1
9.0	ARTIFICIAL RECHARGE POTENTIAL	9-3
9.1	Potential Impacts from Storage on the Olinghouse Fan	9-4
9.2	Water Availability for Recharge	10-1
10.0	GROUNDWATER MODEL DEVELOPMENT AND PROJECT IMPACTS	10-1
10.1	Steady State Model	10-3
10.1.1	Hydrologic Budget Measurements and Estimates	10-3
10.1.1.1	Recharge and Inter-Basin Groundwater Flow	10-3
10.1.1.2	Truckee River Flows	10-4
10.1.1.3	Evapotranspiration	

10.1.2	Hydraulic Parameters	10-4
10.1.2.1	Boundary Conditions	10-4
10.1.2.2	Transmissivity	10-5
10.1.2.3	River Conductance	10-9
10.1.2.4	Canal Conductance	10-9
10.1.2.5	Vertical Leakance	10-10
10.1.3	Steady State Simulation	10-10
10.1.3.1	Groundwater Levels	10-10
10.1.3.2	Truckee River Flows	10-11
10.1.3.3	Comparison with Hydrologic Budget	10-12
10.2	Transient Model Simulations	10-12
10.2.1	Pumpage and Recharge Schedule	10-13
10.3	Other Transient Simulations	10-23
10.3.1	Pumping 7500 Acre-Feet/Year for Ten Years	10-23
10.3.2	Pumping 7500 Acre-Feet/Year for Ten Years With Natural Recharge and Boundaries Only	10-25
11.0	CONCLUSIONS AND RECOMMENDATIONS	11-1
11.1	Conclusions	11-1
11.1.1	Truckee River Flood Plain Aquifer	11-1
11.1.2	Artificial Recharge, Storage, and Recovery in the Dodge Flat Area	11-2
11.1.3	Perennial Yield of the Dodge Flat Groundwater System	11-3
11.2	Recommendations	11-3
11.2.1	Truckee River Flood Plain Aquifer	11-3
11.2.2	Artificial Recharge, Storage, and Recovery in the Dodge Flat Area	11-4
11.2.3	Perennial Yield of the Dodge Flat Groundwater System	11-4

APPENDICES

APPENDIX A	INTERPRETIVE GEOLOGIC CROSS-SECTIONS	A-1
APPENDIX B	SOLUTE MASS BALANCE ESTIMATES – DODGE FLAT	B-1
	Part 1: Equivalent Stratigraphic Thickness of Evaporite	B-1
	Part 2: Lake Mass Balances	B-6
	Part 3: Conclusion	B-7
APPENDIX C	TRUCKEE RIVER SOLUTE MASS BALANCES	C-1
	C.1 Truckee River Median Flows	C-1
	C.2 Mass Balance Expressions	C-6
	C.3 Alternative Determination of Truckee River Flows	C-8
	C.4 Mass Balance Results	C-9
	C.5 Evapotranspiration	C-9
APPENDIX D	USE OF CUMULATIVE AVERAGES TO ESTIMATE THE MAGNITUDES OF PROCESSES IMPACTING LOWER TRUCKEE RIVER	D-1
APPENDIX E	HYDRAULIC CONDUCTIVITY ESTIMATES FOR THE TRUCKEE RIVER AQUIFER	E-1
APPENDIX F	COMPARATIVE GEOCHEMISTRY	F-1
	F.1 Soluble Paleosol Cations and Ion Exchange	F-1
	F.2 Surface Water Ion Sources	F-1
	F.3 Geothermal Waters	F-2
	F.4 Evaporite Mineral Ion Sources	F-5
	F.4.1 Stoichiometric Mineral Dissolution	F-5
	F.4.2 Proportion of Evaporites Within the Stratigraphic Column	F-7
	F.4.3 Mass Flux from Ancient Lakes	F-7
	F.4.4 Conclusions Regarding Evaporite Mineral Solute Sources	F-7
	F.5 Fernley Area Waters	F-10
APPENDIX G	FERNLEY CREDIT STORAGE WATER SUPPLY ANALYSIS SIERRA HYDROTECH	

TABLES

<u>NO./TITLE</u>	<u>PAGE</u>
SECTION 4.0 – HYDROGEOLOGIC SETTING	
4.1 Truckee River Gaging Stations	4-1
4.2 Map Number, Water Level, Location, and Use Data for Selected Wells in the Dodge Flat Area	4-3 – 4-4
SECTION 5.0 – GROUNDWATER FLOW SYSTEM	
5.1 Transmissivity Estimates for Alluvium in the Dodge Flat Area	5-6
5.2 Dodge Flat Recharge Estimates	5-8
5.3 Potential Groundwater Recharge to the Dodge Flat and the Truckee River	5-5
5.4 Truckee River Baseflow Gains	5-13
5.5 Regression Data for Truckee River Flows	5-13
5.6 Monthly Truckee River Flow Statistics, in cfs	5-14
5.7 Estimated Hydraulic Conductivities Within the Truckee River	5-17
5.8 Estimated Hydraulic Properties of the Truckee River Aquifer	5-19
5.9 Estimated Potential Yields of the Truckee River Aquifer	5-21
SECTION 6.0 – SURFACE-WATER RESOURCES	
6.1 Mountain Front Runoff from Selected Drainages Tributary to Dodge Flat	6-2
SECTION 7.0 – WATER RESOURCES BUDGET	
7.1 Water Resources' Budget for Dodge Flat	7-1
7.2 Comparison of Baseflow Gains and Wadsworth Groundwater Input	7-6
SECTION 8.0 – WATER QUALITY	
8.1 Ground and Surface Water Compositions in the Dodge Flat Region	8-3 – 8-4
8.2 Solute Proportion Changes Down the Olinghouse Fan	8-2

SECTION 10.0 – GROUNDWATER MODEL DEVELOPMENT AND PROJECT IMPACTS

10.1	Transmissivity Values of Dodge Flat Lithologies	10-5
10.2	Transmissivities of the Truckee River Aquifer	10-9
10.3	Simulation Calibration Wells	10-11
10.4	Actual vs. Simulated River Flows	10-11
10.5	Comparison of Dodge Flat and Truckee Canyon Steady State Model Budget with USGS	10-12
10.6	Simulated Pumpage and Recharge Annual Volumes	10-13
10.7	Actual vs. Simulated River Flows Through 1999	10-14
10.8	Actual vs. Simulated River Flows Through 2004	10-14
10.9	Actual vs. Simulated River Flows Through 2009	10-17
10.10	Actual vs. Simulated River Flows Through 2014	10-17
10.11	Actual vs. Simulated River Flows Through 2019	10-20
10.12	Actual vs. Simulated River Flows Through 2024	10-23
10.13	Actual vs. Simulated River Flows Through 2008 Pumpage 7500 af/y, No Artificial Recharge	10-23

APPENDIX B – SOLUTE MASS BALANCE ESTIMATES – DODGE FLAT

B.1	Basin Volume Calculations, Dodge Flat	B-3
-----	---------------------------------------	-----

APPENDIX C – TRUCKEE RIVER SOLUTE MASS BALANCES

C.1	Monthly Truckee River Flow Statistics	C-1
C.2	Truckee River Flows, Regressed Data Set	C-2 – C-5
C.3	Concentrations, Flows, and Fluxes in the Lower Truckee River	C-10
C.4	Solutes in Groundwater Entering the Truckee River	C-11

APPENDIX D – USE OF CUMULATIVE AVERAGES TO ESTIMATE THE MAGNITUDES OF PROCESSES IMPACTING LOWER TRUCKEE RIVER

D.1	Truckee River Flow Statistics for Months of November and December	D-5
-----	---	-----

D.2 Aquifer Storage Calculation

D-6

**APPENDIX E – HYDRAULIC CONDUCTIVITY ESTIMATES FOR THE
TRUCKEE RIVER AQUIFER**

**E.1 Hydraulic Conductivities Assigned to Various Lithologic Categories
From Drillers' Logs of Wells in the Truckee River Aquifer**

E-2

**E.2 Thickness and Estimated Conductivities of Screened Intervals in
Selected Major Wadsworth Area Wells**

E-3

**E.3 Thickness and Estimated Hydraulic Conductivities Selected in the
Truckee River Aquifer**

E-4 – E6

**E.4 Truckee River Floodplain Widths Used to Estimate Width of the
Fluvial Aquifer**

E-7

E.5 Average Transmissivities from CH2Mhill Data

E-8

FIGURES

<u>NO./TITLE</u>	<u>PAGE</u>
SECTION 2.0 – INTRODUCTION	
2.1 Regional Location Map Showing Study Area	2-2
2.2 Lower Truckee River Corridor Project Area	2-4
SECTION 4.0 – HYDROGEOLOGIC SETTING	
4.1 Well Location Map	4-2
4.2 Conceptual Hydrostratigraphy Section B-B'	4-6
4.3 Conceptual Tertiary Stratigraphy	4-8
SECTION 5.0 – GROUNDWATER FLOW SYSTEM	
5.1 Groundwater Budget Components for the Dodge Flat Groundwater Basin	5-2
5.2 Water Table Elevations for the Dodge Flat Area	5-3
5.3 Recharge Sub-Basins	5-4
5.4 Truckee River Aquifer Segments for Transmissivity Estimates	5-18
SECTION 7.0 – WATER RESOURCES BUDGET	
7.1 Conceptual Water Budget, Truckee River Aquifer	7-3
SECTION 8.0 – WATER QUALITY	
8.1 Location Map and Groundwater Elevations for Lower Olinghouse Fan Wells	8-5
8.2 Solute Contours – Total Dissolved Solids	8-6
8.3 Solute Contours – Sulfate	8-7
8.4 Solute Contours – Chloride	8-8
8.5 Solute Contours – Bicarbonate	8-9
8.6 Solute Contours – Sodium	8-10
8.7 Solute Contours – Calcium	8-11
8.8 Solute Contours – Magnesium	8-12
8.9 Solute Contours – Boron	8-13
8.10 Olinghouse Fan Monitor Wells TDS Concentration Profile Along C-C'	8-15
8.11 Olinghouse Fan Monitor Wells Sulfate Concentration Profile Along C-C'	8-16
8.12 Olinghouse Fan Monitor Wells Chloride Concentration Profile Along C-C'	8-17
8.13 Olinghouse Fan Monitor Wells Sodium Concentration Profile Along C-C'	8-18
8.14 Olinghouse Fan Monitor Wells Na:Cl Ratio Along C-C'	8-19
8.15 Olinghouse Fan Monitor Wells CO ₄ :Cl Ratio Along C-C'	8-20
8.16 Well Water Analyses, Lower Olinghouse Fan	8-22
8.17 Well Water Analyses, Olinghouse Mine Pit Area	8-23
8.18 Composition of Groundwater Input to Flow System	8-25

SECTION 9.0 – ARTIFICIAL RECHARGE POTENTIAL

9.1 Recharge Area Location Map	9-2
---------------------------------------	------------

SECTION 10.0 – GROUNDWATER MODEL DEVELOPMENT AND PROJECT IMPACTS

10.1 Model Domain and Steady State Groundwater Elevations	10-2
10.2 Geology Upper Layer	10-6
10.3 Geology Lower Layer	10-7
10.4 Distance – Drawdown Plot	10-8
10.5 Stress Period 1 Drawdown, in Feet, Through 1999	10-15
10.6 Stress Period 2 Drawdown, in Feet, Through 2004	10-16
10.7 Stress Period 3 Drawdown, in Feet, Through 2009	10-18
10.8 Stress Period 4 Drawdown, in Feet, Through 2014	10-19
10.9 Stress Period 5 Drawdown, in Feet, Through 2019	10-21
10.10 Stress Period 6 Drawdown, in Feet, Through 2024	10-22
10.11 10-Year Drawdown, in Feet, Pumpage 7500 Acre-Feet/Year, No Artificial Recharge	10-24
10.12 10-Year Drawdown, in Feet, Pumpage 7500 Acre-Feet/Year, No Other Stresses, No Artificial Recharge	10-26

APPENDIX A – INTERPRETIVE GEOLOGIC CROSS-SECTIONS

A.1 Cross Section A-A'	A-1
A.2 Cross Section B-B'	A-2
A.3 Cross Section M-M'	A-3
A.4 Cross Section N-N'	A-4
A.5 Cross Section O-O'	A-5

APPENDIX B – SOLUTE MASS BALANCE ESTIMATES – DODGE FLAT

B.1 Simplified Basin Area and Average Cross Section	B-2
--	------------

APPENDIX C – TRUCKEE RIVER SOLUTE MASS BALANCES

C.1 Probability Plot of Selected Truckee River Flows	C-7
---	------------

APPENDIX D – USE OF CUMULATIVE AVERAGES TO ESTIMATE THE MAGNITUDES OF PROCESSES IMPACTING LOWER TRUCKEE RIVER AQUIFER

D.1 Cumulative Averages, All Months	D-2
D.2 Cumulative Averages, November and December	D-3
D.3 Cumulative Averages, January – October	D-4

APPENDIX F – COMPARATIVE GEOCHEMISTRY

F.1	Geothermal Water Analyses	F-3
F.2	Waters from Stoichiometric Dissolution of Evaporite Minerals	F-6
F.3	Major Groundwater Constituents Sample Sites N of TCID Canal	F-8
F.4	Surface Water Constituents Along Fernley Drain System	F-9
F.5	Surface Water Constituents Truckee River and Steamboat Creek	F-11



SECTION 1.0

EXECUTIVE SUMMARY

In April 1997, the Environmental Protection Agency funded a grant request by the Town of Fernley, Lyon County, Nevada to evaluate water resource options to meet current and future demands. Waterresource Consulting Engineers, Inc. was selected by the Town to evaluate three water resource options that would potentially meet the needs of a regional water supply plan serving the Fernley and Wadsworth areas. The three options evaluated are: utility of developing the flood plain aquifer adjacent to the Truckee River in the vicinity of Wadsworth; the feasibility of using the groundwater system underlying Dodge Flat for artificial recharge of Truckee River water, temporary storage of the water, and subsequent recovery through wells for distribution; and the potential for developing natural groundwater resources from the Dodge Flat aquifer system. Key to understanding the complex hydrogeology of the area was the development of a three dimensional groundwater and surface water flow model that replicates the hydrogeology as presently understood and simulate not only the movement of groundwater from natural recharge areas in the mountain blocks to discharge areas along the Truckee River, but also the flow in the river. Numerous water resource management scenarios were simulated to determine impacts to the groundwater system and the Truckee River.

Study results found the Truckee River flood plain aquifer has the capacity to provide 7,500 acre-feet/year (af/y) to serve the regional water needs of Wadsworth and Fernley and can probably provide larger volumes for future needs. Virtually all groundwater recharge to the flood plain aquifer comes from the Truckee River, about 10 cubic feet/second. Model results indicate that under current river flow conditions withdrawing a total of 7,500 af/y for ten years from three wells at a rate of 2,500 af/y per well results in a drawdown of about 20 feet, virtually all of the water is supplied from the river. The model was further tested by pumping the same amount for the same time, but only relying on the groundwater system, no recharge from the river or the Truckee Canal and no discharge by evapotranspiration. This scenario simulates a worst case, long-term drought and shows water levels in the groundwater system declined slightly over 60 feet; nearly fifty percent (50%) (35,000 acre-feet) of the water is captured from the Fernley groundwater basin, a third (26,000 acre-feet) of the water is supplied from storage within the flood plain aquifer and the remainder (14,000 acre-feet) is supplied by the entire recharge from Dodge Flat. Water level declines can be easily altered by increasing the number of wells and the distance between them. A major concern though is the quality of the groundwater from the Fernley basin which may require treatment. The source of the groundwater is speculated to be runoff from agricultural irrigation that infiltrates into the groundwater system and leakage from the Truckee Canal in the Fernley area. Additionally, there may be a geothermal component to these flows.

Artificial recharge is simply taking water from one source, usually surface water, and injecting it into the groundwater system through wells or allowing the water to infiltrate to the groundwater system from surface basins. The recharge water can then be recovered at a later time to meet demand. This technique and the advantages and disadvantages are widely discussed in the scientific literature and is used by numerous water managers to enhance existing water resources. The hydrogeology of the Dodge Flat area is suitable for the storage and recovery of recharged Truckee River water. There is, however, a limited area of about two square miles in the west central part of the valley that contains the best water quality, generally below 400 mg/l in total dissolved solids and this should be the target area for recharge. Outside of this area and towards the river water quality becomes poor, but still within the secondary drinking water standards. There is ample room in the aquifer to store many thousands of acre-feet of water, but some water will be degraded by the abundance of salts in the sediments and groundwater and that is the only adverse impact by mixing Truckee River water with the natural groundwater. However, short-term storage up to five years of 5,000 to 10,000 acre-feet would probably result in minor degradation and not cause a

measurable increase in groundwater discharge to the Truckee River. If the recharge project is operated by injecting river water during the winter and spring and recovering it during the following summer potential water quality degradation will be minimized.

A water supply scenario (see Section 10.2.1) was designed and modeled to match expected growth and water demand in the Wadsworth and Fernley areas starting in 1998 and extending through 2024 with an artificial recharge project beginning on Dodge Flat by the year 2005. Total pumpage in the last year of the scenario equals 15,540 acre-feet. The artificial recharge during the simulation period (5,000 af/y) provides a significant amount of water (100,000 acre-feet) which keeps groundwater levels up. Average flow of the Truckee River at the Nixon gage by the last year of the scenario decreased by approximately 7 cfs, mostly in response to pumping along the river.

The recharge project is complicated by potential non-project groundwater development in close proximity to the proposed artificial recharge project. The Dodge Flat groundwater basin is theoretically overdrafted by existing pumping permits that allow more water to be pumped per year than is recharged naturally by precipitation. Currently, 1998, there is virtually no pumping from the Dodge Flat aquifer; however, Alta Gold's mining operation in Olinghouse Canyon will start soon and they are permitted to withdraw about 500 af/y from a well just to the north of the proposed recharge project area. Additionally, Nevada Land and Resources has groundwater permits to pump about 3,000 af/y, exceeding the entire perennial yield of the basin.

The natural recharge to the Dodge Flat hydrographic area is estimated by a standard technique at 1,400 af/y, about 100 acre-feet of that amount goes directly to the river from the Truckee Range on the east side of the valley. The actual recharge may approach 2,000 af/y because of groundwater recharge from precipitation below 5,000 feet altitude (not commonly accepted) and the contribution from mountain front runoff, but both sources are unproved at this time. An analysis of solute loading to the Truckee River from Dodge Flat indicates the 1,400 acre-feet of recharge is a reasonable estimate.

The acquisition of groundwater rights on Dodge Flat by a regional water supply entity increases the available supply options. A regional entity could use the Truckee River flood plain aquifer for base flow and during extreme low-flow periods when the river is virtually dry the regional demand could be partially met with natural groundwater from Dodge Flat or a combination of artificial recharge water if that project is considered economically feasible. In addition, part of the supply could be furnished by pumping from the Fernley groundwater basin. Thus, four sources, Truckee River flood plain aquifer, artificial recharge, Dodge Flat aquifer system, and the Fernley aquifer give water managers wide latitude to optimize the water resources.



SECTION 2.0

INTRODUCTION

Currently, the major source of groundwater for Fernley, Nevada, is secondary recharge from Truckee River water diverted by the Truckee Canal for irrigation of agricultural lands. Groundwater used by Fernley undoubtedly has a minor component furnished by natural recharge within the hydrographic basin. Wadsworth, which includes the urbanized area of the Pyramid Lake Paiute Tribe, has approximately six quasi-municipal wells and numerous domestic wells that tap into the saturated sediments associated with the flood plain of the Truckee River. Additionally, there is a subdivision that is served by Washoe County from two wells that pump from this same aquifer, as well as various non-Tribal, private domestic and irrigation wells.

The competition for limited Truckee River water and difficulties in meeting water quality standards have required water managers to evaluate different water supply options to satisfy various interests and to optimize the use of the river. There is concern over the quality of agricultural return flows in groundwater that moves from the Fernley area to the Truckee River. This water is high in dissolved solids and degrades the quality of the Truckee River, particularly during low flows. A regional water supply project has been proposed for the Fernley and Wadsworth area, which, if successful, will reduce Fernley's dependence on groundwater in the Fernley Basin and provide additional water resources (including supplemental peak demand capacity and drought storage) for both Wadsworth and Fernley.

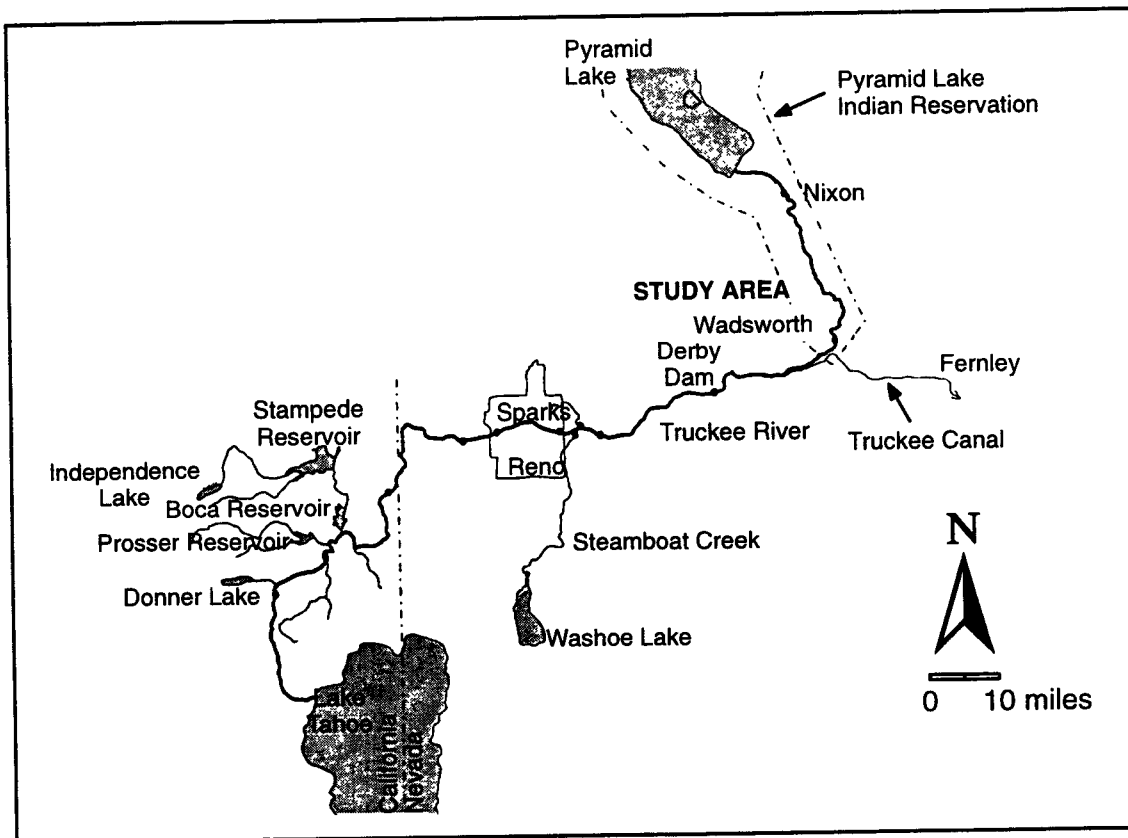
There are two principal aquifer systems providing water to users in the Dodge Flat and the Wadsworth areas. The Dodge Flat aquifer system is made up of saturated sediments starting at about 100 – 200 feet below land surface, depending on location. The aquifer system underlies the entire valley area, is recharged by precipitation falling in the Pah Rah Range to the west, and discharges to the Truckee River flood plain aquifer and subsequently to the river. The Truckee River flood plain aquifer system is much smaller in size than the Dodge Flat aquifer, occupying a narrow strip of saturated river sediments underlying, adjacent to, and on both sides of the river. However, the recharge to the flood plain aquifer is much greater than the Dodge Flat aquifer simply because it is recharged by the river. The Dodge Flat aquifer grades into the flood plain aquifer some unknown distance west of the river.


2.1 Acknowledgements

Numerous individuals and agencies have provided valuable assistance, data, and interpretations that assisted greatly in the production of this report, most notably Leonard Crowe, Gail Prockish, and Mike Widmer, Washoe County Department of Water Resources. Others who have provided data and assistance include Ted Fitzpatrick (Nevada Land and Resource Company, NLRC, formerly Southern Pacific Land Company SP Land), Ed DePaoli (Rancher), Joe Mortinson (S Bar S), John Bell (Nevada Bureau of Mines and Geology), Wright Parks (Alta Gold Corp.), and Catherine D. MacDonald (Nature Conservancy).

2.2 Location

The Truckee River headwaters at Lake Tahoe in the Sierra Nevada Mountains, flows eastward past the Reno-Sparks metropolitan area, turns northward near the towns of Fernley and Wadsworth, and terminates at Pyramid Lake on the Pyramid Lake Paiute Tribe reservation (Figure 2.1). The lower Truckee River corridor, for the purpose of this report, begins at Derby Dam, the diversion dam for the Truckee Canal that transfers water from the Truckee River drainage to the Carson River drainage, and ends at Numana Dam.



 wateresource consulting engineers, inc. <small>THE SHARPS COMPANY - DENVER, NEVADA - OROVILLO</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8518.1142 DATE 10/28/88 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Regional Location Map Figure 2.1		

Derby Dam is about 20 miles east of Sparks, Nevada and Numana Dam is approximately 30 river miles downstream from Derby Dam. The lower Truckee River corridor includes the urbanized areas of Wadsworth and Fernley and the rural area of Dodge Flat. The region is accessible east of Reno and Sparks by U.S. Interstate 80 and from the south and north by Alternate U.S. 95. Figure 2.2 is a location map showing the lower Truckee River corridor and other relevant features in the project area.

2.3 Purpose and Scope

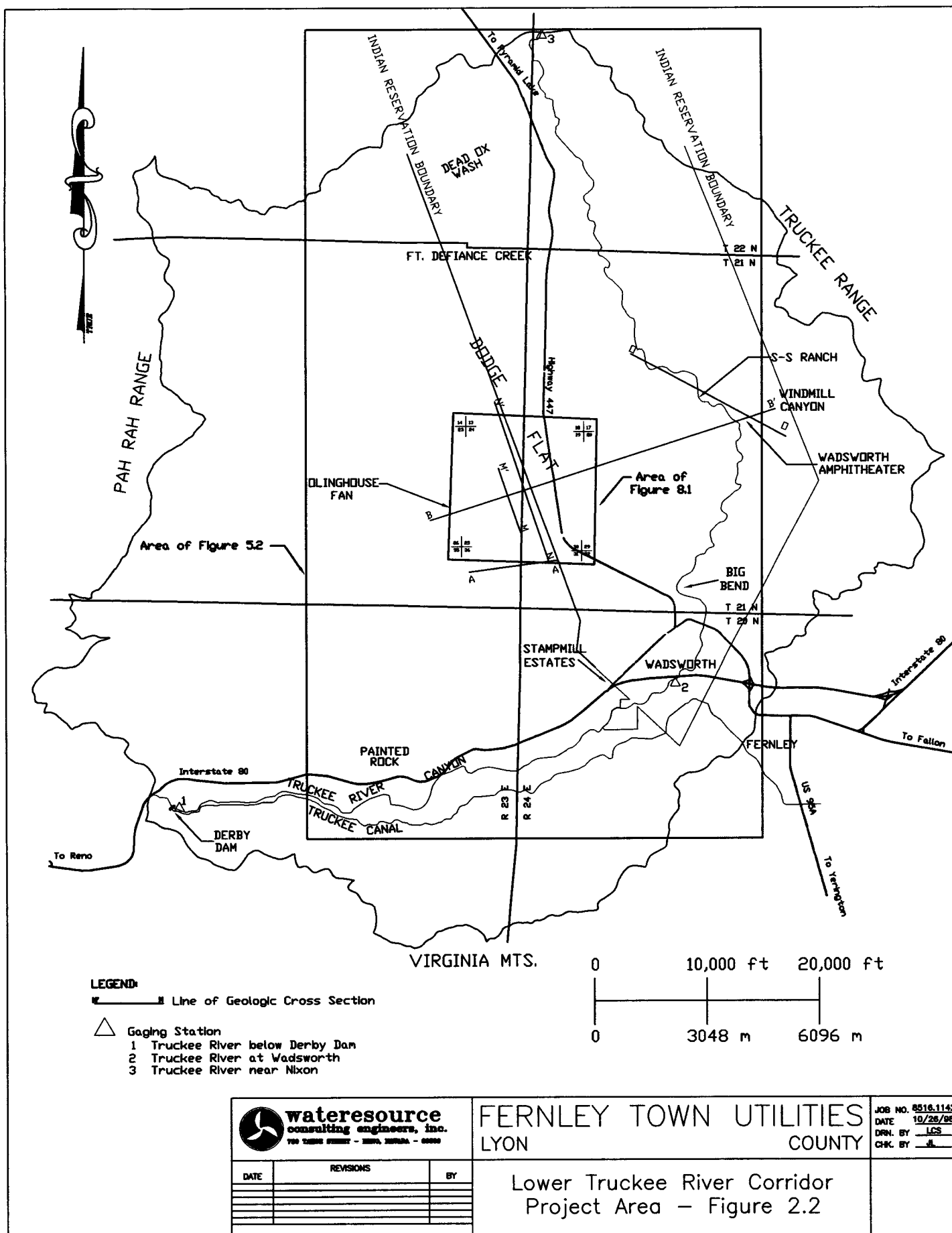
The purpose of this study is to evaluate three water supply options for the Fernley and Wadsworth area by determining: (1) if it is feasible to maximize the use of the Truckee River flood plain aquifer for the combined Wadsworth/Fernley area; (2) the feasibility to artificially recharge untreated Truckee River water into the groundwater system underlying Dodge Flat and to recover the water through wells for distribution in the Wadsworth/Fernley area; and (3) to evaluate the perennial yield of the groundwater system underlying Dodge Flat. To assess the viability of each option, it is necessary to measure and estimate the hydraulic properties of the aquifer systems, evaluate impacts to these systems and the Truckee River, and to determine the chemical compatibility of the recharged water with the groundwater. It is also necessary to ascertain the chemical impacts to the recharged water as it moves through the unsaturated zone if recharge basins are used.

To perform these evaluations, this report examined: previous geologic mapping and soil characterization studies; stratigraphic information and water table measurements obtained from well logs; past surface and groundwater geochemical analyses; and earlier estimates of transmissivity and other aquifer hydraulic properties. These were integrated with data acquired specifically for the present investigation that entailed: aerial photographic interpretation; GPS identification of selected wells and geochemical sample sites; geochemical surface and groundwater sampling and analyses for major ions, selected minor ions and deuterium-oxygen-18 isotopes; interpretation of a ground-based gravity and airborne resistivity-EM geophysical surveys; and aquifer transmissivities obtained from an aquifer test.

A groundwater model of the area was developed as part of the present investigation to aid understanding the hydrogeologic processes that control groundwater recharge, movement, discharge, and geochemistry. The model was used to evaluate the interaction between the Truckee River and the flood plain aquifer, to help define the artificial recharge process, and to site recharge facilities and recovery wells including optimum well locations in the Truckee River flood plain. A geochemical mixing model was used to evaluate the compatibility of the Truckee River water used for artificial recharge and the groundwater.

2.4 Previous Investigations

The first hydrologic work in the area was by Russell (1885, Plate 1) who delineated the extent of Pleistocene Lake Lahontan. The Truckee River, which bounds Wadsworth and the Dodge Flat area on the south and east and the Fernley area on the north during its course to Pyramid Lake, was a major contributor to ancient Lake Lahontan, not only of water, but also of sediment. Lahontan age lake sediments attained a thickness of perhaps several hundred feet in the Fernley area (W. Harrigan, geologist, Wateresource Consulting Engineers, Inc., oral communication) and approach 200 feet in the Dodge Flat area. Benson (1978) lists the maximum high stand of the lake at about 4,370 feet above sea level (rounded), which occurred at 13,800 years before present (y.b.p.), and indicates (1978) there was a higher stand prior to 40,000 y.b.p. These observations were further refined by Benson and Thompson (1987a, b), and Benson (1993), who detail lake level fluctuations. Melhorn (1978) described pre-Lahontan lacustrine sedimentation.



The first water resources investigation in the area was by Sinclair and Loeltz (1963), who determined the major source of recharge for the Fernley area was irrigation water supplied by the Truckee Canal and that the river gravels underlying the Wadsworth area were recharged from the Truckee River. Additionally, they described an upper and lower aquifer system and provided data on water quality. Van Denburgh, *et al.* (1973) evaluated the water-resources of the entire Truckee River Basin in Nevada including the Fernley and Dodge Flat areas. These workers estimated water budget components and were the first to quantify return flows to the Truckee River. Subsequently, Van Denburgh and Arteaga (1979) revised the water budget and refined the amount of return flow to the Truckee River from the Fernley area. The U.S. Soil Conservation Service conducted soil surveys in the area (1975; 1980) and evaluated several surficial hydrologic parameters.

Bratberg (1980) assessed the hydrogeology of Dodge Flat and its relation to flow and quality changes in the Truckee River; he concluded that its input to the river was minor. He also evaluated the disposal of Reno/Sparks waste water by irrigation in the Dodge Flat area. Water managers in the Reno and Sparks area during the late 1980's explored the feasibility of improving the lower Truckee River water quality by artificially recharging the groundwater system in the Dodge Flat area with wastewater at a rate of about 20 million gallons per day (mgd) (about 22,000 acre-feet/year). Their hope was that water quality would improve as the recharged water moved down gradient toward the Truckee River between Wadsworth and Nixon. CH2MHill (1990) conducted the feasibility study and determined that the transmissivity of the sediments was sufficient to recharge the 20 mgd per day from several basins located near the mountain front. Their investigators (1990, p. 7) estimated the travel time from the recharge basins to the river to be on the order of 30-70 years and concluded that the recharged wastewater would not degrade the Truckee River (compared to original concentrations) when it returned as groundwater. They further predicted that the recharge water would lose about half of its nitrogen and most of its phosphorus during transit to the river.

Lebo and others (1994) identified and evaluated nonpoint sources of pollution originating on the Pyramid Lake Paiute Tribe Reservation and discharging to the Truckee River. Shepard Miller, Inc., consultants for Alta Gold, prepared four reports (1997a-d) that characterize the hydrology of the mountain block in close proximity to the proposed mining operations in the Olinghouse Canyon drainage. PTI Environmental (1997) numerically evaluated the impacts to the Truckee River resulting from Alta Gold's mining operations.

The geology of the area was first mapped by Bonham (1962), who divided the valley-fill sediments in the project area into two units: older alluvium and the more recent lake sediments of Pleistocene age. Subsequent mapping by Morrison and Davis (1984a, b) and Morrison and Frey (1965) extended the Lahontan age allostratigraphic units of Morrison (1964) into the eastern part of the Dodge Flat area.

Bell (1984) mapped Quaternary faulting in the alluvium and described the relative age of the earth movements. In the project area these are: older Pleistocene faults that extend into the alluvium in the extreme western part of the project area; Holocene faults that transect large parts of Dodge Flat; and more recent historical ground rupture such as the Olinghouse fault (1869) that tails off into the Dodge Flat alluvium near its contact with the mountain block (Sanders and Slemmons, 1979). There is some controversy over the actual date of movement on this fault, but geomorphic indications suggest a very recent break (Bell, 1984). Examination of aerial photographs during this project has identified additional linear features in the valley and on the Olinghouse fan that probably represent recent faulting.

The concern with faulting in the alluvium in the project area derives from its potential impacts on the groundwater system. Faults act as conduits for groundwater flow in some cases, as barriers to flow in others, and can serve as conduits for hydrothermal fluids. Active faulting during sedimentation can lead to local variation in aquifer properties such as thickness and conductivity. Moreover, on a regional scale, fault movement has governed the evolution of the physiography of basins and their recharge areas.



SECTION 3.0

PHYSIOGRAPHIC SETTING

The Fernley-Wadsworth-Dodge Flat area and the valleys of the lower Truckee River corridor are within the Basin and Range physiographic province, described by Fenneman (1931) as a series of north trending basins bounded by parallel to subparallel mountain ranges. The project area also lies within the Alluvial Basins Groundwater region of Heath (1984), and is part of the Great Basin, a region of internal drainage within the Basin and Range Province (Norris and Webb, 1990). Surface flows from runoff that reach the Truckee River terminates at Pyramid Lake about 20 miles north and downstream from the community of Wadsworth. Groundwater from natural recharge in the mountains and secondary agricultural return flows also discharge into the Truckee River. Most of the return flow is from the Fernley area, but all agricultural land within the river corridor discharges to the river in a like manner.

The principal hydrologic feature in the area is the Truckee River, which originates in Lake Tahoe about 100 river miles west and upstream from the Fernley-Wadsworth area and terminates about 30 river miles north and downstream at Pyramid Lake (Figure 2.1). As the river emerges from the Truckee Canyon on an easterly course it is bounded on the north by the south end of the Pah Rah Range and on the south by the Virginia Mountains. It turns north at what is referred to locally as the 'Big Bend', about three miles northwest of the Town of Fernley (Figure 2.2). The urbanized area of Wadsworth is concentrated in the general area of the Big Bend, mostly north and west of the river with some commercial development on the east side. Homes and farmland extend northward, down-river for several miles. The Truckee Range bounds the river on the east throughout its course north from Big Bend to Pyramid Lake. The principal project area of Dodge Flat is located west of the river and northwest of Wadsworth on fluvial gravels, lake sediments, and detrital material eroded from the Pah Rah Range.



SECTION 4.0

HYDROGEOLOGIC SETTING

The hydrology of the area is dominated by the Truckee River. There are three key gauging stations that define its flows as it transits the Dodge Flat hydrologic area. Table 4.1 lists these stations, their locations, and their flows for the indicated periods of record. According to Bostic, *et al.* (1996), the annual mean flow at Wadsworth for the period 1965 - 1996 was ~529,000 af/y or ~730 cubic feet/second (cfs). The use of means to describe flows is somewhat misleading because they disproportionately reflect extreme flow events common in the Truckee River system. Also, the Truckee Canal diverts Truckee River water around the gage below Derby Dam and returns some of it, in the form of canal spills and irrigation water, to the river upstream of the gage at Wadsworth. For calculations within the present study, median, rather than average, flows were used. The Truckee River is partially controlled by numerous upstream lakes/reservoirs and diversion canals. It receives inflow from perennial and ephemeral drainages and groundwater throughout its course. Return flows reach the river from irrigation and waste water treatment facilities.

TABLE 4.1
TRUCKEE RIVER GAGING STATIONS¹

Station Name	Station Number ²	Annual Mean Flow (cfs)	Period of Record ³	Location
Below Derby Dam	10351600	382	1918-1996	T20N R23E NW¼ SE¼
at Wadsworth	10351650	730	1965-1996	T20N R24E SW¼ NW¼ S3
near Nixon	10351700	518	1958-1996	T22N R24E SW¼ NW¼ S18

¹ Data from Bostic, *et al.*, 1996.

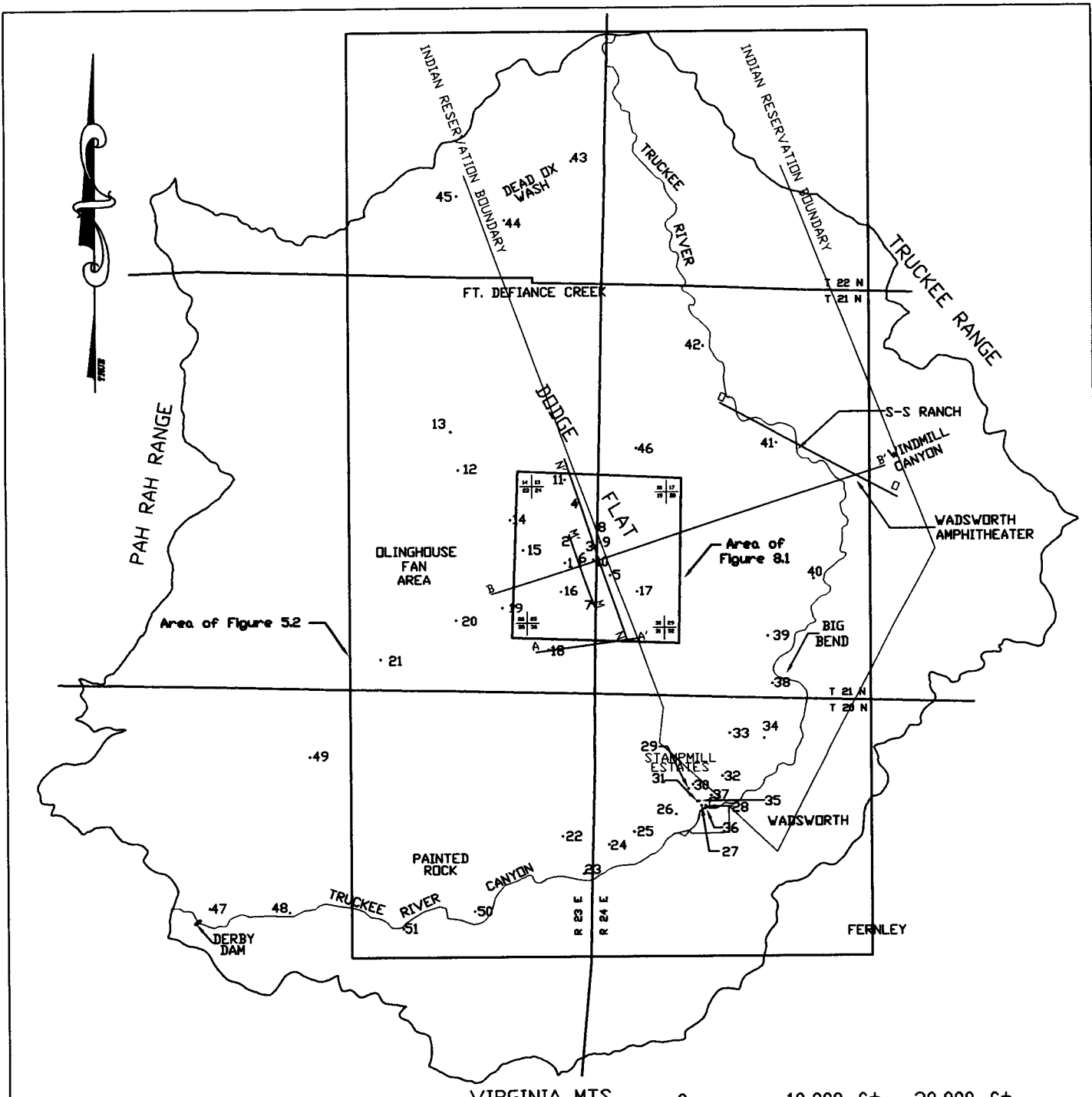
² Station numbers are assigned by the U.S.G.S.

³ Water year is October 1 - September 30. Locations shown on Figure 2.2.

Local discharge to the river from the Dodge Flat area consists largely of agricultural return flows, both surface and groundwater, leakage from the Truckee irrigation canal (Van Denburgh, *et al.*, 1973), surface water runoff, and groundwater flow that originates in the surrounding mountains as recharge. These fault-bounded mountains are the Pah Rah and Truckee Ranges, which align roughly north by northwest and delimit an alluviated valley roughly 20 miles long by 6 miles across that begins near the town of Fernley and terminates at Pyramid Lake. The project region (see Figure 4.1) lies within the southern portion of that valley. It is roughly 10 miles long by 6 miles across, and is bordered on the north by Dead Ox Wash, on the south by the Truckee River, on the west by the Pah Rah Range, and on the east by the Truckee Range. The major areas of interest are Dodge Flat and the Olinghouse alluvial fan, which are underlain by valley-fill alluvial, fluvial, and lacustrine sediments. Information concerning the relationships between these units has been acquired or derived from a variety of sources.

4.1 Data Sources

Figure 4.1 shows the location of the wells and borings used in the present investigation, and Table 4.2 lists their salient features. Most are recorded with the Office of the State Engineer. A number of additional wells are not shown; although those logs were examined, due to a combination of topographic relief and



LEGEND
 — Line of Geologic Cross Section
 50 Well & Map Number


 wateresource consulting engineers, inc. <small>700 TOWN CENTER - DENVER, COLORADO - 80202</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/28/98 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Well Location Map Figure - 4.1		

TABLE 4.2
MAP NUMBER, WATER LEVEL, LOCATION, AND
USE DATA FOR SELECTED WELLS IN THE DODGE FLAT AREA

Map No.	Original Ownership	UTM Coordinates N	UTM Coordinates E	Legal Description Permit T-R	Well Head Altitude (ft)	Static Level (ft)	Water Level Altitude (ft)	Date Measured	Perforated Interval Top Bottom	Thick-ness	Pump Rate	Date Drilled
1	CH2Mhill ¹	4 393 003	298 592	MW-1 21n, 23e	4239.22	202.99	4036.23	08/11/97	237 257	20	N.A.	09/08/90
2	"	4 393 561	298 729	MW-2 21n, 23e	4218.16	182.07	4036.09	08/11/97	197 217	20	N.A.	09/12/90
3	"	4 393 383	299 317	MW-3 21n, 23e	4188.75	152.57	4036.18	08/11/97	200 220	20	N.A.	09/15/90
4	"	4 394 406	298 937	MW-4 21n, 23e	4188.28	153.14	4035.14	08/11/97	200 220	20	N.A.	09/18/90
5	"	4 392 702	299 668	MW-5 21n, 24e	4191.9	156.17	4035.73	08/11/97	195 215	20	N.A.	09/21/90
6	"	4 392 990	298 950	MW-6 21n, 23e	4215.01	178.77	4036.24	08/11/97	210 230	20	N.A.	09/26/90
7	"	4 392 007	299 240	MW-7 21n, 23e	4228.83	193.04	4035.79	08/11/97	208 220	12	N.A.	09/29/90
8	Olinghouse	4 393 840	299 343	23581 21n, 23e	4193.09	145	4048.09	02/16/82	289 720	431	600	02/16/82
9	NV Land N	4 393 472	299 439	46908 21n, 24e	4182.88	145.79	4037.09	08/12/97	50 700	650	1000	09/10/96
10	NV Land S	4 393 073	299 269	42919 21n, 23e	4182.98	156.89	4026.09	08/12/97	150 700	550	N.R.	09/25/93
11	DePaoli	4 394 953	298 604	720 21n, 23e	4191.18	37	4154.18	08/12/97	44 85	41	N.R.	11/15/48
12	Carros	4 395 200	296 072	1673 21n, 23e	4396	18	4378	05/26/51	53 63	10	N.R.	05/26/51
13	Ferguson	4 396 100	295 900	2619 21n, 23e	4989	32	4957	11/16/53	146 186	40	N.R.	11/16/53
14	Phillips Pet.	4 394 000	297 300	24773 21n, 23e	4718	>300	<4418	08/01/83	Not screened			08/01/83
15	SP Land	4 393 300	297 600	SPW-2 21n, 23e	4324	280	4044	<06/81	Not screened: HSI, 6/81			<06/81
16	James	4 392 300	298 500	929 21n, 24e	4150	12	4138	04/22/49	Not recorded			04/22/49
17	PLPT	4 391 792	300 293	10404 21n, 24e	4192	94	4098	11/07/68	Various between 230 and 455			11/07/68
18	Shoemaker	4 390 900	298 200	15819 21n, 23e	4317	>265	<4052	09/02/76	Not screened			09/02/76
19	SP Land	4 391 900	297 100	SPW-4 21n, 23e	4495	388	4107	<06/81	HSI re-drilling of 19173; not screened			<06/81
20	SP Land	4 391 600	296 000	SPW-1 21n, 23e	4633	>310	<4323	<06/81	Not screened: HSI, 6/81			<06/81
21	Phillips Pet.	4 390 700	294 200	24773 21n, 23e	4961	>300	<4661	08/01/83	Not screened			08/01/83
22	Sun River	4 386 500	298 500	25989 20n, 23e	4324	186	4138	11/12/85	180 390	210	20	11/12/85
23	McCord	4 385 500	298 700	16666 20n, 23e	4142	35	4107	07/18/77	Construction not reported.			07/18/77
24	Gilpin	4 386 300	299 600	10943 20n, 24e	4183	35	4148	09/94	Construction not reported. WL from SEA, 1994			03/11/70
25	Anderson*	4 386 600	300 200	33121 20n, 24e	4203	180	4023	11/12/85	437 457	20	12	11/12/85
26	Nellemann	4 387 000	301 200	22860 20n, 24e	4124	25	4099	09/94	95 125	30	20	05/26/81
27	Ranbeth	4 387 200	301 800	20163 20n, 24e	4101	40	4061	07/20/79	150 190	80	18	07/20/79
28	Waligora	4 387 200	301 900	24878 20n, 24e	4101	66	4035	03/26/83	102-122 240-302	82	20	03/26/83
29	Waligora	4 387 600	301 500	22285 20n, 24e	4124	31.5	4092.5	09/94	280 300	20	100	09/30/80
30	Dunmore	4 387 700	301 600	23315 20n, 24e	4127	18	4109	11/28/79	60-125 190-225	80	400	11/28/79

¹ Designated as MW in Table 8.1.

TABLE 4.2 (CONTINUED)
MAP NUMBER, WATER LEVEL, LOCATION, AND
USE DATA FOR SELECTED WELLS IN THE DODGE FLAT AREA

31	Dunn	4 387 300	301 700	20229	20n, 24e	NE/SW/8	4109	15	4094	08/03/79	191-231	271-300	69	40	11/28/79
32	Mini Mart	4 387 900	302 300	24814	20n, 24e	NE/NE 8	4094	68	4026	09/94	143	163	20	14	08/16/83
33	De Paoli**	4 388 920	302 480	14621	20n, 24e	NW/SW 4	4114	45	4069	12/08/74	47	140	93	N.R.	12/08/74
34	Dancer	4 388 800	303 300	40258	20n, 24e	SW/SE 4	4068	60	4008	12/11/92	123	143	20	17	12/08/74
35	Canton W+	4 387 304	301 749	1149	20n, 24e	NW/SE 8	4089.26	19.99	4069.27	09/04/97	15	20	5	220	11/10/49
36	Canton C+	4 387 139	301 884	5195	20n, 24e	NW/SE 8	4090.58	21.67	4068.91	09/04/97	32	48	16	30	04/13/60
37	Canton E+	4 387 439	302 035	5194	20n, 24e	SW/NE 8	4089.26	24.74	4064.52	09/04/97	23	46	23	N.R.	04/14/60
38	Leyva	4 390 100	303 500	19215	21n, 24e	NE/SW 33	4117	10	4107	12/16/78	110	130	20	N.R.	12/16/78
39	PLPT/Calico	4 391 200	303 400	50319	21n 24e	NW/NE 33	4045	5	4040	10/27/95	179	199	20	20	10/27/95
40	Burns	4 392 600	304 500	18078	21n, 24e	NW 27	4029	17	4012	05/16/78	85	105	20	15	05/16/78
41	S Bar S	4 395 810	303 628	14226	21n, 24e	NE/NE/ 16	4017.6	8	4009.6	09/04/97	210-230	360-380	40	100	10/09/74
42	PLPT	4 398 100	301 900	50128	21n, 24e	SE/SW/ 5	4003	15	3988	04/27/95	15	45	30	N.R.	04/27/95
43	Abraham	4 402 500	298 800	4496	22n, 23e	Sec. 25	4429	174	4255	07/21/58	174	185	11	N.R.	04/27/95
44	BIA-PLPT	4 401 100	297 200	20569	22n, 23e	SE/NW 35	4692	80	4612	12/14/79	158	178	20	20	12/14/79
45	Dead Ox	4 401 673	296 072	3948	22n, 23e	NW/SE/27	4824.51	95.65	4728.86	10/01/57	148	158	10	2	10/01/57
46	Cooper	4 395 700	300 300	SB-4	21n, 23e	SW/NE 8	4140	>80	<4060	---	Soil Test Boring by HLA for Cooper & Assoc.				
47	Kelly	4 384 800	290 100	7948	20n, 23e	NE/SW 19	4203	10	4193	03/22/68	42	47	5	60	03/22/68
48	Artlip	4 384 700	292 000	9992	20n, 23e	SW/NE 20	4230	18	4212	03/22/68	30	38	8	20	03/22/68
49	Richie	4 384 400	294 400	22770	20n, 23e	NW/SW 22	4183	27	4156	05/01/81	110	130	20	17	05/01/81
50	Ferretto	4 384 500	296 200	20905	20n, 23e	SW/NW 23	4222	41	4181	11/07/79	60	80	20	34	11/07/79
51	Sievert	4 388 400	292 500	23258	20n, 23e	NE/NE 8	5463	>500	<4963	09/09/81	Not Perforated - No Water				

Additional wells selected as input points for estimated transmissivities but not used for ground water contours

52	Taylor	4 385 500	299 000	16669	20n, 23e	SE/SW 13	4150	30	4120	07/25/77	N.R.	N.R.	N.R.	20	07/25/77
53	PLPT	4 389 600	303 600	12599	20n, 24e	NE/NE 4	4088	51	4037	09/07/72	88	118	30	200	09/07/72
54	PLPT	4 393 900	306 000	50316	21n, 24e	SW/NW 23	4078	53	4025	10/17/95	238	258	20	20	10/17/95
55	PLPT	4 394 700	305 300	19205	21n, 24e	SW/SE 15	4005	1	4004	11/30/78	104	144	40	60	11/30/78
56	PLPT	4 396 900	303 000	19204	21n, 24e	SW/SW 9	4032	46	3986	12/01/78	102	142	40	25	12/01/78
57	PLPT	4 400 400	301 000	50514	22n, 24e	NE/SE 31	3984	11	3973	04/28/95	20	25	5	N.R.	04/28/95

*=anomalous water level, not used to construct contours

** coordinates from well shown on U.S.G.S. 7.5' topographic sheet

+ well number assignment is best guess based on owner's name and depth to water. Well 1149 is erroneously recorded in 20n 24e, s. 5 with State Engineer.

Wells shown are those used to obtain water levels, chemical analyses, or transmissivities.

location uncertainty there was insufficient control on the wellhead and static water table elevations to permit their incorporation in this study.

Most lithologic data for the Olinghouse fan derive from diagrams of relatively shallow monitor wells labeled 1 through 7 (McCleary, 1990). Supplemental information was obtained from drillers' logs for six water wells located on Dodge Flat that have been recorded with the Nevada State Engineer. Two shallow boring logs by Cooper and Associates (1980) of Portland, Oregon, were obtained from Hydro-Search, Inc. (HSI, now HSI Geotrans). One other Cooper hole (S. 20, T. 21 N., R. 24 E.) described in Bratberg (1980) enabled stratigraphic correlation between the Olinghouse fan and the units of the Wadsworth Amphitheater, a geomorphic feature adjoining east side of the Truckee River near Windmill Canyon (Figure 5.4). Numerous other logs from wells along the river provided data defining the Truckee River flood plain aquifer.

Morrison and Davis (1984a) described the stratigraphic section at the Wadsworth Amphitheater based upon the designations and age determinations of Morrison (1964) for the Carson Sink. This same work provided the basis for Melhorn's (1978) interpretation of Lahontan age and earlier lacustrine sediments found in the Carson Sink. Benson (1993), Benson, *et al.* (1991), and Benson and Thompson (1987 a, b) since have modified those prior age estimates. In this report, wherever possible absolute ages derive from these workers, while the stratigraphic usage remains consistent with that of Morrison and Davis (1984a, b) and Melhorn (1978).

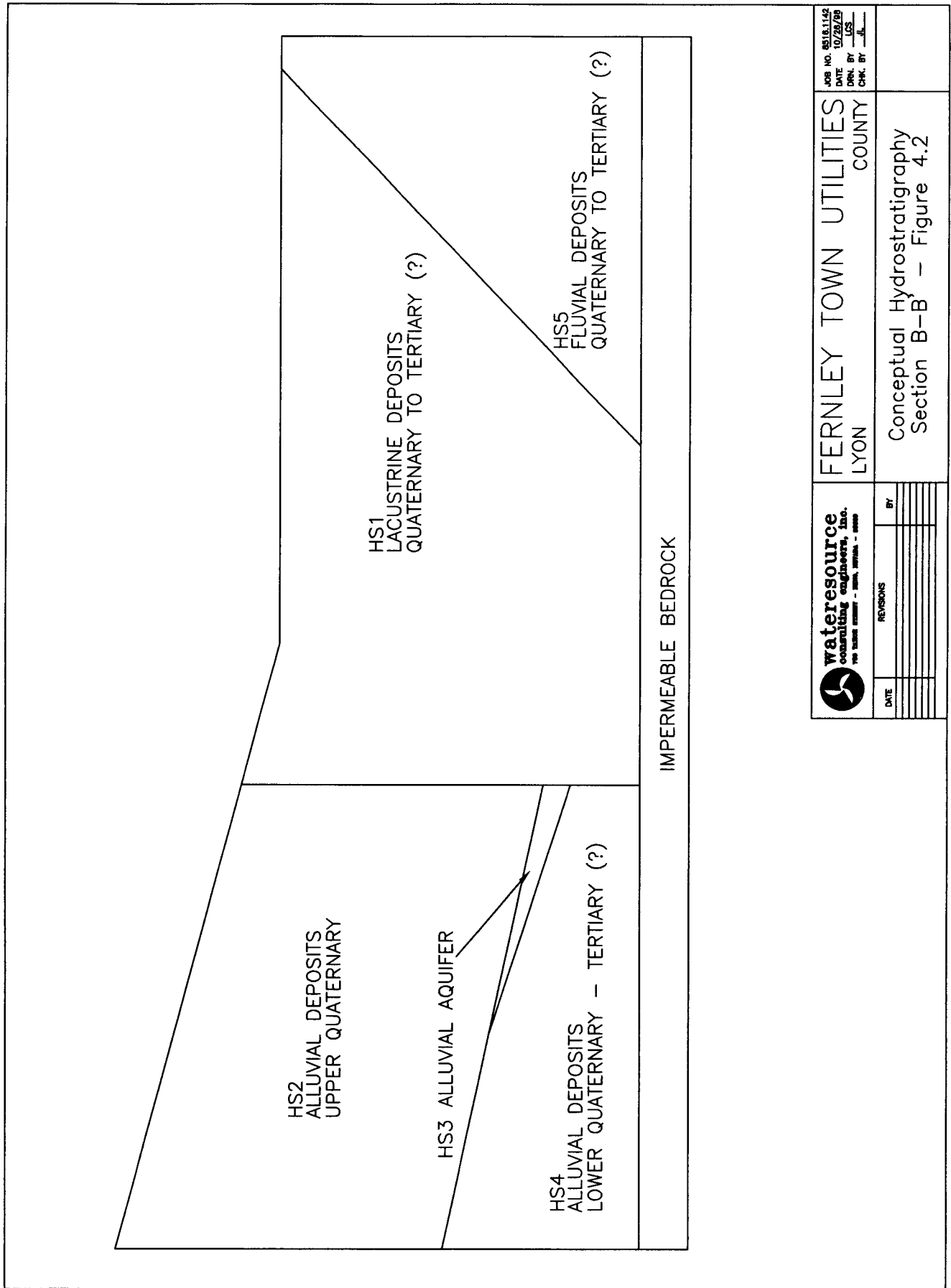
Multiple information sources invariably produce inconsistencies in lithologic descriptions. This effect is especially pronounced when correlating alluvial stratigraphy from drillers' well logs. At Dodge Flat, identification of interbedded lacustrine units from such descriptions is particularly important, since these probably supply solutes to groundwater (Bratberg, 1980; Sinclair and Loeltz, 1963). Alluvial fans themselves often contain soluble salts (Bull, 1972), but groundwater samples on the Olinghouse fan show relatively low solute concentrations (CH2MHill, 1990). Small playas formed at the distal ends of fans and on valley bottoms during periods of desiccation are a possible salt source, as are ancient soil horizons and pelludal units. Given the present limited stratigraphic resolution, sediments emplaced in playa and pelludal environments would be indistinguishable from lacustrine, fine-grained fluvio-deltaic, or fluvial overbank deposits. Ancient soils (paleosols) can not be discerned in the drillers' logs.

Because of the potential for fine-grained sediment to supply salts, in the following stratigraphic description it has conservatively been assumed that all intervals with abundant clay or silt represent lacustrine units, although within the context of a more detailed study the possibility of fluvio-deltaic and overbank deposits should be considered for those portions of the basin transgressed by the ancestral Truckee River. It should be borne in mind that the significance of fine-grained deposits lies not in the precision of stratigraphic assignments but in their relationship to solute loading and in defining the basinal hydrostratigraphy.

4.2 Hydrostratigraphic Units

The primary objectives of this section are to define specific hydrostratigraphic units in the area around the Olinghouse fan and to identify possible groundwater solute sources. Along with water balance estimates, this information has been incorporated into a numerical flow model that will help evaluate the potential for artificial aquifer recharge and its impact on water quality on the natural groundwater system and in the lower Truckee River.

Five principal hydrostratigraphic units have been delineated in the Dodge Flat alluvial basin (Figure 4.2). At the base of the Olinghouse fan, the uppermost (HS-1) is dominated by lacustrine sediments that locally contain alluvial and fluvial deposits, the top portion of which is unsaturated.



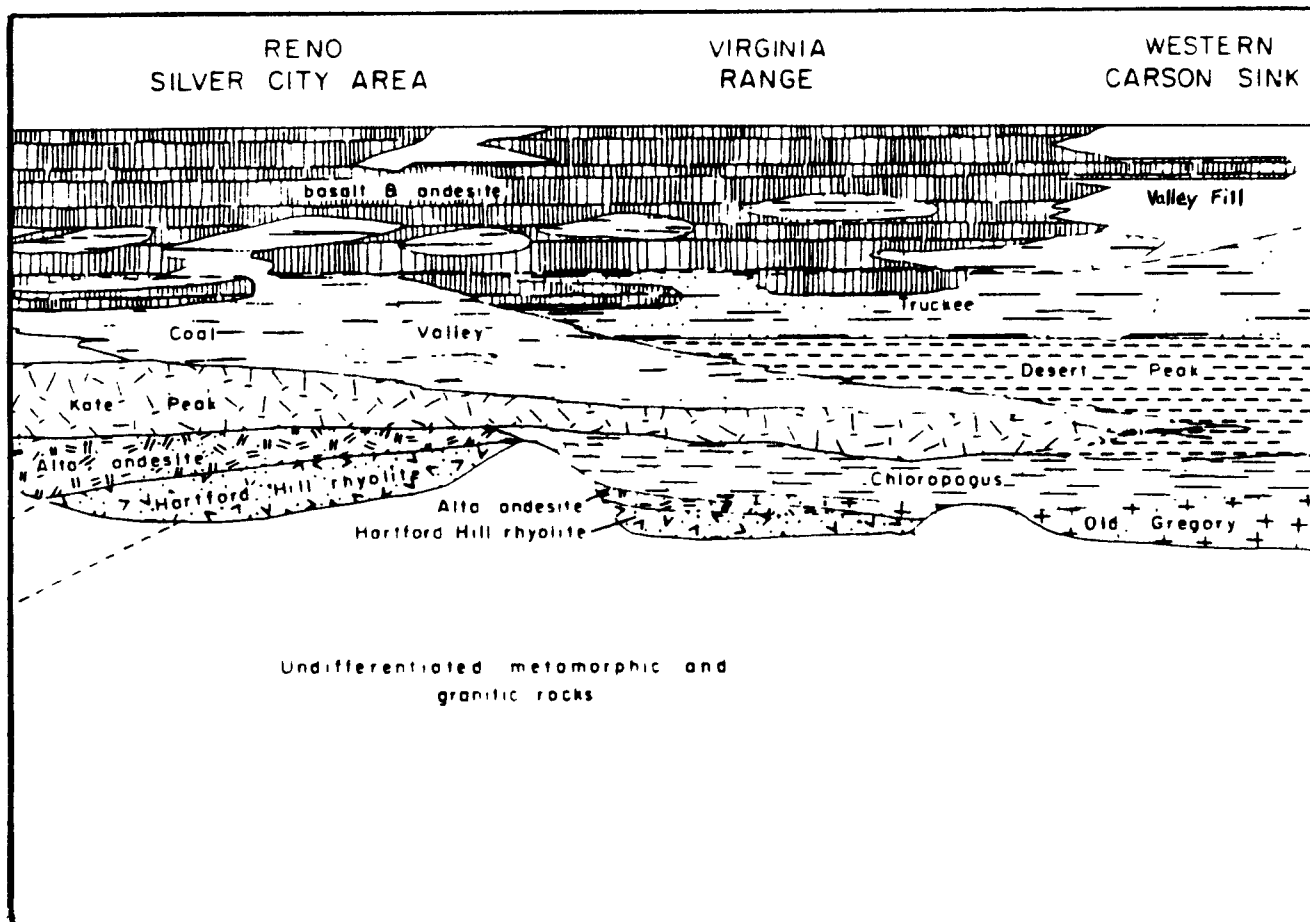
It is this unit that would be saturated first if infiltration basins are used for artificial recharge. This unit is also situated in the central and eastern parts of Dodge Flat, where it extends to depth and contains sediments of pre-Lahontan age. Unit HS-1 overlies and interfingers laterally with HS-2, saturated alluvial fan deposits comprised of gravel, sand, and minor clay. Unit HS-2 is exposed at the base of the Pah Range on the west side of the study area, and at depth may extend two miles or more toward the basin center. The third hydrostratigraphic unit, HS-3, underlies HS-1 and HS-2, and was intersected in three deep water wells on and near the base of the Olinghouse fan. It consists of porous boulder to gravel conglomerate with some sand, is poorly indurated, and yields water readily to wells; thus it is considered the principal aquifer system and would be the target unit if well injection is used for artificial recharge. Beneath HS-3 and above bedrock are well-consolidated alluvial fan gravels containing sand and minor clay that constitute HS-4. The fifth unit, HS-5, forms a wedge beneath and east of HS-2, and overlies HS-3. It consists of fluvial deposits associated with the ancestral and present Truckee River. Units HS-4 and HS-5 rest upon bedrock.

The upper portions of HS-1, HS-2, HS-5, and, in mountain block recharge areas, the bedrock, lie within the vadose zone. Bedrock beneath the valley and Units HS-3, HS-4 are below the water table. Each hydrostratigraphic unit encompasses different groupings of the heterogeneous sediments that lie beneath the area. These sediments result from a complex geologic history that includes intermittent inundation, desiccation, alluvial fan growth, and contemporaneous subsidence related to block faulting.


4.3 Tertiary-Quaternary Geologic Summary

Following the collapse of the Mesozoic arc-trench system that lay off the Pacific coast of North America, subduction south of the Mendocino fracture zone continued until early Oligocene (Norris and Webb, 1990). In the ensuing quiescent interlude, the highlands formed during that period were denuded and terrigenous sediments were deposited in what is now California and western Nevada. Subsequent basin-and-range extension and associated volcanism began in western and central Nevada about 35 to 39 m.y. ago during late Oligocene time (Tschanz and Pampeyan, 1970; Kleinhampl and Ziony, 1985). This activity is first represented in the Pah Rah Range by the Hartford Assemblage, which rests on Mesozoic plutonic rocks and metasediments (Figure 4.3). The Hartford Assemblage is dominated by mafic to acid volcanic rocks, volcanoclastics, and volcanic-derived sediments, but also contains lacustrine and alluvial fan deposits. Succeeding volcanism and sedimentation is represented by andesitic flows, breccias, and intercalated sediments of the Kate Peak and Desert Peak formations, culminated by basalt flows and valley-fill deposits ranging in age from Tertiary to Recent. Beneath Dodge Flat, Mesozoic and Tertiary units act as bedrock for alluvial, fluvial, and lacustrine units of Pliocene, Pleistocene, and Holocene age (Bonham and Papke, 1969; Sinclair and Loeltz, 1963).

Faulting has strongly impacted this stratigraphic succession. The study area lies within the Walker Lane, a region of tectonism that has remained active from 23 m.y.b.p. until the present (Bonham and Papke, 1969). Despite its primarily strike slip character, vertical fault movement along that zone has exceeded 3000 feet adjoining the Pah Rah mountains (Sinclair and Loeltz, 1963) and 4000 feet elsewhere (Bonham and Papke, 1969). Geophysical investigation for this project identified gravity lows that predicated upon a density contrast of 0.67 suggest ~900 feet of valley-fill sediment above bedrock at Dodge Flat and as much as ~2500 feet within the basin depocenter, which trends north northwest – east southeast, parallel to the Walker Lane (Carpenter, 1997; Hartley, 1997). On Dodge Flat, sediments as young as upper Pleistocene show offset (John W. Bell, oral communication; Sanders and Slemmons, 1979).



Modified from Bonham & Papke, (1969)

 waterresource consulting engineers, inc. <small>THE TOWN OF LYON - 1998, 1999 - 2000</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 0218.1142 DATE 08/20/98 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Conceptual Tertiary Stratigraphy Figure 4.3		

Fringing the basin are alluvial fan deposits which probably range in age from Pliocene to Recent (Bonham and Papke, 1969). These fans interfinger with lake sediments and probably with fluvial deposits of the ancestral Truckee river. The extent to which the fans penetrate the basin center is not known, but well logs at the toe of the Olinghouse fan show alluvial deposits within about 2.5 miles of the deepest part of the basin (Carpenter, 1997; CH2MHill, 1990).

Alluvial fan depositional processes include sheet flows, transport in braided streams, and debris flows that deposit pebble to boulder gravel, grit, sand, and silt. These often initially form lobate sheet-like bodies that are reworked by intermittent aggrading streams, giving rise to discontinuous lenses of extremely coarse to fine sediment (Bull, 1972). Variable but high hydraulic conductivities and transmissivities frequently characterize such material. On Dodge Flat, alluvial paleofans containing paleosols interfinger with finer-grained lacustrine sediments. These basin-fill units control the subsurface hydrology of the study area and have been penetrated by a small number of wells, the data from which provide the basis for stratigraphic determinations. Stratigraphic correlations are depicted in the geologic cross-sections contained in Appendix A.

4.4 Dodge Flat - Olinghouse Fan Stratigraphy

Presumed pre-Lahontan units have been given arbitrary designations based on lithology, but wherever possible, sediments thought to be of Lahontan age have been assigned alloformation¹ names according to the nomenclature of Morrison and Davis (1984b) and Morrison (1964). That stratigraphy was inferred from lithologic descriptions combined with assumptions regarding the maximum reported thickness of an alloformation, the elevation of a particular unit's base, and the relationships between alloformations in the Carson Sink from Morrison (1964).

Bedrock: Probable Kate Peak formation andesite was recorded by HSI (1982) during a re-evaluation of the Mongolo Test Hole (well permit number 19173, assigned by the State Engineer). Previous examination by Water Development, Inc., had misidentified this as blue-green shale, which is recorded on the State Engineer's log. No bedrock was observed in any of the other Dodge Flat area wells. Examination of provisional geologic maps by Garside and Bonham (1997a, b) suggest that Hartford Assemblage and later Tertiary rocks probably underlie the western portion of the study area. These probably extend beneath its eastern section, though the Desert Peak formation may be present there (Bonham and Papke, 1969). For groundwater modeling purposes, Kate Peak andesite and the Hartford Hill formation rhyolite are assumed to be an impermeable basement that lies beneath poorly consolidated valley-fill sediments (see Appendix A, Sections B-B').

4.4.1 Pre-Lahontan Sediments

In Washoe County, pre-Lahontan alluvial, fluvial, and lacustrine deposits of Quaternary age have been described (Bonham and Papke, 1969; Melhorn, 1978). Much of the Olinghouse fan is probably of pre-Lahontan Quaternary age. However, well data from Dodge Flat do not permit distinction between Quaternary and Tertiary, so in the cross-sections appended to this report all non-Lahontan deposits are prefixed "QT" and numbered 1 through 4 in order of increasing age (Appendix A).

Unit QT4: Only three deep wells intersected the lowermost sedimentary unit, QT4, which is comprised of cemented gravel. In well 19173, QT4 is about 100 feet thick above andesite

¹A mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities (NACSN, 1983, p. 865)

bedrock. Elsewhere (wells 42919, and 46908), no bedrock was observed, though depths exceed 500 feet. This unit probably represents a series of alluvial deposits, presumably containing soil horizons, and comprises hydrostratigraphic unit HS-4 (Figure 4.2). Whether it grades laterally into fluvial or lacustrine sediments beneath the Truckee River or Wadsworth is assumed but not proven; in the vicinity of Dodge Flat none are apparent. An age for this unit equivalent to the Tertiary Desert Peak or Coal Valley Formations would be probable only if olivine basalt boulders were absent within it (Bonham and Papke, 1969), so in the absence of further information it is presumed to be younger than these formations. Its contact with overlying alluvial deposits is based upon drillers' estimates of the degree of induration.

→ Unit QT3: Locally overlying QT4 are bouldery gravels of Unit QT3, which beneath the lower Olinghouse fan equates with hydrostratigraphic unit HS-3. Its thickness ranges from 40 to 80 feet. Drillers' logs suggest that the unit may be less consolidated than QT4, and thus potentially a good aquifer; this coupled with lithology provides the basis for stratigraphic correlation. In well 42919, it immediately underlies units of probable lacustrine origin. Like QT4, the eastward extent of QT3 is unknown, since it was intercepted only in wells 19173, 42919, and 46908. For groundwater modeling purposes the region east of these wells is assumed to contain fluvial sediments and thus lies within HS-1 (Figure 4.2). It is conceivable that drill cuttings that were interpreted as QT3 represent instead discontinuous, poorly indurated gravel intervals in otherwise well-consolidated alluvium. Transmissivities have been adjusted to account for that possibility.

Unit QT2: Unit QT2 was recorded in only three wells, and may be geographically restricted. Its clays, clayey silts, and clayey sands are taken to represent pre-Lahontan lacustrine sedimentation equivalent to the "PE" unit of Morrison and Davis (1984b). They have been assigned to a distinct lithostratigraphic unit because of their thickness, which in one well (42919) is approximately 60 feet.

It is possible that QT2 correlates with the lowermost portions of the Pleistocene Eetza Alloformation of Morrison (1964) and (Morrison and Davis, 1984b), but if so the Eetza is at least twice as thick at this site (about 200 feet) as reported elsewhere. Because of its altitude, it is unlikely that QT2 corresponds to the major lacustrine interval described within the Rye Patch Formation by Melhorn (1978). It is included within Unit HS-1 of the conceptual hydrostratigraphic model (Figure 4.2).

Unit QT1: Unit QT1 is dominated by consolidated alluvial sediments above and laterally interfingering with QT2. It may encompass the Paiute Alloformation of Morrison and Davis (1984b) and Morrison (1964). However, on the west side of the basin it underlies a sandy zone designated a possible Paiute equivalent on the basis of lithologic similarity to Paiute Alloformation exposures in the Wadsworth Amphitheater. Probable fluvial deposits on the east side of Dodge Flat near the Truckee River are also assigned to QT1 based on their projection beneath the Eetza Formation of Morrison and Davis (1984a).

In the vicinity of the Olinghouse fan monitor wells, QT1 is composed of gravel locally containing silt, sand, or boulders and varies in thickness from 25 to 60 feet. It exhibits intermittent cementation and local indurated zones that may correspond to paleosols. Two well-developed argillic soils have been recognized from a surface trench on the upper portions of the fan, where QT1 may thicken to as much as 400 feet. The principal sediment transport direction during QT1 deposition may have been NE to ENE, as inferred from present-day solute contours, water levels, and lithology described in well logs.

Designation of alluvium as QT1 is predicated on the observation of both Eetza and Schoo highstand shorelines incised into the Olinghouse fan. Much of the present fan therefore predates Lake Lahontan. For hydrostratigraphic purposes, the alluvial western portion of QT1 has been grouped with Lahontan age alluvium into unit HS-2. The fluvial eastern portion is of unknown thickness and is part of hydrostratigraphic unit HS-5.

4.4.2 Lake Lahontan and Equivalent Sediments

Pleistocene climatic fluctuations resulted in the repeated expansion and desiccation of Lake Lahontan, with concomitant adjustment of alluvial fans, shifting of the Truckee River between basins, and changes in its character from aggradational to degradational (Hostetler and Benson, 1987; Benson and Thompson, 1987; Benson, *et al.*, 1991). Primarily alluvial Lahontan-age deposits on the Olinghouse fan have been designated part of hydrostratigraphic unit HS-2, while those portions of the Dodge Flat basin dominated by lake sediments are considered HS-1 (Figure 4.2). A fairly small region of fluvial origin near the river forms a window of HS-5 on the present land surface. In HS-1 and HS-2 formational units have been delineated from correlations between the Cooper and Associates drill hole and the Wadsworth Amphitheater (Morrison and Davis, 1984b).

Paiute Alloformation: A veneer a few feet thick of Paiute Alloformation sand and gravel is exposed in the Wadsworth Amphitheater. This unit, representing an interpluvial lasting as much as 150,000 years, is defined in outcrop by a well-developed soil horizon (Cocoon geosol) and its stratigraphic position beneath the Eetza Alloformation (Morrison, 1964; Morrison and Davis, 1984a). Elsewhere, the Paiute can exceed 70 feet in thickness and characteristically includes several soil horizons (Morrison and Davis, 1984b). Based on elevation, a silty sand interval in the Cooper and Associates hole has provisionally been assigned to this alloformation, but in the absence of a demonstrable soil profile that interval could equally well lie within the lower part of the Eetza. Many of the higher pre-Lahontan alluvial units recognized in drill holes and designated QT-1 could lie within the Paiute Alloformation.

Eetza Formation: Morrison and Davis' (1984b) Eetza Alloformation represents multiple pluvial intervals from about 400 to 110 k.y. ago, during much of which time a relatively deep lake was present at Dodge Flat. Lowstands during this period may have lowered the lake elevation below about 4065 feet (1238 m) and exposed much of the Dodge flat area (Hostetler and Benson, 1987). Several sub-aerial depositional episodes during Eetza time were designated the S Bars Formation, by Morrison and Frye (1965). At such times, alluvial fans probably prograded toward the basin center. Deep-water lacustrine sediments of the Eetza thus probably interfinger with alluvial deposits near the toe of the present-day Olinghouse fan. However, the latest Eetza highstand cut a shoreline that persists today midway up the fan, and deposited a thin veneer of silt and clay sediment. Despite some reworking and aggradation, much of the Olinghouse fan, therefore, must predate late Eetza time. Tentative identification of surficial pre- and post-Eetza alluviation on the Olinghouse fan has been made based upon aerial photographs.

Units designated as Eetza include lacustrine silt and clay but also contain some bouldery clay, sand, and gravel deposits, which is consistent with the observations of Morrison and Davis (1984a, b). In the project area, delineation of its stratigraphic base derives from a combination of lithology, elevation, and maximum thicknesses reported elsewhere, but it is somewhat arbitrary in that QT2 clay and silt may represent an unprecedented but nevertheless plausible thickness of Eetza sedimentation. In addition, portions of the

underlying QT1 alluvium may interfinger with basal Eetza lacustrine deposits. Similarly, the upper contact of the Eetza with the Wyemaha Alloformation is somewhat arbitrary. The Wyemaha, a thin layer of which overlies the Eetza in the Wadsworth Amphitheater, was not shown on the Olinghouse fan cross-sections, although equivalent alluvial units may be present, since the Wyemaha represents a significant interpluve (Morrison, 1964).

Sehoo and Indian Hills Formations: The contact of the Eetza (and Wyemaha) with the overlying Sehoo and Indian Hills alloformations was established by coupling lithology with elevation, since Morrison's (1964) definitive Churchill soil horizon could not be discerned in well logs. The lacustrine Sehoo alloformation spans a series of pluvial and interstadial periods from about 25,000 y.b.p. to 12,000 y.b.p. and consists of silt and clay with local minor sand. Its lateral alluvial counterpart is the Indian Hills Formation. Gravel and sand intervals in drill holes at the base of the Olinghouse fan appear to interfinger with lake sediments and so have been tentatively designated Indian Hills.

Hydrostratigraphic unit assignments are based upon lithology. Where significant Eetza and Sehoo are present, all Lahontan age units are assigned to hydrostratigraphic unit HS-1; otherwise, they are merged with QT1 into HS-2.

Younger Deposits: Post-Sehoo fluvial, alluvial, and eolian deposits occur throughout the study area, and frequently consist of reworked Pleistocene sediments. These generally are of limited hydrostratigraphic significance, with two possible exceptions. The first, recent fluvial material along the Truckee River, is included in hydrostratigraphic unit HS-5. The second is dune sand situated northeast of Fernley and Wadsworth. Those sands may be underlain by lacustrine sediments representing pluvial intervals, but if their development is representative of past interpluves, relatively thick eolian deposits may be present at depth beneath what appears today to be a topographic and groundwater divide. This area also coincides with a zone of deep sedimentation along the Walker Lane structure (Carpenter, 1997) and may permit ingress of water from east of Fernley northward to the Truckee River near Wadsworth. High solute concentrations reported by CH2Mhill (1990) suggest some groundwater input east of the river.

Results of geophysical surveys performed for this project generally confirm the inferred stratigraphic relationships and indicate the presence of good quality water within alluvial deposits on the Olinghouse fan and elsewhere flanking the western portion of the Dodge Flat groundwater basin. The geophysical investigation encompassed a ground-based gravity survey (Carpenter, 1997) and interpretation by ADGIS, Inc., of airborne multifrequency EM, differential resistivity, and magnetic data obtained from Dighem Surveys of Mississauga, Ontario, Canada, (Hartley, 1998).

To interpret the gravity data, Hartley (1998) assumed a density contrast of 0.67 and concluded that valley-fill deposits in the Dodge Flat alluvial basin range from ~900 feet near the base of the Olinghouse fan to ~2500 feet at its deepest part about a mile southwest of the S-S Ranch (S. 8 and 28, Township 21 North, Range 24 East; UTM approximately 4 292 000 N, 303 000 E to 4 297 000 N, 302 000 E) Beneath Wadsworth, its depth is ~1900 feet. The basin is bowl-shaped, elongate in a NNW-ESE direction roughly parallel to the Truckee River and the trend of the Walker Lane, and contains a deeper segment that extends westward beneath the transmissive units of the Olinghouse fan. It shallows north of Dead Ox Canyon and to a lesser extent southward from Wadsworth toward Fernley.

EM and resistivity data are in accord with geologic interpretations that indicate the presence of alluvial units along the west side of the basin. That part of the basin beneath Dodge Flat for the most part is inferred to contain fine grained silty or sandy units, with common clay-rich strata, particularly in the upper ~150 feet. This is consistent with deposition in lacustrine, fluvial, and fluvio-deltaic environments. Local geologic conditions constrain the resolving power of the techniques employed, particularly below ~150 feet depth, and preclude stratigraphic interpretation below ~400-500 feet depth. Wet conductive clays which appear to be present in the central parts of the basin even further restrict resistivity data. However, visual examination of input data for the differential resistivity profiles given in Hartley (1998) suggest that water of low conductivity and thus potentially good quality is indicated beneath the alluvial deposits of the Olinghouse fan (Hartley, 1998, verbal communication).



There, the zone appears to be between ~1500 and ~2000 feet wide, but because it is present at the maximum resolvable depth, this figure is subject to error. Its presence is limited in other resistivity data. If the zone is assumed to have an average width of ~1000 feet, an extractable water depth of ~500 feet, and a distribution over about half of the Pah Rah range front (~25,000 feet), its volume would be $\sim 1.25 \times 10^{10} \text{ ft}^3$ (~285,000 af). This is equivalent to ~200 years recharge. The geophysical interpretations confirm pump test results which suggest that these units are highly transmissive. Their distribution impacts the Dodge Flat groundwater flow system.

SECTION 5.0

GROUNDWATER FLOW SYSTEM

In the Great Basin, all groundwater starts out as precipitation in the form of rain and snow falling on mountain block recharge areas. That moisture originates in the Pacific Ocean to the southwest, west, and northwest. Much recharged water derives from snow although some winter and summer rains contribute significantly. For the Dodge Flat hydrographic basin, the recharge areas are the Pah Rah Range to the west of Dodge Flat and to a lesser extent the Truckee Range east of the Truckee River. The Truckee Range is not contributory to the Dodge Flat groundwater system in that the little recharge that occurs there discharges directly into the Truckee River, which is in the Dodge Flat hydrographic basin.

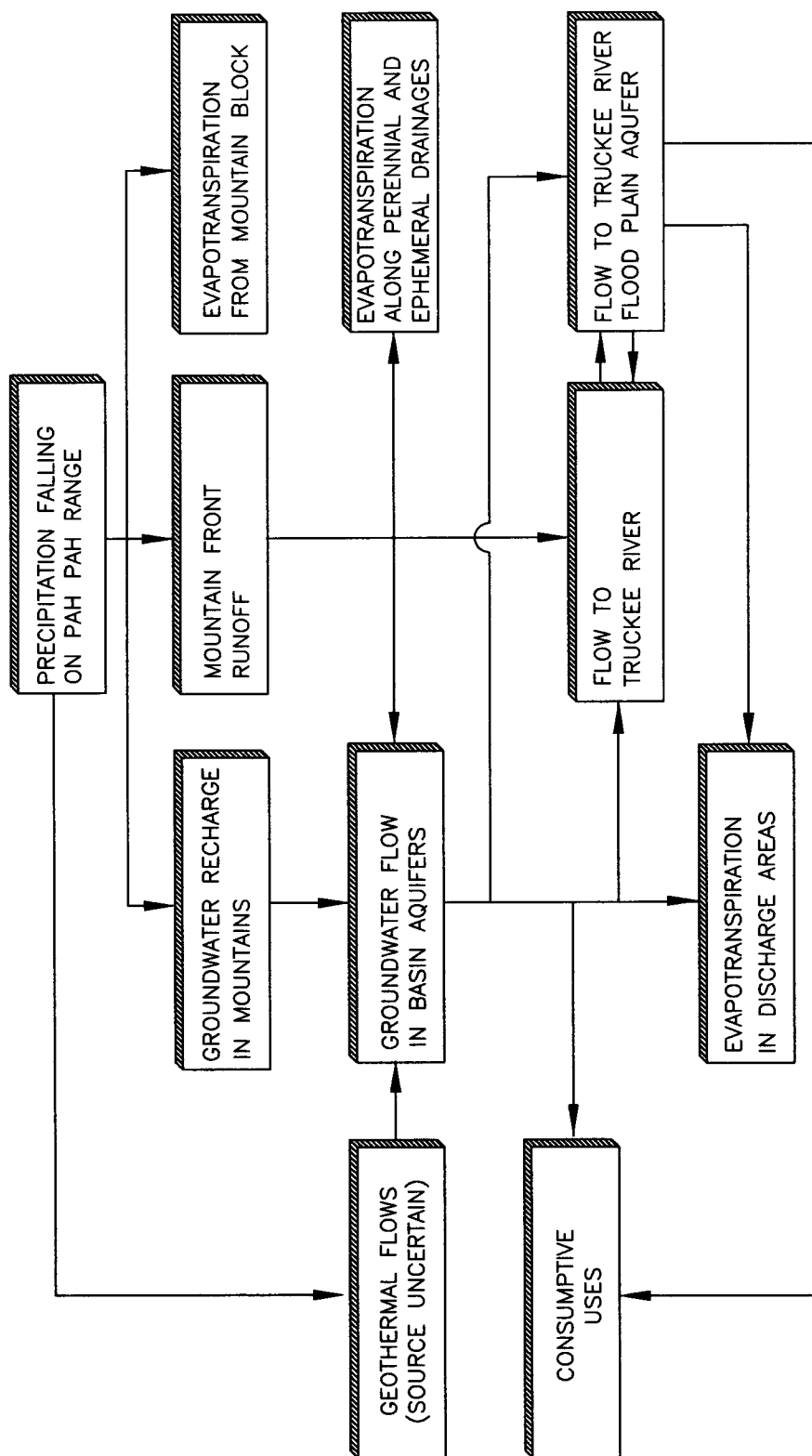
5.1 Dodge Flat

The recharge process is strongly influenced by evaporation. As soon as a precipitation event is over, evaporation from the soil moisture zone and the wetted rock surface begins. Sublimation from snow also begins immediately. Some of the precipitated water thus quickly returns to the atmosphere. A portion may enter ephemeral drainages, and some infiltrates the shallow soil mantle overlying the bedrock. Soil moisture that is used by plant life returns to the atmosphere by way of evapotranspiration. That amount that exceeds the requirements of vegetation and the moisture holding content of the soil infiltrates into the underlying bedrock. Where the soil cover is thin to non-existent, as is the case over large parts of the Pah Rah Range, the water directly enters the bedrock. Some of this groundwater is intercepted by fractures and reappears on or near the base of the mountain block as springflow, where it is subject to further evapotranspiration. The remainder reaches the water table and eventually joins the valley aquifer system. The recharge process for the Dodge Flat hydrographic area is shown in Figure 5.1.

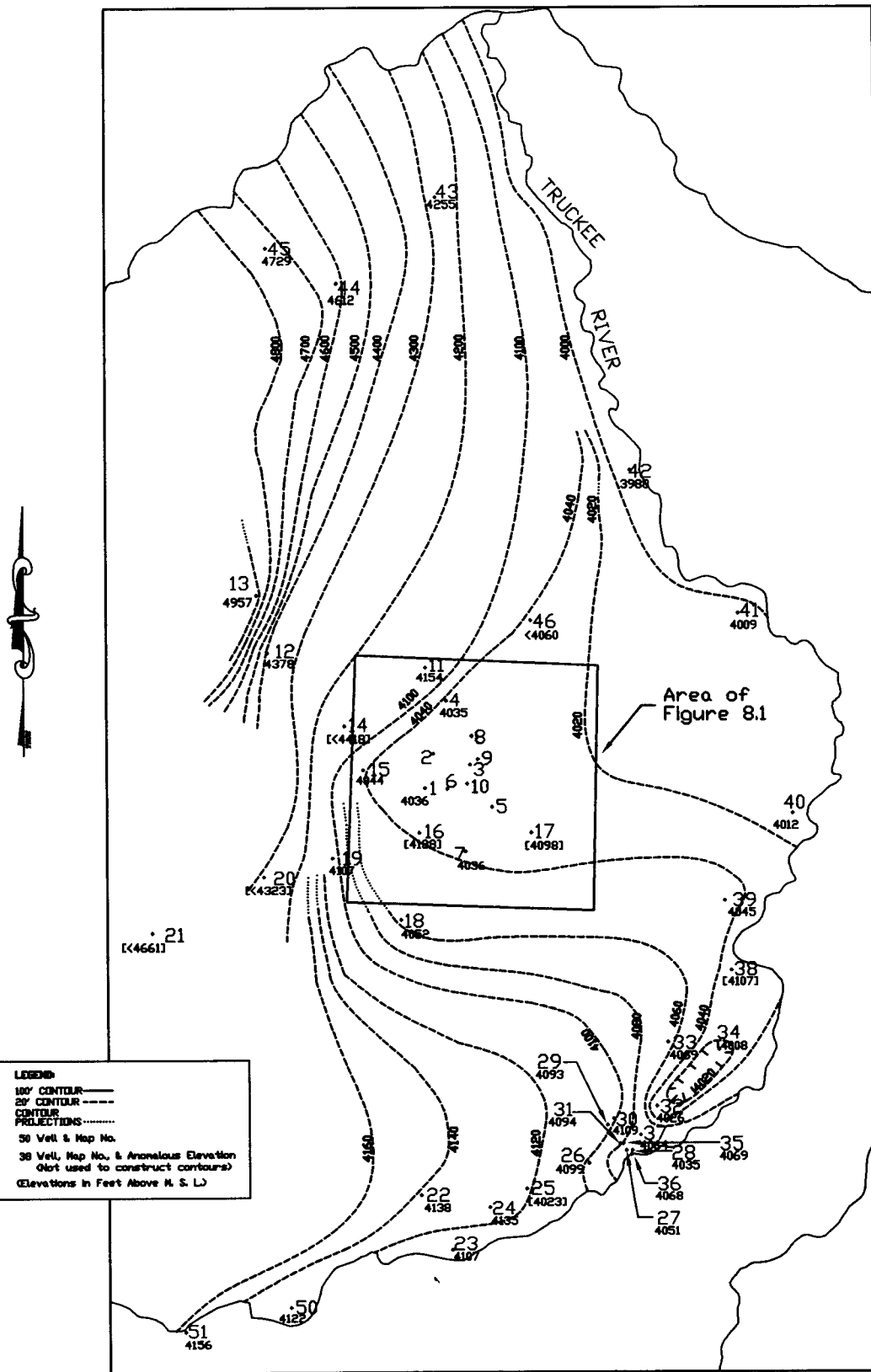
5.1.1 Groundwater Source

Figure 5.2 is a groundwater level map for the Dodge Flat area showing the direction of groundwater flow and well locations used to generate the contours (see Table 4.2 for well descriptions). The flat gradient results from the ability of the sediments to transmit water fairly rapidly. The recharge area for the Dodge Flat aquifer system lies for the most part in the Pah Rah Mountains on its western border. Van Denburgh, *et al.*, (1973) estimate the total precipitation for the Dodge Flat hydrographic area to be 43,000 acre-feet/year, of which only about 1400 af/y enter the groundwater system. The Dodge Flat hydrographic area is considerably larger than is contributory to the smaller Olinghouse fan groundwater system, which does not include the area south of Olinghouse canyon drainage, north of the Fort Defiance drainage, nor any contribution from the Truckee Range east of the Truckee River. Figure 5.3 shows the topographic sub-basins (listed in Table 5.3) used to calculate recharge and outlines that portion of Dodge Flat modeled in the present study.

Two perennial streams that reach into the Dodge Flat area from the Pah Rah Range are Fort Defiance Canyon and Olinghouse Canyon. Both are supported by springflow, and were flowing during the early part of October, 1997. In Fort Defiance Canyon the springs are well within the mountain block, while in Olinghouse Canyon the springs are near the eastern mountain front; local residents indicate that in some years, spring flow is insufficient to cause stream flow. The portion of these flows not lost to evapotranspiration re-enters the groundwater system on the alluvial fans.



Groundwater Budget Components for the Dodge Flat Groundwater Basin and the Truckee River Flood Plain Aquifer – Figure 5.1



waterresource		
CONSULTING ENGINEERS, INC.		
1000 W. 10TH STREET - SUITE 200 - RENO, NV 89502		
DATE	REVISION	BY

FERNLEY TOWN UTILITIES	
LYON COUNTY	
Water Table Elevations for the Dodge Flat Area - Figure 5.2	

JOB NO. 0018.110P
DATE: 04/20/99
DRAWN BY: JES
CHECK BY: JES

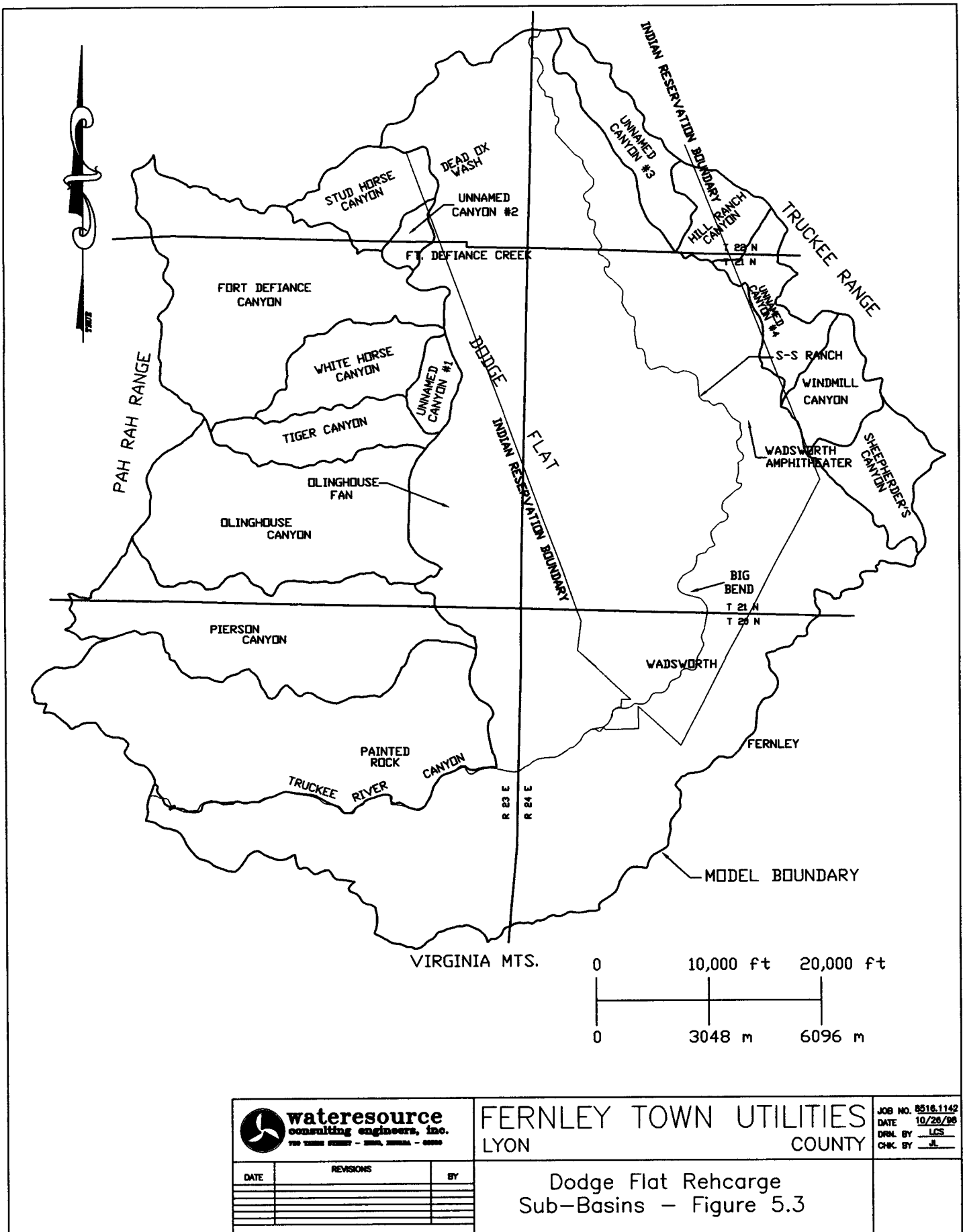


TABLE 5.3

POTENTIAL GROUNDWATER RECHARGE TO DODGE FLAT AND THE TRUCKEE RIVER

Estimated Precipitation						Potential Recharge	
		Altitude Zone (ft)	Area (Acres)	Range (in)	Average (ft)	Percentage of Total Precipitation	Volume (af/y)
Pah Rah Range							
Pierson Canyon		5000-6000	2990	8-12	0.8	2390	0.03
		6000-7000	950	12-15	1.1	1050	0.07
		Sub-Total	3940			3440	140
Olinghouse Canyon		5000-6000	2710	8-12	0.8	2390	0.03
		6000-7000	1550	12-15	1.1	1700	0.07
		7000-8000	700	15-20	1.5	1050	0.15
		Sub-Total	4960			5140	345
Tiger Canyon		5000-6000	900	8-12	0.8	720	0.03
		6000-7000	440	12-15	1.1	480	0.07
		7000-8000	150	15-20	1.5	230	0.15
		Sub-Total	1490			1430	90
Unnamed Canyon #1		5000-6000	170	8-12	0.8	140	0.03
		Sub-Total	170			140	5
White Horse Canyon		5000-6000	1490	8-12	0.8	1190	0.03
		6000-7000	280	12-15	1.1	310	0.07
		Sub-Total	1770			1500	35
Fort Defiance Canyon		5000-6000	2490	8-12	0.8	1990	0.03
		6000-7000	2870	12-15	1.1	3160	0.07
		7000-8000	1550	15-20	1.5	2320	0.15
		Sub-Total	6910			7470	60
Unnamed Canyon #2		5000-6000	240	8-12	0.8	190	0.03
		Sub-Total	240			190	5
Stud Horse Canyon/Dead Ox Wash		5000-6000	1130	8-12	0.8	900	0.03
		6000-7000	80	12-15	1.1	90	0.07
		Sub-Total	1210			990	30
OROGRAPHIC RECHARGE TO DODGE FLAT WEST OF THE TRUCKEE RIVER TOTAL							1300
Truckee Range							
Unnamed Canyon #3		5000-6000	360	8-12	0.8	290	0.03
							10
Hill Ranch Canyon		5000-6000	300	8-12	0.8	240	0.03
							10
Unnamed Canyon #4		5000-6000	190	8-12	0.8	150	0.03
							5
Windmill Canyon		5000-6000	430	8-12	0.8	340	0.03
							10
Sheepherders' Canyon		5000-6000	540	8-12	0.8	430	0.03
							15
OROGRAPHIC RECHARGE TO THE TRUCKEE RIVER FROM THE EAST TOTAL							50
Virginia Range							
		5000-6000	80	8-12	0.8	60	0.03
							<5
OROGRAPHIC RECHARGE TO THE TRUCKEE RIVER FROM THE VIRGINIA RANGE							Minor
TOTAL		22,600				21,800	

Based upon the Maxey-Eakin method applied to individual sub-basins.

Recharge estimates are rounded. Painted Rock sub-basin discharges a minor amount directly to the Truckee River.

5.1.2 Groundwater Movement

Water that is not intercepted by fractures to feed springs continues its downward course beneath the valley. Some of this water undoubtedly enters the groundwater system high on the alluvial fans where they lie directly on the mountain block, but most appears to enter the basin-fill aquifers from underlying volcanic rocks that are broken by high angle faults located near the contact between the mountain front and valley fill deposits. Groundwater may rise along the mountain front structures because they probably are more permeable than the surrounding rocks. For Dodge Flat there are no data available to substantiate this process, but it has been described in other regions.

Though faulting might provide conduits for groundwater to access the Olinghouse fan aquifers, its impact on horizontal flow within the basin-fill sediments, which are heterogeneous and anisotropic, can not presently be gauged. Investigators have described Quaternary faults that behave as conduits, while others act as groundwater barriers and still others appear to have no control on groundwater flow. For example, Dutcher and Garrett (1963) described the hydrologic properties of fault barriers in the San Bernardino area, California. They attributed the impediment of groundwater flow across those barriers to several possible conditions: (1) local and incomplete offset of gravel beds against clay beds; (2) sharp local folding of beds near the faults, causing impervious clay beds to be upturned across the direction of water movement; (3) carbonate cementation within the gravel and sand beds immediately adjacent to the fault; and (4) development of secondary clayey gouge zones along the faults.

The maximum difference in water levels across faults that these workers report is 120 feet. Other investigators have reported various groundwater offsets: Durbin (1978) reported a 300 foot water table difference across the Randsburg-Mojave fault in Antelope Valley, California; Katzer and others (1984) describe a 40 ft offset in a small basin south of Reno, Nevada; while Bell and Katzer (1987) were unable to find any groundwater elevation change across fault scarps in Dixie Valley, Nevada.

Recent structures transecting basin-fill sediments are common in many basins within the Basin and Range. Based on low-sun-angle photographs, at least two subtle northwest trending lineaments (not to be confused with Pleistocene beach bars) that appear to be tectonic in origin are present on the Olinghouse fan about a mile east of the mountain front. They transect both Lahontan sediments and pre-Lahontan alluvium, but display no apparent offset. Similar features cut Lahontan lake beds near the center of Dodge Flat. Possible faults have also been delineated during the geophysical investigations conducted for this project (Carpenter, 1997; Hartley, 1998). None of these appear to have impacted groundwater flow, but the water-level data may not suffice to detect any offset in water table elevations.

5.1.2.1 Hydraulic Properties

Groundwater aquifers can be thought of as large conduits that transport water from recharge areas to discharge areas. The movement of groundwater through the various types of rock (including unconsolidated sediments) is controlled by the hydraulic properties of the rock. The principal properties that can be measured by conducting aquifer test are conductivity, transmissivity, and storage. Hydraulic conductivity is a measure of how rapidly a given mass of groundwater moves through the aquifer. Transmissivity is the property that measures the capability of

an aquifer to transmit a given volume of water and is based on the hydraulic conductivity and the saturated thickness of the aquifer. The storage coefficient is simply a measure of the amount of water in the aquifer and is defined as the volume of water released or taken into storage per unit surface area of the aquifer per unit change in head. Table 5.1 lists the values that were determined from aquifer tests below the Olinghouse fan and from estimates made for other alluvial areas on Dodge Flat.

TABLE 5.1
TRANSMISSIVITY ESTIMATES FOR ALLUVIUM
IN THE DODGE FLAT AREA

TRANSMISSIVITY, in gpd/ft	SOURCE
93,000 ¹	Present Study
95,300 ²	NLRC, 1997
90,300 ³	NLRC, 1997
286,000 ⁴	NLRC, 1997
12,500 ⁵	Bratberg (1980)
14,000 – 25,000 ⁶	Campana (1978)

- 1 Obtained using Cooper-Jacob method and two monitor wells.
- 2 Obtained applying Cooper-Jacob method to early drawdowns on a single well.
- 3 Obtained applying Theis method to early drawdowns on a single well.
- 4 Obtained applying both Theis and Cooper-Jacob methods to intermediate time drawdowns on a single well.
- 5 Estimated by analogy to other deposits and interval consistency within a flow model.
- 6 Estimates reported by Bratberg (1980) as personal communication; data origin not stated.

There are two types of aquifers in the study area, confined/semi-confined, and unconfined. The principal system underlying Dodge Flat, termed informally for this report the Pah Rah aquifer, is considered confined/semi-confined because the sediments overlying it have low hydraulic conductivities and restrict the upward movement of water from the aquifer. The confining unit is comprised mostly of Quaternary lacustrine silts and clays. The aquifer sediments underlying the confining beds are made up of alluvial sand and gravel with some interbedded silt and clay and have very high water transmitting capabilities. The source of most of these sediments is presumably the Pah Rah Range to the west; it is not known how far to the west. Fluvial material may have been transported by the ancestral Truckee River from greater distances, but it is considered unlikely that the river significantly encroached into the extreme western portions of Dodge Flat.

Two sets of transmissivity data for the alluvial units at the toe of the Olinghouse fan are available (Table 5.1). The first comprises summary interpretations of constant drawdown, step drawdown, and recovery tests that were performed on the old

Olinghouse production well (Butcher Boy, #23581, Map No. 8) in 1984 by William E. Nork, Inc., of Reno, on behalf of NLRC (NLRC, 1997). They concluded that the aquifers were probably semi-confined, with transmissivities in the range of 95,000 - 286,000 gpd/ft ($\sim 12,700 - \sim 38,000 \text{ ft}^2/\text{d}$) based respectively on early and late drawdown and recoveries. In the absence of observation wells, an aquifer storage coefficient was not calculated, but specific capacity was estimated to be $\sim 28 - \sim 39$ gpm/ft. For their "worst-case" scenario involving a 650 gpm continuous pump rate, semi-confined aquifer, and no recharge, a well pumping indefinitely would produce $\sim 20 - 25$ feet of drawdown. These workers also advised that better interpretations could be obtained if tests were performed using observation wells.

The second data set was obtained for the present investigation by Carson Pump in November, 1997. A new well (NV Land North, #46908) was pumped at 900 gpm for 3 days. Drawdown and recoveries were measured there, at NV Land South (#42919), and MW-3. Transmissivities were calculated to be in the range of 93,000 gpd/ft and storativity ~ 0.018 using the Jacob-Straight Line method. These results are consistent with those of William E. Nork, Inc. (NLRC 1997) and when compared to other estimates for Dodge Flat indicate the presence of a highly transmissive aquifer in the vicinity. This interpretation is also suggested by the groundwater elevation map of Figure 5.2.

Because water quality is poor at the site of Nevada Land's wells, the potential artificial recharge storage and recover (ASR) facility will probably be constructed approximately one mile to the south, within a zone of excellent quality water indicated by monitor wells and geophysical interpretation. Further tests on the Olinghouse fan (on Dodge Flat) within the zone of good quality water must be undertaken, prior to the initiation of an ASR project; however, the lithologic similarity and proximity to the tested wells suggests this area has a high probability of being a successful ASR site.

5.1.2.2 System Yield

Total recharge to the Olinghouse canyon drainage is estimated for the present study to be $\sim 300 \text{ af/y}$ ($\sim 0.4 \text{ cfs}$), approximately one-fourth of the total Pah Rah Ranch recharge to Dodge Flat ($1,400 \text{ af/y}$). This is a relatively small volume compared to the estimated storage requirement of $5,000 - 15,000 \text{ af/y}$ for the proposed ASR system. A volume greater than the natural recharge is expected to be consumed by Alta Gold's mining operation over its anticipated ~ 5 year life ($\sim 500 \text{ af/y}$, PTI, 1997). A variable portion will be taken up during pit dewatering, but for the most part mine process water will be obtained from the Alta Gold #2 well, which is in a region of poor-quality groundwater and will draw from Dodge Flat below the base of the Olinghouse fan. Drawdown on Dodge Flat is predicted to stabilize at ~ 16 feet within one year of pumping, and return to ~ 11 ft during reclamation (PTI, 1997).

5.1.2.3 Storage

Apart from hydrologic considerations, the amount of water that can be stored in the Olinghouse fan aquifer depends in large measure on design criteria such as: method (well injection vs. infiltration basin), requisite water volume, well siting, input and withdrawal frequencies, and pumping rates. Solute acquisition by the artificially stored water will derive from mounding into previously unsaturated sediments, downgradient movement, and mixing with lower-quality waters. These are governed by additional

hydrogeologic factors such as stratigraphy, aquifer transmissivity, the presence of solute sources such as paleosols, and possible geothermal inputs.

5.1.2.4 Recharge

The extent of the proposed well injection significantly exceeds recharge to the Olinghouse fan. As indicated previously, precipitation in the form of rain and snow on the mountain block moves downward by the force of gravity and ultimately reaches the valley-fill groundwater system. Van Denburgh, *et al.* (1973) using the Maxey-Eakin technique (Maxey and Eakin, 1949; Eakin, *et al.*, 1951), estimated a total annual recharge of 1,400 acre-feet to the Dodge Flat hydrographic area. That supposedly derives from 20,700 acre-feet of precipitation falling on 21,870 acres of drainage area above 5,000 feet altitude. Though the Maxey-Eakin method has been challenged by some workers (*e.g.* Watson, *et al.*, 1976), subsequent studies with an additional 20 years of data have indicated that it provides reasonable estimates of recharge (Avon and Durbin, 1994). It therefore has been used in the present investigation, which estimated the total precipitation at 22,000 acre-feet, the contributing drainage area at about 22,600 acres, and the potential recharge also 1,400 af/y. Discrepancies between Van Denburgh's (1973) investigation and the present one are slight and are caused in part by use of different base maps; this study used 1:24,000 scale maps to determine the drainage areas rather than 1:250,000 scale maps. Precipitation amounts for both studies were based on the same U.S. Weather Bureau data. The only new data since that time was collected by Washoe County for the crest and west slope of the Pah Rah Range above 5,000 feet altitude. This differs little from that used by the USGS for the Dodge Flat area and the two valleys to the west, Spanish Springs Valley and Warm Springs Valley. Table 5.2 shows the calculations used during the present study to estimate potential groundwater recharge to the Dodge Flat basin. Table 5.3 shows the same calculations determined from the individual sub-basins shown in Figure 5.3.

TABLE 5.2
DODGE FLAT RECHARGE ESTIMATES

Altitude Zone (ft)	Area (Acres)	Estimated Precipitation		Potential Recharge Fraction of Total Precipitation	Volume (af/y)
		Range (in)	Average (ft) (af/y)		
8000-8366	<5	20-25	1.9 10	0.25	2
7000-8000	2400	15-20	1.5 3600	0.15	540
6000-7000	6170	12-15	1.1 6790	0.07	480
5000-6000	14020	8-12	0.8 11220	0.03	340
Totals	22590		22000		1400 (rounded)

Another technique for computing groundwater recharge is described by Dettinger (1989) and is called the Chloride Balance Method. This technique assumes that Cl⁻ ion is conservative and therefore that a mass balance exists between input of chloride to and its output from recharge-source areas. Input is from atmospheric dry fallout and that dissolved in precipitation. In the output process, water from precipitation infiltrates into the mountain block above an altitude of 5,000 feet, mobilizes the chloride there and transports it to the valley groundwater system. Infiltration is calculated from:

$$[1] \quad I = \frac{PC_p}{C_i}$$

where I is the average recharge rate (acre-feet/year, af/y), P is the average precipitation rate (af/y), C_p is the average chloride concentration of bulk precipitation on the recharge area (mg/l), and C_i is chloride concentration of groundwater in the basin (mg/l). For a study in Spanish Springs Valley immediately to the west of Dodge Flat, Berger, *et al.*, (1997) used a total chloride fall-out value of 0.38 mg/l to represent the recharge area in the Pah Rah Range. The total precipitation on the drainage area determined for the present study is 27,000 af/y. The chloride concentration of the groundwater in the mountain block near the range front was determined from a water supply well for the Olinghouse mine area and is 8 mg/l. Substituting the above values into the above equation gives:

$$[2] \quad 22,000 \text{ af/y } (0.38 \text{ mg/l } / 8 \text{ mg/l}) \approx 1,000 \text{ af/y (rounded)}$$

This value is less than the recharge estimated using the Maxey-Eakin method, but of the same magnitude. Chloride values in the valley-fill aquifers of Dodge Flat cannot be used because they have been augmented from lithologic or geothermal sources. These low-quality waters flow beneath Dodge Flat into the Truckee River aquifer system and ultimately into the river itself.

5.2 Truckee River Flood-Plain Aquifer

Groundwater modeling for the present study incorporates two reaches of the Truckee River as domain boundaries: Derby to Wadsworth, and Wadsworth to the Nixon gage. Hydrologic assessment of these reaches required estimating the magnitude of water sources, which are dominated by river flows and recharge from groundwater. Water quality and aquifer properties were also ascertained during this portion of the present study.

Flows in the Truckee River vary substantially from month to month, while major changes in groundwater systems can be presumed to take place on far longer time scales, perhaps on the order of years, decades, or even centuries. Groundwater inputs to the Truckee River flood-plain aquifer were therefore treated as constant to establish boundary conditions for the numerical modeling. To characterize the groundwater system using Truckee River solute fluxes, averaging was necessary to evaluate conditions over the longer time scales appropriate to groundwater movement. This approach suppressed the effect of erratic river flows while examining the two reaches that bound Dodge Flat.

5.2.1 Groundwater Sources

Groundwater sources within and bordering the Dodge Flat study area include: the Truckee River itself; orographic recharge to the Pah Rah, Truckee, and Virginia Ranges; and subsurface returns from agricultural applications. Leakage from the Truckee Canal south of the Truckee River is a source of water to the river between the Derby and Wadsworth's gages and to the Fernley area. Geothermal inputs and possible additional subsurface flows may be present east of the river, but at this time are speculative. The volume of flows deriving from each source are different for each reach of the river.

5.2.1.1 Derby-Wadsworth Reach

Natural orographic recharge along the reach between Derby and Wadsworth is not large and originates in the Virginia and Pah Rah Ranges. This is augmented by a minor amount of primary and a major amount of secondary recharge from the Fernley area. The principal aquifers are within fluvial sediments adjacent to the Truckee River, but there is minor production from flanking alluvial deposits. In the upstream portions of this reach, most water originates from the river itself or, along its south bank, from leakage along the Truckee Canal (Sinclair and Loeltz, 1963).

Detailed portrayal of the part of the reach that lies between Fernley and Wadsworth is beyond the scope of this study. Previous efforts (Sinclair and Loeltz, 1963; Van Denburgh, *et al.*, 1978; Bratberg, 1980) have broadly described its hydrologic characteristics, but details concerning water balance, head distributions, groundwater flow paths, and solute loading are complex and currently the subject of a separate investigation by the Desert Research Institute (Alan McKay, DRI, oral communication, 1998). Although the present study incorporates this reach as part of a domain boundary in its numerical evaluation, it relies heavily upon the descriptions of previous workers.

The Fernley-Wadsworth area is dominated by fluvial sediments deposited by the ancestral Truckee River that are capped by Lahontan age lacustrine units (Sinclair and Loeltz, 1963). Stratigraphic relationships at Dodge Flat determined for the present investigation suggest that sediments from pre-Lahontan lacustrine episodes may also be present in the Fernley area. Most wells along this reach produce from within the fluvial units. Sinclair and Loeltz (1963) state that two aquifers are present in the Fernley area: an upper phreatic aquifer with generally poor water quality, and a lower confined aquifer containing good water. No further description was made as to depth or geographic distribution. Examination of well logs recorded with the State Engineer suggests that a thick sequence dominated by clays is present roughly between 100 and 200 feet depth. Production from the zone above the clays takes place at differing depths, usually <~70 feet. Wells that penetrate the lower aquifer differ from one another, usually producing from various zones deeper than ~200 feet. Variable production depths result from different wellhead elevations and the heterogeneous nature of fluvial sediments. For the purposes of groundwater modeling, this study combines hydrologic properties for both fluvial aquifers. Results are discussed in Section 5.2.2.1.

Recharge to the fluvial aquifers between Fernley and Wadsworth derives largely from subsurface and possibly surface agricultural return flows, Truckee Canal

leakage, and the river itself. Currently, the exact means by which these flows reach the Truckee River is unclear since a groundwater divide is present beneath Fernley and gradients are to the northeast and northwest in the principal agricultural areas. Bratberg (1980), using head gradients between this divide and north to the river combined with transmissivities determined from well tests, estimated the agricultural component to be ~7.3 cfs (~5300 af/y), roughly consistent with earlier figures of ~5.8 cfs (~4200 af/y) (Van Denburgh, *et al.*, 1973). Results from the present study indicate inputs of about twice this amount (see Section 7.0). The Virginia Range and Dodge Flat may also supply minor amounts of water to the river between Fernley and Wadsworth, as suggested by topography and groundwater contours (Figure 5.2). Flows of unknown magnitude may possibly enter the river from beneath the dune field northeast of Fernley, as evidenced by solute concentrations observed in wells by the DRI (Alan McKay, oral communication, 1998), CH2Mhill (1990), and from nearby geothermal areas (Garside and Schilling, 1979). In the absence of data, these are assumed to be negligibly small, though this may not be the case (McKay and Bohm, 1998).

5.2.1.2 Wadsworth-Nixon Reach

The second model domain boundary, the reach between Wadsworth and the Nixon gage was divided for the present investigation into two segments: from the north side of Wadsworth to Windmill Canyon, and from Windmill Canyon to the Nixon gage. This division was necessary to retain a number of domestic and agricultural wells within each segment sufficient to permit transmissivity estimates to be made for the Truckee River aquifer.

In his investigation, Bratberg (1980) referred to two slightly different segments along this reach: Wadsworth to the S-S Ranch, and the S-S Ranch to Dead Ox Wash. The S-S Ranch is located approximately one mile down river from Windmill Canyon, and the Nixon gage is situated approximately two miles down river from Dead Ox Wash. Bratberg's (1980) segments, thus, correspond approximately to those used in the present study.

The water budget along this reach is poorly understood, but was estimated first by Bratberg (1980) and again for this study. Bratberg (1980) assumed that low flows in the Truckee River of <~50 cfs represented baseflow conditions, and calculated a net gain to the river of ~16 cfs (~14,000 af/y) between Wadsworth and the Nixon gage. Based upon his one-time stream flow measurements, he determined that the river received ~11.8 cfs (~8500 af/y) between Wadsworth and the S-S, which far exceeds the estimated recharge from the Dodge Flat hydrographic area of ~1.9 cfs (~1400 af/y; this study). Bratberg (1980) judged the amount of agricultural return and springflow below Wadsworth to be small, probably <1.3 cfs (~1000 af/y), and determined that the net gain below Wadsworth of ~13 cfs originated largely from agricultural application in the Fernley-Wadsworth areas. He then extrapolated inflows downstream of the S-S under the assumption that the inflow per unit length of river was the same. His estimated gains and those of the present study (Appendix D) are shown in Table 5.4.

TABLE 5.4
TRUCKEE RIVER BASEFLOW GAINS

River Reach	Bratberg	Present Investigation	
	One-Day Low-Flow, in cfs	Low-Flow Median, in cfs	Cumulative Averages, in cfs
Derby-Wadsworth	3.0	13.0	Not Calculated
Wadsworth-Nixon	16.0	14.9	15.0

Flow gains between Wadsworth and the S-S (Bratberg, 1980): 11.8 cfs

5.2.1.3 Groundwater Solute Input

To confirm Bratberg's (1980) estimates of the average groundwater input along the Wadsworth-Nixon reach, the present investigation used a mass balance approach based on solute concentrations and measured monthly flows in the Truckee River at the Derby, Wadsworth, and Nixon flow gage sites (see Appendices B and C). Records of monthly average flows were obtained (USGS, 1997), but the period of record differs for each site. The longest continuous set of measurements was made at Derby, spanning the water years 1919 to 1997. Periods of record at Wadsworth and Nixon overlapped that at Derby for the past 33 and 46 years, respectively. For those intervals, linear regression analyses were performed using Derby flows as a basis. Results indicate that flows at Derby are highly correlated to those at the other stations ($R^2 > 99\%$) (Table 5.5). Regression coefficients were then applied to the Derby flows to estimate those at Wadsworth and Nixon for years when no measurements were made using the expressions:

Wadsworth Flow = [(Derby-Wadsworth X Coefficient) * Derby Flow] + Derby-Wadsworth Constant

Nixon Flow = [(Derby-Nixon X Coefficient) * Derby Flow] + Derby-Nixon Constant

TABLE 5.5
REGRESSION DATA FOR TRUCKEE RIVER FLOWS

Derby-Wadsworth		Derby-Nixon		Wadsworth-Nixon	
Constant	10.885	Constant	26.520	Constant	30.011
Std Err of Y Est.	99.919	Std Err of Y Est.	85.700	Std Err of Y Est.	71.240
R Squared	0.991	R Squared	0.991	R Squared	0.995
X Coefficient	1.0742	X Coefficient(s)	1.0400	X Coefficient	0.9557
Std Err of Coef.	0.0058	Std Err of Coef.	0.0045	Std Err of Coef.	0.0038

Linear regression coefficients relating flows at Truckee River measurement stations. Because flows at Derby Dam have the longest period of record, these were selected as the independent variable in the calculations. Wadsworth-Nixon coefficients are shown for comparison.
Data source: USGS (1997).

The regressed data set was used to estimate groundwater input along the Wadsworth-Nixon reach. Table 5.6 lists the mean, median, sample standard deviation, coefficients of variance, and flow differences between measurement stations for all months of the year and for the low-flow, low ET months of November and December only. As discussed more fully in Appendix D, the best representation of groundwater input to the Truckee River between Wadsworth and Nixon was obtained from the difference between median flows, rather than mean flows. The figure of ~14.9 cfs (~10,800 af/y) obtained from median flows agrees well with Bratberg's (1980) determinations, and moreover derives from a much greater number of measurements. When used in conjunction with mass fluxes in the Truckee River, this figure also produces estimates of groundwater solute concentrations that accord reasonably with observations from Dodge Flat wells and with Bratberg's (1980) calculations. Additionally, log-probability plots suggest a log normal distribution for low volume Truckee River flows, again indicating the median to be more representative than the mean for the period of record.

TABLE 5.6
MONTHLY TRUCKEE RIVER FLOW STATISTICS, IN CFS

	All Months				Months of November And December Only			
	Median	Mean	Standard Deviation	Coefficient of Variance	Median	Mean	Standard Deviation	Coefficient of Variance
Derby	47.5	401.3	756.5	1.9	24.1	247.9	562.5	2.3
Wadsworth	61.9	441.9	814.6	1.8	37.1	277.2	600.0	2.2
Nixon	72.1	443.9	789.1	1.8	52.0	284.6	585.9	2.1
Differences between flows at the stations:								
	Medians	Means			Medians	Means		
Derby- Wadsworth	14.4	40.6			13.1	29.3		
Wadsworth- Nixon	10.2	2.0			14.9	7.4		

Truckee River flow statistics derived from the regressed data set, in cfs.
Data source: U.S.G.S. monthly average flow data, 1918-1997

5.2.1.4 Conclusion

Results of the calculations summarized in Appendix C suggest that both groundwater flow and solute loadings to the Wadsworth-Nixon reach may be slightly less than those estimated by Bratberg (1980), but of the same general magnitude. Based on a limited set of measurements, Bratberg (1980) estimated that groundwater inflow to the lower Truckee River between Wadsworth and the S-S Ranch is ~12 cfs (~8700 af/y), and the total between Wadsworth and Nixon is ~16 cfs (~11,600 af/y). The present study uses a different set of data to determine base flow and estimates the gain between

Wadsworth and Nixon to be ~15 cfs (~10,900 af/y). Part of this gain is from groundwater recharge to the Dodge Flat hydrographic area estimated to be ~1.9 cfs (~1400 af/y), which results in a net gain of ~13 cfs (~9400 af/y) from other sources. During warmer months, the total gain is diminished by evapotranspiration (ET), estimated to be ~7 cfs (5,100 af/y) by Van Denburgh, *et al.* (1973), and ~5 to ~6 cfs (~3,600 to 4,300 af/y) by this study (Appendix D). However, for modeling purposes, the total ET from Derby to Nixon was estimated at 14,000 af/y.

The principal water source for the Truckee River aquifer is the river itself. Along the Fernley-Wadsworth reach and near Wadsworth on the Wadsworth-Nixon reach, groundwater inflow, though volumetrically low compared to river flows, is significant in terms of solute loading. For Dodge Flat, subsurface orographic recharge is ~1.9 cfs (~1400 af/y), while other groundwater sources, possibly derived from agricultural applications near Wadsworth and Fernley, input ~13 cfs (~9400 af/y). Groundwater movement within the Truckee River aquifer is dominated by those processes.

5.2.2 Groundwater Movement

Monthly average Truckee River flows at Wadsworth range between ~23 cfs and ~7200 cfs, with an average of ~442 cfs and a median of ~62 cfs. In the subsurface, these fluctuations probably dampen within a few hundred feet of the river itself.

Principal movement directions inferred on a regional basis generally apply to the immediate vicinity of the river as well. The limited available groundwater elevation data for Dodge Flat are shown in Figure 5.2. These data originate from water level measurements made in wells surveyed for the present investigation and from levels recorded in drillers' logs with the State Engineer. Because in recorded well logs, sites are described no closer than to the quarter-quarter section, these are subject to location errors of at least several hundred feet, with corresponding elevation errors. Accordingly, wells were chosen to minimize the impact of topography on groundwater elevations.

Groundwater contours correspond broadly to topography, and the dominant movement on Dodge Flat generally trends west to east away from the Pah Rah range toward the Truckee River. Gradients steepen in the northern and extreme southern portions of the study region. The former probably implies lower transmissivities in that area's alluvial deposits, while the latter may derive from a combination of elevated bedrock and paucity of data points. The dominant piezometric feature in the central region is a broad zone of lower water table relief that trends east by northeast from the Olinghouse fan toward the S-S Ranch indicating major flow in that direction. This results from the presence of the highly transmissive alluvial deposits defined by the monitor well field and the Olinghouse production wells (NLRC, 1997). Groundwater flow in this area is thus southeast and northeast toward the well field in the west central Dodge Flat area, and then east by northeast toward the Truckee River.

Figure 5.2 also shows a groundwater depression in the Truckee River aquifer southwest of the Big Bend, just inside the PLPT Reservation boundary. This probably derives from municipal pumpage for Wadsworth. That recharge largely derives from the river is suggested by somewhat shallower gradients on the side facing it. Because of the high transmissivity in the fluvial aquifer, drawdown from pumpage is generally slight.

5.2.2.1 Hydraulic Properties

Transmissivities within the Truckee River aquifer have been recorded for a number of Wadsworth area wells (CH2MHill, 1990; SEA, 1994). In the present study, new transmissivity estimates were made which compared favorably with these previous values. The procedure involved selection of four calibration wells for which good aquifer test and lithologic data were available. These wells provided information against which estimates for hydraulic properties elsewhere in the Truckee River aquifer could be compared. Drillers' lithologic logs of each calibration well were examined and the recorded lithologies were categorized. A hydraulic conductivity was assigned to each lithologic category based on typical values reported in Freeze and Cherry (1979). An average hydraulic conductivity was then computed for the screened portion of the calibration wells based on these assignments, assuming flow parallel to horizontal layering.

The transmissivity obtained from pump tests of each calibration well was divided by the thickness of its screened interval to produce a figure for hydraulic conductivity. For the four calibration wells, these were tabulated and the results compared to the estimated hydraulic conductivities. To provide a better estimate, the input conductivity figures derived from Freeze and Cherry (1979) were then adjusted until a satisfactory fit was obtained between calculated and measured conductivities. Only minimal adjustment was necessary, and moreover the adjusted input hydraulic conductivities all remained within ranges typical of their respective lithology as reported in Freeze and Cherry (1979). Data used for these computations are shown in Appendix E.

Table 5.7 derives from Appendix E and compares calculated against measured conductivities for the four wells. Two correspond within ~15%, one within ~30%, and the other within 1%. These are extremely close fits since for a given lithology conductivities can readily vary by two or more orders of magnitude (Freeze and Cherry, 1979). Note also that the transmissivities for the wells are within the range reported by Bratberg (1980) for the Truckee River aquifer.

The adjusted conductivities determined for each lithology were then applied to selected wells within the Truckee River aquifer. This entailed dividing the aquifer into five segments: (1) West of Painted Rock in the Truckee Canyon; (2) between Painted Rock and the PLPT reservation boundary; (3) reservation boundary to the north side of Wadsworth; (4) Wadsworth to Windmill Canyon; and (5) Windmill Canyon to the fish hatchery at the northern boundary of the study area (Figure 5.4). Within each segment, wells were selected that lay within the fluvial aquifer and were sufficiently deep to provide a reasonable lithologic representation. Adjusted conductivities were assigned to stratigraphic intervals within each well as determined from drillers' logs. From these, the overall conductivity for the entire well was computed, again assuming horizontal flow and stratification. Results from each well in an aquifer segment were then arithmetically averaged to estimate the hydraulic conductivity for that segment. These are summarized in Table 5.8 and discussed and documented more fully in Appendix E.

Transmissivities used in the numerical modeling were obtained by multiplying the average conductivity for each aquifer segment with its thickness. Bedrock was intersected in only a few of the wells used to assess hydraulic conductivity: two

TABLE 5.7
ESTIMATED HYDRAULIC CONDUCTIVITIES
WITHIN THE TRUCKEE RIVER

Comparison of estimated and calculated hydraulic conductivities for Wadsworth and Stampmill Estates wells. *

	<i>Estimated Conductivity</i>	<i>Measured Conductivity</i>	<i>Transmis- sivity</i>	<i>Screened Interval (ft)</i>	<i>Ratio K_{meas}/K_{est}</i>	
Stampmill West	187	188	15000	80	1.01	
Stampmill East	343	294	30000	102	0.86	
Wadsworth Prod. #1	196	224	22400	100	1.14	
Wadsworth Prod (New)	1965	2500	50000	20	1.27	
				Average	1.002	=Ratio Factor

Conductivity estimates based on CH2MHill (1990) transmissivity and well construction data for the Wadsworth area (Truckee River Aquifer Segment 3).

<i>Arithmetic Mean</i>	<i>Geometric Mean</i>
1756 gpd/ft ²	767 gpd/ft ²
235 ft/d	103 ft/d

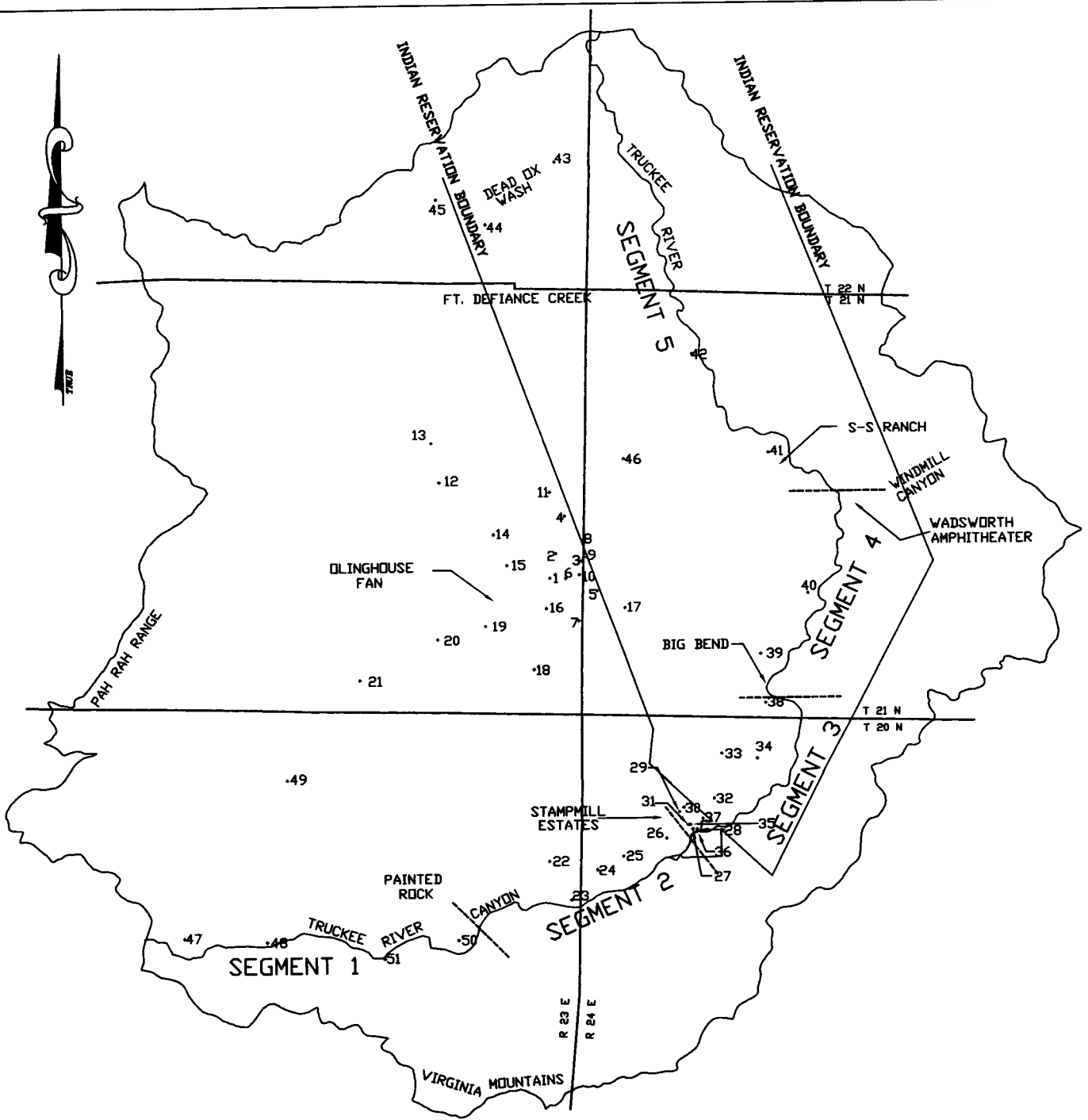
Transmissivity ranges based on pump test interpretations. Data from Wadsworth and Stampmill Estates area (Truckee River Aquifer Segment 3). *

	<i>High</i>	<i>Middle</i>	<i>Low</i>
Stampmill West	18,207	15,000	6,336
Stampmill East	44,000	30,000	8,297
Wadsworth Prod. #1	22,440	22,400	4,803
Wadsworth Prod. (New)	60,000	50,000	50,000

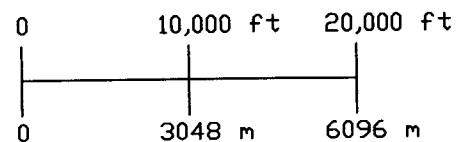
Transmissivity range given in Bratberg (1980) for Truckee River aquifer: 20,000 - 40,000


* Units are gpd/ft.² for conductivity and gpd/ft. for transmissivity.

Measured and estimated hydraulic conductivities within the Truckee River aquifer near Wadsworth. Data sources: SEA, 1993; Washoe County Utilities, 1995; CH2MHill, 1990; Bratberg, 1980.



LEGEND:
50 Well & Map Number
----- Segment Break



 waterresource consulting engineers, inc. <small>700 THREE STREET - BEND, UTAH - 89001</small>		
DATE	REVISIONS	BY

FERNLEY TOWN UTILITIES
LYON COUNTY

Truckee River Aquifer Segments
for Transmissivity Estimates
Figure 5.4

JOB NO. 8518.1142
DATE 10/28/99
DRN. BY LCS
CHK. BY JL

TABLE 5.8
ESTIMATED HYDRAULIC PROPERTIES
OF THE TRUCKEE RIVER AQUIFER

Segment	Assigned Conducti- vities gpd/ft ²	Conductivities Adjusted using Ratio Factor		Average Depth To Bedrock	Average Transmissivity		Segment Description
		gpd/ft ²	ft/day		gpd/ft	ft ² /day	
Segment 1	1181	1184	158	70	83099	11136	West of Painted Rock Exit
Segment 2	631	632	85	158	99921	13391	Painted Rock -> Reservation Boundary; includes Stampmill
Segment 3	1017	1019	136	171	173948	23311	Reservation Boundary -> Wadsworth; includes Production Well
Segment 4	604	605	81	258	155729	20870	Wadsworth->Windmill Canyon
Segment 5	238	238	32	306	72711	9744	Windmill Canyon -> Hatchery
Mean	734	736	98	193	141506	18964	Combined mean for all segments

Segment properties are averages obtained from selected wells within each. Conductivity data are those from Tables E.1, E.2 and E.3.

Note that depths to bedrock are minimal: estimates for Segments 3, 4, and 5 are based on maximum drilled depths and only 3 bedrock intersections flanking the course of the Truckee. Gravity data suggest up to 2700 feet of sediment in the area adjoining the river on the west. Much of that may be fluvial.

Conductivities used in the estimation process were selected from ranges reported in Freeze and Cherry (1979) for the appropriate lithology. These were adjusted to provide a best fit with pump test data after conversion to English units. Interpretation of pump tests gave a range of possible transmissivities, which are shown on the following page. The most reasonable were selected to represent actual aquifer transmissivity. Note that correlation of lithology and transmissivity was made only for the screened intervals in the tested wells. To estimate hydraulic properties of the thickness of the Truckee River aquifer, each lithologic unit in a borehole was assigned a conductivity and an average taken for the entire hole assuming flow parallel to horizontal stratification.

each from Segments 1 and 2, and one from Segment 3. Within those segments, the depths to bedrock were exceeded elsewhere by wells that did not reach bedrock, so aquifer thickness was obtained by averaging the depth to bedrock and the maximum well penetration. For the remaining segments, aquifer thicknesses were conservatively taken to be the maximum recorded drill depth. Depths to bedrock are shown in Table 5.8 and Appendix E. They range between ~70 feet in Segment 1 and >300 feet in Segment 4. Particularly for Segments 3, 4, and 5, the tabulated depth should be considered minimal, since sediment thicknesses downstream from Wadsworth are substantially in excess of 300 feet (Carpenter, 1997; Hartley, 1998). Estimated transmissivities for each segment in ft^2/d are: (1) ~11,000; (2) ~13,000; (3) ~23,000; (4) ~21,000; and (5) ~9,700, with an average of ~19,000. In the model, an average value of 20,000 ft^2/d is used.

5.2.2.2 System Yield

The maximum system yield depends upon aquifer transmissivity and is limited by recharge. If, for simplicity, a 1000-foot aquifer width, a 10-foot drawdown, and Darcian flow are assumed, the maximum possible yield for each segment can be estimated by multiplying its length, the transmissivity figures from Table 5.8 and a gradient of 0.01 ft/ft . Even with these conservative assumptions, the results, shown in Table 5.9, indicate that in any segment the capability of the aquifer to transmit water is a significant proportion of the total Truckee river flow.

5.2.2.3 Storage

The maximum contained water within each aquifer segment is the product of its volume and its average effective porosity. Aquifer volume depends upon the depth and areal extent of the fluvial deposits associated with the present and ancestral Truckee River (Hydrostratigraphic Unit HS5, see Figure 4.2). A minimum volume can be estimated by assuming that fluvial deposits underlie only the present channel, and a thickness equal to the average bedrock depth calculated from maximum well penetration. These assumptions are reasonable in that most wells penetrate only near-surface deposits close to the river. Outside of the floodplain, lacustrine sediments comprise most of the upper portion of the stratigraphic section, and groundwater quality is poor, suggesting that its source is not the Truckee River. Assuming further that effective porosity is ~20% (Freeze and Cherry, 1979), the total amount of water contained within the river aquifer (Segments 1-5) is ~200,000 acre-feet, or about four times the median annual Truckee River flow at Wadsworth (Table 5.9).

5.2.2.4 Recharge

Much of the water contained within the aquifer derives from the Truckee River itself. Limited orographic recharge takes place, mostly from the Pah Rah range into Dodge Flat and thence to the river (~1.9 cfs). Between Wadsworth and Nixon, flows in the Truckee River increase by ~15 cfs, an amount substantially greater than that orographic recharge. That gain is consistent with solute concentrations on Dodge Flat and with observed solute fluxes in the river (Appendix C, Tables C.3 and C.4). Thus, we conclude that approximately 2 of the 15 cfs gain is from Dodge Flat and the remainder from east and south of the river. Bratberg (1980) suggests that most of the gain takes place between Fernley

TABLE 5.9
ESTIMATED POTENTIAL YIELDS OF TRUCKEE RIVER AQUIFER

a) Aquifer yield by segment assuming Darcy flow, a gradient of 0.01, and transmissivities and depths from Table 5.10.

Segment	Transmissivity ft ² /d	Segment Length (ft.)	Gradient	Yield Ft ³ /d	af/y	Proportion, in percent, of Median Annual Wads. Flow
Segment 1	11136	20000	0.01	2.2E+06	19,000	42
Segment 2	13391	24000	0.01	3.2E+06	27,000	60
Segment 3	23311	15000	0.01	3.5E+06	29,000	65
Segment 4	20870	16000	0.01	3.3E+06	28,000	62
Segment 5	9744	40000	0.01	3.9E+06	33,000	73
Mean	18964	115000	0.01	2.2E+07	180,000	408
Weighted Mean	14065	115000	0.01	1.6E+07	140,000	302

b) Aquifer volume and contained water by segment assuming a porosity of 0.2, unconfined conditions, and depths from Table 5.8.

Segment	Average Porosity	Average Aquifer Width (ft)	Aquifer Thickness (ft)	Contained Sediment Volume (ft ³)	Contained Water Volume ft ³	acre-feet	Proportion, in percent, of Median Annual Wads. Flow
Segment 1	0.2	1000	70	1.4E+09	2.8E+08	6500	14.4
Segment 2	0.2	1400	158	5.3E+09	1.1E+09	24000	54.5
Segment 3	0.2	4200	171	1.1E+10	2.2E+09	49000	110.3
Segment 4	0.2	3800	258	1.6E+10	3.1E+09	72000	160.6
Segment 5	0.2	1500	306	1.8E+10	3.7E+09	84000	188.0
Mean	0.2	2400	193	5.3E+10	1.1E+10	244000	544.0
Weighted Mean	0.2	2000	193	4.4E+10	8.9E+09	204000	453.8

c) Truckee River flows at Wadsworth .

	cfs	ft ² /d	af/y
Mean Annual Wadsworth Flow Rate	442	3.8E+07	320,000
Median Annual Wadsworth Flow Rate	62	5.3E+06	45,000

Flow rates based on regressed monthly average flows in cfs

Transmissivities, potential yields, and contained water as volumes and proportions of median annual Wadsworth flows. Calculations assume Darcy flow and a gradient of 0.01.

and Wadsworth, and between Wadsworth and the S-S ranch, corresponding roughly to Segments 3 and 4 in the present study. Characterization of that input is the subject of ongoing investigations by DRI; previous workers have attributed it to surface and subsurface returns from agricultural application near Fernley (Sinclair and Loeltz, 1963; Bratberg, 1980; Van Denburgh and Arteaga, 1985). Because of its magnitude and solute content, it is important in assessing the regional water resources along the lower river.

5.3 Discharge from Dodge Flat and the Truckee River Aquifer

Discharge from the Dodge Flat region today probably differs little from that of pre-development times and is by springflow, evapotranspiration, and groundwater outflow to the Truckee River. On Dodge Flat proper the depth to water precludes phreatophytes except at the DePaoli stock well where the depth to water is about 35-40 feet (probably a perched aquifer). Approximately three acres of greasewood are located immediately down gradient from this well. The stand is scanty, with about 15 percent density, and probably does not use more than about two acre-feet per year. Within the mountain block, particularly along the mostly perennial Fort Defiance Creek, evapotranspiration is estimated to be less than 100 acre-feet per year.

Evaporation-induced losses to the major Dodge Flat groundwater system are negligible, and except near springs plant roots do not penetrate the water table. Thus, there is no major evapotranspirative enhancement of solute concentrations and associated degradation of water quality on the lower Olinghouse fan or Dodge Flat. Deuterium-oxygen-18 analyses by McKay and Bohm (1998) suggest that evaporation is significant only in the mountain block recharge areas and along perennial streams.

5.3.1 Predevelopment Conditions

No specific data are available concerning predevelopment groundwater conditions in the Truckee River aquifer or on Dodge Flat. Present consumption on Dodge Flat near the Olinghouse fan is minimal, on the order of ~10 af/y, mostly from stock wells, and so it is unlikely that predevelopment conditions differed substantially from current conditions.

Present-day regional flows are toward the river from adjoining areas such as Dodge Flat. Except for the groundwater depressions near Wadsworth (Figure 5.2), predevelopment groundwater levels over much of the Truckee River aquifer probably differed little from those observed today: water levels near the river approximately equal the river elevation, though in some areas local groundwater gradients probably have reversed from their predevelopment directions.

Changes in lower Truckee River flows due to agricultural diversions have probably not influenced regional groundwater gradients on Dodge Flat to a large extent, though water levels adjoining the Truckee River may have been affected. For example, in a 300 foot thick aquifer, a 6-foot drop in water-level elevation will induce only a ~2% gradient change. Similarly, seasonal fluctuations in water levels will damp out within a comparatively short distance of the river.

5.3.2 Present Condition and Pumpage

Presently, groundwater flows within the Truckee River aquifer are generally toward the river from adjoining recharge areas, apart from localized drawdowns around domestic wells. An exception to this pattern can be seen in Figure 5.3, which shows a groundwater depression in the eastern part of aquifer Segment 2 and the western part of Segment 3. This depression

probably results primarily from Wadsworth municipal pumpage and from the two Stampmill Estates municipal wells. Because transmissivities are generally high within the aquifer, drawdowns at the river tend to be small.

5.3.2.1 Pumpage

Maximum pumpage at Stampmill Estates is proposed to be ~600 gpm (~1.4 cfs ≈ ~1000 af/y) for total build-out (SEA, 1994). The Indian Health Service reports that all dwellings in Wadsworth are on the municipal system, which at the same use rate indicates ~1.2 cfs (~870 af/y) withdrawn. This is in reasonable concurrence with municipal use reported to the BLM (1997) of 783 af/y (~1.1 cfs). Assuming a 50% return flow, Stampmill Estates and Wadsworth combined consume a net ~940 af/y (~1.3 cfs) and return a like amount to the river's groundwater system.

Elsewhere along the Truckee River aquifer, domestic use is limited: a total of 10 wells of all types are reported for Segment 1; 24 in Segment 2 (includes Stampmill Estates); 30 in Segment 3; 18 in Segment 4; and 17 in Segment 5 (includes S-S Ranch irrigation well). If all were domestic wells, these correspond to 38, 91, 68, and 65 af/y respectively for Segments 1,2,4, and 5, for a total of 262 af/y (~0.4 cfs). At a 50% return flow, these figures would indicate a minimum additional consumption of ~0.2 cfs (~150 af/y). Some of these wells are agricultural; some lie within the municipal areas and have been included twice in the above water use estimates. If the net effect of these inherent errors is relatively small, pumpage estimates from well data, when summed with municipal pumpage, give a total loss to the Truckee River aquifer from domestic consumption of ~1200 af/y (~1.7 cfs). Table 4.2 shows use categories for all Dodge Flat wells incorporated in the present study.

5.3.2.2 Irrigation

Irrigation in the Dodge Flat area is essentially confined to regions on both sides of the Truckee River sourced by the fluvial aquifer. A large proportion (~850 af/y) is used by the S-S Ranch (PTI, 1997). Annual duties appropriated by the State Engineer total ~550 af/y (BLM, 1997), but a proportion of this (~350 af/y) is assigned to springs and is probably unused. Van Denburgh, *et al.*, (1973) estimated ~1000 irrigated acres along the river, corresponding to ~3000 af/y net evapotranspiration. Assuming a 25% return flow, irrigation losses to the Truckee River aquifer in the vicinity of Dodge Flat probably are between ~850 af/y (~1.2 cfs) and ~3000 af/y (~4.1 cfs).

5.3.2.3 Mining

Proposed mining activities by Alta Gold will over a 5-year mine life withdraw ~500 af/y (~0.7 cfs) of poor-quality water from production wells at the base of the Olinghouse fan. This figure may decrease to ~400 af/y (~0.6 cfs) for an additional two years during reclamation (BLM, 1997). A maximum possible additional five years' pumpage may be required should new developments extend reserves beyond the presently estimated limits. Current pumpage at the Paiute gravel pits, about a mile north of Wadsworth, withdraws an unknown quantity of water from fluvial deposits adjoining the river on its east bank. This water apparently is returned directly to the river, so losses there are likely to be small.

5.3.2.4 Summary

Present consumption exclusive of mining from the Truckee River aquifer between Derby and Nixon is in the range of ~2.2 cfs (~1600 af/y). Most of this withdrawal takes place in the vicinity of Wadsworth. It is compensated mainly by recharge from the river itself, but other sources such as irrigation return flows, TCID canal leakage, and possible flows of unknown origin also contribute locally (Bratberg, 1980; this study). Characterizing these additional flows is beyond the scope of the present investigation, and is the subject of study by DRI (Alan McKay, oral communication, 1998).



SECTION 6.0

SURFACE WATER RESOURCES

Surface water resources on and around Dodge Flat are dominated by the Truckee river. Springs are present within the Pah Rah range, but only a few are found on Dodge Flat itself, and their flows are small. Other springs are found adjoining the Truckee River on its east bank between Wadsworth and the S-S Ranch. Flows to these originate largely from agricultural returns and constitute at most ~1.3 cfs (~1000 af/y) (Bratberg, 1980).

Surface streamflows are minimal. Higher within the Pah Rah range are several semi-perennial creeks (e.g., Olinghouse Creek, Fort Defiance Creek, Jones Creek) and a number of ephemeral drainages. However, only under extreme runoff conditions do any of these extend significantly onto the alluvial fans bordering Dodge Flat (BLM, 1997). The vast majority of orographic recharge takes place in the mountain block.

6.1 Truckee River

Despite an extensive reservoir and diversion system, flows in the Truckee River are erratic. Monthly average Truckee river flows are summarized in Appendix C and Table 5.6. The regressed data from the present study show a minimum monthly flow of ~23 cfs (~16,500 af/y) at Wadsworth, a maximum of ~7200 cfs (~5,200,000 af/y), a mean of ~440 cfs (318,000 af/y), and a median of ~62 cfs (~44,800 af/y). Evapotranspiration losses, between Wadsworth and Derby, range between ~7 cfs (~5000 af/y) as estimated by Van Denburgh, *et al.* (1973) and ~13 cfs (~9,400 af/y) estimated for this study.

River flows are augmented by groundwater input along the reach between the Truckee River gages at Wadsworth and near Nixon. Bratberg (1980) for the year 1979 estimated a subsurface discharge to the river between Wadsworth and the S-S Ranch of ~11.1 cfs (~8,000 af/y) and between the S-S and Nixon of ~7.4 cfs (~5350 cfs), for a total of ~18.5 cfs (~13,400 af/y). Based on median flows from those low-flow months when evapotranspiration was also minimal, the present investigation arrived at a figure of ~15 cfs (~10,800 af/y) between Wadsworth and Nixon. This gain cannot be observed at high flows, simply because of the magnitude of the river flows. Bratberg (1980) estimated that above ~1000 cfs, bank storage mechanisms temporarily withdraw water, resulting in a net loss between Wadsworth and Nixon. Examination of regressed monthly average flow data suggests that the loss mechanism is most evident between ~550 cfs and ~2200 cfs.

6.2 Mountain Front Runoff

Mountain front runoff, as indicated previously, is one of three components of precipitation that falls on the mountain block. The other two are groundwater recharge and evapotranspiration. Even though these are separate processes they are greatly interrelated. Mountain front runoff is defined as the volume of surface water that crosses the contact between the consolidated rocks of the mountain block and the unconsolidated sediments of the alluvial basin. This occurs when the infiltration capacity of the soil and rock and the evapotranspiration rate is exceeded by the volume of available water. Precipitation that infiltrates through the soil mantle, escapes evapotranspiration and moves down-gradient, may contact a topographic irregularity, forming springs or seeps. Similarly, fractures in the mountain block intercept groundwater flow and provide a conduit to the surface where the water emerges. Thus, groundwater may reappear through specific springflow orifices or as diffuse springflow and is considered to be surface water. This surface water is subject to evapotranspiration during its time of exposure. Springflow and runoff that do not reach a drainage channel in sufficient volume to reach the river either evapotranspire or infiltrate to the groundwater system. Depending on the individual drainage, surface water at the mountain front may have a

groundwater component. Similarly, groundwater may have been influenced by surface processes taking place in recharge areas. Isotopic data collected for the present investigation indicate this to be the case on the Olinghouse fan (McKay and Bohm, 1998).

For the Dodge Flat hydrographic area Van Denburgh, *et al.*, (1973, Table 10, p. 35) estimated the mountain front runoff at 200 af/y. This differs significantly from the results presented in Table 6.1 which are based on the methods of Hedman and Osterkamp (1982). The table lists the estimated runoff from the various drainages tributary to Dodge Flat and shows a total runoff of 1,000 acre-feet/year; this is five times greater than the amount estimated by Van Denburgh, *et al.* (1973), and approximately three times that estimated by JBR Environmental in the Environmental Impact Study for ALTA Gold (BLM, 1997).

TABLE 6.1
MOUNTAIN FRONT RUNOFF FROM SELECTED
DRAINAGES TRIBUTARY TO DODGE FLAT

Drainage, listed from south to north	Type ¹	Active channel width, in feet ²	Average annual flow, in acre-feet ²	Channel material Characteristics
Pierson	E	5	100	Bed is coarse sand, banks are gravel and 3-5 in diameter rock
Olinghouse	E	3	50	Bed and banks gravel and coarse sand, banks have small cobbles
Frank Free	E	4	80	Bed and banks mostly sand
Tiger	E	4	90	Bed coarse gravel, up to 8 in, banks same with cobbles
White Horse	E	4	90	Bed and banks gravel and rock up to 5 in diameter
Fort Defiance	P	3	400	Bed and banks gravel with small cobbles 4-6 in diameter
Dead Ox	E	7	200	Bed mostly sand and gravel with some 3-4 in diameter rock, banks are soil and gravel up to 4 in diameter

TOTAL (rounded) 1,000

1. E is ephemeral, P is perennial less than 80 percent of the time.

2. Based on techniques described by Hedman and Osterkamp (1982)

Both methods are based on regional relationships and channel geometry measurements, but those of Hedman and Osterkamp (1982) are more widely accepted and take into account the character of the channel sediments and the estimated length of time a drainage flows.

The fate of the 1,000 acre/year is uncertain. In part, it depends on the timing and the character of the runoff. Flow resulting from summer storms exits the mountain block and mostly evapotranspires back to the atmosphere. Some of the flow in the drainages resulting from melting snow and winter rain undoubtedly infiltrates through the channel bed to the water table after passing the mountain front-alluvial fan contact. Isotopic evidence suggesting that evapotranspiration that has impacted recharge waters on Dodge Flat has been reported by McKay and Bohm (1998) and support the infiltration of surface water runoff to the groundwater system.



SECTION 7.0

WATER RESOURCES BUDGET

The water resources of the Dodge Flat area are dominated by the Truckee River and its spatially associated aquifer system to the extent that withdrawals from that aquifer will impact river flows to Pyramid Lake. Any regional resource assessment therefore must take into account the complex budget of the Truckee River aquifer, many components of which are unquantifiable at present. By comparison, the water resource budget for Dodge Flat is both smaller and simpler. It is more readily quantified, albeit empirically, since interaction with the Truckee River aquifer takes place only along their shared boundaries.

7.1 Dodge Flat

Figure 5.1 depicts the groundwater budget components for Dodge Flat and Table 7.1 quantifies the water resources budget. Groundwater sources are dominated by subsurface recharge from the Pah Rah range (~1300 af/y). Other contributions are sufficiently minor to lie within the error limits for recharge. Surface streamflow and springflows, all of limited volume, frequently arise from emergent recharge waters. Part of this emergent water is lost to evapotranspiration, and the remainder re-enters the groundwater system. The existence of geothermal contributions on Dodge Flat remains unproven, but if present these are also likely to be small (see Section 8.1.1).

TABLE 7.1
WATER RESOURCES' BUDGET
FOR DODGE FLAT

INFLOW	ACRE-FEET
Precipitation (22,000 acre-feet/year)	
Recharge	1,400
Mountain Front Runoff	1,000
Groundwater (from Fernley Basin)	9,000
Truckee Canal Return Flow, Ground- and Surface Water	34,000
Truckee River, below Derby Dam	291,000
Total (rounded)	336,000
 OUTFLOW	
Evapotranspiration (19,600 from mountain block)	
Phreatophytes Plus Cropland	14,000
Urban Use	700
Truckee River at Nixon	321,000
Total (rounded)	336,000

Losses include minor evapotranspiration near springs, surface streams, and stock wells. Domestic consumption in the amount of 1-3 af/y is supplied by a localized perched water table to a handful of residences south of the Olinghouse fan. Presently, there is no industrial consumption, but in the near future proposed mining activities in the Olinghouse district will withdraw ~500 af/y of mostly poor-quality groundwater for a period of about five years (perhaps as much as 10 years), followed by an additional 500 af/y for an unknown period of time. This water will be used for processing, reclamation, and dust

abatement, and thus lost to the groundwater system. Although the volume withdrawn exceeds the ~300 af/y estimated recharge to the Olinghouse Canyon drainage, it is not expected measurably to impact flows in the Truckee River, according to PTI (1997).

Based upon basin volumes inferred from gravity data and an assumed porosity of 20%, an order of magnitude estimate for the total volume of water contained beneath Dodge Flat is ~7,000,000 acre-feet, or roughly 18 times the annual flow of the Truckee River (Appendix B, Table B.1). Because much of this water is inaccessible, a well penetration depth of ~100 feet into the saturated zone provides an estimate for useable volume of ~110,000 acre-feet. These figures presume unconfined conditions, where the specific yield of an aquifer approximately equals its effective porosity.

A large proportion of Dodge Flat water is poor-quality, but resistivity interpretations suggest that a zone of good quality water may be present in alluvial deposits flanking the Pah Rah range (Paul Hartley, Adgis, 1998, oral communication). The presence of this water was indicated by geochemical sampling of monitor and production wells near the base of the Olinghouse fan (see Table 8.1). The width, depth, and water quality of this zone necessarily must vary depending upon lithology and local orographic recharge. However, the volume of fresh water was crudely estimated at ~1% of total contained basinal water assuming a volume of the fresh water zone proportional to its width (Appendix B, Figure B.1, Table B.1).

Groundwater flow underlying Dodge Flat ultimately enters the Truckee River aquifer. Transmissivity estimates and numerical modeling indicate that a large proportion of this flow enters the river between Wadsworth and the S-S Ranch. Similar conclusions were drawn by Bratberg (1980) and during the present investigation based upon solute loadings in the river. Even though these flows from Dodge Flat contribute only a minor volume to the water budget of the fluvial aquifer, any consumption of groundwater from Dodge Flat will ultimately result in less water reaching the Truckee River.

7.2 Truckee River Flood Plain Aquifer

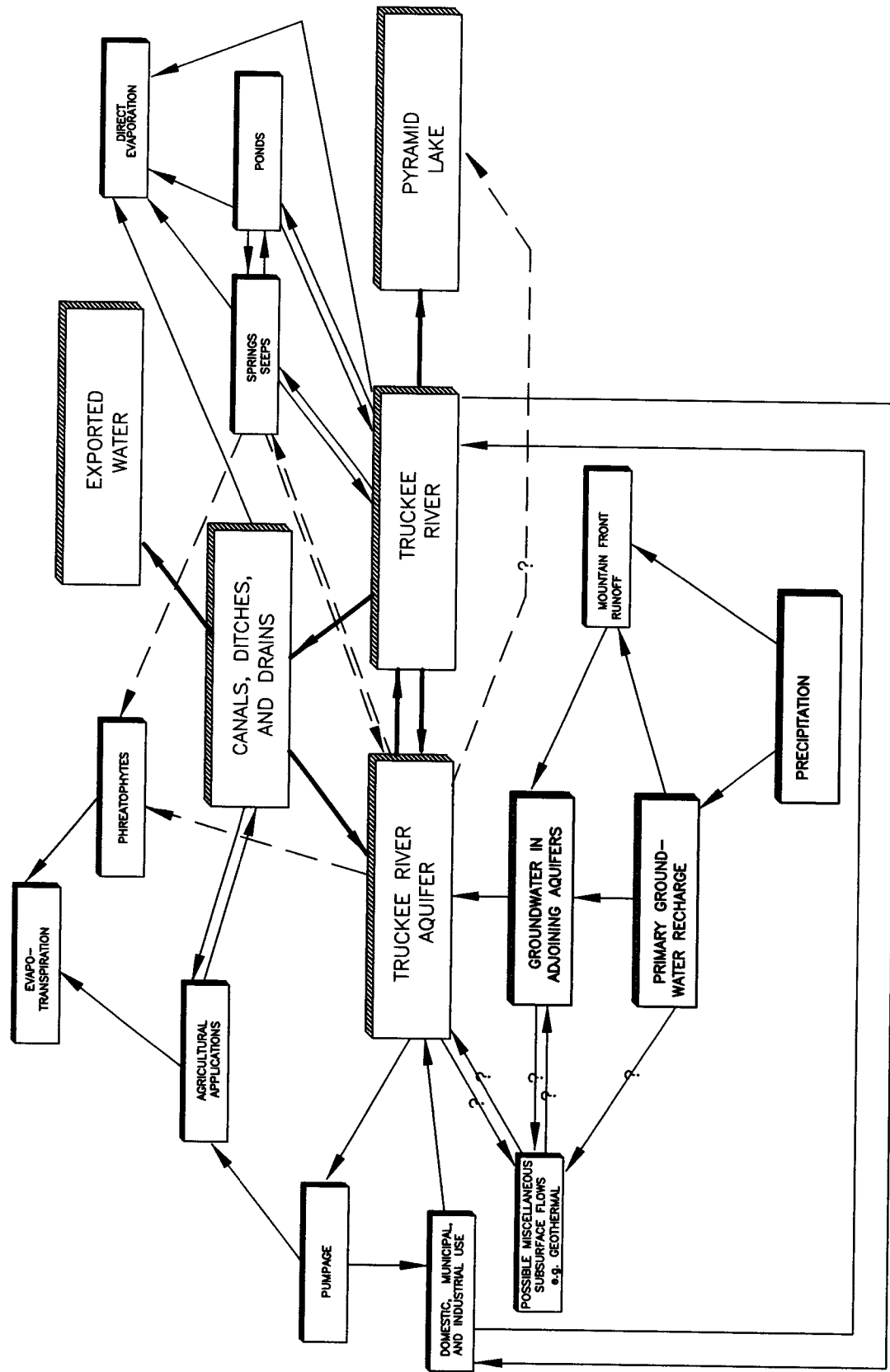
As indicated in Figure 7.1, the water budget for the Truckee River aquifer is complex, and for the most part unquantifiable at the present time. Much of that complexity arises from the sheer length of the aquifer and the number of interrelated hydrologic processes that take place within and along it. Their characterization is the subject of ongoing investigation by the Desert Research Institute. Accordingly, the following discussion addresses the water budget in a conceptual, rather than quantitative, fashion, dealing in turn with inputs, losses, storage, and the impact of an aquifer recharge, storage, and recovery (ASR) system. Problem areas are identified.

Inputs to the aquifer include primary groundwater recharge, mountain front and other surface runoff, possible geothermal flows, spring seepage, and various potential secondary flows such as leakage from ditches and canals, excess irrigation application, and municipal, domestic, and agricultural returns. The greatest single water source to the aquifer is the Truckee River.

7.2.1 Sources and Losses

Primary groundwater recharge takes place in the surrounding mountain ranges. The amount supplied from the Virginia and Truckee ranges is small, the former entering the fluvial aquifer in the Truckee canyon upstream of Wadsworth (Figure 5.3 and Table 5.3) and the latter downstream of it. The Pah Rah range supplies minor volumes within the canyon, but the majority of its recharge enters the groundwater system underlying Dodge Flat. Surface streamflows, mostly storm runoff, are minimal, as are springflows (BLM, 1997), some of which originate secondarily from agricultural applications (Bratberg, 1980). The magnitude of possible geothermal flows is

CONCEPTUAL WATER BUDGET



unknown, though probably small, based upon the mass balance estimates of Appendix F. The remaining inputs derive directly or indirectly from the river itself in the form of secondary flows.

The principal secondary flow derives from irrigation water, which is diverted from the Truckee River into the Truckee Canal at Derby Dam, and at a few minor ditches near Wadsworth. For the period 1967-1996, the average Truckee Canal diversion was ~179,000 af/y (~247 cfs) (TCID, 1997). Bratberg (1980) reports diversions at the other ditches to be on the order of 1,000 af/y. Losses from the Truckee Canal consist mostly of seepage, and return flow from canal regulation, and for the same time interval have been calculated by difference to average 20,500 af/y (~28.3 cfs) between gages at Wadsworth and Hazen. The median loss is ~20,800 af/y (~28.7 cfs) (TCID, 1997). In the Truckee canyon where the canal parallels the river, a large portion of that seepage directly enters the fluvial aquifer and ultimately the river itself. At Wadsworth and Fernley, leakage enters the Fernley groundwater system. Owing to differing bed characteristics and construction materials, it is unlikely that seepage is uniform along the canal. Nevertheless, as shown in Figure 7.1, estimates of losses along the Derby-Wadsworth segment of the canal (~12.5 cfs) roughly equal gains in the Truckee River along that same reach based on median winter month flows (~13.1 cfs, see Table 5.6); they also differ little from median gains for all months of the year (~14.4 cfs), though they diverge widely from average gains (~40.6 cfs). Canal loss estimates for the Derby-Wadsworth segment of the canal were determined using the per mile losses of ~1.4 cfs (~800 af/y per mile) attributed to the Wadsworth-Hazen segment. Further analysis of canal losses is beyond the scope of the present investigation, but is important to understanding groundwater flow in the Fernley basin (see Section 7.3).

Other secondary inputs to the Truckee River shown in Figure 7.1, consist of return flows from agricultural, municipal, and domestic uses. These include excess irrigation application, drainage water from gravel pits, treated sewage, and septic discharge. The Truckee Canal supplies most irrigation water to the Fernley area, but water is returned from several minor ditches above and below Wadsworth (Bratberg, 1980; Lico, *et al.*, 1992).

Known losses to the river aquifer include: ET from crops and phreatophytes; agricultural, municipal, and domestic consumption; and surface water evaporation from springs, canals, transient ponds, and the river itself. The largest of these losses is ET, which is estimated to be ~14,000 af/y (~19 cfs) for the region between Derby and Nixon; of this, ~9,000 af/y is lost below Wadsworth. It is also conceivable, though unproven, that water from within the fluvial or adjoining aquifers enters fractures and later reappears as geothermal flow. These losses are likely to be small.

The magnitude of river-aquifer interactions relative to other flows indicates that activities affecting the river aquifer will impact the Truckee River. This is evident from Figure 5.2, in which drawdown from pumpage at Stampmill Estates and Wadsworth produces water table gradients away from the river. A realistic zone of potential development might extend about three miles upstream and downstream of Wadsworth. Those segments of the river aquifer (see Table 5.9(b), Segments 3 and 4; and Table 5.6) contain ~120,000 acre-ft of water, roughly twice the median (and average annual) Truckee River flow at Wadsworth, and three times its baseflow. Depending on aquifer properties and hydraulic gradient, the potential yield of that segment may be on the order of 100,000 af/y (~140 cfs), comfortably in excess of median flows and approximately one-third of average flows (Tables 5.6 and 5.9(a)).

7.2.2 Water Balance

Presently, the water balance in the Truckee River aquifer between Derby and Nixon embraces a number of factors requiring additional quantification. Chief among them are ET losses, returns to the river from that portion of the Truckee Canal south and west of Wadsworth, and subsurface returns along the reach between Stampmill Estates and Windmill Canyon (which includes aquifer segments 3 and 4, Figure 5.4). This is termed the Wadsworth-Fernley reach, and constitutes a domain boundary for the numerical modeling effort in the present study. Subsurface flows along this boundary involve both agricultural returns and additional canal losses in the Fernley area. Because the Wadsworth gage on the Truckee River is situated in the approximate center of that reach, an unknown proportion of this subsurface flow bypasses the gage, and is not recorded. There is thus no direct way to estimate those inflows based purely on measurements of river stage, and the magnitude of the Fernley area subsurface flow remains an open question which is presently under investigation by the Desert Research Institution.

To develop an estimate for Wadsworth-Fernley subsurface flow (9000 af/y), a regional water balance was constructed and the amount obtained by difference. Although this required a number of assumptions, the result compares favorably with other workers' efforts (Van Denburgh and Arteaga, 1985). In the water balance, the net gain in average flows between the Derby and Nixon gages was matched with other combined inputs and loss estimates (Section 10.1.3). Inputs were: recharge from Dodge Flat (1400 af/y); Truckee Canal leakage and regulating flows (all of which return to the river) (20,000 af/y); and subsurface flows along the Wadsworth-Fernley reach. Recharge was calculated for the present study (Section 5.1). The canal figures were obtained from total loss figures supplied by the Truckee-Carson Irrigation District (TCID), pro-rated to the length of the canal segment west of Wadsworth. Output to the system between Derby and Nixon was dominated by evapotranspiration (14,000 af/y); that figure originated with Van Denburgh and Arteaga's (1985) determinations of phreatophyte and crop acreages (see Section 10.3.1). The subsurface input of 9000 af/y (~12.4 cfs) appears to conform reasonably with other estimates of baseflow gain for the Wadsworth-Nixon reach. These are ~9400 af/y (~14.9 cfs) (this study, Section 5.2 and Appendices C and D) and ~9500 af/y (Bratberg, 1980). Which figure is correct can not be determined at present; all can be justified based upon a realistic set of assumptions.

To establish inputs (exclusive of canal losses and recharge) between Derby and Wadsworth using Truckee River flows, three variables must be determined: (1) subsurface flow along the Wadsworth-Fernley reach; (2) the percentage of that flow that bypasses the gage; and (3) which (median or mean) is an appropriate measure of river flow. Table 7.2 lists the discrepancies that arise under different baseflow, bypass percentage, and Wadsworth-Fernley input scenarios.

Baseflows are measured or inferred for the Truckee River between Wadsworth and Nixon, and include those of Bratberg (1980) and those from the present study. The latter are obtained from the median winter months (14.9 cfs), the mean from winter months (~7.4 cfs), and the mean of monthly flows for all seasons (~2 cfs). The median of winter flows was used since it provides the best match with solute mass balance (Section 8.0). On the other hand, the winter month mean best matches the water balance used in the present numerical study. Use of a mean to describe baseflow under these conditions is permissible since anomalously high flows that distort the average for the most part are excluded. The presence of such high flows made use of the overall mean unrealistic.

Because the Wadsworth gage is roughly in the center of the Wadsworth-Fernley reach, the percentage of groundwater that bypasses the gage is assumed for calculation purposes to be either 50% or 60%. This is geologically plausible. The gage is situated close to the axis of the Dodge

TABLE 7.2
COMPARISON OF BASEFLOW GAINS AND
WADSWORTH GROUNDWATER INPUT

Baseflows	Wadsworth-Nixon Baseflow Gains, Less Dodge Flat Recharge	Input Along Wadsworth-Fernley Domain Boundary									
		If 9000 af/y			If 16,000 af/y			If 18,000 af/y			
		Amount Bypassing Wadsworth Gage		Discrepancy If Bypass Is	Amount Bypassing Wadsworth Gage		Discrepancy If Bypass Is	Amount Bypassing Wadsworth Gage		Discrepancy If Bypass Is	
		50%	60%		50%	60%		50%	60%	50%	60%
Bratberg ¹ (1980)	9500	4500	5400	5000	4100	8000	9600	9000	10,800	500 ⁴	500 ⁴
This Study ¹	9400	4500	5400	4900	4000	8000	9600	9000	10,800	400 ⁴	400 ⁴
Winter Medians	4000	4500	5400	(-500) ³	(-1400) ³	8000	9600	9000	10,800	N/A	N/A
Winter Means											
All Flow ² Means	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

¹ Flow gains below Wadsworth under different scenarios in af/y after subtracting Dodge Flat recharge estimate of 1400 af/y.

² Implication is that all flow must enter above gage. This is unrealistic and contradicts observation.

³ Indicates that flows balance if a small percentage bypasses gage.

⁴ Indicates that flows approximately balance.

Flat basin, as inferred from gravity determinations (Carpenter, 1997), and that basin lies along the Walker Lane fault zone (Bonham and Papke, 1969). Highly conductive fluvial and alluvial units are therefore likely to be present in that area on both sides of the gage. Furthermore, the bedrock plausibly may be faulted and conductive. Field observation of saline spring water also suggests some input downstream of the gage.

Three hypothetical inputs are shown in Table 7.2 for the Wadsworth-Fernley domain boundary: 9000 af/y, 16,000 af/y, and 18,000 af/y. Each concurs reasonably with a different set of flows and bypass assumptions. If baseflows on the Wadsworth-Nixon reach are represented by the winter month mean (substantially equal to that of Bratberg, 1980), then an additional 5500-7500 af/y subsurface flow above the gage can be assumed. This implies that the total input along the Wadsworth-Fernley reach may be as much as ~16,000 to ~18,000 af/y (~22-25 cfs). Though these figures require reassessment of the water balance, they are plausible. Appendix D suggests a maximum ET loss of ~10,100 af/y (~14 cfs) below the Wadsworth gage is possible. This corresponds to a total ET in the model domain of ~16,500 af/y. Similarly, the average per mile canal leakage figures may not be representative of that along the portion upstream from Stampmill Estates. A canal leakage in the range of 15,000-17,000 af/y added to the higher ET figures could easily redress the water balance differences obtained using median river flows. Alternatively, some of the differences could be compensated if a higher proportion of groundwater flow entered the river upstream from the Wadsworth gage.

By comparison, a 9000 af/y inflow along the Wadsworth-Fernley boundary coupled with a bypass proportion of 50%-60% suggests that 4500-5400 af/y enter the river below the Wadsworth gage. These figures correspond well with the baseflow gain between Wadsworth and Nixon of ~5400 af/y (~7.4 cfs) obtained using winter month mean flows (Table 5.6), but are significantly less than the ~11,000 af/y (~15 cfs) determined using solute mass balances (Section 8.2 and Appendix C).

Resolution of these conflicts is not yet possible, and is beyond the scope of this investigation. From a geologic standpoint, there is no present justification to adjust bypass percentages. To estimate baseflow gain, two fundamental alternatives thus present themselves: (1) use median winter river flows that conform to solute mass balance calculations but require adjustment of other gain-loss parameters, or (2) use mean winter river flows that match previous workers' gain-loss estimates but not solute mass balance. Although the latter was selected for the present modeling effort, the former nevertheless provides a basis for estimating solute loadings to the Truckee River.



SECTION 8.0

WATER QUALITY

The regional aspects of this study address water quality issues, of which one aspect considers impacts to the river by the diversion of irrigation water to an artificial recharge, storage, and recovery (ASR) system. The quality of artificially recharged water at the ASR site is also a concern, since various processes may degrade water injected into an aquifer. The second regional component involves basin-scale evaluation and quantification of solute loadings to the lower Truckee River. This is an important first step in assessing which factors contributing to solute loading are controllable. These factors derive from hydrogeologic properties and strongly influence engineering parameters such as system siting, capacity, and design.

Water quality evaluation utilizes information generated by hydrologic modeling of groundwater movement within the Dodge Flat basin, the Truckee River aquifer, and more specifically on the Olinghouse fan itself. However, a feedback loop exists, in that water quality information has been used to constrain hydrologic inputs at model boundaries (see Section 5.2.1.3). In particular, to quantify groundwater movement to and from the Truckee involved considering solute mass balances derived from stream flow measurements and from chemical analyses of surface and groundwater. Justification of this mass balance approach rests on estimating the magnitude and plausibility of other potential solute sources.

8.1 Determination of Possible Solute Sources

To determine and implement a strategy that enables control of solute loadings requires understanding input processes and assessment of potential ion sources. This same knowledge also aids engineering planning, design, and cost optimization. Current management objectives for the Fernley-Wadsworth-Dodge Flat region are predicated upon earlier investigations in which lacustrine sediments are presumed the principal source of dissolved salts to regional groundwaters. The intent of this section is to weigh that concept against others, which include geothermal inputs, surface runoff, and ion release and exchange from clays, particularly those in paleosols. Results of this examination based on comparative major ion geochemistry suggest that lacustrine sediments are perhaps the most plausible source for dissolved salts, but that geothermal contributions are very possible. Interpretation of D-¹⁸O isotopic analyses by McKay and Bohm (1998) suggests alternatively the strong possibility of a geothermal solute contribution, with a lesser likelihood of a sedimentary origin. A mixed source is therefore highly probable, with the added complication that the groundwater composition may further be modified significantly by ion exchange mechanisms, weathering reactions, and mineral dissolution.

The evaluations in this section are based on data derived from previous studies and from sampling specifically undertaken for the present project. They relied heavily on determination of groundwater flow paths on Dodge Flat and comparisons between dissolved solute compositions for a number of waters. It should be cautioned that too limited a data-set poses the risk of over-interpretation, and that the assumptions used during the evaluation process always be borne in mind when drawing conclusions.

8.1.1 Descriptive Geochemistry

The first component of the geochemical investigation was descriptive, and entailed consolidating the aqueous geochemistry of the Olinghouse fan and the Dodge Flat region into solute contours and trilinear plots. Perusal of these diagrams provides insight as to the source and fate of waters on the Olinghouse fan, and provided a basis for the second investigative component, which examined potential solute sources by undertaking order of magnitude solute flux and mass balance calculations.

8.1.1.1 Solute Contours

Geochemical sampling of groundwater was performed by CH2MHill (1990) and McKay and Bohm (1998) for 7 monitor and 3 production wells located on or near the base of the Olinghouse fan (see Figures 4.1 and 5.2. Delineate well nos. for reference). CH2MHill (1990) reported major ion concentrations for all wells, and trace elements for the monitor wells only. The present study tested for major elements, trace elements, and isotopes. Sample results are shown in Table 8.1. WATERESOURCE, for this report, excerpted groundwater elevations, TDS, boron, and major ion concentrations from its own measurements and from CH2MHill (1990) and contoured them on a 1:24 000 scale topographic overlay (Figures 8.1 – 8.9). Major ion concentration contours are plotted in Figures 8.2 – 8.8. Figure 8.9 depicts boron (b) concentration.

The contour maps show that on the lower Olinghouse fan all ionic species and TDS increase along an east by northeast to northeast direction, reaching maxima beneath the present valley floor. That direction parallels the local flowpath estimated from groundwater contours taken on 10/14/97 (Figure 5.4) and in 9/90 (CH2MHill, 1990). The local groundwater contours are consistent with the regional contours (Figure 5.2). There is little change in pH, which is slightly alkaline (~8), along this flowpath. Low solute concentrations characterize waters above the toe of the fan, as exemplified by approximately 300-500 ppm TDS about 50 ppb (B) in MW-1 and MW-7. These values increase to over 800 ppm and 1700 ppb respectively in the area north and east of MW-3. Table 8.2 shows the proportionate increase of these ions, B, and TDS along line C-C' relative to their initial concentrations.

TABLE 8.2
SOLUTE PROPORTION CHANGES
DOWN THE OLINGHOUSE FAN

Solute	Mole Ratio Change
TDS	2.9x
Na	5.4x
Ca	2x – 1.4x
Mg	2.7x – 1.3x
Cl	3.8x
SO ₄	4.2x
HCO ₃ -	-0.87x
B	53x

Change in molar proportions of selected solutes along line A-A' relative to initial concentrations. Line A-A' represents a path down the groundwater flow gradient near the base of the Olinghouse fan along which solute concentrations increase.

TABLE 8.1
GROUND AND SURFACE WATER COMPOSITIONS
IN THE DODGE FLAT REGION

Sample Site Name	Collection Date	Major Ions (ppm)										Minor Ions (ppb)	
		pH	Ca	Mg	Na	K	HCO3	CO3	SO4	Cl	TDS Major ions by sum	B	F
a) Composition of Dodge Flat Waters. Sources: CH2MHill (1990) and McKay and Bohm (1998)													
DF 1 (spring)	11/03/97	8.01	38.5	11.4	17	3.24	182		10.8	12.7	275.64		NA
DF 2 (spring)	11/03/97	7.83	17.9	5.28	10.1	3.1	95.3		4.25	3.75	139.68		NA
DF 3 (spring)	11/03/97	8.03	39.8	13.3	20.8	2.69	211		11.3	12.3	311.19		NA
MW-1	1990	n.r.	77.7	14.8	41.7	2.6	107		190	54.4	488.2	0.061	0.09
MW 1	11/12/97	8.06	64.8	11.6	37.1	2.45	118		138	39.6	411.55		NA
MW-2	1990	8.66	42.6	5.8	206	2.2	94		410	68.3	828.9	1.72	5.87
MW 2	11/12/97	8.22	43	5.53	216	2.26	88.9		404	71	830.69		5.8
MW-3	1990	8.6	48.3	7.47	201	2.5	99		424	75.3	857.57	1.7	5.65
MW-4	1990	8.9	43	1.9	206	5.3	82		419	72.7	829.9	1.8	6.35
MW 4	11/12/97	8.19	44.3	1.45	221	5.89	80.2		412	70.4	835.24		6.3
MW-5	1990	n.r.	116	20	49.7	2.8	94.6		333	69.4	685.5	0.096	0.09
MW-6	1990	8.09	102	18.7	45.9	2.5	97.2		285	62.7	614	0.038	0.09
MW-7	1990	7.76	44.3	7.1	30.4	2.6	114		93.4	20	311.8	0.051	0.1
MW 7	11/12/97	8.2	47.9	7.77	28.7	2.61	116		84.8	21.4	309.18		NA
Dead Ox	11/13/97	8.23	38	10.5	29.3	1.33	203		15.8	12.3	310.23		NA
Nevada Lands #2 Well	11/17/97	8.12	56.4	7.53	196	3.4	89.8		400	71.4	824.53		4.5
Alta Gold Wells, averaged	12/11/97	7.84	61.4	16.8	30	1.53	299		28	10.5	447.23		NA
Frank Free Cyn. (spring)	12/11/97	8.1	190	39.7	34.2	1.74	246		453	11.8	976.44		NA
S-S Well	12/11/97	8.38	4.44	1.54	117	2.3	230		47.8	33.4	436.48		NA
DePaoli	1990	8.06	n.r.	n.r.	216	n.r.	n.r.		373	71.4	660.4	1.96	n.r.
b) Olinghouse Mine Well Averages. Source: Shepherd Miller (1997)													
Production Well 1 Avg.		7.76	66.6	18.7	33.2	1.39	216		29.8	9.2	374.89		Sr 1.5
Monitor Well 01 Avg.		7.93	47.1	1.62	38.3	6.78	112		75.8	7.8	289.4		1.3
MW 03 Avg.		7.67	213.6	40.1	43.3	1.69	296		437	9.41	1041.1		2.65
MW 04 Avg.		8.14	82.2	2.92	52	1.97	119.7		170.5	12.5	441.79		3.15
MW 06 Avg.		7.79	125	6.3	60.9	1.71	112.6		323	12.8	642.31		4.98
Average All Wells		7.858	106.9	13.9	45.5	2.7	171.3		207.2	10.3	557.8		2.7
c) Stoichiometric Dissolution of Minerals, 1000 mg/ 1 liter. Source for mineral compositions: Gaines et al. (1997)													
Gypsum			215						516				
Trona					307		533			160	1000		
Thenardite					331				690		1021		
Halite					397					603	1000		
Equal Proportions			45		262		112		358	162	939		
3:3:3:1 Mixture			61		335		153		346	104	999		
d) Waters from Selected Geothermal Sites. Source: Garside and Schilling (1979)													
Site 272 Well			16	1	154		56	8	168	114	517		
Site 269 Well			239	0.2	1126	168	38		339	188	2098.2		
Moana Avg. of Selected Wells			25.7	4.2	238.5	8.6	129.6		351.8	105.3	863.7		
Steamboat Avg. of Selected Wells			40.7	13.4	348.6	18.5	241.9	12.3	162.6	401.6	1239.6		
Eagle Salt Works Avg.			32	2	839		61	19	334	955	2242		
Patua #1 (Hazen)			70		550		67		41	865	1593		
Patua #2 (Hazen)			55	1.5	620	38	100		400	820	2034.5		
e) Solutes in Truckee River Water. Sources: NDEP (1997); Bratberg (1980)													
Steamboat Cr. 1988 Avg.			3.7	15.2	104	12.1	234.3		62.7	98.3	530.3		
Below Reno, overall Avg. @ High Flows			9.8	3.4	9.4	1.7	49.6		8.8	6.7	89.4		

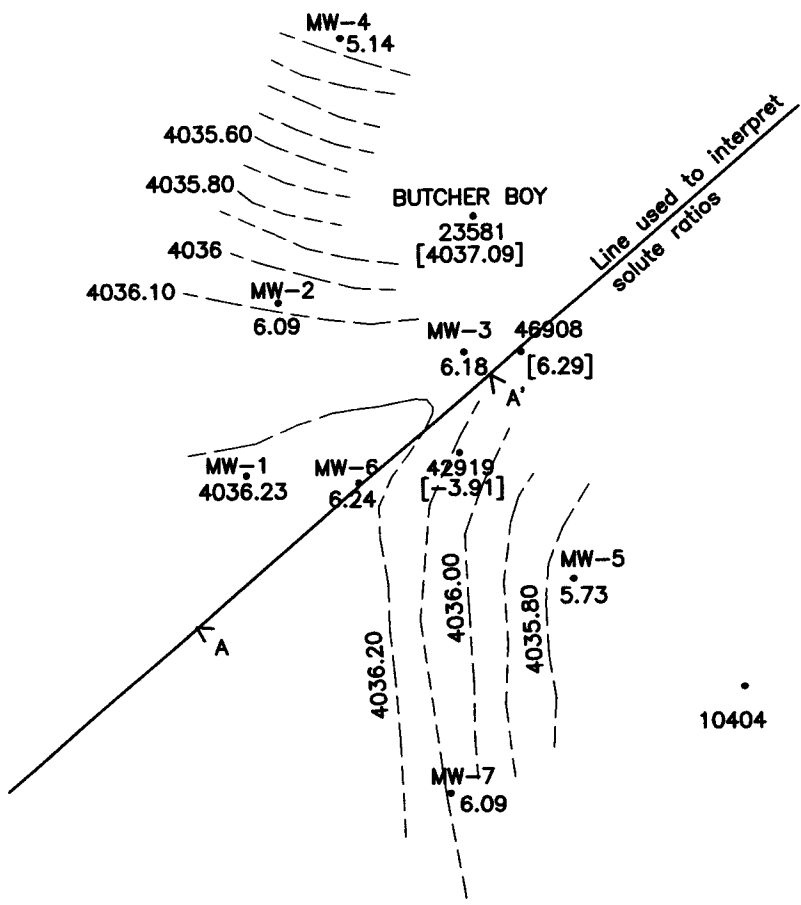
TABLE 8.1
GROUND AND SURFACE WATER COMPOSITIONS
IN THE DODGE FLAT REGION

Sample Site Name	Collection Date	Major Ions (ppm)									TDS Major ions by sum	Minor Ions (ppb)	
		pH	Ca	Mg	Na	K	HCO3	CO3	SO4	Cl		B	F
Below Reno, overall Avg. @ Moderate Flows			12	4.4	12.8	1.8	57.8		128	9.6	226.4		
Below Reno, overall Avg. @ Low Flows			33.6	15.1	60.3	7.8	134		73.4	72.2	396.4		
Nixon, 1988 Avg., Low Flow Conditions			48.1	21.6	93.2	8.5	148.1	5	112.8	124.7	562		
Wadsworth, 1988 Avg., Low Flow Conditions			26.9	9.9	32.1	4.9	139	0.8	35.7	21	270.3		
Tracy, 1988 Avg., Low Flow Conditions			22.3	7.5	26.6	4.6	94.2		18.1	12.2	185.5		
Nixon, 1973-80 Avg.			28	11	43	4	98	7.2	49	52	292.2		
Wadsworth, 1973-80 Avg.			19	7	21	3	99	1.1	22	13	185.1		
Derby, 1973-80 Avg.			17	6	18	3	88	0.6	16	13	161.6		
Tracy, 1973-80 Avg.			16	6	18	3	85	0.93	16	13	157.93		
f) Calculated Groundwater Inputs to Lower Truckee. Source: Bratberg (1980)													
Derby to the S-S Ranch			62	24	83	7	155		143	100	574		
Wadsworth to S-S Ranch			76	32	89	7	164		211	121	700		
S-S Ranch to Nixon Gage			65	34	327	17	152		69	569	1233		
Weighted Mean, Fernley Area Wells			79	37	138	16	166		192	199	827		
g) Major Groundwater Constituents, Sites North of TCID Canal. Source: Rowe et al. (1991)													
Site 72, FWA-1 Well Avg.		8.4	15.3	3.8	106.7	4.1	287	4.7	22	12.7	456.3	396	
Site 73, FWA-2 Well Avg.		8.6	4.2	2.5	220	9.6	556	7	21.5	11	831.8	640	0.65
Site 74, FWA-2A Well Avg.		7.8	25	18	64	28	333	0	19.5	13	500.5	493	
Site 75, FWA-2B Well		7.6	37	24	20	24	273	0	20	13	411	370	0.3
Site 76, FWA-3A Well Avg.		8.7	2.4	1.5	2.5	12	522	20	19	13	592.4	960	
Site 77, FWA-3B Well		8.4	2.2	1.8	220	11	520	4	24	19	802	1400	0.6
Site 78, FWA-3 Well Avg.		8.4	3.4	3.7	230	11.5	499.5	16	85.3	17.5	866.9	1200	
Site 79, FWA-4 Well Avg.			2.8	2.5	237.5	14.3	525.8	3.5	84.3	17.8	888.5	1250	
Site 80, FWA-5 Well Avg. N. of Fernley Drain		10.4	15.5		735	30	769	0	850	180	2589.9	3300	0.4
Fernley Well Avg. (Bratberg)			79	37	138	16	166		192	199	827		
Fernley Well Avg. (Sinclair & Loeltz)			87	26	219	30	275	2	50	555	1244		0.4
h) Major Surface Water Constituents, Sites North of TCID Canal. Source: Rowe et al. (1991). Fernley Area Well Averages. Source: Sinclair and Loeltz (1963); Bratberg (1980)													
Site 45, Streiff Drain		8.3	24.4	15	134	17.4	408.7	0	69.2	21.2	689.9	754	0.3
Site 44, Fernley Drain		8.2	29.6	19.6	111	15.3	322	0	134.3	47.3	679.1	730	
Site 43, A-Drain		7.8	31	18.5	108.8	10.4	255.6	0	29.4	32.6	486.3	606	
Site 46, Mid-Drain		8.36	33.4	19	203.8	20.4	407	5.6	224.6	43.4	957.2	920	
Site 47, South Pond		9.4	48.3	75	2326.7	98	653	133.2	3100	1286.7	7720.9	9116	
Site 48, North Pond		9.1	30	61	1500	68	539	65	1900	960	5123	6900	
Site 49, Northeast Pond		9.4	20.3	207.2	8360	274.7	874	697.4	8220	5880	24534	32240	

Major and selected minor ion components of ground and surface waters. Areas described include the Dodge Flat and Fernley areas, the Truckee River, and selected geothermal sites from the region. These were used to construct trilinear plots of Figures 14 - 35.

14 | 13
23 | 24

18 | 17
19 | 20

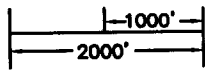



26 | 25
35 | 36

30 | 29
31 | 32



- LEGEND:
- [-3.91] INDICATES ANOMALOUS
 - 4036.20 GROUNDWATER CONTOUR IN FEET ABOVE MEAN SEA LEVEL
 - MW-5 WELL LOCATION



 waterresource consulting engineers, inc. <small>700 TOWN STREET - BIRMINGHAM, ALABAMA - 35203</small>		
DATE	REVISIONS	BY

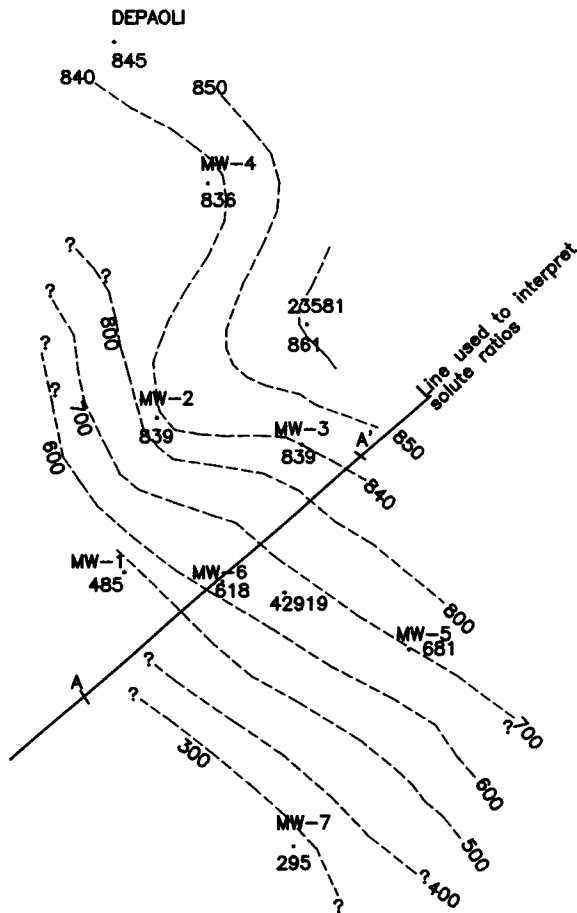
FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/28/99
DRN. BY LCS
CHK. BY J.L.

Well Location Map and Groundwater Elevations for Lower Olinghouse Fan
Figure 8.1

14 | 13
23 | 24

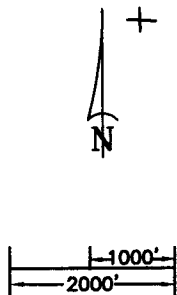
18 | 17
19 | 20




LEGEND:

- 300 LINE OF EQUAL CONCENTRATION, in mg/L
- MW-7 WELL LOCATION

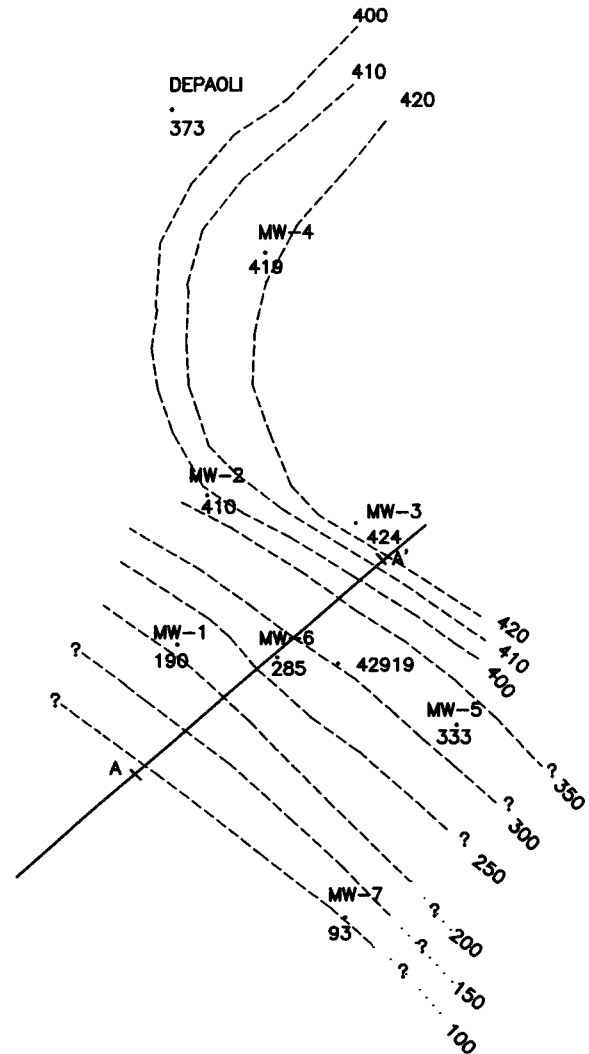
DATA SOURCE: CH2MHILL, 1990



 wateresource consulting engineers, inc. <small>THE TOWN OF LYON - LYON, ILLINOIS - 60135</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/28/89 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Solute Contours Total Dissolved Solids—Figure 8.2		

14 | 13
23 | 24

18 | 17
19 | 20




LEGEND:

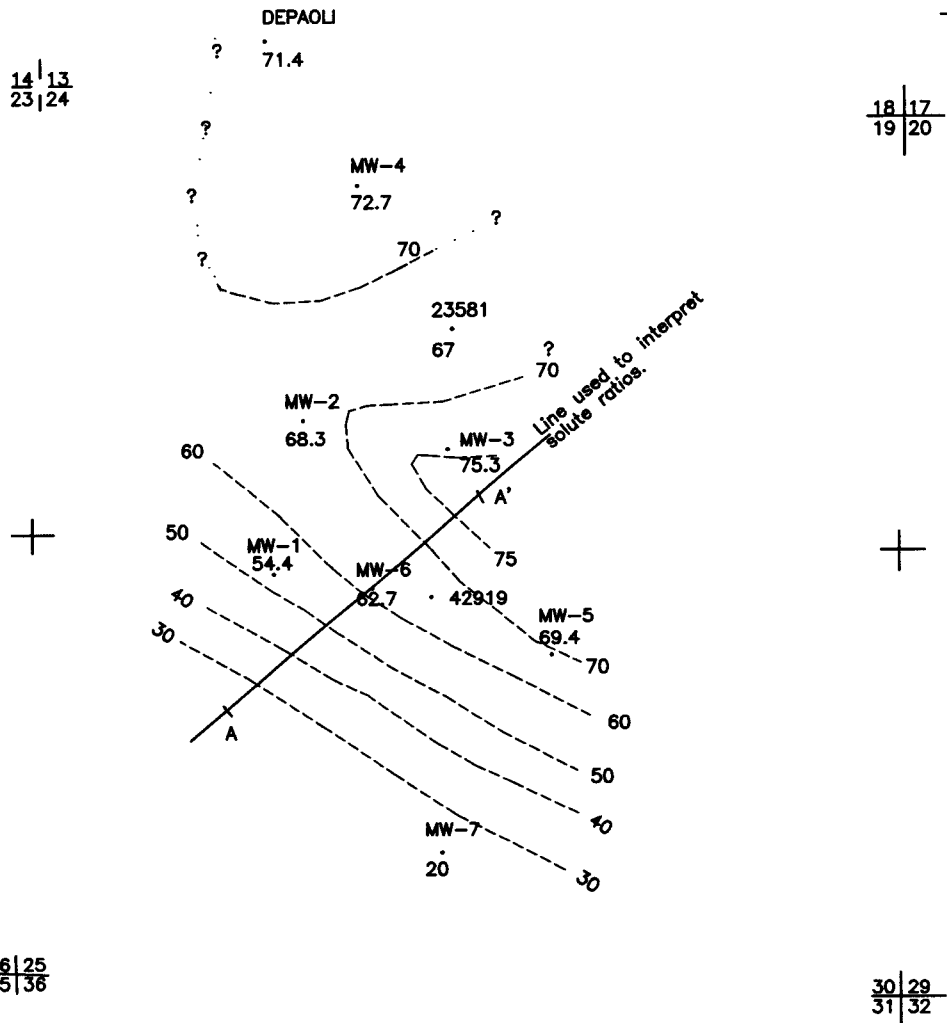
- 300 LINE OF EQUAL CONCENTRATION, in mg/L
- MW-7 WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'

 waterresource consulting engineers, inc. <small>700 TADON STREET - DENVER, COLORADO - 80202</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/28/88 DRN. BY LCS CHK. BY
DATE	REVISIONS	BY	Solute Contours Sulfate - Figure 8.3		



LEGEND:


----- 30 LINE OF EQUAL CONCENTRATION, in mg/L

MW-7 WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'

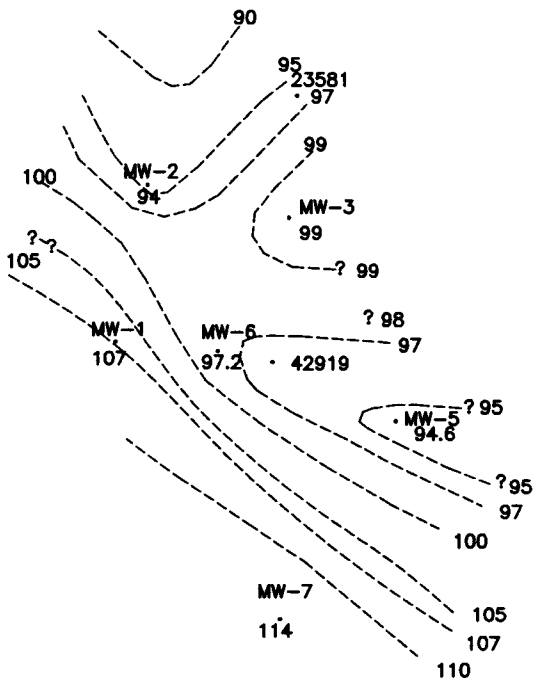
 waterresource consulting engineers, inc. <small>750 TANKER STREET - BIRMINGHAM, ALABAMA - 35203</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/26/98 DRN. BY LCS CHK. BY LCS
DATE	REVISIONS	BY	Solute Contours Chloride - Figure 8.4		

14 | 13
23 | 24

18 | 17
19 | 20

DEPAOLI
82

MW-4
82



LEGEND:

----- 100 LINE OF EQUAL CONCENTRATION, in mg/L

MW-7
· WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/26/88
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Solute Contours
Bicarbonate - Figure 8.5

14 | 13
23 | 24

18 | 17
19 | 20

DEPAOLI
216
?
? 206
MW-4
206

+

+

+

30 | 29
31 | 32

LEGEND:

----- 100 LINE OF EQUAL CONCENTRATION, in mg/L
MW-7 WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/28/89
DRN. BY LCS
CHK. BY JL

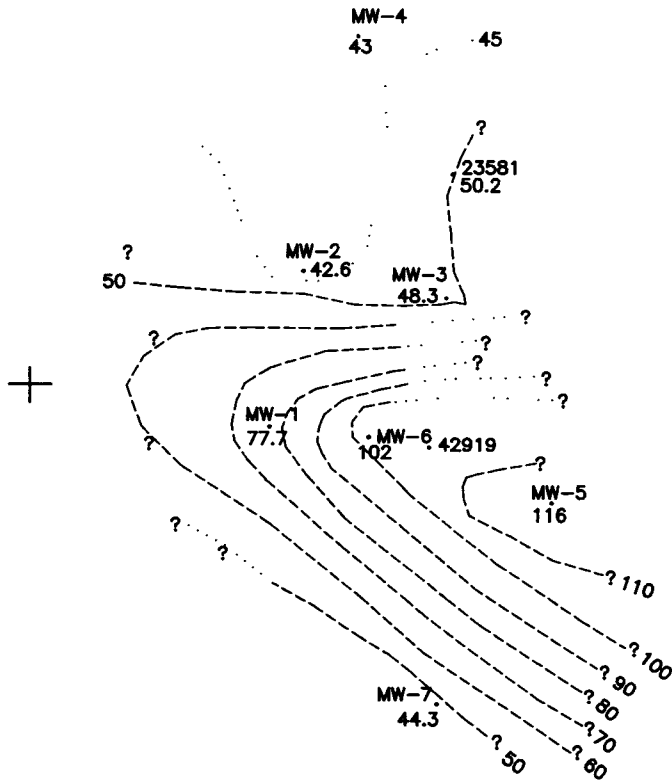
DATE	REVISIONS	BY

Solute Contours
Sodium - Figure 8.6

DEPAOLI

14 | 13
23 | 24

18 | 17
19 | 20



26 | 25
35 | 36

30 | 29
31 | 32

LEGEND:

--- 80

LINE OF EQUAL CONCENTRATION, in mg/L

MW-7

WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8515.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Solute Contour
Calcium - Figure 8.7

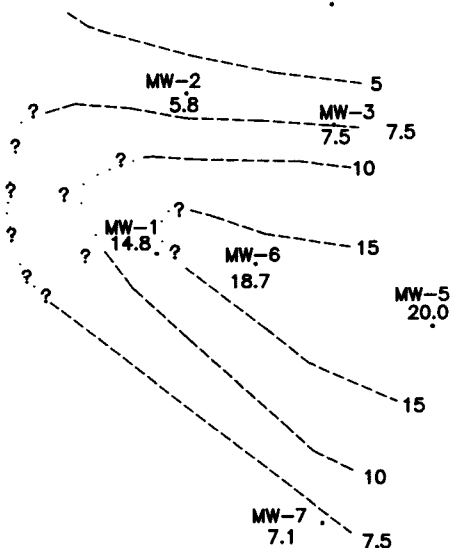
14 | 13
23 | 24

DEPAOLI
2.8

18 | 17
19 | 20

MW-4
1.9

23581



26 | 25
35 | 36

30 | 29
31 | 32

LEGEND:

----- 15 LINE OF EQUAL CONCENTRATION, in mg/L
MW-7 WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'

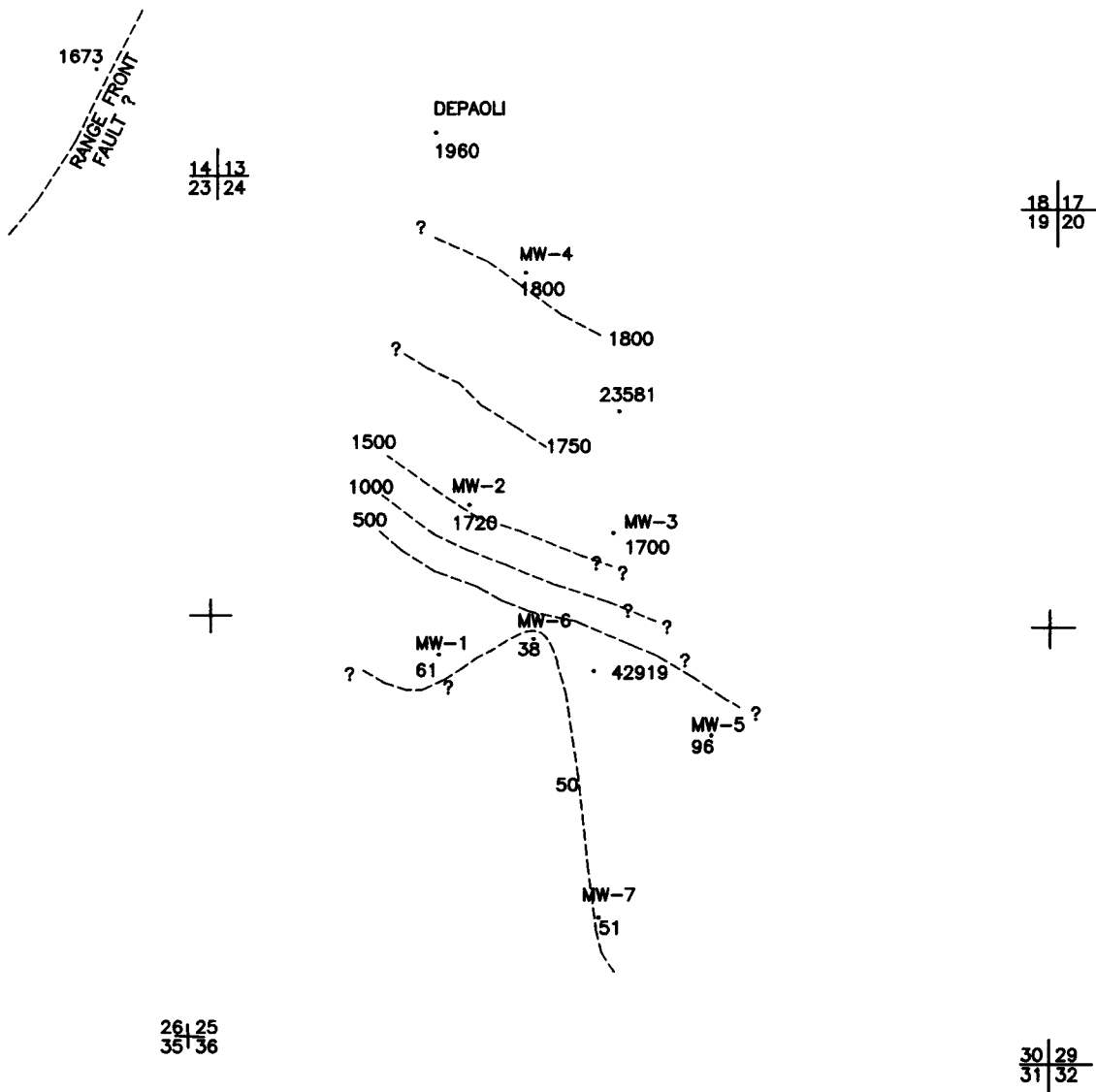
wateresource
consulting engineers, inc.
700 TOWN STREET - SUITE 200, BURLINGTON, ONTARIO - L7R 4K6

FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/28/99
DRN. BY LCS
CHK. BY J.L.

DATE	REVISIONS	BY

Solute Contours
Magnesium - Figure 8.8



LEGEND:

----- 1000 LINE OF EQUAL CONCENTRATION, in $\mu\text{g/L}$

MW-7
WELL LOCATION

DATA SOURCE: CH2MHILL, 1990



1000'
2000'



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/28/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

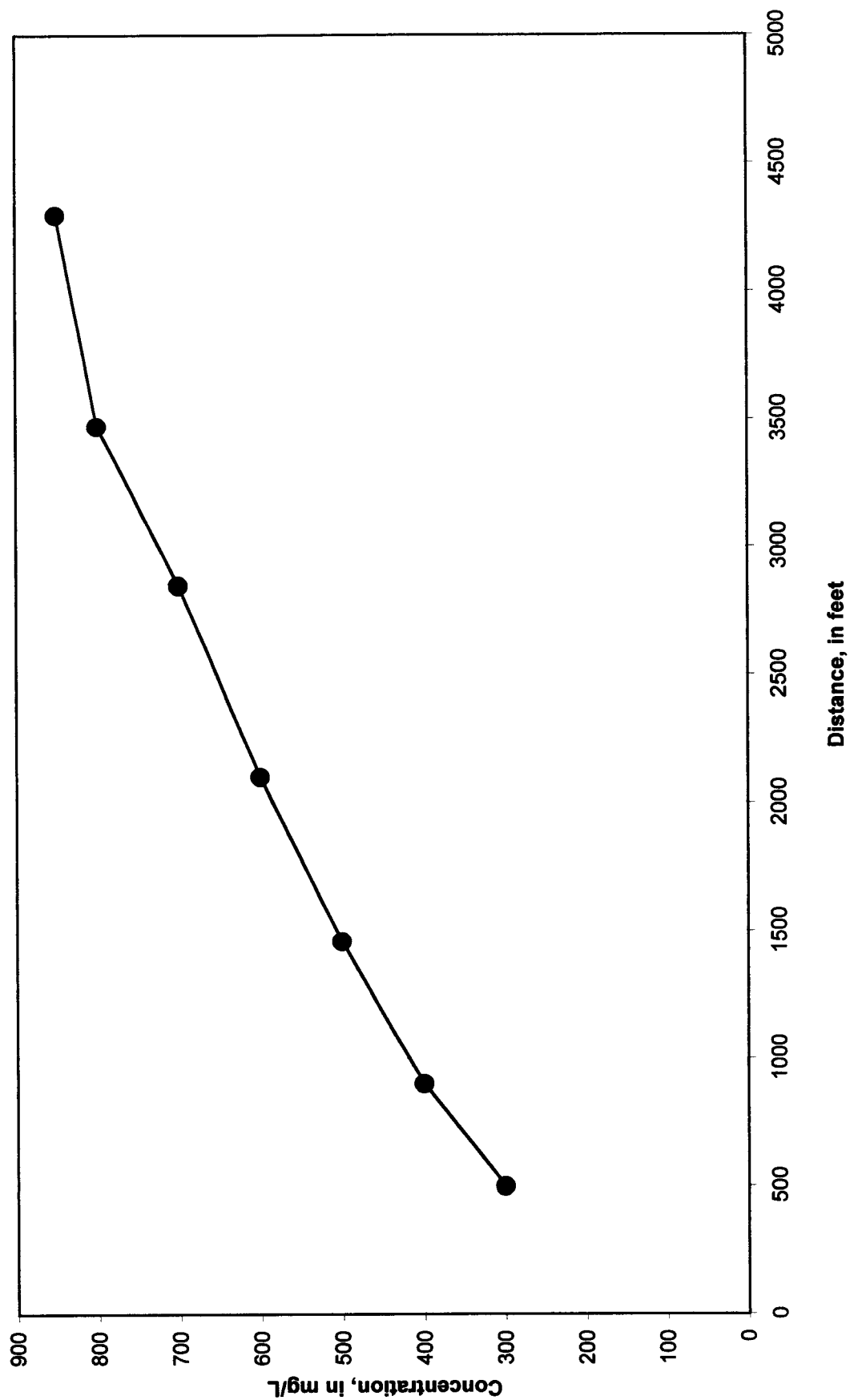
Solute Contours
Boron - Figure 8.9

Figures 8.10 – 8.15 depict concentration profiles constructed along line C-C' for TDS, $\text{SO}_4^{=}$, Cl^- , Na^+ , Na^+/Cl^- ratio and $\text{Na}^+/\text{SO}_4^{=}$ ratio. These were obtained from the contours in Figures 8.2, 8.3, 8.4 and 8.6, and although generated from interpolations of a limited data set, are instructive. The profiles show a fairly constant if rapid down-gradient rise in TDS and $\text{SO}_4^{=}$ (Figures 8.10 and 8.11). The Cl^- line is somewhat erratic, with jumps at about 1500 feet and again at 2900 feet from point C, but nonetheless reasonably linear (Figure 8.12); Cl^- therefore is not conservative. Near 2,500 feet, Na^+ increases (Figure 8.13), but its gains are offset by more a rapid growth in Cl^- concentration, so that Na^+/Cl^- gradually diminishes before rising (Figure 8.14). This may indicate exchange of Na^+ for Ca^{++} in clays, but if so would require precipitation of CaCO_3 since Ca^{++} does not increase in proportion and $\text{CO}_3^{=}$ concentrations drop.

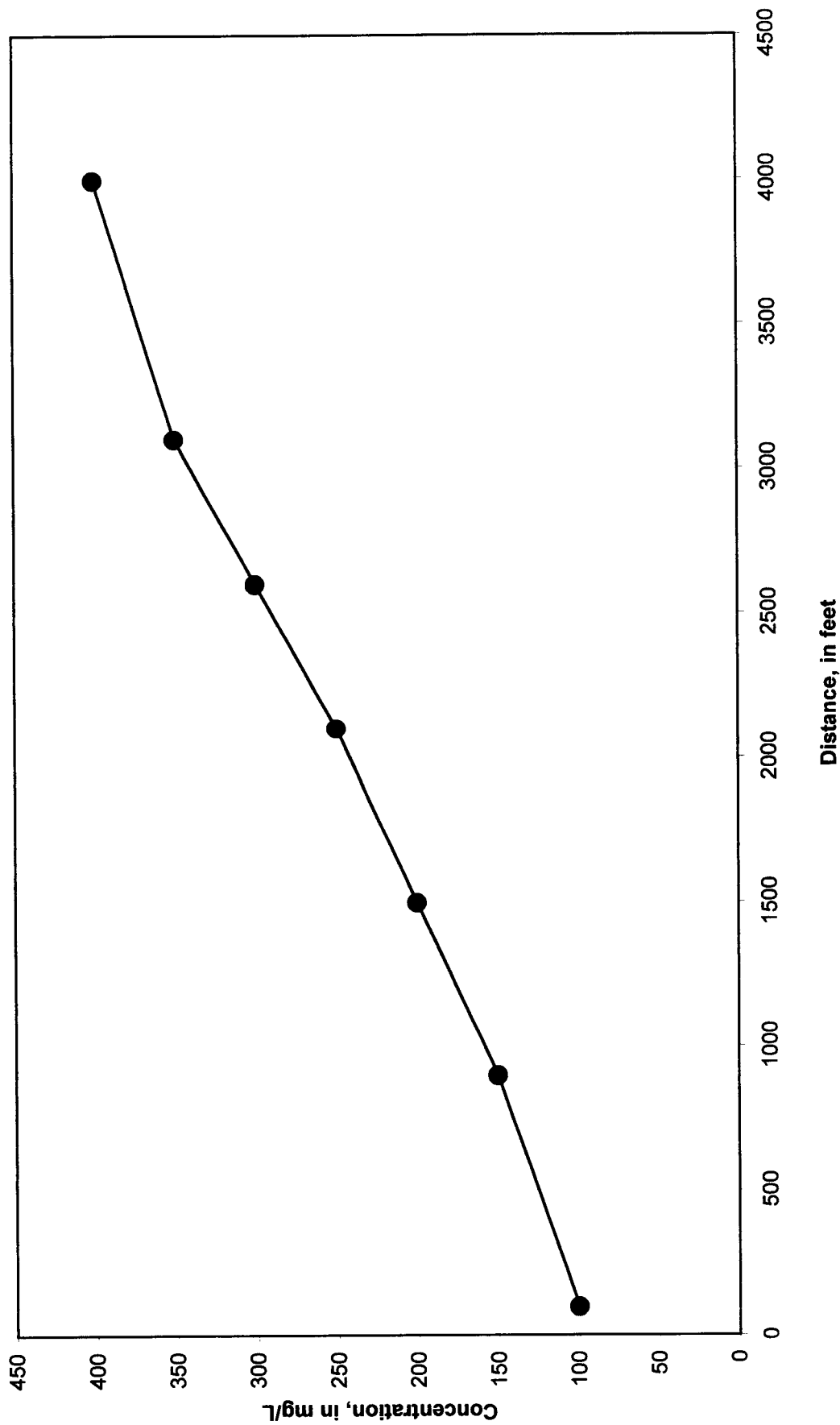
The jump in Cl^- near 2900 feet (Figure 8.12) coincides roughly with a major Na^+ increase at ~2500 feet and corresponding sudden increases in the Na^+/Cl^- and $\text{Na}^+/\text{SO}_4^{=}$ ratios (Figures 8.14 and 8.15). These observations suggest solute (Na^+ , $\text{SO}_4^{=}$) input in the area between MW-6, MW-3, and Well No. 42919. It is in this same vicinity that the proportion of fine-grained sediments also increases dramatically (see Appendix A, Section B-B').

Groundwater composition along the down-gradient path appears to reflect ongoing input of solute from the saturated sediments as opposed to evapoconcentration infiltration of precipitation. Since at the elevation of the monitor wells infiltration is negligible (Eakin, *et al.*, 1951; Maxey and Eakin, 1949), water passing through vadose zone sediments probably does not significantly contribute dissolved solids to the aquifer. Evapoconcentration is precluded because of the deep water table (~150 feet). Lacustrine sediments, however, are increasingly abundant within the saturated stratigraphic section at and beyond the base of the fan, in which region the water quality declines. The spatial proximity of increased solute concentrations to lacustrine sediments and distal fan deposits suggests that these units and perhaps associated paleosols may yield salts to groundwater. This will affect ASR design: even if soluble ions have been flushed from upslope portions of the fan, mounding into previously unsaturated sediment and increased downgradient flux may degrade water that is artificially emplaced.

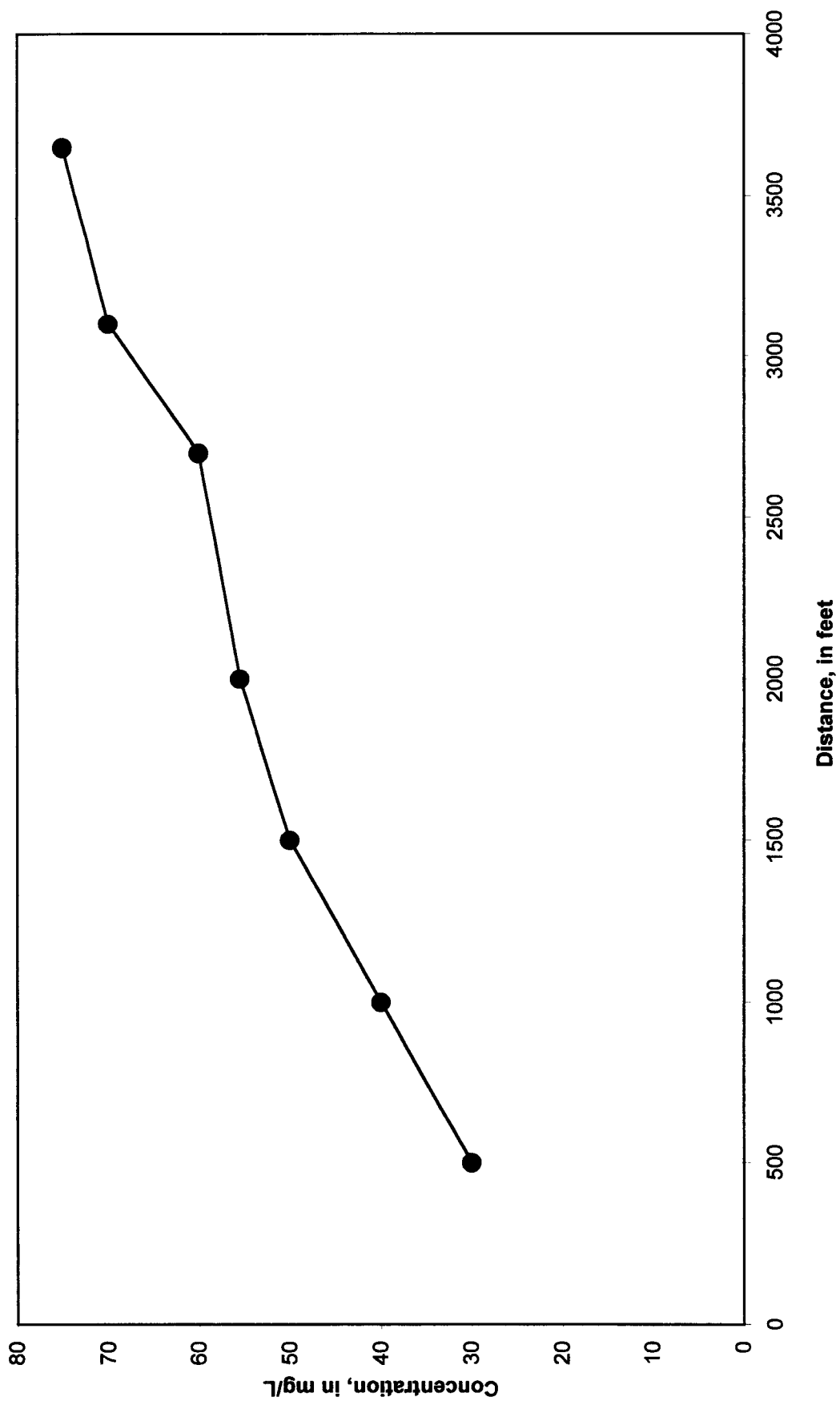
The anomalous boron in some of the Dodge Flat wells may likewise indicate ionic sources within fine-grained sediments or soils. Because borates are highly soluble, its presence in sediments also often suggests arid conditions suitable to evaporite deposition, such as playas or groundwater seeps. Localized ephemeral playas or pelludal conditions might have existed during periods of desiccation, although these environments are not described in available geologic references. Field investigation undertaken for the present study has, however, identified gypsum-bearing horizons within Sehoo clays. Soluble efflorescent crusts also are present along these strata. Evaporation-dominated environments might have retained fluorine, which is present in elevated concentrations in some saline lakes and is a constituent of certain evaporate minerals (Jones, 1965; Smith, 1979; Gaines, *et al.* (1997).



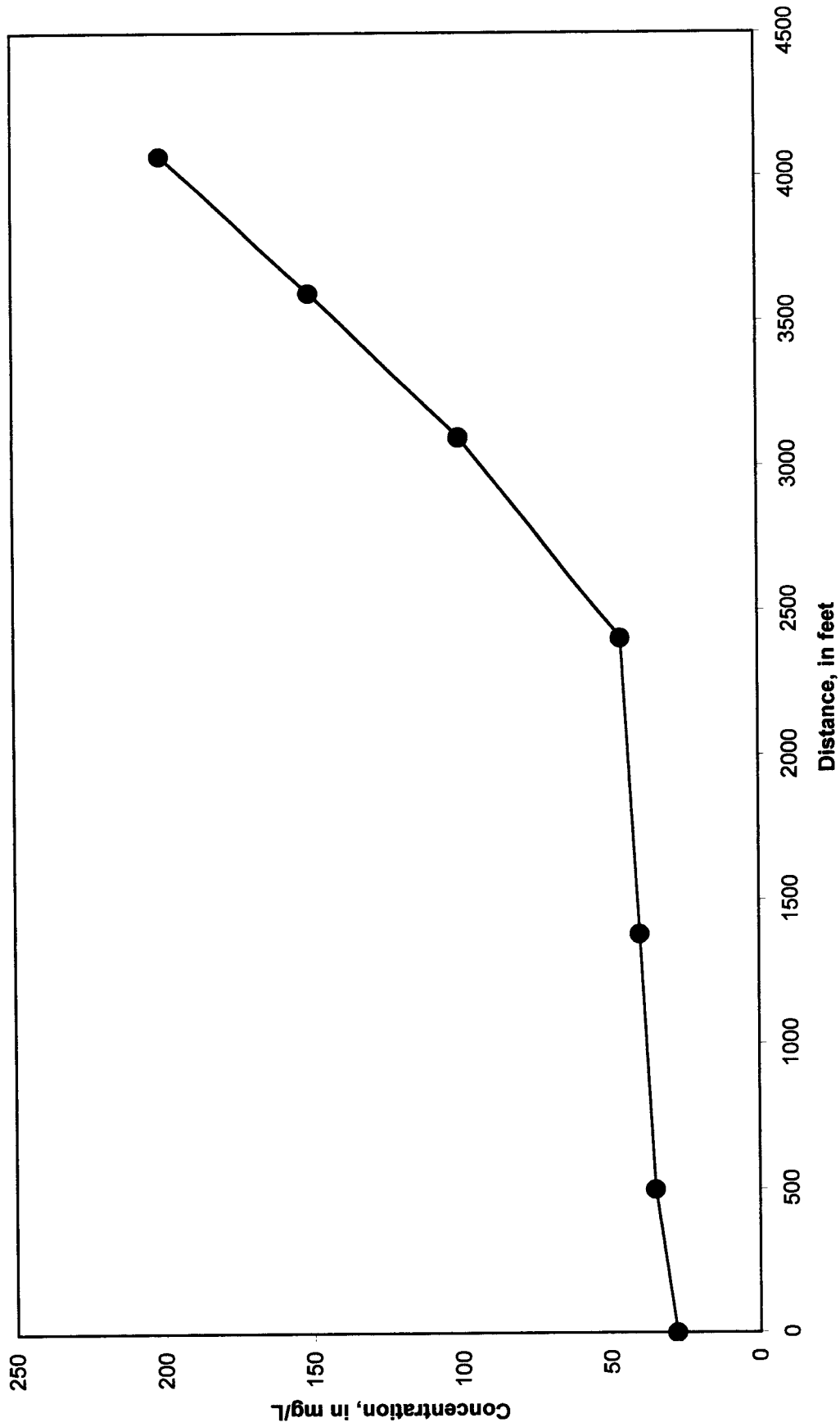
**Olinghouse Fan Monitor Wells
TDS Concentration Profile Along C-C'
Figure 8.10**



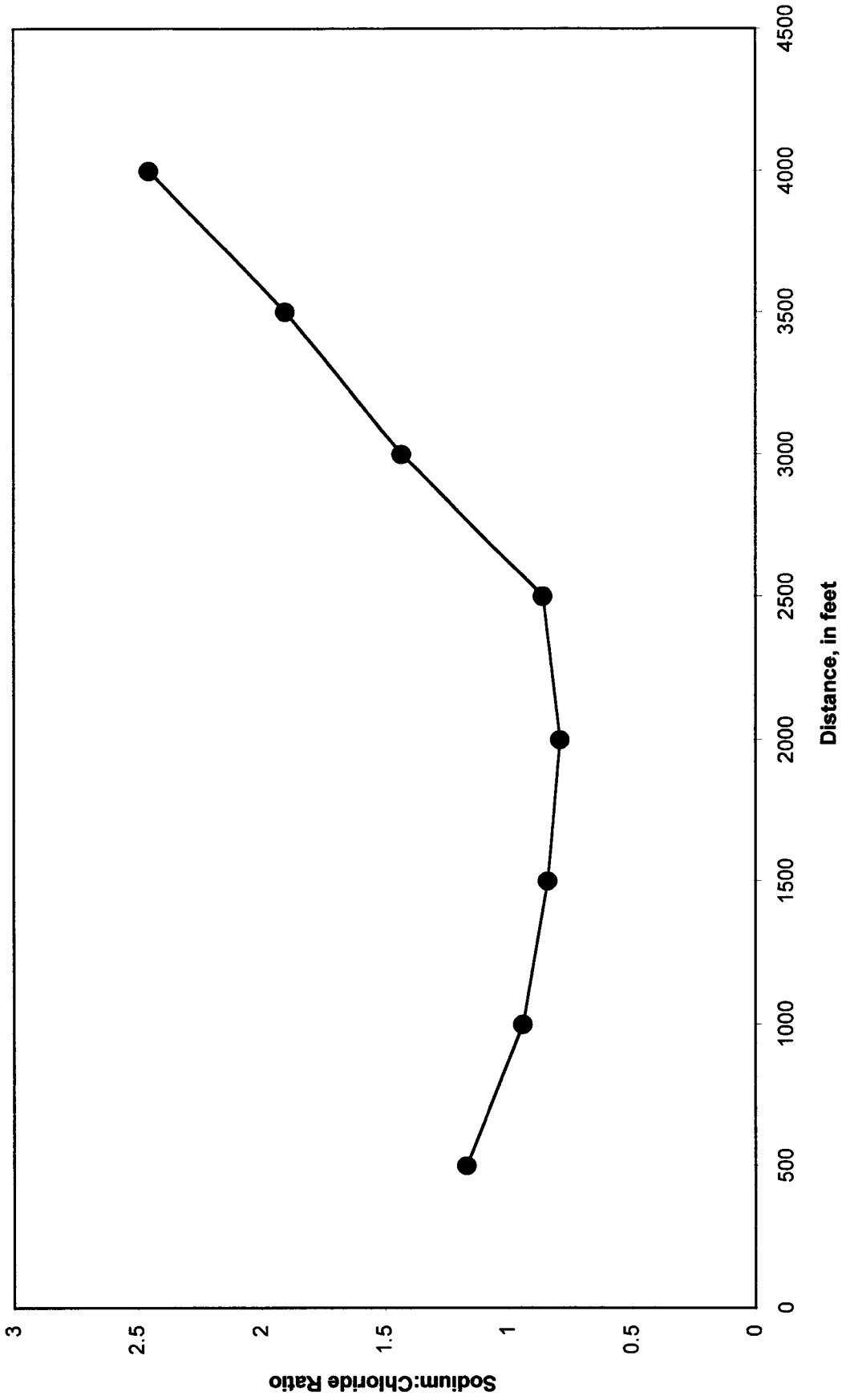
Olinghouse Fan Monitor Wells
Sulfate Concentration Profile Along C-C'
Figure 8.11



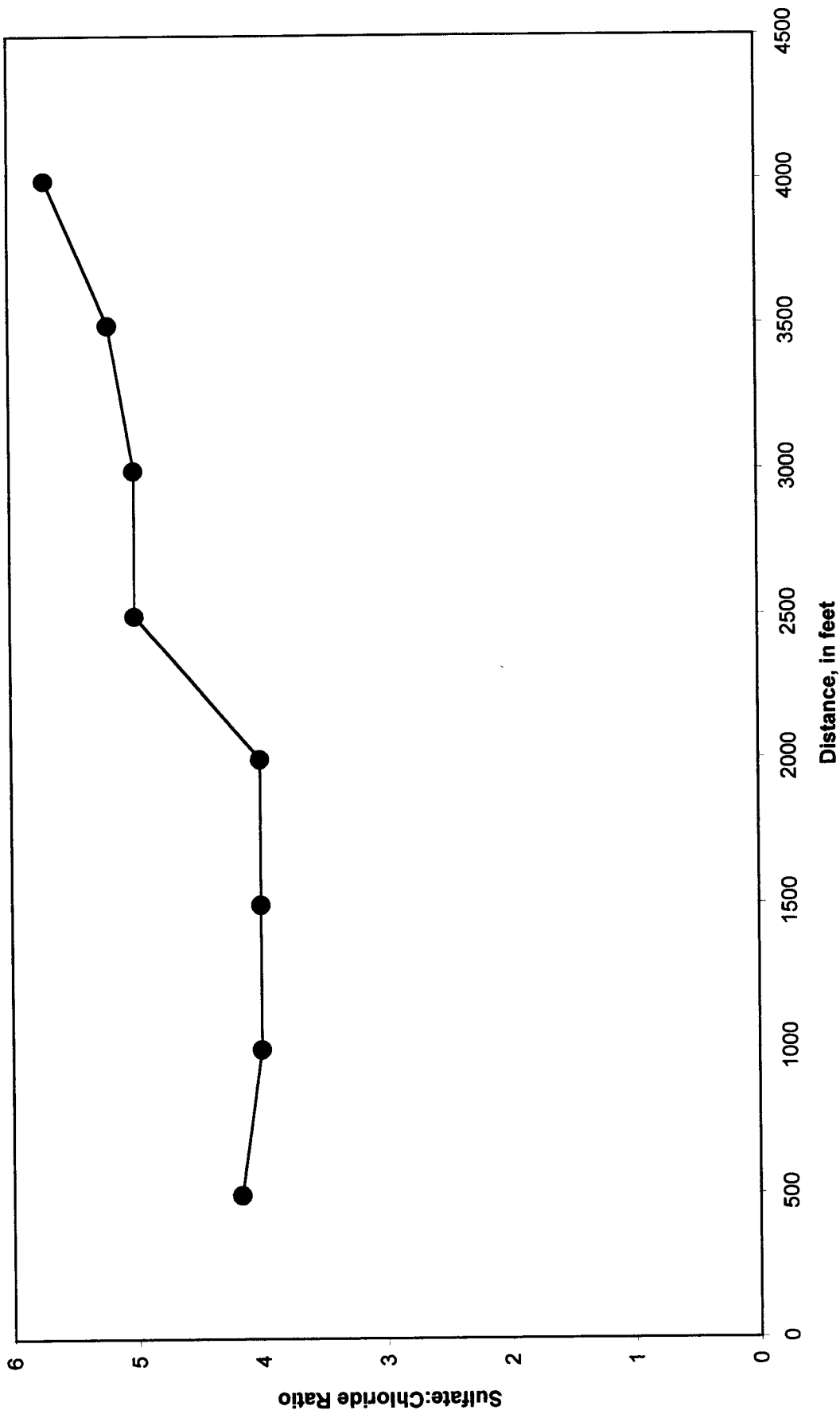
Olinghouse Fan Monitor Wells
Chloride Concentration Profile Along C-C'
Figure 8.12



**Olinghouse Fan Monitor Wells
Sodium Concentration Profile Along C-C'
Figure 8.13**



**Olinghouse Fan Monitor Wells
Sodium:Chloride Ratio Along C-C'
Figure 8.14**



Olinghouse Fan Monitor Wells
Sulfate:Chloride Ratio Along C-C'
Figure 8.15

It is also possible that boron, fluorine, and perhaps additional ions derive from sources other than evaporation. One such source is hydrothermal upwelling along faults, despite the absence of direct field evidence of geothermal activity on the upper Olinghouse fan, which is transected by a youthful fault zone (Bonham and Papke, 1969; Robyn, 1994). Boron and fluorine are common constituents of geothermal waters in western Nevada (Garside and Schilling, 1979). Dodge Flat lies within the tectonically active Walker Lane, and hot springs are present regionally. Moreover, temperature readings from wells near the base of the fan are slightly above normal for the area (McKay and Bohm, 1998; NLRC, 1997). Geothermal input is therefore conceivable within the Dodge Flat hydrographic basin. If present along its southern and eastern boundaries, thermal waters may contribute significantly to the Fernley groundwater system, in which case the reduction of secondary recharge resulting from agricultural applications may have little impact on solute loading in the Truckee River. That and related issues are currently under study by DRI.

8.1.1.2 Trilinear Diagrams

To ascertain potential solute sources to ground and surface water, both published and non-published references concerning aqueous geochemistry were reviewed. Results were combined with chemical analyses conducted specifically for the present project. The main objective of these efforts were to characterize the groundwater and its sources in the Olinghouse fan area; and to establish Truckee River flow and concentration boundary conditions that would facilitate groundwater modeling.

8.1.1.3 Olinghouse Fan Water Sources

The trilinear plots in Figure 8.16 depict the samples from the Olinghouse fan monitor and production wells that were used to generate the solute profiles. The plots show two fairly distinct clusters: a moderately dilute $\text{Ca}^{++}\text{-Mg}^{++}\text{-SO}_4^{\text{--}}\text{-CO}_3^{\text{--}}$ water characteristic of the topographically elevated portions of the area, and a higher TDS, $\text{Na}^+ \text{-SO}_4^{\text{--}}$ water at the base of the fan. This clustering reflects the same rapid lateral composition and concentration changes shown on the solute contours, which indicate the presence of good quality water higher on the fan, and lower quality water at its toe.

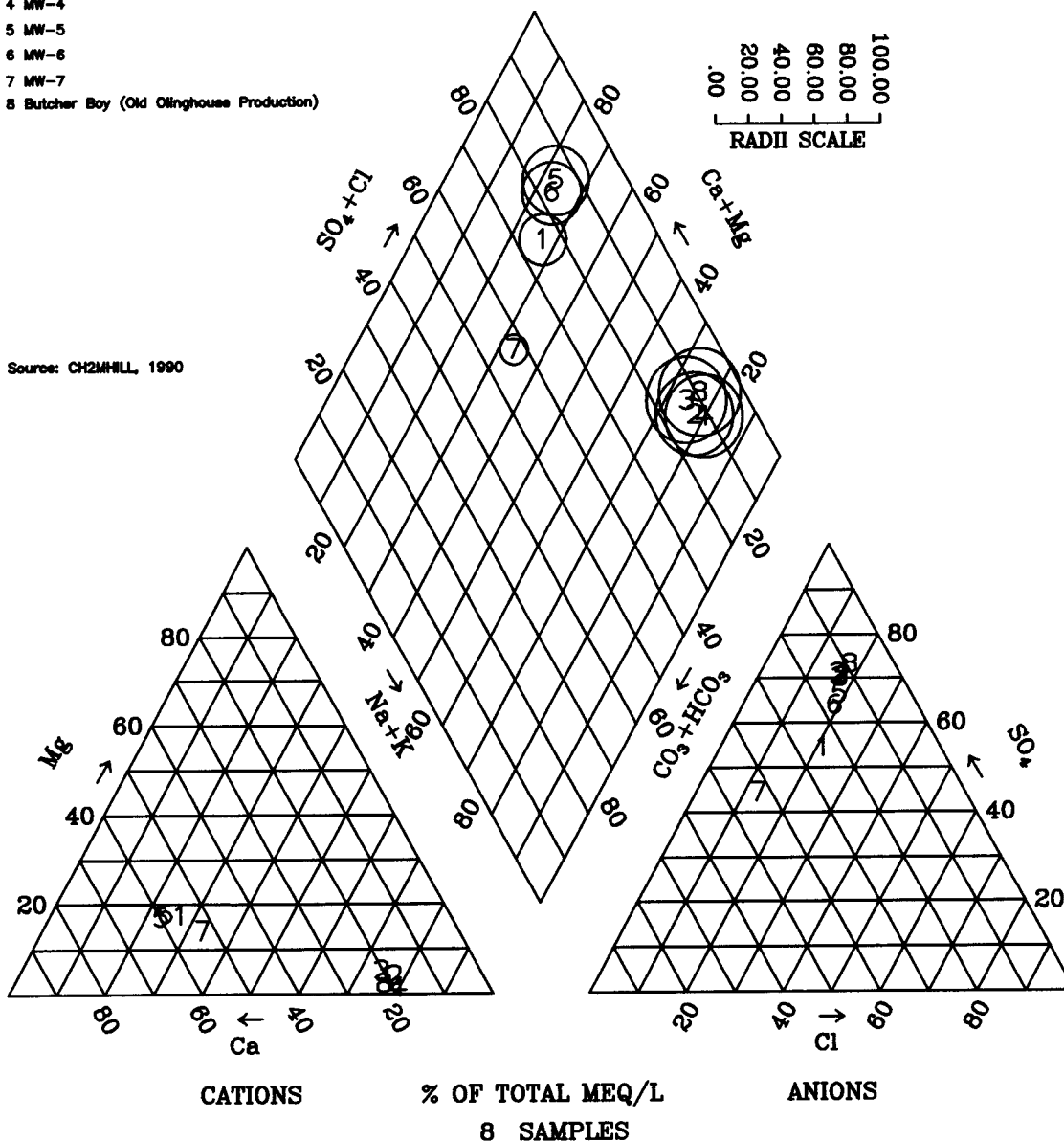
Water well analyses listed in Table 8.2 are from the Alta Gold Corporation mine area, on the Olinghouse fan. These vary from dilute $\text{Ca}^{++}\text{-Mg}^{++}\text{-Na-CO}_3^{\text{--}}$ waters (PW-1) to high-TDS $\text{Ca}^{++}\text{-Mg}^{++}\text{-SO}_4^{\text{--}}\text{-CO}_3^{\text{--}}$ (MW-3), which probably indicates localized flow through rock that has been differentially altered and weathered (Shepherd Miller, 1997d). Some of the samples contained TDS levels that are unacceptable for drinking water. However, for major ions and TDS, the arithmetic average of all mine area waters is similar to that found on the higher portions of the Olinghouse fan, which meets drinking water standards.

The trilinear diagram shown in Figure 8.17 depicts these compositions and the arithmetic average of the five mine pit waters. The average (Sample 6) suggests a moderately dilute $\text{Ca-Mg-SO}_4^{\text{--}}\text{-CO}_3^{\text{--}}$ water. Comparison with Figure 8.16 reveals a general compositional similarity between the mine area water and that of MW-1, MW-5, and MW-6, the up-gradient wells on the lower Olinghouse fan. Water

Dodge Flat Monitor Wells

- 1 MW-1
- 2 MW-2
- 3 MW-3
- 4 MW-4
- 5 MW-5
- 6 MW-6
- 7 MW-7
- 8 Butcher Boy (Old Olinghouse Production)

Source: CH2MHILL, 1990



DATE	REVISIONS	BY

FERNLEY TOWN UTILITIES
LYON COUNTY

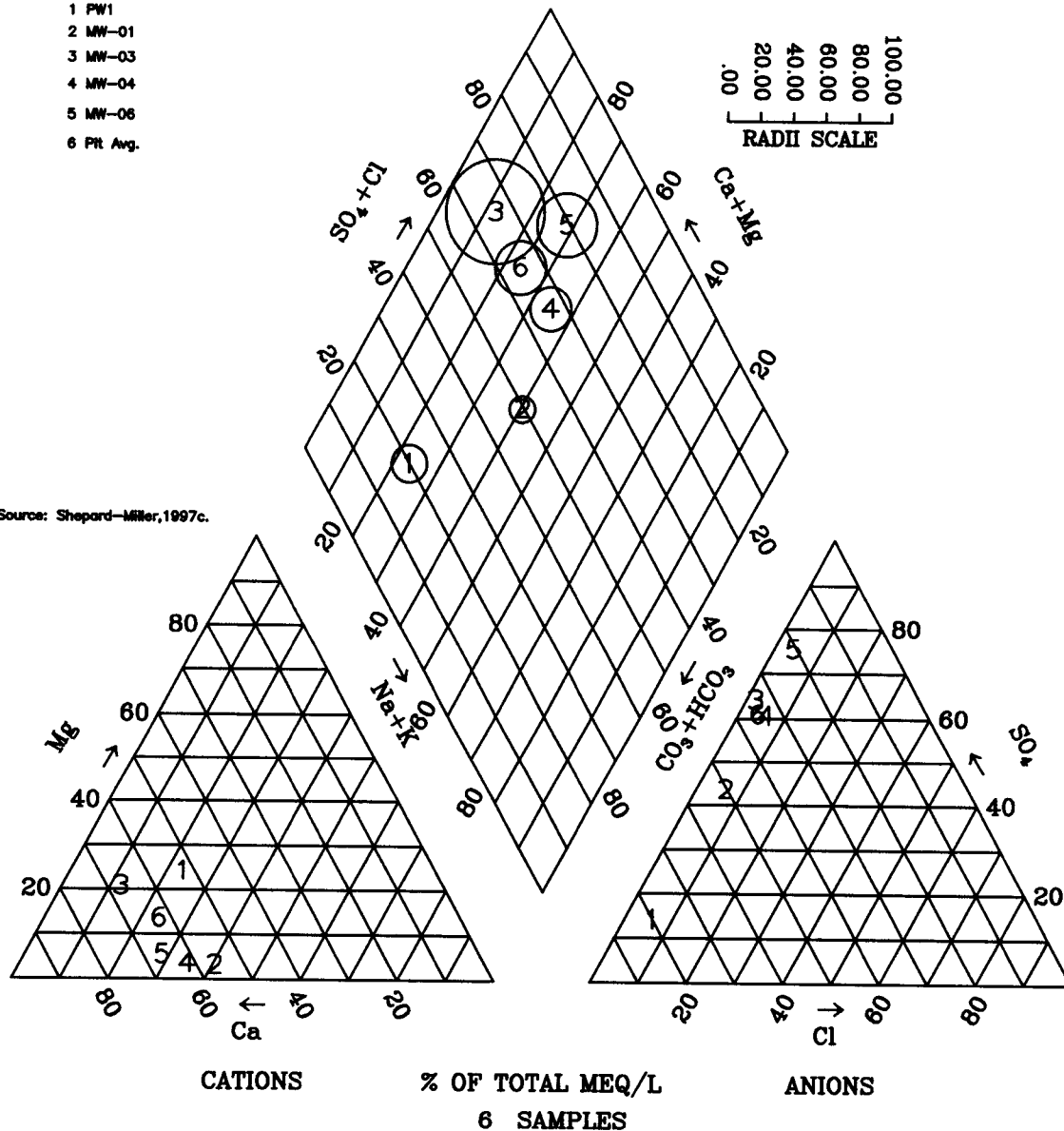
JOB NO. 8516.1142
DATE 10/26/99
DRN. BY LCS
CHK. BY JL

Well Water Analyses
Lower Olinghouse Fan - Figure 8.16

Alta Gold Monitor Wells

- 1 PW1
- 2 MW-01
- 3 MW-03
- 4 MW-04
- 5 MW-06
- 6 Pit Avg.

Source: Shepard-Miller, 1997c.



DATE	REVISIONS	BY

FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

Well Water Analyses
Olinghouse Mine Pit Area - Figure 8.17

with the mine pit average composition would evolve to that found in the lower fan monitor wells by acquiring a small amount of $\text{SO}_4^{=}$ and losing $\text{CO}_3^{=}$. Such evolution could readily be accomplished through dissolution of gypsum and precipitation of calcite. Both are present in the weathered, oxidized propylitic andesite that hosts the Olinghouse Mine (Shepherd-Miller, 1997). In this environment, gypsum derives from oxidation of pyrite, which often is abundant in nonweathered hydrothermally propylitized andesite associated with epithermal precious metals deposits.

The compositional similarities and plausibility of the reactive process suggest that water on the lower fan is sourced in bedrock within the mountain block near the head of the fan. Isotopic analyses by McKay and Bohm (1998) suggest a more complex history including pre-recharge evaporation and mixing with basinal water that may in part derive from geothermal sources. Both scenarios nevertheless are consistent with the conceptual model for natural recharge used in the present investigation, and with geophysical interpretations that suggest good quality water within alluvial material bordering the Pah Rah range (Hartley, 1998).

The next step in the water quality evaluation was to examine possible origins for solutes in waters at the base of the Olinghouse fan and on Dodge Flat proper. This necessitated incorporating solute fluxes and mass balance calculations, and formed the second component in the investigation of possible groundwater ion sources.

8.1.2 Sources of Ions to Dodge Flat Groundwater

In the specific area of the Olinghouse fan, investigation by CH2MHill (1990) and Cooper and Associates (1980) showed no evidence of solute contamination from the slime ponds emplaced during past placer mining activities. No other anthropogenic sources are present in the area. Possible natural solute origins include:

- ion release from soils
- surface water flows
- geothermal fluids
- dissolution of evaporite minerals deposited within fine-grained lacustrine sediments during interpluves

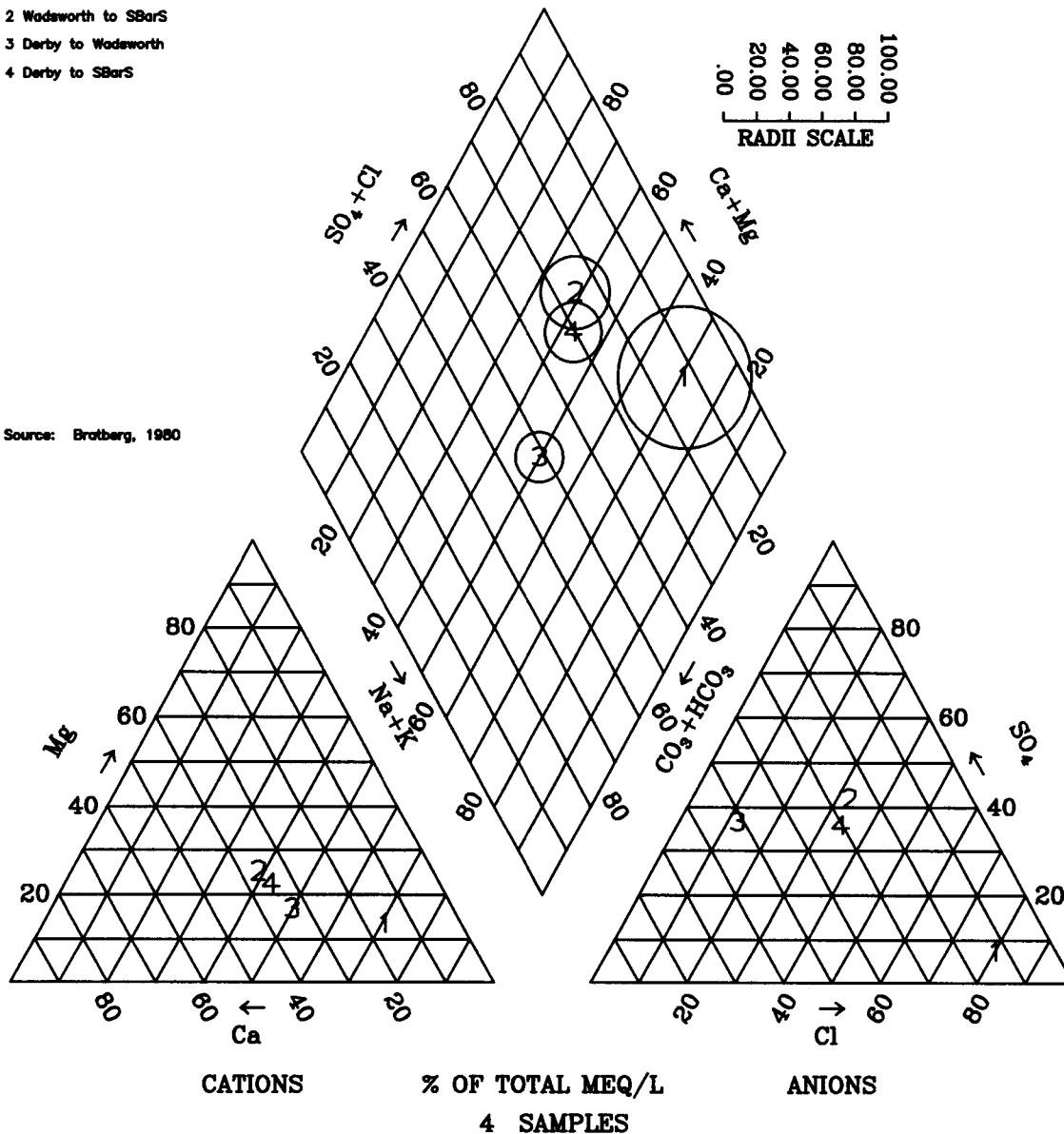
Comparison between waters derived from different sources was undertaken using trilinear diagrams. In addition, order of magnitude mass balance calculations were performed to establish limits on the capability of those sources to provide ions.

Dodge Flat groundwater compositions differ somewhat from Bratberg's (1980) calculated groundwater inputs to the lower Truckee River system which are shown in Appendix C, Tables C.3 and C.4, and plotted in Figure 8.18. Between the S-S Ranch and Nixon, the calculated input TDS is ~50% higher than in wells at the base of the lower Olinghouse fan. Cation proportions are somewhat alike, but the calculated input contains both a concentration and a proportion of $\text{SO}_4^{=}$ that is much higher than that found on Dodge Flat. Bratberg's estimates of Cl^- concentration in groundwater recharged to the Truckee are higher than in the Dodge Flat samples, but because of the higher TDS the proportion of Cl^- is much the same.

Truckee River Reach

- 1 SBarS to Nixon
- 2 Wadsworth to SBarS
- 3 Derby to Wadsworth
- 4 Derby to SBarS

Source: Bratberg, 1980



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Composition of Groundwater Input
to Flow System - Figure 8.18

Simply mixing Truckee River water at Wadsworth with that from the lower Olinghouse fan will not produce the loadings of Na^+ and $\text{SO}_4^{=}$ observed in the Truckee River at Nixon. This suggests that the input process at Dodge Flat consists of more than simple inflow of lower Olinghouse fan water: in particular, additional Na^+ and $\text{SO}_4^{=}$ must be supplied. Additional solute sources, either from within sediments or perhaps from geothermal fluids, are indicated.

The calculations discussed in Appendices B, C, and F indicate that on Dodge Flat groundwater solutes could derive either from the dissolution of evaporite minerals or from geothermal waters. Contributions from soluble ions in paleosols are also possible. Groundwater composition also could be modified significantly by cation exchange reactions.

As a consistency check of Bratberg's (1980) estimates, a composition close to typical Truckee River water at Nixon can be obtained by mixing river water from the Tracy-Fernley reach (Figure F.5, Appendix F) with his calculated Fernley-S-S and S-S-Nixon input waters (Figure 8.18). For the present investigation, solute mass fluxes provided an additional check on Bratberg's (1980) results. These involved estimating flows and solute balances within the Truckee River (see Section 5.0 and Appendices B, C, and D).

8.2 Truckee River Solute Mass Balances

Table C.3, Appendix C, shows average Truckee River flows, average concentrations of major ions, and the fluxes of those ions for the years 1980-1997 at Tracy, Wadsworth, and Nixon (NDEP, 1997; USGS, 1997). Based upon arithmetic averages, the river gains roughly 40 cfs along the reach between Tracy and Wadsworth. Total flux of most solutes is also higher at Wadsworth than at Tracy. Dividing the differences in flux for each ion by the flow gains provides estimates of requisite solute concentrations in the input water. These are geologically reasonable.

At Nixon, however, flows average only ~1.9 cfs higher than at Wadsworth, though the median flow gain is ~14.9 cfs (Table 5.6). If it is assumed that all solute remains in the river, *i.e.*, that bank storage and groundwater recharge by the river to surrounding aquifers are negligible, and further, that the solute loading derives only from recharge along the reach (~1200 af/y), unrealistically high solute concentrations are required in the recharge water: ~2% of halite saturation, and grossly supersaturated as regards calcite and gypsum. Appendix C, Table C.4, Appendix C, lists estimated solute concentrations in groundwater inflow under this set of assumptions.

These apparent contradictions indicate that the solute loading process along the lower Truckee is complex, and consists of more than simple recharge from adjoining mountain blocks. Analysis of the magnitude of additional inflow and contained solute has been carried out in Appendix C and Section 5.2, which describes the Truckee River Aquifer.

8.3 Conclusion

Solutes which enter the Dodge Flat aquifer system near the base of the Olinghouse fan may originate from evaporite minerals contained in the enclosing sediments, from geothermal waters, or from a combination of both. If present, geothermal inputs would probably be volumetrically undetectable, yet could supply significant dissolved salts to the groundwater in that area. The question of relative evaporite and geothermal contributions to the Dodge Flat groundwater system can not be resolved based on currently available data. Sulfur isotopic analyses may prove more valuable in that regard, but are beyond the scope of this study.

Simple mass balance calculations and the observed presence of soluble non-silicate mineral phases suggest, although they do not prove, that evaporite dissolution is the more probable ion source. These same calculations and hydrogeophysical interpretations indicate that other sources, such as paleosols, could not in themselves supply sufficient solutes to account for the observed concentrations in groundwater. Stratigraphic similarities elsewhere beneath Dodge Flat and near Fernley and Wadsworth imply that the same solute loading mechanism may operate in those areas as well.

The interpretation of differential resistivity data hints at a local zone of good quality water in alluvial units on the western flank of Dodge Flat. Its volume may be in the order of 100, or more, times annual recharge. The existence of such a zone also suggests that beneath Dodge Flat solutes are added to input groundwater, but sheds no light on the mechanism.



SECTION 9.0

ARTIFICIAL RECHARGE POTENTIAL

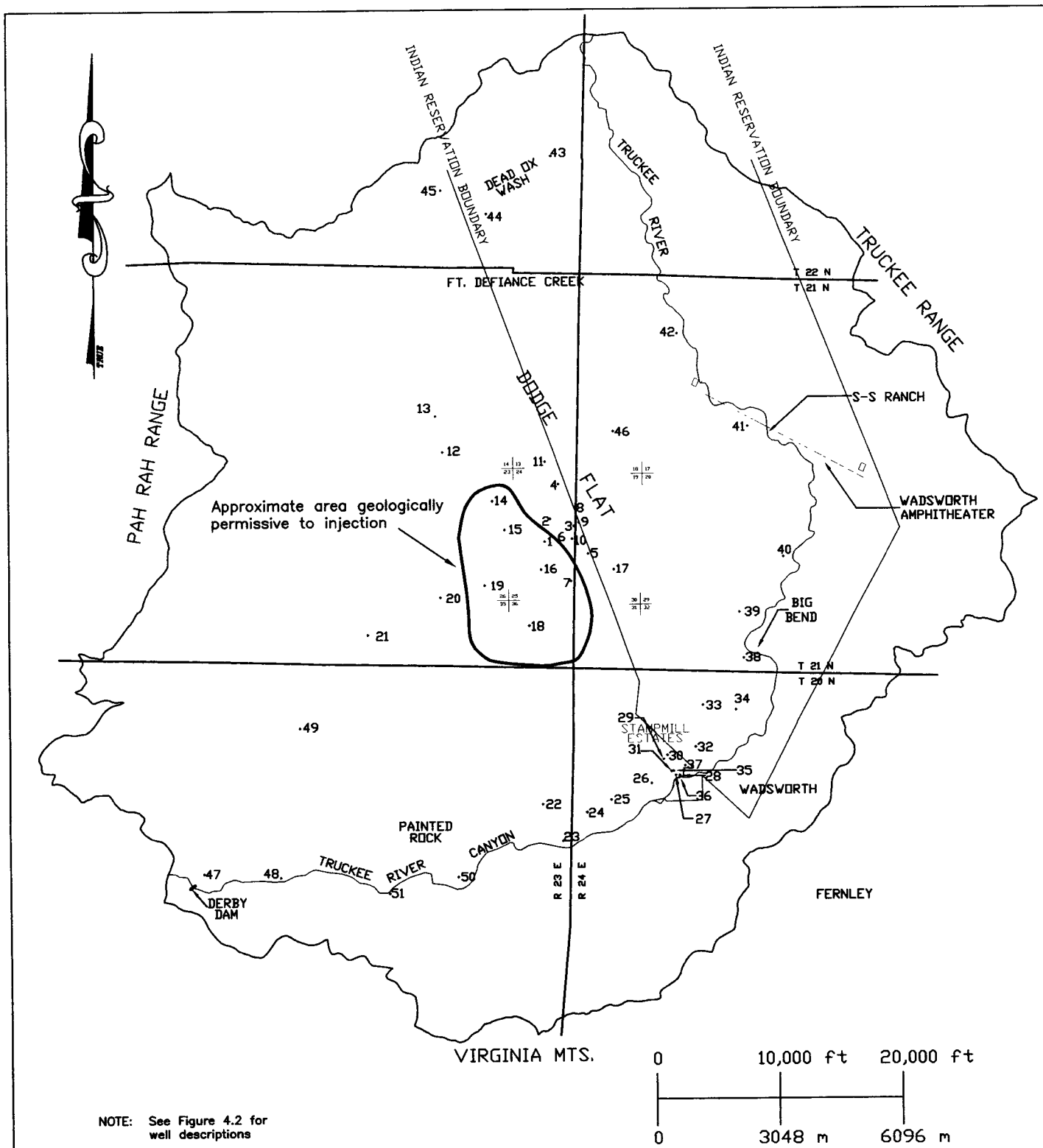
Artificial recharge is taking water from one source, usually surface water, and injecting it into the groundwater system through wells or allowing the water to infiltrate to the groundwater system from surface basins. The recharge water can then be recovered later to help meet demand. Todd (1965, p. 252) list two reasons for artificial recharge; relief of overdraft and use of the aquifer as distribution system storage. These broad categories are consistent with the findings of other investigators. This technique and the advantages and disadvantages are widely discussed in the scientific literature and in Nevada specifically by Brothers and Katzer (1990), Bernholtz, *et al.* (1991), Johnson, *et al.* (1997), and Katzer (1997). Artificial recharge is widely used across the country by numerous water managers to enhance existing water resources. In general this technique is cost effective, however a cost benefit analysis as described by Boardman, *et al.* (1996) should be completed for the specific project presented in this report. Similar evaluations of artificial recharge have been made by Reichard and Bredehoeft (1984) and Katzer, *et al.* (1998).

It has been proposed that Fernley acquire surface water rights out of the Truckee River and use those rights to recharge the groundwater system underlying Dodge Flat and recover the water for distribution to Fernley or additionally, as part of a regional water facility, to also serve Wadsworth. This evaluation is the first attempt to determine the suitability of the groundwater system to store Truckee River water for later recovery for municipal uses.

Artificial recharge by well injection into the groundwater system underlying Dodge Flat is feasible and is the preferred method of augmenting the groundwater resources simply because of the large acreage that may be required for recharge basins (CH2Mhill, 1990) and the potential for the infiltrating water to mobilize solutes in the sediments the recharge water must pass through to reach the groundwater table. Based on aquifer test data the saturated sediments that make up the aquifer system have the ability to accept large amounts of water. Artificial recharge through wells will bypass the lacustrine (fine-grained lake bed) sediments and allow injection into the underlying principal aquifer system. The chemistry of the lake bed sediments, both saturated and unsaturated, is dominated by various salts that will degrade recharge water. There is an area, about two square miles, on the central to west side of Dodge Flat that contains relatively good water quality, less than 500 mg/l total dissolved solids and it is this area that recharge, from a water quality basis, would be most successful (see Figure 9.1). Outside of this area and towards the river water quality becomes poorer, but still within the secondary drinking water standards.

Artificial recharge by well injection will require treatment of the river water prior to injection. The cost of treatment, together with the cost of diverting the water from the river and conveying to the treatment facility/recharge wells location, will need to be integrated into the cost benefit analysis noted previously herein. The cost benefit analysis is beyond the scope of this report.

There is ample room in the aquifer to store many thousands of acre-feet of water, but some water will be degraded by the abundance of salts in the sediments and groundwater and that is the only adverse impact by mixing Truckee River water with the natural groundwater. A geochemical mixing model called NETPATH developed by Plummer, *et al.* (1991) showed virtually no adverse chemical impact caused by mixing Truckee River water with natural groundwater. Calculations indicate that water from MW-1 is slightly supersaturated with respect to calcite, dolomite and aragonite. This is due to the precipitation kinetics of these species, and is commonplace (Drever, 1988). On the other hand, both Truckee River water and water from MW-7 are significantly under-saturated with regards to these phases. An equal mixture of Truckee River water and that from MW-1 will be slightly over-saturated. Because of kinetic effects, it is unlikely



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Recharge Area Location Map
Figure 9.1

that precipitation of these carbonates will occur; however, full reaction path geochemical simulations should be undertaken as part of an aquifer storage and recovery (ASR) feasibility investigation.

Short-term storage up to five years of 5,000 to 10,000 acre-feet/year would probably result in minor quality degradation of the recharged water, but would not cause a measurable increase in groundwater discharge to the Truckee River. If the recharge project is operated by injecting river water during the winter and spring and recovering it during the following summer potential water quality degradation will be minimized.

Groundwater modeling results indicate that with current water demand projections developed by Waterresource Consulting Engineers, Inc. (written communication, 1998) shown in Table 10.6, and starting to recharge 5,000 acre-feet/year in the year 2005, there will be no serious overdrafts until about 2025. At that time artificial recharge will need to be increased.

9.1 Potential Impacts from Storage on the Olinghouse Fan

Although additional modeling in conjunction with subsequent feasibility studies is necessary, order of magnitude estimates regarding the extent and shape of the groundwater surface subsequent to injection can be made based upon the effect of the Dodge Flat pump tests. In the following example, injection wells, rather than infiltration ponds, are considered the optimum ASR method. This is based on the large acreage required for infiltration (CH2MHill, 1990), associated evaporative losses, and acquisition of solutes from the fine-grained lacustrine sediments and paleosols through which infiltrated water must pass.

The effects on the water table of injection at 900 gpm (~1450 af/y) can be considered the opposite of the withdrawals performed for the pump tests, assuming continuity of aquifer properties into those portions of the aquifer that receive the injected water (Freeze and Cherry, 1979). Based upon drawdown measurements, the mounding from a single injection well would raise the piezometric surface by ~50 ft (to ~100 feet below land surface) at the well site, and by <1 foot at ~1000 - 1500 feet. The additive effects of four identical injection wells spaced ~500 feet apart might therefore raise the water table perhaps as much as 10 feet midway between them. These figures are order-of-magnitude estimates only, assuming additivity of injection curves. Precise impacts must be appraised by a detailed feasibility study.

Assuming a transmissivity of ~225,000 gpd/ft and an aquifer thickness of ~500 feet gives a hydraulic conductivity for the alluvial aquifer of ~60 ft/d. Under a hydraulic gradient of ~50/1000, that conductivity gives a specific discharge of ~30 ft/d, and at 20% porosity, an average linear velocity of ~150 ft/d. The rapidity of this flow suggests that the injection well field should be situated as far as possible upfan from the low-quality groundwater on Dodge Flat. However, ion release from paleosols could contribute to the solute loading of injected fresh water, depending on the proportion of paleosols in the alluvium. Calculations in Appendix B, based on soil sampling by CH2MHill indicate that upon saturation, 1 ft³ of paleosol potentially could supply ~1400 mg/kg of solute to its pore water. If paleosols comprise ten percent (10%) of a newly saturated alluvial aquifer, the solute concentration in the injected water would increase by ~140 mg/kg. This addition of salts will be magnified to the extent that the groundwater mound encounters fine-grained sediments, which potentially may cause solutes. Although this preliminary analysis suggests that downgradient flow of freshly injected water poses a greater risk of water quality degradation than does mounding within the aquifer, further modeling efforts are essential to quantify the respective impacts of the two processes. Furthermore, ASR feasibility investigation must include additional drilling and detailed characterization of the Olinghouse fan deposits. In addition to the technical aspects associated with the Olinghouse fan storage area, other concerns revolve around water acquisition options.

9.2 Water Availability for Recharge

It is assumed for the purposes of this report that the water available for recharge to the Dodge Flat ASR Project will come from the Truckee River. The water rights for the recharge program will be acquired by the Town of Fernley from the Truckee Carson Irrigation District (TCID). It was further assumed that Fernley will be allowed to use the TCID water rights obtained from the Fernley area TCID irrigation rights. Ongoing negotiations between the Pyramid Lake Paiute Tribe and the Town of Fernley are addressing this issue. Also, it was assumed that Fernley will be allowed to use and store the Truckee Division (of TCID) distribution system loss. The distribution system loss is estimated to be in the order of 1/3 of the water rights acquired by the Town of Fernley. It is emphasized that the State Engineer has NOT ruled on the losses issue.

To evaluate the impact of storing and using these rights by the Town of Fernley, Sierra Pacific Power Company's Truckee River modeler (Sierra Hydrotech) modeled various scenarios relating to the Town of Fernley's storing Truckee River water rights. The model utilized for this study was the Truckee River monthly operational model used for the Truckee River Operating Agreement Environmental Impact Statement/Environmental Impact Report (TROA EIS/EIR) analysis. The analysis period was for 95 years (1901-1995). Several assumptions were utilized in the performance of this model. Appendix G contains the May 5, 1997 Fernley Water System Supply Analysis performed by Sierra Hydrotech for the reader's reference.

In the analysis, water storage requirements were evaluated based on several alternatives, three of which are discussed in this section. The first alternative was a storage requirement using the agricultural diversion demand schedule which provides for diversion of water from the Truckee River to the Truckee Canal from March through November of each year. The second alternative utilized a municipal and industrial demand schedule which diverts water twelve months of the year. The third alternative evaluated was a water exchange along with the M & I demand schedule. The M & I demand schedule, again, diverted water for twelve months with the maximum month being in the order of 13% of the annual diversion and a minimum month a little over 5% of the annual diversion. For the purposes of this modeling study, a diversion requirement from the Truckee River was assumed to be 4,500 acre feet per year, based on a water supply requirement schedule developed by Wateresource Consulting Engineers, Inc., for the Fernley Town Utilities.

The agricultural demand schedule modeling included limitations on Fernley's storage ability whenever Truckee River flow was less than necessary for Truckee River Water Quality Settlement Agreement purposes. The average annual supply for the study period was 4,425 acre feet with the smallest annual supply being 2,105 acre feet. The number of years when the 4500 acre feet could not be provided was four years. Each of those years' shortages occurred in the month of November only. The maximum storage requirement for this demand schedule was 1,820 acre feet.

The M & I demand schedule analysis provided an average annual supply for the study period of 3,792 acre feet with the smallest annual supply being 2,250 acre feet. However, the number of years when the 4500 acre feet could not be delivered increased to 69 years. The shortages occurred primarily in the winter because either there were storage spills during wet years or the Truckee River Water Quality Settlement Agreement summer restrictions prevented accumulation of enough storage for Fernley during November through March. The maximum reservoir storage requirement was 1,370 acre feet.

The M & I demand schedule with water exchanges assumed that it would be feasible to have seasonal exchanges of water supply among Fernley, TCID and Pyramid Lake. Assuming that the Truckee Division water supply can be related to pooled water storage in Lake Tahoe and Boca, it

would then be possible for Fernley to convert and store water during the winter. This would be based upon assurances that water for Truckee Division rights would be available during the upcoming irrigation season using seasonal exchange water borrowed from either the Carson Division of TCID or from Pyramid Lake. This water would either be diverted to serve Fernley's winter demand or put into Fernley's storage during the winter and conversely, during the summer, an equivalent amount of water would be released to the Carson Division or Pyramid Lake, as appropriate, through an exchange. This demand schedule analysis provided an annual average supply of 4,417 acre feet, with a minimum annual supply in the order of 3,717 acre feet. The number of short years when the 4,500 acre feet could not be delivered decreased to 33 years with 31 of those years occurring in the month of November only. The maximum reservoir storage required for this demand schedule was 5,460 acre feet.

An M & I schedule is more desirable for the Town of Fernley because of the 12-month demand requirement; however, an agricultural schedule may be feasible in that the winter demands, November through March, are the lowest of the year, and the demand requirement could be provided by groundwater from the Fernley area with or without treatment as required during this period to meet M & I demands.



SECTION 10.0

GROUNDWATER MODEL DEVELOPMENT AND PROJECT IMPACTS

MODFLOW is a three dimensional groundwater flow model that simulates groundwater movement through gridded layered cell blocks by solving a series of finite difference equations. These equations preserve the quantity of ground water in the modeled area. For any further detail regarding the flow model, the MODFLOW documentation (McDonald and Harbaugh, 1988) should be consulted.

The first step in developing a groundwater flow model is the formulation of a conceptual hydrogeologic model of the area to be mathematically represented. This conceptual model is based upon the available hydrologic data, inferences based on observations of similar hydrologic settings, and assumed conditions or expected ranges of conditions for parameters that have not been measured or are not readily estimated for the subject hydrologic basin.

The next step in the groundwater flow model development process is to construct a numerical or mathematical representation of the conceptual model. This requires generation of a grid system covering the hydrologic area. The grid system can be either single or multiple layers with each cell in the model being identified by grid row, column, and layer designation. Usually the grid size and number of layers are chosen based on the amount of available hydrologic data for the particular basin. Each cell is given a number of parameters (i.e. transmissivity, storage (in transient scenarios), conductive characteristics for river and spring flow, recharge where appropriate, and rates of evapotranspiration when the water levels are within a set distance from land surface) which control water flow through the model.

The approach taken in the development of the ground- and surface water model of the Dodge Flat area, including the Truckee Canyon area from Derby Dam to Dodge Flat, was to produce a steady state model. The area encompassed by the model is shown in Figure 10.1. It includes the Truckee River from Derby Dam to the Nixon gage, and also shows the steady state groundwater levels. The steady state model is intended to replicated as closely as possible the hydrologic system such as annual mean Truckee River flows, groundwater recharge, and evapotranspiration as defined by the USGS (Van Denburgh, *et al.* (1973)) while attempting to match existing groundwater levels. Important "constants" become the amount of water entering the system or the recharge, inter-basin groundwater flow, river and canal flow and leakage, as well as water leaving the area by evapotranspiration and canal and river flow. River gage records at Derby, Wadsworth, and Nixon as well as groundwater water levels serve as calibration points.

Once the steady state model is calibrated to represent the Dodge Flat and Truckee River flow system, transient simulations are then conducted to measure the impact of pumping and recharging the groundwater system over time. The following details the development of the steady state model and then the various transient scenarios and resulting simulated impacts.

10.1 Steady State Model

A one-half mile grid, 32 rows by 32 columns, consisting of two layers, was constructed to simulate hydrologic conditions in the Dodge Flat and Truckee Canyon. Both the upper alluvial fill and surrounding consolidated rock outcroppings and the lower consolidated rocks were modeled as confined fixed transmissivity units. The flood plain aquifer is considered unconfined. Conceptual hydrologic budget inflows consisting of groundwater recharge, inter-basin groundwater flow (from the Fernley area), and measured flows at the Truckee River Derby Dam gage and Truckee Canal were inputs to the steady state model. Parameters such as transmissivities, vertical leakance between

layers, and river and canal leakance values, were calculated based on aquifer tests and used in the model to simulate ground- and surface water flow quantities and paths. Conceptual hydrologic budget outflow consists of evapotranspiration. Simulated Truckee River flows at the Wadsworth and Nixon gages (simulating leakage from and gains to the river) compared to the actual gage record and measured groundwater levels provide for calibration of the parameters included in the steady state model. The simulation of conceptual hydrologic budget inflows and outflow are discussed in detail below. Then the calculations or estimates used in parameter selection (i.e. transmissivity, vertical leakance, etc.) which was dependent on geology and aquifer test data are discussed. Finally the simulated results consisting of Truckee River flows and groundwater levels are discussed and compared with actual values in the calibration section.

10.1.1 Hydrologic Budget Measurements and Estimates

10.1.1.1 Recharge and Inter-Basin Groundwater Flow

Primary recharge to the Dodge Flat groundwater system occurs from the infiltration of precipitation occurring in the higher elevations. Dodge Flat receives the majority of its recharge from the Pah Rah Range bordering the valley on the west side. Van Denburgh, *et al.* (1973) estimated the recharge, based on the method described by Eakin, *et al.* (1951), to Dodge Flat to be about 1,400 af/y. This recharge was confirmed in this study using the most recent larger scale maps (1:24,000). Digital elevation data were used to generate and distribute recharge based on the Maxey-Eakin method (Eakin, *et al.*, 1951) with the factors defining percent of infiltration listed for Dodge Flat in the report by Van Denburgh, *et al.* (1973). Figure 5.3 shows the recharge areas and Table 5.3 shows the recharge values used in the model. Based on this method, the recharge for Dodge Flat was simulated in the model to be about 1,400 af/y.

Based on difference of median flows between gages, approximately 15 cfs (11,000 af/y) is estimated to enter the Dodge Flat area and reach the Truckee River between Derby and Nixon based on analysis of Truckee River flow described in Section 5.0. A total of ~9000 af/y is thought to enter the river from the Fernley area (Van Denburgh and Arteaga, 1985), and this is the figure used in the numerical simulations (see Section 7.0). The model was allowed to calculate the amount of interbasin flow entering the Dodge Flat Basin by utilizing general head boundaries and conductances. These are discussed in more detail in the hydraulic parameter section. The model simulated an inter-basin flow from the Fernley area of about 8300 af/y.

10.1.1.2 Truckee River Flows

The Truckee River flow at Derby Dam was used as an input to the model. The mean flow data derived from the regressed USGS monthly average flow data from 1918 to 1997 for the Derby Dam, Wadsworth, and Nixon gages were used as input and as calibration data. These flow data are 401.3 cfs at the Derby Dam gage, 441.9 cfs at the Wadsworth gage, and 443.9 cfs at the Nixon gage. The statistical analysis that produced these values is discussed in detail in Section 5.0, Appendix C.1 and Appendix E.

The modeled results and the comparisons with the gaged data is discussed in detail in Section 10.1.3.

10.1.1.3 Evapotranspiration

Evapotranspiration (ET) was simulated in the Dodge Flat and the Truckee Canyon segment by using the MODFLOW ET module. Maximum rates and extinction depths are specified and ET is calculated linearly, based on depth to water, with zero ET at the specified extinction depth and maximum ET occurring when the water table is at land surface.

Van Denburgh, *et al.* (1973, Table 15) estimates the acreage of phreatophytes and irrigated lands in Dodge Flat to be 2200 and 950 respectively. They further estimated the combined phreatophyte and irrigated acreage in the Truckee Canyon segment to be 1500 acres for a total acreage of 4650. Assuming an annual consumptive use of 3 feet per year per acre, and local evapotranspiration rates, the total evapotranspiration equals about 14,000 af/y (19.3 cfs) between Derby and Nixon. Approximately two-thirds of this, or ~9400 af/y (~13 cfs) takes place downstream from the Wadsworth gage.

The 7.5 minute USGS topographic maps along with Plate 1 from Van Denburgh, *et al.* (1973) were used to estimate the amount of phreatophytes and irrigated lands occurring in each of the model cells. Because the overall evaporation rate assumed of 3 feet per acre is constant for each area regardless of the actual variable depth to water, a greater potential ET rate had to be specified in the ET module to develop the volume calculated based on the areas specified by Van Denburgh, *et al.* (1973). An extinction depth of 20 feet was used with a annual rate of 5.3 feet per year which is higher than the listed 3 feet per year to compensate for the overall rate considering depth to water. The total evapotranspiration in the steady state model equals about 13,500 af/y (18.6 cfs).

10.1.2 Hydraulic Parameters

The hydraulic parameters govern how the water introduced by recharge, river or canal leakances, or inter-basin flow moves through the modeled area to the areas of discharge. For a steady state simulation the important hydraulic characteristics are transmissivity, boundary conditions (conductances), river and canal leakances and, since this is a two layer model, vertical leakance. These parameters are discussed below:

10.1.2.1 Boundary Conditions

The Dodge Flat basin was modeled as a "free body" tied to general head boundaries outside the existing basin boundary. The water levels specified for the general head boundaries were based on Van Denburgh, *et al.* (1973) and Thomas, *et al.* (1986). Conductances were established to simulate the estimates for inflow as well as match existing water levels.

As stated above, Van Denburgh and Arteaga (1985) estimate approximately 12 cfs to enter the Truckee River between the Wadsworth and Nixon gages. Much of this water is consumed by evapotranspiration resulting in little difference between the mean values of the Wadsworth and Nixon gages. The model simulated about 8300 af/y, or about 11 cfs entering the Dodge Flat Basin from the Fernley area. This is essentially the same amount previously estimated, however the simulated gage at Nixon did not need additional water as explained below. Again the basin hydrology is driven by evapotranspiration, and the current distribution of

phreatophytes and irrigated lands does not require any additional water from the Fernley area.

10.1.2.2 Transmissivity

Transmissivity values were assigned based on aquifer test data and geology. Unpublished maps by the Nevada Bureau of Mines and Geology (Garside and Bonham, 1997 a, b) and the Washoe County 1:250,000 scale geologic map in Bonham and Papke (1969) were used to classify the geology into transmissivity zones. Figure 10.2 shows a simplified version of the surface geology in the modeled area as obtained from those maps. Because most of the near surface in the region is unsaturated, for modeling purposes, a subsurface geologic map was compiled by combining the surface geology with geophysical, and stratigraphic interpretations. This provided the second layer for the groundwater flow model, and is shown in Figure 10.3.

The four lithologies in Figures 10.2 and 10.3, and their transmissivities, are shown in Table 10.1, for the upper and lower model layers, respectively.

TABLE 10.1

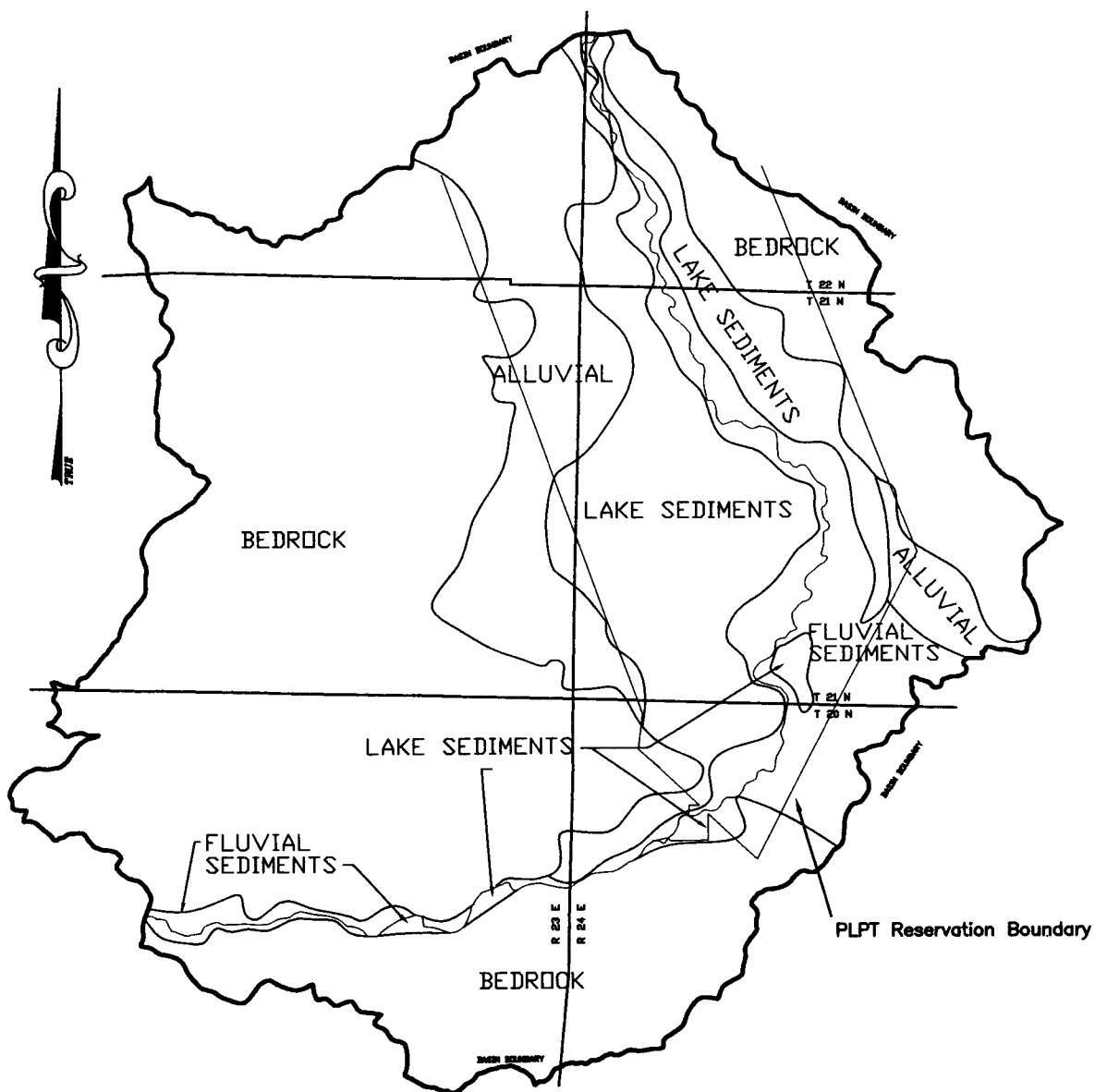
TRANSMISSIVITY VALUES OF DODGE FLAT LITHOLOGIES

Geologic Type	Upper Layer ft²/day	Lower Layer ft²/day
Bedrock Volcanics	50	50
Alluvial	10,000	5000
Lake Sediments	5000	700
Fluvial Sediments	20,000	10,000

The values for the alluvial system and the fluvial sediments, in the upper layer, are most important when considering matching the simulated groundwater levels with actual measured values. The value of 10,000 ft²/day is slightly lower than the transmissivity value calculated from the aquifer test of 93,000 gpd/ft or about 12,000 ft²/day. The value of 20,000 ft²/day for the fluvial sediments is based on the mean value of the various river segments as shown in Table 10.2. The actual river leakance is calculated for each segment as described below.

An aquifer test was conducted on the Olinghouse fan in the Dodge Flat area as part of this investigation. A well owned by Nevada Land and Resources (Nevada Land North) was pumped at 900 gpm for about 3 days. Water level data from three observation wells, MW-3 (a distance of 495 feet from the pumping well), the Nevada Land South well (a distance of 1423 feet from the pumping well), and the Olinghouse Well (a distance of 1248' from Alta Gold #2). These wells are included in Figures 10.1 and 4.1. These data were used to prepare Figure 10.4, which is a distance drawdown plot at 1000 minutes (0.694 days). The transmissivity for this area is calculated to be about 93,000 gpd/ft with a storage coefficient of 0.018.

Transmissivities of the aquifer along five Truckee River segments in the modeled area were calculated based on estimated conductivities and aquifer thicknesses.



LITHOLOGIES:

FLUVIAL AQUIFER (RIVER)
 LAKE SEDIMENTS
 ALLUVIAL MATERIAL
 (OLDER + YOUNGER)
 BEDROCK VOLCANICS

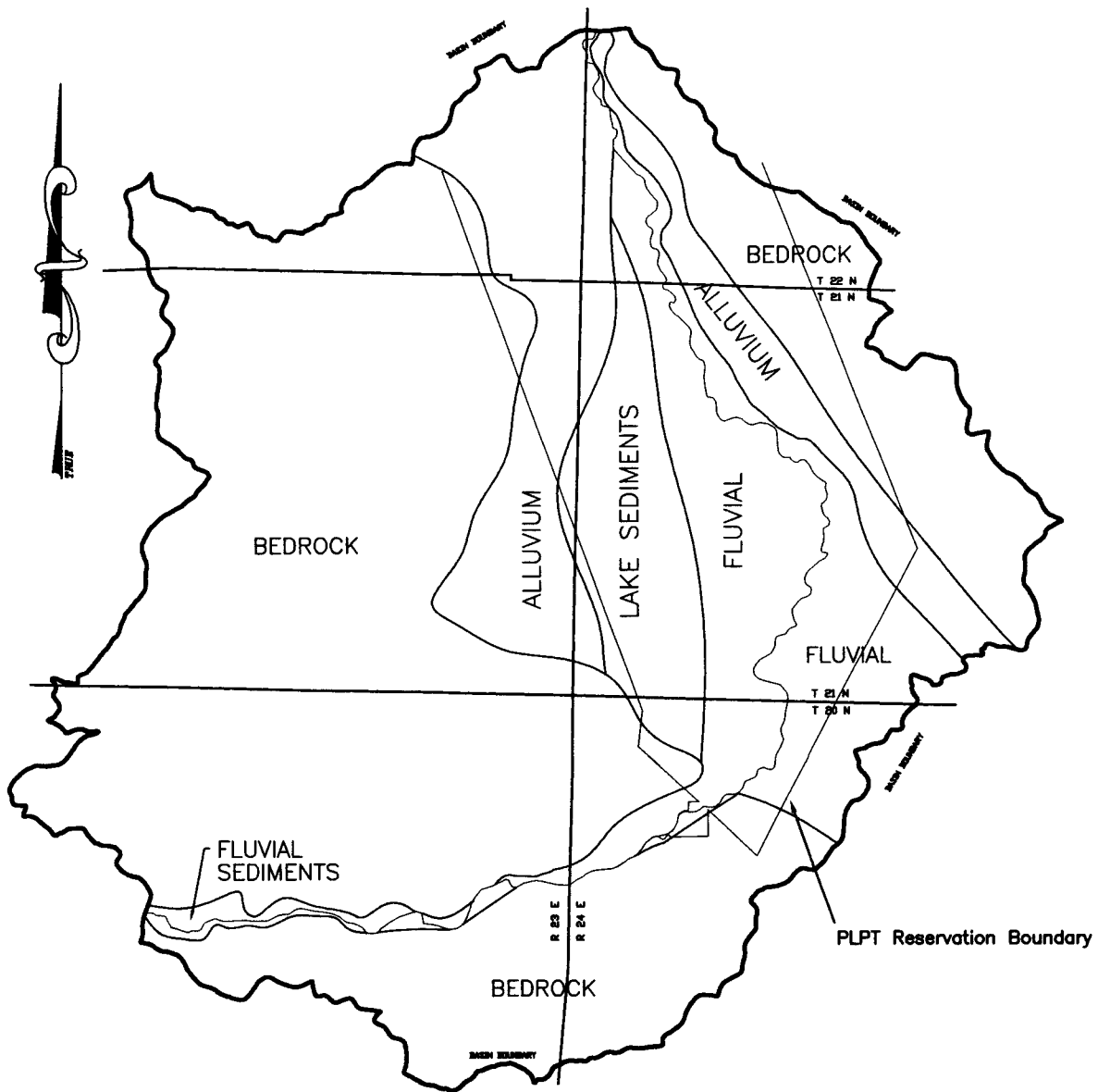


FERNLEY TOWN UTILITIES
 LYON COUNTY

JOB NO. 8516.1142
 DATE 10/28/99
 DRN. BY LCS
 CHK. BY JL

DATE	REVISIONS	BY

Geology Upper Layer
 Figure 10.2



LITHOLOGIES:

FLUVIAL AQUIFER (RIVER)
 LAKE SEDIMENTS
 ALLUVIAL MATERIAL
 (OLDER + YOUNGER)
 BEDROCK VOLCANICS

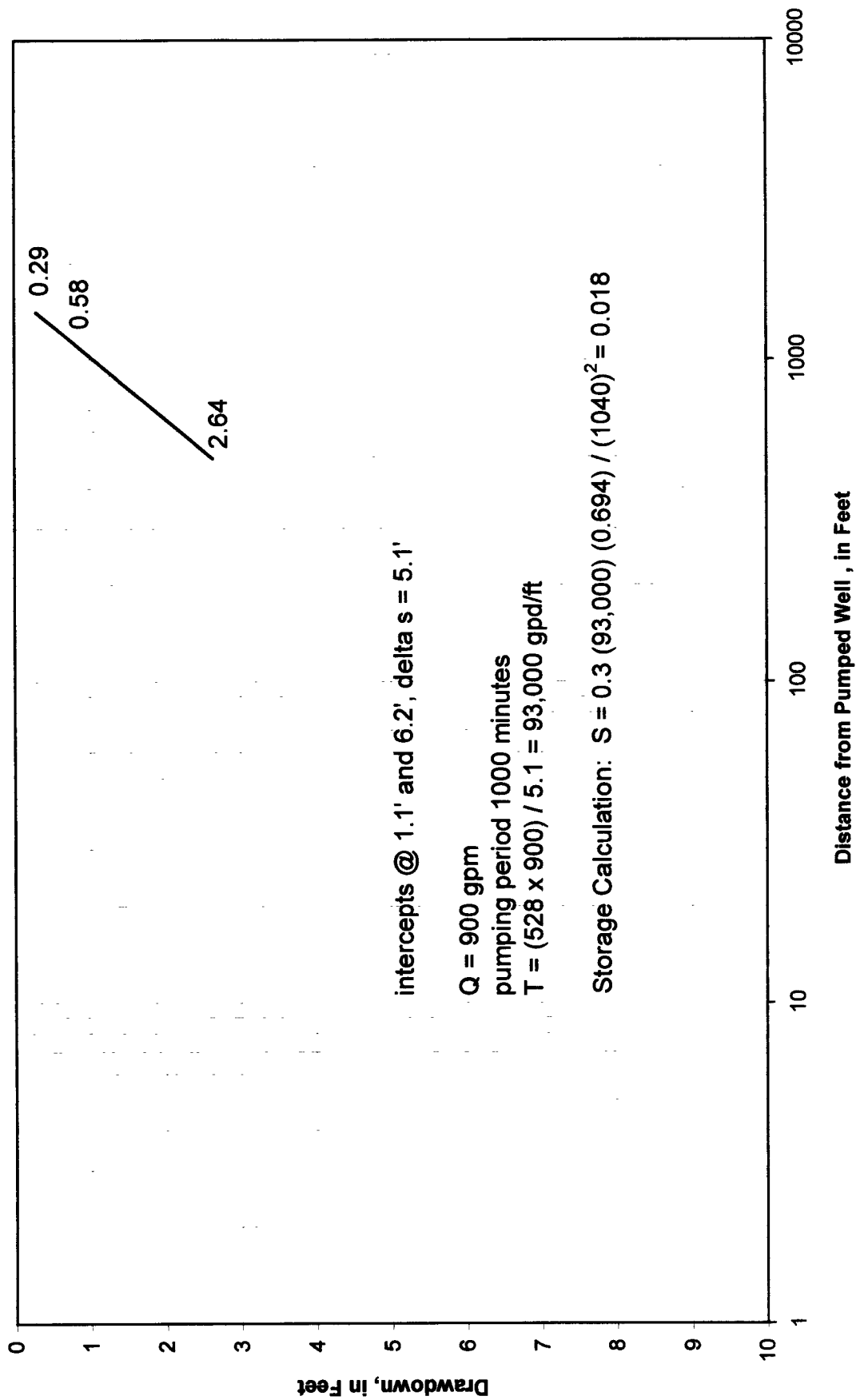


FERNLEY TOWN UTILITIES
 LYON COUNTY

JOB NO. 8516.1142
 DATE 10/28/98
 DRN. BY LCS
 CHK. BY JL

DATE	REVISIONS	BY

Geology Lower Layer
 Figure 10.3



Distance - Drawdown Plot
Figure 10.4

Figure 5.4 shows these segments and Table 10.2 lists their transmissivities and combined arithmetic mean.

TABLE 10.2
TRANSMISSIVITIES OF THE TRUCKEE RIVER AQUIFER

Segment	Average Transmissivity ft ² /day
#1 West of Painted Rock Exit	11,100
#2 Painted Rock to Reservation Boundary	13,400
#3 Reservation Boundary to Wadsworth	23,300
#4 Wadsworth to Windmill Cyn	20,900
#5 Windmill Cyn to Hatchery	9,800
Combined Weighted Mean for all segments (based upon the product of average conductivity and average depth to bedrock)	19,000

In calibrating the model, water levels from 19 wells were used, as is discussed in detail in Section 10.1.3. Generally, the simulated groundwater levels on the Olinghouse fan are slightly lower than the actual measured values, which would indicate that a lower transmissivity value should be used or there is additional water in the basin not accounted for in the model. Most probably there is some mountain front runoff not accounted for in the model entering the basin. Since the groundwater recharge in this area only equals about 1400 af/y, mountain front runoff approaching 1000 af/y could be significant if 20 percent were recharge. Because the model was developed to simulate the aquifer responses to artificial recharge and pumpage, it was thought that the transmissivity values reported above are appropriate since they closely match values from actual tests.

10.1.2.3 River Conductance

The MODFLOW “stream module” (Prudic, 1989) was used to simulate the Truckee River interaction with the underlying aquifer. The stream module allow the input of river flow rates and calculates stream losses and gains from interactions with the aquifer.

The Derby Dam, Fernley West, Wadsworth, and Olinghouse 7.5' USGS topographic maps were used to estimate the length of the river reaches within each of the grid nodes. The width of the river was also estimated and on average found to be about 1000 feet. River bed material commonly has a lower hydraulic conductivity than the underlying aquifer. The vertical conductivity of the Truckee River bed was assumed to be about 25 percent of the hydraulic conductivity of the underlying aquifer. The river bed thickness was assumed to be about 10 feet. These values were used to calculate the conductance for each of the river grid nodes.

10.1.2.4 Canal Conductance

The MODFLOW “river module” (McDonald and Harbaugh, 1988) was used to simulate leakage from the Truckee Canal. The simpler river module allows leakage by specifying a head and vertical conductance.

The Derby Dam and Fernley west 7.5' USGS topographic maps were used to estimate the length of the canal reaches within each of the grid nodes. The width of the canal was specified as 50 feet and the depth at 8 feet. The dimensions were based on engineering drawing of bridges crossing the canal and are representative of the canal throughout the modeled area. Conductances were calculated as specified above for the river reaches, however the vertical conductivity was thought to be higher than the vertical conductivity for the river bed and was assumed to be 50 percent of the aquifer hydraulic conductivity.

10.1.2.5 Vertical Leakance

The vertical leakance value establishes the connection between the upper and lower model layers and were calculated as generally specified by McDonald and Harbaugh (1988) based on assumptions of an overall general thicknesses. The layers were simulated as fairly well connected and for simplicity the value of 1×10^{-5} was used.

10.1.3 Steady State Simulation

The following discusses the calibrated results of the steady state simulation. Groundwater levels and Truckee River flows are discussed in detail as well as the simulated basin water budget.

10.1.3.1 Groundwater Levels

The potentiometric surface resulting from the steady state simulation for Dodge Flat and the Truckee River Canyon is shown in Figure 10.1 with the actual water levels imposed.

Table 10.3 shows the 19 wells used for calibration and the differences between the actual and simulated water levels for the Dodge Flat and Truckee Canyon model. These measurements can be found in the complete well inventory found in Table 4.2 with the same ID numbers.

The 19 wells were chosen because they represent the system spatially and many were located in the field with a Global Positioning System (GPS) (Carpenter, 1997; McKay and Bohm, 1998). Of the 19 wells, four wells are located in or near the mountain block and are probably representative of a localized or perched water table. If these four wells are not included when evaluating the calibration, all of the simulated water levels of the 15 remaining wells are within 50 feet of the actual level, 73 percent are within 25 feet, and 50 percent are within 10 feet.

Considering the elevations specified as input and the simulated groundwater elevations are representative of one node which encompasses a half mile by half mile area, the match of the simulated values with the actual values appear to be reasonable. Therefore, the steady state model provides a reasonable simulation of the potentiometric surface.

TABLE 10.3
SIMULATION CALIBRATION WELLS

Location	ID Number	Actual WL	Simulated WL	Difference	Comments
NE/NE 25	7	4036	4022	14	GPS
NW/SW 19	9	4037	4017	20	GPS
NW/SE 14	12	4378	4120	258	Local GPS
C/ 30	17	4034	4025	9	GPS
NW/NW 13	22	4138	4144	24	
SW/NW 18	24	4148	4099	49	
SE/SW 8	26	4099	4082	17	
NE/NE 8	32	4026	4070	-44	
NW/SW 4	33	4069	4049	20	GPS
SW/SE 4	34	4008	4058	-50	
NW/SE 8	35	4069	4076	-7	GPS
NW/NE 33	39	4040	4037	3	
NW 27	40	4012	4025	-13	
NE/NE 16	41	4010	4006	4	GPS
SE/SW 5	42	3988	3990	-2	
SEC. 25	43	4255	3964	291	Local
SE/NW 35	44	4612	3974	638	Local
NW/SE 27	45	4729	4059	670	Local GPS
NE/NE 8	50	4181	4144	37	

10.1.3.2 Truckee River Flows

As stated above the Truckee River gages at Derby Dam, Wadsworth, and Nixon were used as input and as calibration points. It became evident that the evapotranspiration is the most sensitive function impacting the hydrologic system. The simulated flows compared to the actual are listed in Table 10.4.

TABLE 10.4
ACTUAL vs. SIMULATED RIVER FLOWS

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated	401.3 (input)	415 +27 (canal)	447.9

When comparing the difference in means between the Derby Dam gage and the Wadsworth gage, it is evident that there has to be another inflow of water besides the leakage from the canal, provided the ballpark leakage estimate of 1600 af/y per mile is close. The model simulated about 21 cfs of canal leakage and only about 14 cfs of ET loss was simulated upstream of the Wadsworth gage, leaving about 7 cfs, or about 5000 af/y being consumed by evapotranspiration below the Wadsworth gage. To match the approximate 442 cfs at the Wadsworth gage and to compensate for 13 cfs of ET below it, the canal returns had to be estimated at 27 cfs or about 20,000 af/y.

Again, evapotranspiration becomes the most important or sensitive parameter to the calibration of the steady state model. If further refinement is desired, Landsat TM (thematic mapper) imagery can be obtained to more closely define irrigated lands and phreatophyte areas.

10.1.3.3 Comparison with Hydrologic Budget

Table 10.5 compares the hydrologic budget simulated by the steady state model with the actual budget as defined by Van Denburgh, *et al.* (1973).

The steady state simulation is thought to be an accurate representation of the hydrologic budget. The MODFLOW model packages were used to formulate transient simulations of pumpage and recharge to evaluate scenarios including existing development in the Dodge Flat area and to provide additional water to the Fernley area.

TABLE 10.5
COMPARISON OF DODGE FLAT AND TRUCKEE
CANYON STEADY STATE MODEL BUDGET WITH USGS

	USGS Van Denburgh, <i>et al.</i> (1973)	Steady State Model (rounded)
INFLOW:		
Recharge	1,400	1,400
From Fernley Area	9,000	8,300
Truckee River at Derby Dam	291,000	291,000
Canal Leakage	14,000	15,400
Canal Returns (Outflow-Inflow)	20,000	20,000
Total:	335,400	336,100
OUTFLOW:		
ET	14,000	13,600
Truckee River at Nixon	321,400	324,000
Total:	335,400	337,600

Van Denburgh, *et al.* (1973) hydrologic budget, all values af/y.

10.2 Transient Model Simulations

The steady state model discussed above was utilized to predict potential impacts from groundwater pumping and recharge in the Dodge Flat area. The following discusses the pumpage and recharge schedules simulated. Transient simulations require storage coefficients to be specified to predict recharge and pumping cones of impression and depression. The storage coefficient of 0.018 calculated from the aquifer test discussed above was used for the upper model layer. This is probably somewhat conservative for the floodplain aquifer but was used since this aquifer was only a pumping source not a recharge area.

S for layer 2?

10.2.1 Pumpage and Recharge Schedule

Pumpage, recharge and recharge recovery were simulated for the Dodge Flat area while pumpage only was simulated in the Wadsworth, S Bar S Ranch, and Stampmill areas. The transient scenario begins in 1998 and ends in 2025 with recharge beginning in 2005 and continuing through 2024 and recovery of recharge water beginning in 2010.

Pumpage was simulated for Alta Gold in the Dodge Flat area beginning at 500 af/y in 1998 and increasing to 1000 af/y in 2010 and continuing throughout the simulation. Other pumpage in the Dodge Flat area simulated is the development of a water right by the Town of Fernley beginning at 350 af/y and ramping up to 1400 af/y in 2020 as shown in Table 10.6. Recharge in the Dodge Flat area on the Olinghouse fan for the Town of Fernley begins at 5000 acre-feet in 2005 and continues throughout the simulation, utilizing six wells. These same wells are used to begin recovery of the recharged water in 2010 for a volume of 2250 af/y and ramp up to 4500 af/y in 2020 until the end of the simulation.

Other pumpage areas in the model are the Town of Wadsworth (including the Pyramid Lake Paiute Tribe Reservation), pumpage at the S Bar S Ranch, and pumpage to service the Stampmill development. Pumpage in the Wadsworth area consists of pumpage to serve the Town of Wadsworth and pumpage in the area developed to serve the Fernley area. All pumpage and recharge numbers are in af/y.

TABLE 10.6
SIMULATED PUMPAGE AND RECHARGE ANNUAL VOLUMES

	1998-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024
Alta Gold	500	500	500	1000	1000	1000
Wadsworth (town)	400	430	480	530	585	640
S Bar S	300	300	300	300	300	300
Stampmill	100	120	140	160	180	200
Fernley*		1100	1650	4450	6675	8900
Wadsworth (area)✓		750	1125	1500	2250	3000
Dodge Flat✓		350	525	700	1050	1400
Recharge			5000	5000	5000	5000
Recovery✓				2250	3375	4500
Residual Recharge			5000	2750	1625	500

(all values in acre-feet)

1300

- * Fernley is the sum of the Wadsworth (Fernley) pumpage, the Dodge Flat pumpage and the recovered recharge water designated Recovery

The following discusses the results of the transient simulation for each increment specified above and includes a figure illustrating the change in groundwater levels and a table summarizing the change in Truckee River flows at the Wadsworth and Nixon gages.

Years 1998-1999

The first stress period simulates pumpage of 1300 af/y for two years, as shown in Table 10.6. The pumpage from Wadsworth, Stampmill, and S Bar S is in the fluvial aquifer near the Truckee River. The Alta Gold pumpage of 500 af/y is on Dodge Flat and in this area drawdowns are about 6 feet for the two

year of pumping. Figure 10.5 shows drawdown at the end of the first stress period. Table 10.7 shows the minimal simulated impact pumpage had on the flow in the Truckee River, reducing the flows at Wadsworth by about 1 cfs and at Nixon by about 2 cfs.

TABLE 10.7
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 1999

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 1999)	401.3 (input)	440	441

Years 2000-2004

The second stress period continues the transient simulation for another five years from 2000 through 2004 for a total simulated time of seven years. During this five years the fluvial aquifer pumpage increases slightly 50 af/y with additional pumpage of 750 af/y in the Wadsworth area, simulated for the Fernley area. The alluvial aquifer is pumped at a rate of 350 af/y (Dodge Flat) to meet Fernley's demands and Alta Gold pumpage remains at 500 af/y. As shown in Table 10.6 , total pumpage for Fernley equals 1100 af/y and other pumpage equals 1350 af/y.

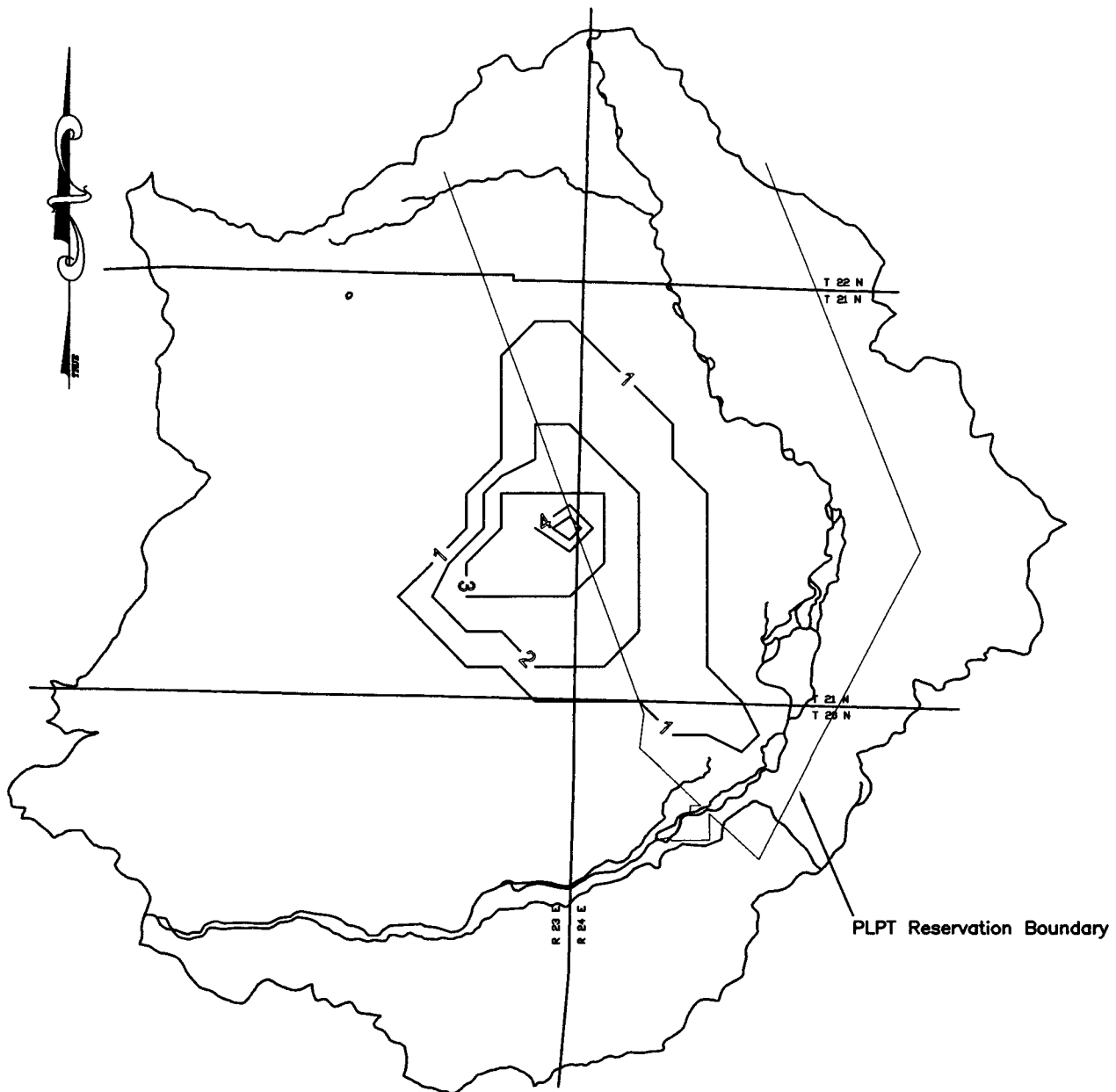
Figure 10.6 shows the drawdown at the end of 2004 after seven years of simulation. The maximum drawdown is about 9 feet with 2 feet in the fluvial aquifer. Table 10.8 shows the simulated flows at the gages, with about 3 cfs reduction at the Nixon gage.

TABLE 10.8
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2004

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2004)	401.3 (input)	440	440

Years 2005-2009

The third stress period continues the transient simulation for another five years from 2005 through 2009 for a total simulated time of 12 years. During this five years the fluvial aquifer pumpage increases another 70 af/y with additional pumpage of 375 af/y (for a total of 1125 af/y) in the Wadsworth area, simulated for the Fernley area. The alluvial aquifer is pumped at a rate of 525 af/y (Dodge Flat) to meet Fernley's demands and Alta Gold pumpage remains at 500 af/y. However, recharge in the alluvial aquifer begins during this simulation at a rate of 5000 af/y. As shown in Table 10.6, total pumpage for Fernley equals 1650 af/y and other pumpage equals 1420 af/y (for a total pumpage of 3070) and recharge equals 5000 af/y for a net gain to the groundwater system of 1930 af/y.

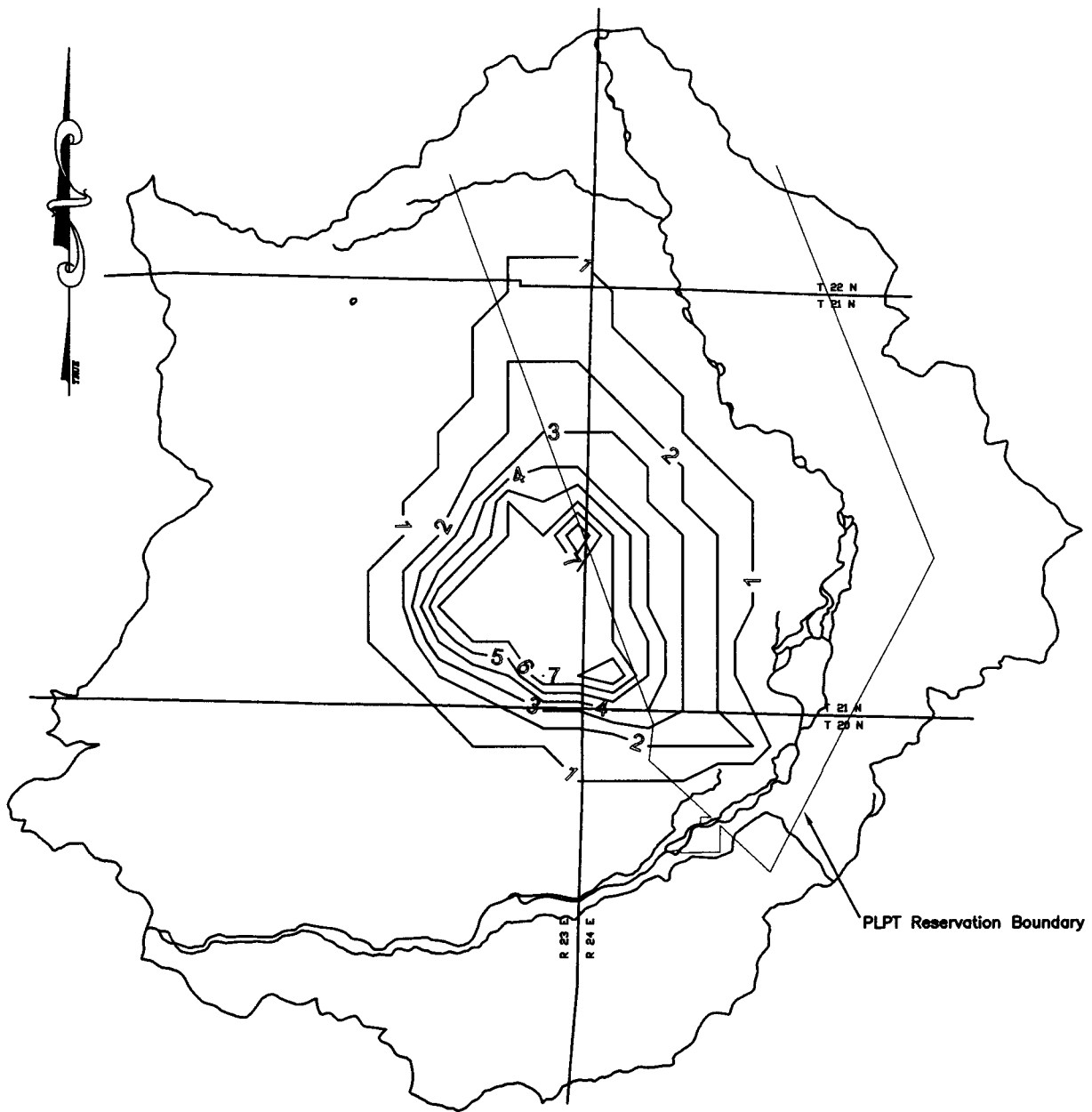


FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/26/96
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Stress Period 1 Drawdown, in Feet
Through 1999 - Figure 10.5




 wateresource consulting engineers, inc. <small>700 TOWNSEND STREET - SUITE 200, RENO, NEVADA - 89509</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. <u>8516.1142</u> DATE <u>10/26/99</u> DRN. BY <u>LCS</u> CHK. BY <u>JL</u>
DATE	REVISIONS	BY	Stress Period 2 Drawdown, in Feet Through 2004 - Figure 10.6		

Figure 10.7 shows the aquifer response at the end of 2009 after twelve years of simulation. As the figure indicates, the recharge of 5000 af/y for the five years overshadows any impacts from pumping. The maximum rise in water levels is about 105 feet. Table 10.9 shows the simulated flows at the gages, with about a 6 cfs increase at the Nixon gage. Therefore, the recharge is masking the impact of pumpage in the fluvial aquifer and increasing heads in the aquifer satisfying evapotranspiration and increasing leakage into the river.

TABLE 10.9
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2009

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2009)	401.3 (input)	441	449

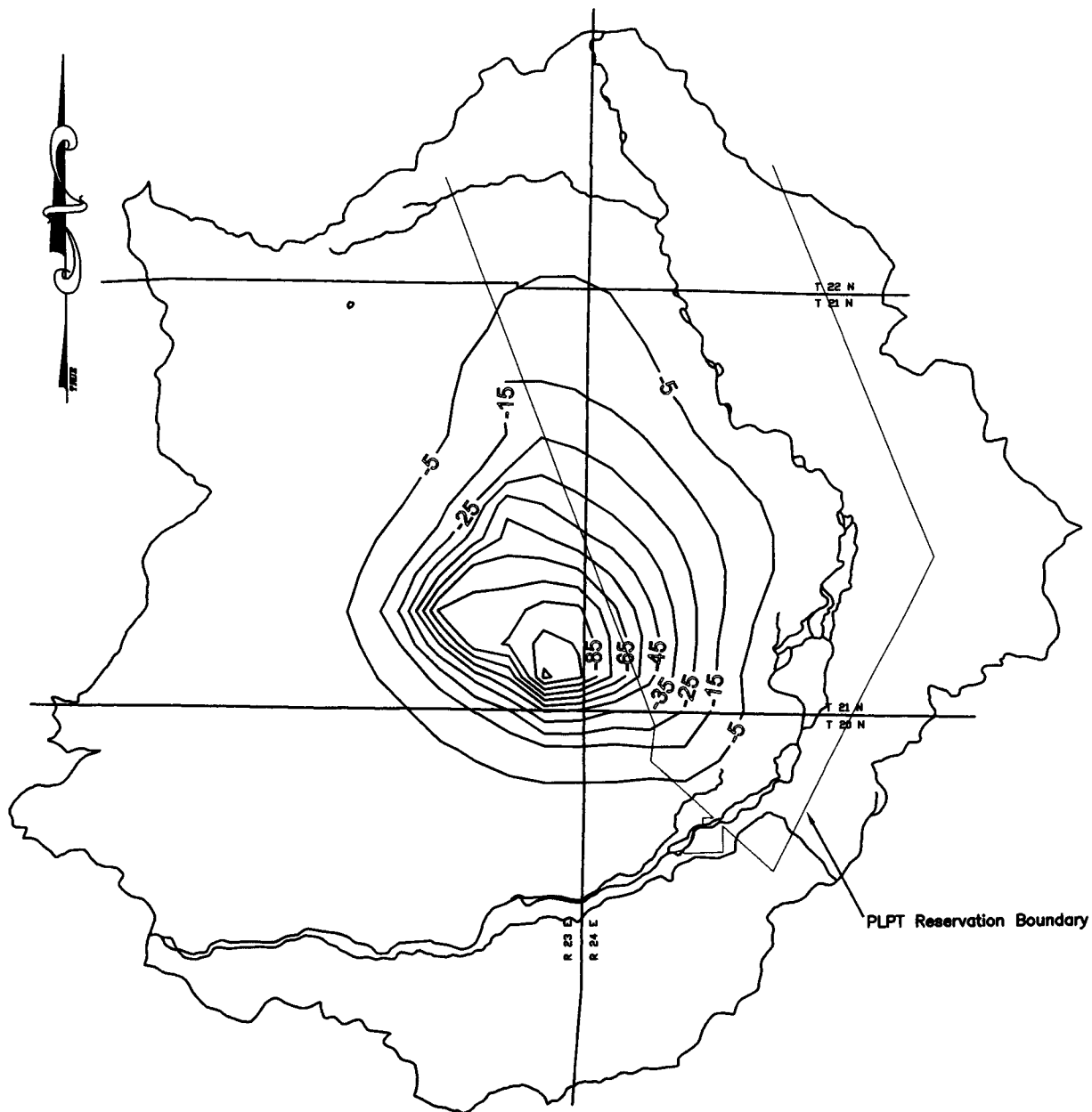
Years 2010-2014

The fourth stress period continues the transient simulation for another five years from 2010 through 2014 for a total simulated time of 17 years. During this five years the fluvial aquifer pumpage increases another 70 af/y with additional pumpage of 375 af/y (for a total of 1500 af/y) in the Wadsworth area, simulated for the Fernley area. The alluvial aquifer is pumped at a rate of 700 af/y (Dodge Flat) to meet Fernley's demands and Alta Gold pumpage increases to 1000 af/y (assumes mine expansion). Recharge in the alluvial aquifer continues at 5000 af/y; however, recovery begins for Fernley at a rate of 2250 af/y. As shown in Table 10.6, total pumpage for Fernley equals 4450 af/y and other pumpage equals 1990 af/y (for a total pumpage of 6440) and recharge equals 5000 af/y.

Figure 10.8 shows the aquifer response at the end of 2014 after 17 years of simulation. As the figures indicates, the recharge is counter balancing the impacts from pumping. The maximum rise in water levels is now about 60 feet, about a 45 feet reduction since 2009. Table 10.10 shows the simulated flows at the gages, with about a 3 cfs increase at the Nixon gage (a 3 cfs reduction from 2009). Therefore, the recharge is still masking the impact of pumpage in the fluvial aquifer and increasing heads in the aquifer, satisfying evapotranspiration and still resulting in a slight increase in leakage into the river.

TABLE 10.10
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2014

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2014)	401.3 (input)	440	445.6



Note: minus sign indicates a
rise in water levels.

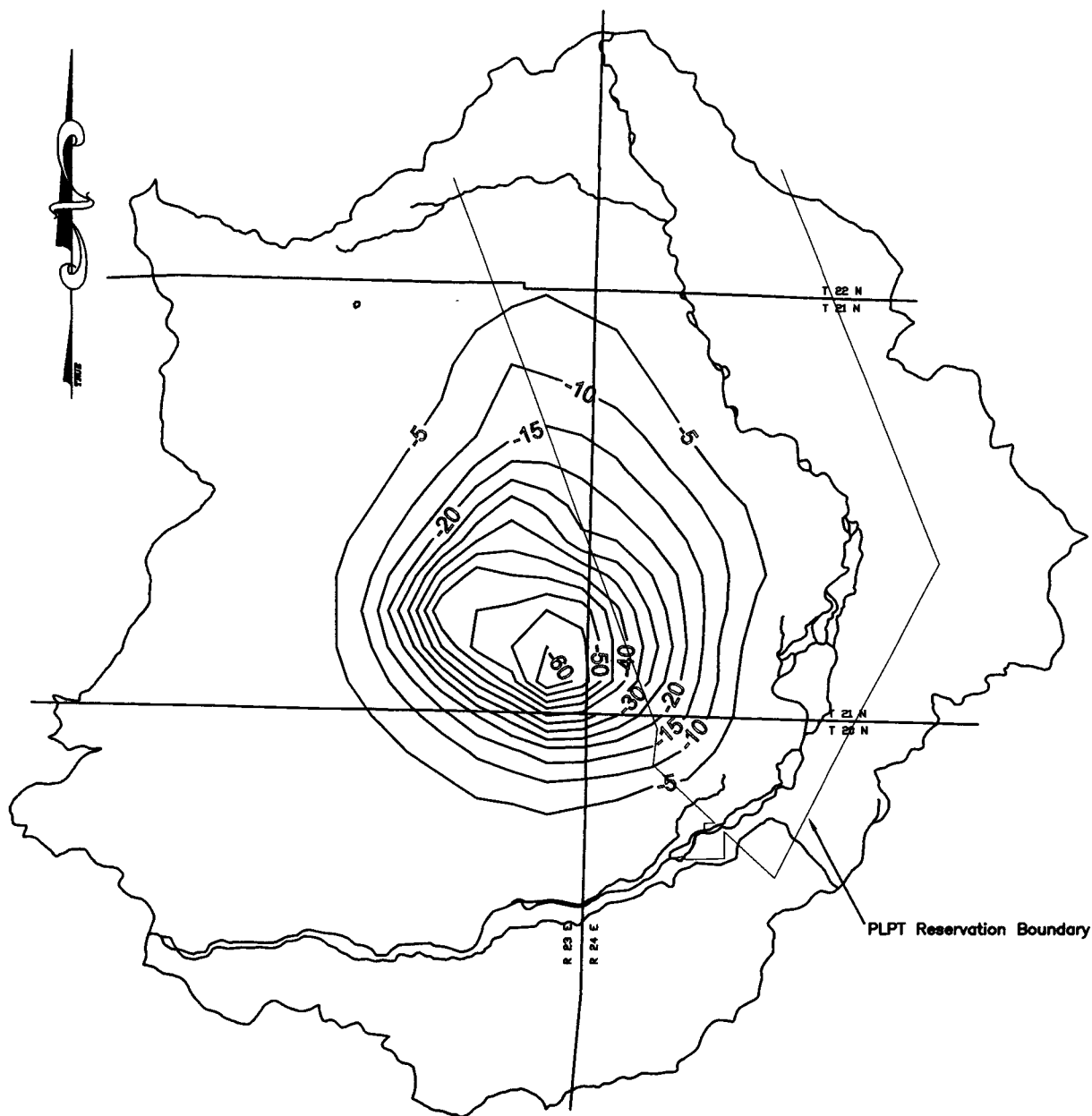


FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Stress Period 3 Drawdown, in Feet
Through 2009 - Figure 10.7



Note: minus sign indicates a
rise in water levels.



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Stress Period 4 Drawdown, in Feet
Through 2014 - Figure 10.8

Years 2015-2019

The fifth stress period continues the transient simulation for another five years from 2015 through 2019 for a total simulated time of 22 years. During this five years the fluvial aquifer pumpage increases 75 af/y (for a total pumpage of 2065) with additional pumpage of 750 af/y (for a total of 2250 af/y) in the Wadsworth area simulated for the Fernley area. The alluvial aquifer is pumped at a rate of 1050 af/y (Dodge Flat) to meet Fernley's demands and Alta Gold pumpage remains at 1000 af/y. Recharge in the alluvial aquifer continues at 5000 af/y; however recovery increases for Fernley to 3375 af/y. As shown in Table 10.6, total pumpage for Fernley equals 6675 af/y and other pumpage equals 2065 af/y (for a total pumpage of 8740) and artificial recharge equals 5000 af/y.

Figure 10.9 shows the aquifer response at the end of 2019 after 22 years of simulation. As the figure indicates, the recharge is still counter balancing the impacts from pumping; however a slight drawdown of just over a foot is observed in the fluvial aquifer in the Wadsworth area. The maximum rise in water levels is now about 32 feet, about a 30 feet reduction since 2014 and about a 70 feet reduction since the end of the first recharge stress period in 2009. Table 10.11 shows the simulated flows at the gages, with about a 2 cfs decrease at the Nixon gage from steady state conditions and a 5 cfs reduction from 2014. Therefore, the recharge is masking the impact of pumpage and evapotranspiration however, the impacts of pumpage are reducing the leakage into the river.

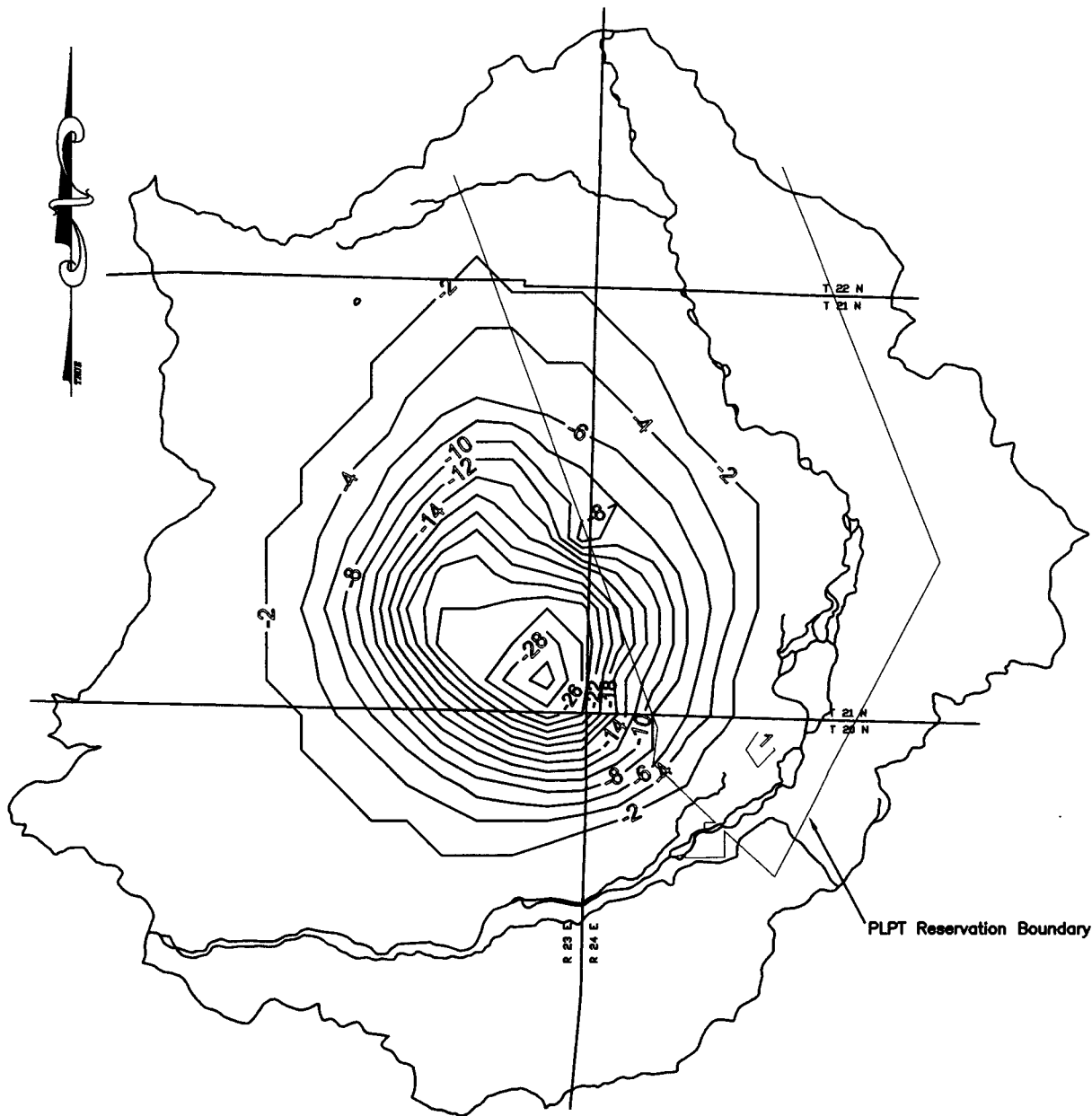
TABLE 10.11
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2019

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2019)	401.3 (input)	440	441


Years 2020 -2024

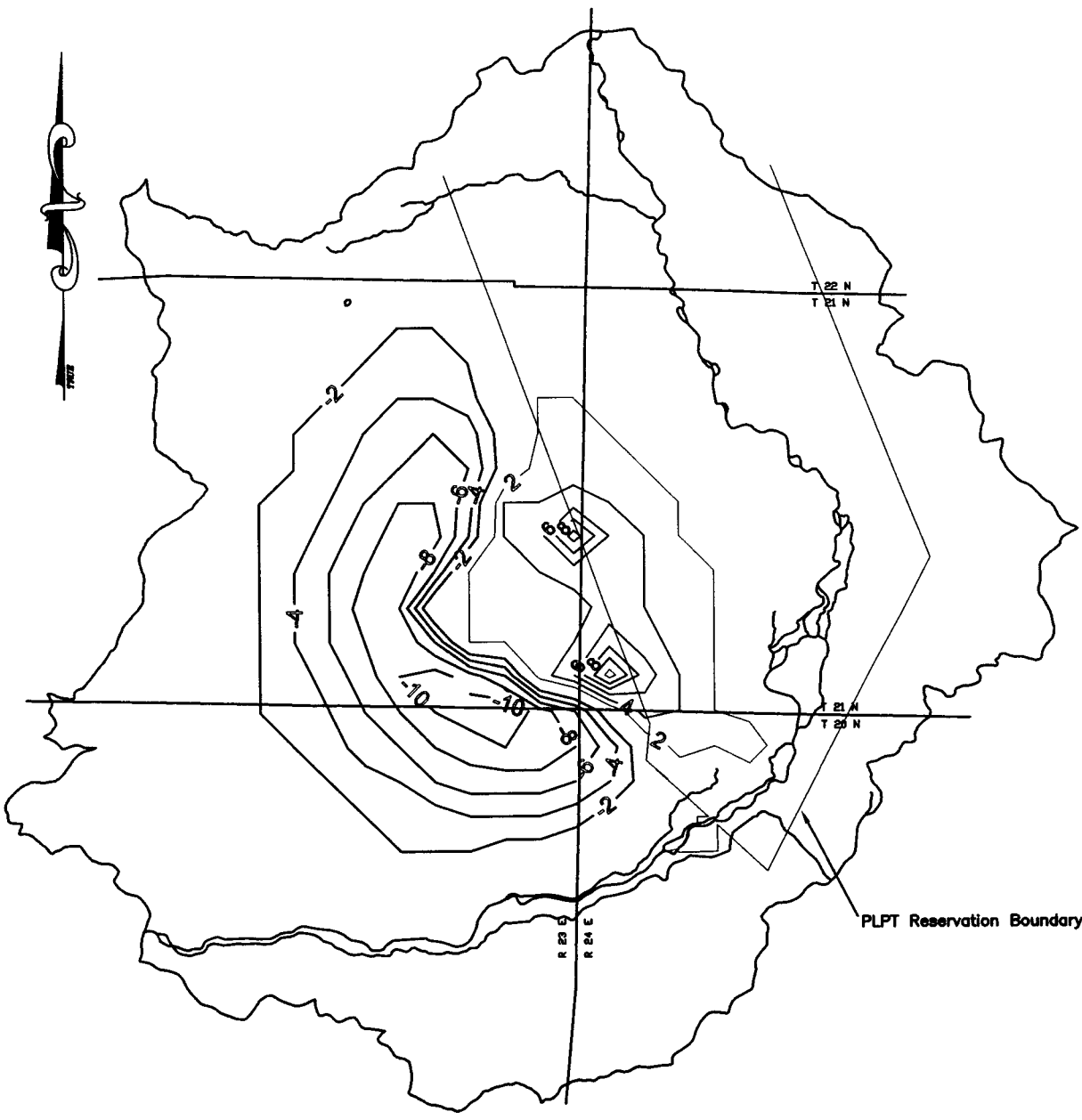
The final and sixth stress period continues the transient simulation for another five years from 2020 through 2024 for a total simulated time of 27 years. During this five years the fluvial aquifer pumpage increases another 75 af/y with additional pumpage of 750 af/y (for a total of 3000 af/y) in the Wadsworth area simulated for the Fernley area. The alluvial aquifer is pumped at a rate of 1400 af/y (Dodge Flat) to meet Fernley's demands and Alta Gold pumpage remains at 1000 af/y. Recharge in the alluvial aquifer continues at 5000 af/y; however recovery increases for Fernley to 4500 af/y. As shown in Table 10.6, total pumpage for Fernley equals 8900 af/y and other pumpage equals 2140 af/y (for a total pumpage of 11,040) and artificial recharge equals 5000 af/y.

Figure 10.10 shows the aquifer response at the end of 2024 after 27 years of simulation. As the figure indicates, the recharge built up over the simulation is counter balancing the impacts from pumping; however drawdowns are increasing from the Alta Gold and Dodge Flat pumpage equaling about 10 feet and 12 feet, respectively. The maximum residual rise in water levels is now about 12 feet, about a 20 foot reduction since 2019 and a 95 foot reduction since the end of the first recharge stress period in 2009. Table 10.12 shows the simulated flows at the gages, with about a 7 cfs decrease at the Nixon gage from steady state conditions and a 5 cfs reduction from 2019. Therefore, the recharge is masking the impact of pumpage and evapotranspiration however, the impacts of pumpage in the fluvial aquifer results in reducing the Truckee River flows slightly.



Note: minus sign indicates a rise in water levels.

 waterresource consulting engineers, inc. <small>YOU TALKIN' SCIENCE? - BEND, NEVADA - 89000</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8518.1142 DATE 10/28/99 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Stress Period 5 Drawdown, in Feet Through 2019 — Figure 10.9		



Note: minus sign indicates a rise in water levels.


 wateresource consulting engineers, inc. <small>700 TULSA STREET - TULSA, OKLAHOMA - 74106</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. <u>8518.1142</u> DATE <u>10/25/98</u> DRN. BY <u>LCS</u> CHK. BY <u>JL</u>
DATE	REVISIONS	BY	Stress Period 6 Drawdown, in Feet Through 2024 – Figure 10.10		

TABLE 10.12
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2024

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated(steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2024)	401.3 (input)	439	436

10.3 Other Transient Simulations

Two other transient simulations were run to evaluate the impacts of pumping 7500 af/y from the fluvial aquifer in the Wadsworth area for 10 years. This is the only stress simulated, other pumpage was not included and artificial recharge was not simulated. The first simulation included the Truckee River, Truckee Canal, and evapotranspiration as simulated in the steady state model discussed above. The second simulation did not include the Truckee River, Truckee Canal, or evapotranspiration, it only simulated the 7500 af/y pumpage with only natural recharge from Dodge Flat of 1400 af/y and general head boundaries. The following discussed these simulations.

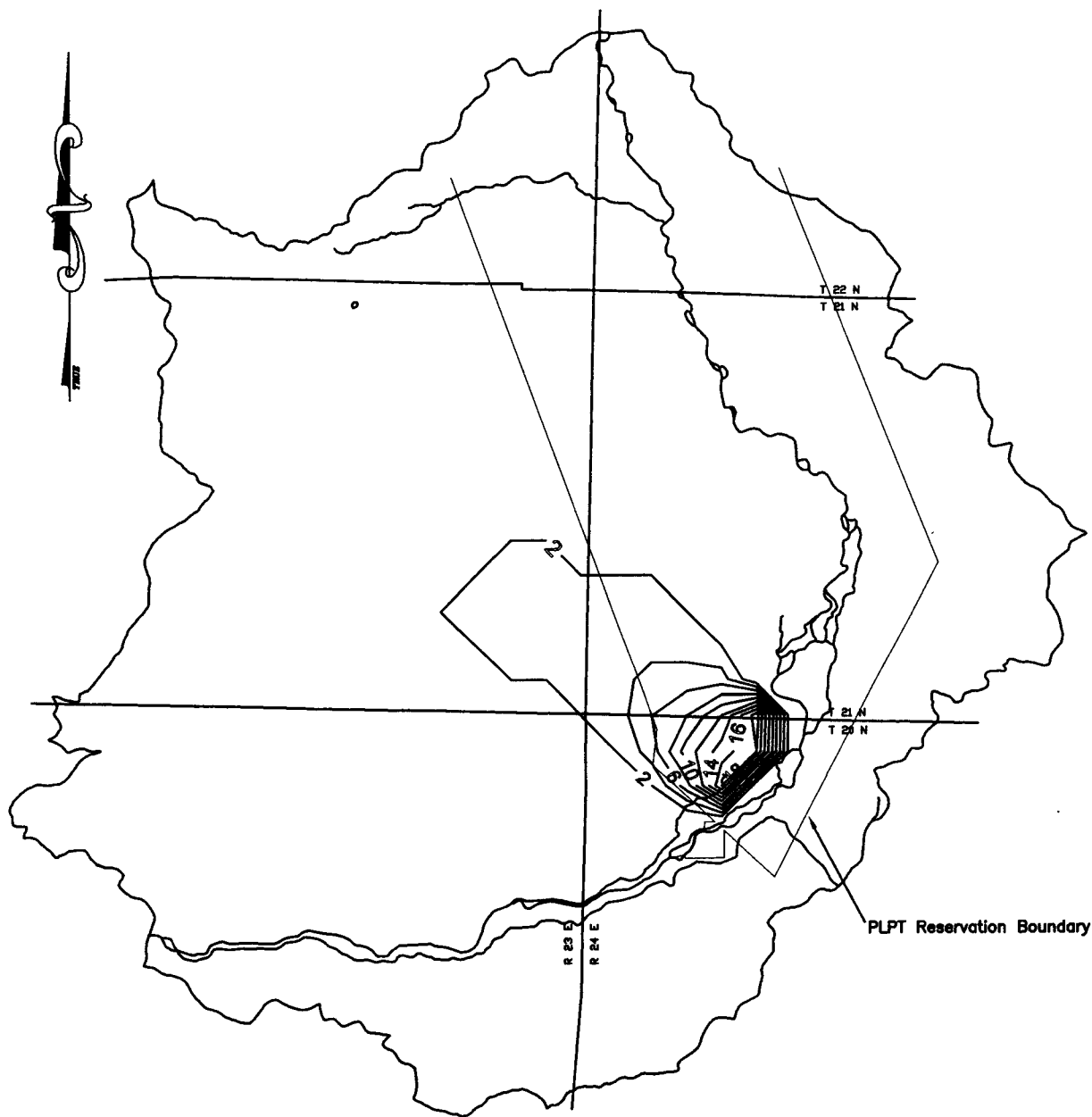
10.3.1 Pumping 7500 Acre-Feet/Year for Ten Years

As stated above, this scenario simulated the impacts of pumping 7500 af/y for ten years equally from three nodes in the fluvial aquifer near Wadsworth. The steady state model, as discussed above, was used. Figure 10.11 shows the drawdown as a result of this pumpage after 10 years. As the figure indicates, the maximum drawdown is about 19 feet. Leakage from the Truckee River is intercepted by the cone of depression resulting in a decline in river flows as shown in Table 10.13.

As Table 10.13 indicates, all the pumpage comes essentially from the river with only a few thousand acre-feet of the total 75,000 acre-feet coming out of storage.

TABLE 10.13
ACTUAL vs. SIMULATED RIVER FLOWS THROUGH 2008
PUMPAGE 7500 af/y, NO ARTIFICIAL RECHARGE

	Derby Dam gage (cfs)	Wadsworth gage (cfs)	Nixon gage (cfs)
Actual	401.3	441.9	443.9
Simulated (steady state)	401.3 (input)	414 +27 (canal) = 441	443
Simulated (end 2008)	401.3 (input)	434	433



FERNLEY TOWN UTILITIES LYON COUNTY

JOB NO. 8516.1142
DATE 10/28/98
DRN. BY LCS
CHK. BY JL

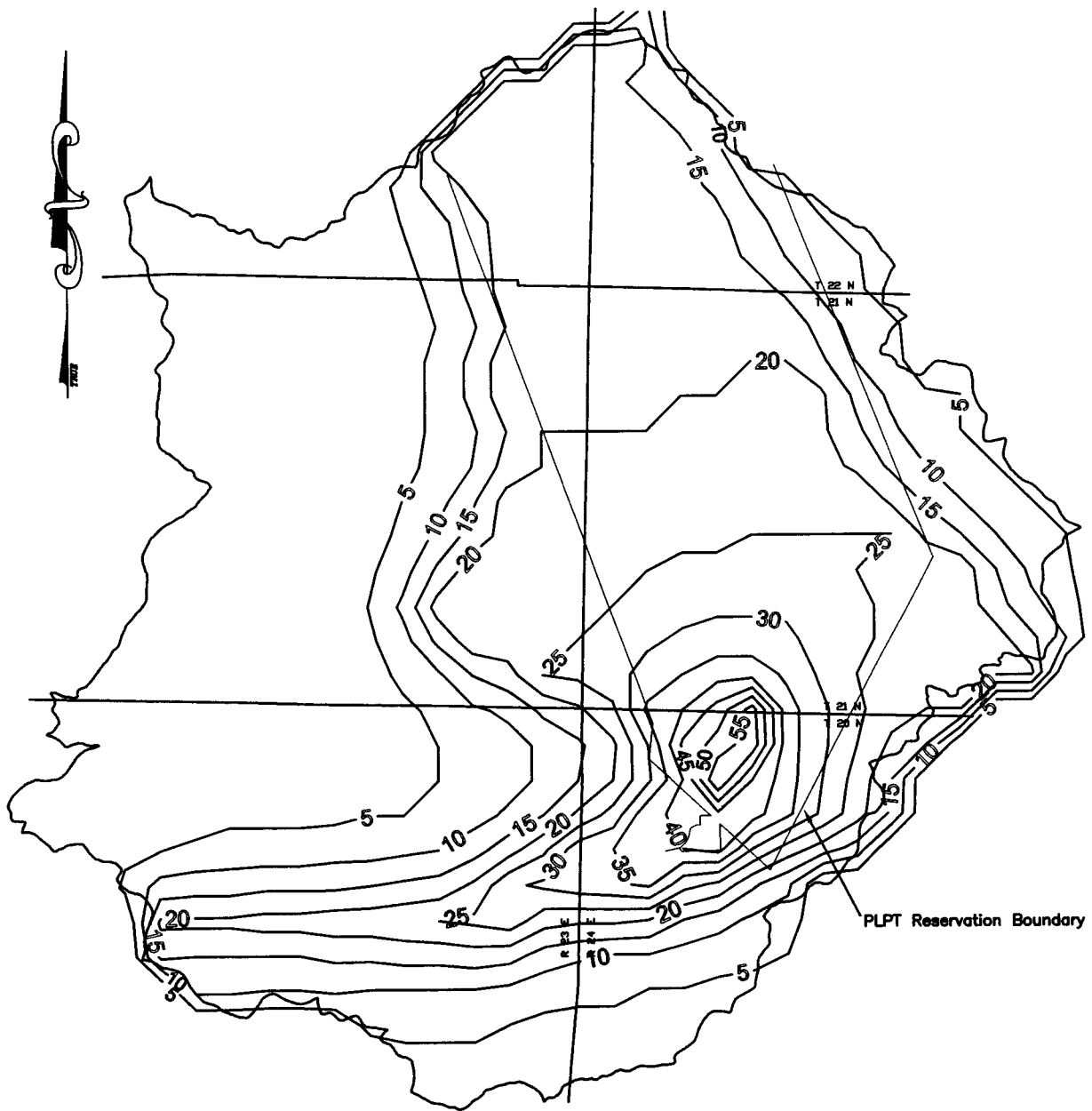
DATE	REVISIONS	BY

10-Year Drawdown, in Feet
Pumpage 7500 A-F/Y, No Other Stresses,
No Artificial Recharge - Figure 10.11

10.3.2 Pumping 7500 Acre-Feet/Year for Ten Years With Natural Recharge and Boundaries Only

As stated above, this scenario simulated the impacts of pumping 7500 af/y for ten years equally from three nodes in the fluvial aquifer near Wadsworth with simulating only the natural recharge of 1400 af/y from Dodge Flat and the general head boundary conditions in the steady state model. Figure 10.12 shows the drawdown as a result of this pumpage after 10 years. As the figure indicates, the maximum drawdown is about 60 feet. Because of the high transmissivity values, the cone of depression spreads out intercepting all the natural recharge and reaching the boundaries.

Of the 75,000 acre-feet pumped in the simulation 14,000 acre-feet comes from the natural recharge, 26,000 acre feet from aquifer storage and 35,000 acre-feet from the general head boundaries. The majority of the flow from the general head boundaries would come from the Fernley area.



FERNLEY TOWN UTILITIES LYON COUNTY

JOB NO. 8518.1142
DATE 10/26/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

10-Year Drawdown, in Feet
Pumpage 7500 A-F/Y, No Artificial Recharge
Figure 10.12



SECTION 11.0

CONCLUSIONS AND RECOMMENDATIONS

11.1 Conclusions

The two water supply options for the Fernley and Wadsworth areas, extensive use of the Truckee River flood plain aquifer and artificial recharge to the Dodge Flat groundwater system, are feasible from a hydrogeologic perspective, but each option has certain constraints and peculiarities. The third water supply option evaluated was the groundwater yield of the Dodge Flat groundwater system; this evaluation confirmed previous yields by Van Denburgh, *et al.* (1973, p. 39), but did define a greater amount of surface water runoff at the mountain front with an unknown percentage ultimately reaching the groundwater system. These options are discussed as follows:

11.1.1 Truckee River Flood Plain Aquifer

There is about a six mile reach of the Truckee River, centered on Wadsworth, that has favorable hydrogeologic properties to support extensive pumping from the aquifer system adjoining the river to the north and west, perhaps up to 10,000 af/y. The Truckee River is the main source of recharge water for this aquifer system with very minor amounts, about 2 cfs, contributed by the recharge from Dodge Flat, most of which enters the river aquifer downstream from this targeted reach. Additional groundwater, about 13 cfs, enters the river aquifer from diffuse points to the south and east, mostly from the Fernley area. The source of this water is uncertain, but previous investigators have attributed it to return flow from agricultural irrigation and seepage loss from the Truckee Canal in the Fernley area. There may also be a geothermal component to this flow, but regardless of the source the quality of water degrades the aquifer system particularly on the east side of the river. And when this water reaches the Truckee River it can degrade the surface water also.

Recharge to the flood plain aquifer takes place throughout the river's bed and banks tying the groundwater levels in the aquifer to the water level of the river at any particular time. Water levels in the aquifer do not respond to a level change as fast as the river does simply because the water has to move through the sediments. The rate of recharge to the aquifer system is controlled by the ability of the sediments to accept water and the duration and magnitude of flow in the river.

Pumping from the flood plain aquifer causes a cone of depression to form around the wells which in turn induces more flow from the river, about 10 cfs. Modeling results indicate that constructing three wells equally spaced about one half mile apart in the flood plain aquifer with an estimated combined capacity of 7,500 af/y (~1,500 gpm/well) and pumping for ten years will create a maximum cone of depression of about 20 feet below land surface (see Section 10.3). Undoubtedly greater pumping capacity could be achieved per well, or more wells could be constructed with wider spacing which would require a fewer number of wells to be pumping to meet any given demand and probably result in less drawdown per well. This would also allow greater utilization from the aquifer system by allowing different groundwater/river segments to be fully recharged by the river and also allow for scheduled (and unscheduled) well maintenance.

The quality of water in the Truckee River and in the flood plain aquifer meets the safe drinking water standards established by the Environmental Protection Agency.

There is concern over the inflow of the poorer quality water from the Fernley area to the aquifer system. Modeling results indicate this water could reach the aquifer system on the west side of the river during prolonged low flow in the river, such as occurs during a drought. Extensive pumping will induce flow from the aquifer system on the south and east side of the river that is connected to the Fernley groundwater basin, because the two systems are really one and in total hydraulic continuity with each other. There is also the potential that the quality of water in the west side aquifer system is at risk from waste water disposal in the Wadsworth area.

11.1.2 Artificial Recharge, Storage, and Recovery in the Dodge Flat Area

Artificial recharge by well injection into the groundwater system underlying Dodge Flat is feasible and is the preferred method of augmenting the groundwater resources. Based on aquifer test data the saturated sediments that make up the aquifer system have the ability to accept large amounts of water. Artificial recharge through wells will bypass the lacustrine (fine-grained lake bed) sediments and allow injection into the underlying principal aquifer system. The chemistry of the lake bed sediments, both saturated and unsaturated, is dominated by various salts that will degrade recharge water. There is an area of about two square miles on the central to west side of Dodge Flat (see Figure 9.1) that contains relatively good water quality, less than 500 mg/l total dissolved solids and it is this area that recharge, from a water quality basis, would be most successful. Modeling results indicate that with current water demand projections (Table 10.6), and starting to recharge 5,000 af/y in the year 2005, there will be no serious overdrafts until about 2025. By that time, total annual pumpage will equal about 15,000 af/y, net pumpage about 10,000 af/y, with artificial recharge of 5000 af/y. Groundwater levels at this point are about 12 feet higher since recharge started in 2005 and the decrease in river flow at Nixon is about 7 cfs. At that time, artificial recharge will need to be increased in order to maintain water levels and not decrease Truckee River flow.

As water is injected into the principal aquifer, which is confined by the overlying lacustrine sediments, it displaces the natural groundwater surrounding the well. Some amount of water will rise into the unsaturated zone and be somewhat degraded by the salts in the sediments. As the recharge water expands outward there will be a zone of mixing on the leading edge that will also be degraded when poorer water quality is encountered. The highest total dissolved solids content of natural groundwater that the recharge water will encounter is about 900 mg/l. Truckee River water varies in total dissolved solids content from under 100 mg/l to about 400 mg/l depending on the flow and the time of the year so when the poorer water quality is encountered by the injected Truckee River water the resultant mixture will be better than the natural groundwater quality.

Groundwater recharge basins present an alternative to deep well injection overcoming the requirement for treatment and potential well clogging problem encountered using turbid Truckee River water for recharge. To stop well clogging the recharge water should be free of turbidity, which means the river water must be treated at the well head; an expensive operation. Recharge basins could be constructed near the mountain front in pre-lacustrine sediments, but there is no way of insuring the water, during its downward migration, would not move laterally into contact with the lacustrine, high salt content, sediments and dissolve those salts thus degrading the recharge water before it reaches groundwater. Additionally, given the uncertainty of the mining industry, it may not be advisable to locate a public water supply facility in somewhat close proximity and down gradient from a gold mining operation that utilizes cyanide in its recovery process.

The Dodge Flat groundwater basin is over appropriated and currently under utilized. However, given the volume of approved groundwater rights (State Engineer's records) it seems likely that future development is not far off. Groundwater pumpage in close proximity to an artificial recharge project creates some additional complexities. First, depending on the location and magnitude of the pumping, the recharge water may end up being pumped by non-ASR project pumpers. Second, this 'other than project pumping' could easily change the hydraulics of the groundwater system and capture more of the better quality groundwater leaving water of poorer quality for recovery by the ASR project. And third, the non-project pumpers benefit without cost by having higher groundwater levels caused by recharge which means less energy costs to pump the water.

11.1.3 Perennial Yield of the Dodge Flat Groundwater System

The total groundwater recharge for the Dodge Flat aquifer system was first estimated by Van Denburgh, *et al.* (1973) to be about 1,400 af/y and there has been scant improvement in techniques and data since then to refine this number. However, this recharge amount is supported by an analysis of solute loading to the Truckee River, done for this study (see Appendix F), that shows this same amount discharges to the river from Dodge Flat. It is probably conservative in that undoubtedly some amount of the estimated 1,000 af/y of mountain front runoff infiltrates to the groundwater system. This is supported by isotopic analyses that show the addition of local surface water to the groundwater system underlying Dodge Flat. Given the uncertainties of the techniques, the actual recharge is estimated to range from a minimum of 1,400 to a maximum of 2,000 af/y and can not be substantiated at this time.

11.2 Recommendations

11.2.1 Truckee River Flood Plain Aquifer

Prior to the initiation of a large scale well construction project to serve the regional water needs, the following work elements should be completed:

1. To fully understand the hydraulics of aquifer interaction with the river a series of monitor wells should be constructed and tested for groundwater hydraulics and water quality over a range of river flows in each of the river segments selected for groundwater production. The PLPT is planning on hydrologic testing (in 1999) on the south side of the river which will provide additional insights into this problem.
2. The impacts to the groundwater system caused by waste water discharge and the application of commercial fertilizer on agricultural lands will require definition.
3. The distribution, groundwater hydraulics, and water quality of the return flow to the flood plain aquifer on the east and south side of the river from the Fernley area needs to be understood in terms of groundwater production from the aquifer on the west and north side of the river. It is anticipated that the current TDS return flow study in the Fernley area by Washoe County (DRI) will provide information to address this issue.
4. Detail mapping of cropland and areas of phreatophytes using the latest LANDSAT scenes will allow for a more accurate groundwater budget to be developed. The most recent estimates are over 25 years old.

5. A single groundwater model of the Fernley and Dodge Flat hydrographic basins should be developed in the future using data from the Dodge Flat model and the model currently under development by the Desert Research Institute for the Fernley area.

11.2.2 Artificial Recharge, Storage, and Recovery in the Dodge Flat Area

1. An engineering and economic feasibility study estimating the costs and benefits of the project should be completed prior to additional planning utilizing the artificial recharge concept. Of particular concern is the cost of transporting the water from the river to the recharge site (including treatment), recovering it, and the facilities required to distribute the water.
2. Hydrogeologic exploration should be initiated to determine the actual extent of the better quality groundwater on Dodge Flat and to further evaluate the basin recharge process.
3. A groundwater management plan is needed to insure potential non-project pumpers do not adversely impact the project.

11.2.3 Perennial Yield of the Dodge Flat Groundwater System

1. A regional water system entity serving both Fernley and Wadsworth should evaluate the benefits from obtaining most or all of the groundwater water rights in the Dodge Flat area and develop a water resource plan.
2. It is highly probable the recharge to Dodge Flat is greater than the 1,400 acre-feet defined by the standard Maxey-Eakin method. Precipitation data for the east side of the Pah Rah Range should be further evaluated, utilizing National Weather Service statistical methods, to refine the available recharge potential. Monitoring sites should be established on the alluvial fan east of the mountain block to measure the downward movement of natural recharge water.
3. Mountain front runoff should be monitored particularly during winter/spring runoff and the fate of the runoff water more closely evaluated.

REFERENCES

REFERENCES

- Anderson, P. L., and Meerschaert, M. M., 1998, Modeling River Flows with Heavy Tails, *Water Resources Research*, v. 34, no. 9, pp. 2271 – 2230.
- Avon, L., and Durbin, T. J., 1994, Evaluation of the Maxey-Eakin Method for Estimating Recharge to Ground-Water Basins in Nevada: *American Water Resources Association Water Resources Bulletin*, v. 30, No. 1, pp. 99 - 111.
- Bell, J. W., 1984, Quaternary Fault Map of Nevada, Reno Sheet: *Nevada Bureau of Mines and Geology, Map 79*.
- Bell, J. W., and Katzer, T. L., 1987, Surficial Geology Hydrology, and Late Quaternary Tectonics of the IXL Canyon Area, Nevada: *Nevada Bureau of Mines and Geology Bulletin 102*, 52 pp.
- Benson, L. V., 1978, Fluctuation in the Level of Pluvial Lake Lahontan During the Last 40,000 Years: *Journal of Quaternary Research*, v. 9, no. 3, p. 300-318.
- Benson, L. V., and Thompson, R. S., 1987a, The Physical Record of Lakes in the Great Basin: Chapter 11 in: W. F. Ruddiman and H. E. Wright, *North America and Adjacent Oceans During the Last Deglaciation, The Geology of North America*, v. K-3, Geological Society of America, 501 pp.
- Benson, L. V., and Thompson, R. S., 1987b, Lake-Level Variation in the Lahontan Basin for the Past 50,000 Years: *Quaternary Research*, v. 28, pp 69 - 85.
- Benson, L. V., 1993, Factors Affecting ^{14}C Ages of Lacustrine Carbonates: Timing and Duration of the Last Highstand Lake in the Lahontan Basin: *Quaternary Research*, v. 39 pp. 163 - 174.
- Benson, L. V., Meyers, P. A., and Spencer, R. J., 1991, Change in the Size of Walker Lake During the Past 5000 Years: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 81 pp. 189 -214.
- Berger, D. L., Ross, W. C., Thodal, C. E., and Robledo, A. R., 1997 Hydrogeology and Simulated Effects of Urban Development on Water Resources of Spanish Springs Valley, Washoe County, West-Central Nevada: *U. S. Geological Survey Water-Resource Investigations Report 96-4297*, 80 pp.
- Bernholtz, A., Brothers, K., and Katzer, T., 1991, Analyses of Aquifer Responses Due to Continued Artificial Recharge of Treated Colorado River Water, Las Vegas Valley, Clark County, Nevada: Arizona Hydrological Society, Proceedings of Fourth Annual Meeting, p. 110-118.
- Blake, G. R., and Hartge, K. H., 1986, Bulk Density: Chapter 13 in *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*, Second Edition, Arnold Klute, editor. Agronomy Series Number 9, Part 1, published by the American Society of Agronomy and the Soil Science Society of America, Madison, WI, 1188 pp.
- BLM, 1997, *Draft Environmental Impact Statement, Olinghouse Mine Project*, U.S. Department of the Interior, Bureau of Land Management, Carson City, Nevada, 104 pp.
- Boardman, A. E., Greenberg, D. H., Vining, A. R., and Weimer, D. L., 1996, Cost-benefit Analysis, Concepts and Practice: Prentice Hall, Upper Saddle River, New Jersey, 493 p.

- Bonham, H. F., 1962, *Areal Geology of the Northern Half of Washoe, County, Nevada*: University of Nevada, Reno, MS Thesis, 83 p.
- Bonham, H. F., and Papke, K. G., 1969, Geology and Mineral Deposits of Washoe and Storey Counties, Nevada: *Nevada Bureau of Mines and Geology Bulletin* 70, 140 pp.
- Bostic, R. E., Kane, R. L., Kipfer, K. M., and Johnson, A. W., 1996, Water Resources Data, Nevada, Water Year 1996: *U. S. Geological Survey Water-Data Report NV-96-1*, 611 pp.
- Bratberg, D., 1980, *Hydrogeology of Dodge Flat and its relation to flow and quality changes in the Truckee River*, University of Nevada, Reno, MS Thesis, 100 pp.
- Brothers, K., and Katzer, T., 1990, Water Banking Through Artificial Recharge, Las Vegas Valley, Clark County, Nevada: *Journal of Hydrology*, 115, 77-103, pp. 77 - 103.
- Brown, W. M., III, Nowlin, J. O., Smith, L. H., and Flint, M. W., 1986, River-Quality Assessment of the Truckee and Carson River System, California and Nevada -- Hydrologic Characteristics: *U.S. Geological Survey Open-File Report 84-576*, 201 p.
- Bull, W.B., 1972, Recognition of Alluvial Fan Deposits in the Stratigraphic Record: in *Recognition of Ancient Sedimentary Environments*, J.K. Rigby and W.K. Hamblin, editors. *Society of Economic Paleontologists and Mineralogists Special Publication No. 16*, pp. 63 - 83.
- Carpenter, T. C., 1997, *Gravity Data Acquisition and Processing, Lower Truckee River Corridor Project, Washoe and Lyon Counties, Nevada*: Report prepared for Waterresource Consulting Engineers, Reno, Nevada, 6 pp., 2 appendices, map, data discs; available upon request from the Fernley Town Utilities' Manager.
- CH2MHill, 1990, *Investigations of Potential Groundwater Recharge and Rapid Infiltration/Extraction Projects at Dodge Flat*: Compilation of Technical Memorandums and Presentations made for the City of Reno by CH2MHill, Inc., 2845 Natomas Park Dr., Sacramento, California.
- Clark, I. D., and Fritz, P., 1997, *Environmental Isotopes in Hydrogeology*, Lewis Publishers, CRC Press, Boca Raton, 328 pp.
- Cockrum, R. K., Warwick, J. W., and McKay, W. A., 1995, Characterization of the Impact of Agricultural Activities on Water Quality in the Lower Truckee River: *University of Nevada, Desert Research Institute Water Resources Center Publication No. 41147*, Desert Research Institute, University of Nevada, Reno, Nevada, 69 pp.
- Cooper and Associates, 1980, logs of test pits and soil borings: Appendix C, Site-Specific Studies for Land Discharge Alternatives, continued within *Expansion of Reno-Sparks Joint Water Pollution Control Plant*, prepared by Kennedy-Jenks Engineers. Data acquired from HSI Geotrans (11/97).
- Dettinger, M. D., 1988, Reconnaissance Estimates of Natural Recharge to Desert Basins in Nevada, U.S.A., by Using Chloride-Balance Calculations: *Journal of Hydrology* v. 106, pp. 55 - 78.
- Drever, J. I., 1988, *The Geochemistry of Natural Waters*, 2nd ed., Prentice-Hall, Englewood Cliffs, New Jersey, 437 pp.

- Durbin, T. J., 1978, Calibration of a Mathematical Model of the Antelope Valley Ground-Water Basin, California: *U.S. Geological Survey Open-File Report 84-576*, 201 pp.
- Dutcher, L. C., and Garrett, A. A., 1963, Geologic and Hydrologic Features of the San Bernardino Area, California: *U.S. Geological Water-Supply Paper 2046*, 51 pp.
- Eakin, T. E., Maxey, G. B., Robinson, T. W., Fredericks, J. C., and Loeltz, O. J., 1951, Contributions to the Hydrology of Eastern Nevada: *Nevada Department of Conservation and Natural Resources Water-Resources Bulletin No. 12*, 171 pp.
- Eugster, H. P., and Hardie, L. A., 1978, Saline Lakes: Chapter 8 in Lerman, A., ed., *Lakes: Chemistry, Geology, Physics*, New York, Springer-Verlag, 363 p.
- Fenneman, N. M., 1931, *Physiography of Western United States*: New York, McGraw-Hill Book Company.
- Freeze, R. A., and Cherry, J. A., 1979, *Groundwater*: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 604 p.
- Gaines, R. V., Skinner, H. C. W., Foord, E. E., Mason, B., and Rosenzweig, A., 1997, *Dana's New Mineralogy*, The System of Mineralogy of James Dwight Dana and Edward Salisbury Dana, Eighth Edition, John Wiley and Sons, New York, 1819 pp.
- Garside, L. J., and Bonham, H. F., (1997a), Wadsworth 7-1/2' Quadrangle Geologic Map: Unpublished Nevada Bureau of Mines map.
- Garside, L. J., and Bonham, H. F., (1997b), Olinghouse 7-1/2' Quadrangle: Unpublished Nevada Bureau of Mines map.
- Garside, L. J., and Schilling, J. H., 1979, Thermal Waters of Nevada: *Nevada Bureau of Mines and Geology Bulletin 91*, 163 pp.
- Hardie, L. A., and Eugster, H. P., 1970, The Evolution of Closed-Basin Brines: *Mineralogical Society of America Special Paper No. 3*, pp. 273 - 290.
- Hardie, L. A., Smoot, J. P., and Eugster, H. P., 1978, Saline Lakes and Their Deposits: A Sedimentological Approach: *Spec. Publs. Int. Assoc. Sedimentology*, v. 2, pp. 7-41.
- Harrill, J. R., J. S. Gates, and J. M. Thomas, 1988. *Major Groundwater Systems in the Great Basin Region of Nevada, Utah, and Adjacent States*, U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C.
- Hartley, P., 1998, *Interpretation of Gravity, Resistivity, and Magnetic Data for the Dodge Flat Region, Lower Truckee River Corridor Project, Washoe and Lyon Counties, Nevada*: Report prepared for Wateresource Consulting Engineers, Reno, Nevada, by Adgis, Inc., 6 pp., 2 appendices, map, data discs; available upon request from the Fernley Town Utilities' Manager.
- Heath, R. C., 1984, Groundwater regions of the United States: *U. S. Geological Survey Water Supply Paper 2242*.

- Hedman, E. R., and Osterkamp, W. R., 1982, Streamflow Characteristics Related to Channel Geometry of Streams in Western United States: *U.S. Geological Survey Water Supply Paper 2193*, 17 p.
- Hostetler, S., and Benson, L. V., 1990, Paleoclimatic Implications of the High Stand of Lake Lahontan Derived from Models of Evaporation and Lake Level: *Climate Dynamics* v. 4 pp 207 - 217.
- HSI, 1982, letter from John V. A. Sharp and Forrest L. Fox of Hydro-Search, Inc., to R. L. Parratt of Southern Pacific Land Company (now Nevada Land and Resource Company) containing: a summary description of geologic logs for 5 production exploration wells on the Olinghouse fan; and pump tests and major ion concentrations for SPW-6 (Butcher Boy Well, now the old Olinghouse production well, #23581).
- Johnson, M., Cole, E., and Brothers, K., 1997, Artificial Recharge in Las Vegas Valley: An Operational History: Symposium Proceedings, 8th Biennial Symposium on the Artificial Recharge of Groundwater, Tempe, AZ.
- Jones, B. F., 1965, The Hydrology and Mineralogy of Deep Springs Lake, Inyo County, California: *U. S. Geological Survey Professional Paper 502A*, 56 p.
- Junge, C. E., and Werby, R. T., 1958, The Concentration of Chloride, Sodium, Potassium, Calcium, and Sulfate in Rain Water over the United States: *Journal of Meteorology*, v. 15 No. 5, pp. 417 - 425.
- Katzer, T., Brothers, K., Johnson, M., Donovan, D., and Cole, E., 1998, A Cost-Benefit-Analysis for the Recharge of Groundwater into the Las Vegas Valley Groundwater System, Clark County, Nevada: Southern Nevada Water Authority, 39 p.
- Katzer, T. L., Durbin, T. J., and Mauer, D., 1984, Water-Resources Appraisal of the Galena Creek Basin, Washoe County, Nevada: *U.S. Geological Survey Open-File Report 84-433*, 59 pp.
- Kleinhampl, F. J., and Ziony, J. I., 1985, Geology of Northern Nye County, Nevada; *Nevada Bureau of Mines and Geology Bulletin 99A*.
- Klotz, J., 1997, Riparian Hydrology and Establishment of Woody Riparian Vegetation: M.S. Thesis, University of Nevada, Reno, Hydrologic Sciences Program, 37 pp.
- Lebo, M. E., Reuter, J. E., and Goldman, C. R., 1994, *Pyramid Lake Paiute Indian Tribe Nonpoint Source Assessment and Management Plan*: Consultants report, Ecological Research Associates, Davis California, 228 pp.
- Leeds, Hill, and Jewett, Inc., 1983. *Technical Report for the White Pine Power Project*, Prepared for Los Angeles Department of Water and Power.
- Lico, M. S., 1992, Detailed Study of Irrigation Drainage in and Near Wildlife Management Areas, West-Central Nevada: Part A. Water Quality, Sediment Composition, and Hydrogeochemical Processes in Stillwater and Fernley Wildlife Management Areas, 1987 - 90: *U. S. Geological Survey Water Resources Investigation Report 92-4024A*, 65 pp.
- Long, D.T., Fegan, N.E., Lyons, W.B., Hines, M.E., Macumber, P.G., and Giglin, A.M., 1992, Geochemistry of Acid Brines: Lake Tytell, Victoria, Australia: *Chemical Geology*, v. 96, pp. 33-52.

- Maxey, G. B., and Eakin, T. E., 1949, Ground Water in the White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: *Nevada Department of Conservation and Natural Resources Water Resources Bulletin No. 8*, 59 pp.
- McCleary, K., 1990, well construction Logs, soil boring logs, and recovery tests for Dodge Flat Wells: Drawings and Field Notes for CH2MHill, Inc., 2845 Natomas Park Dr., Sacramento, California.
- McDonald, M. G., and Harbaugh, A. W., 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: *U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6*.
- McKay, W. A., and Bohm, B. B., 1998, *Analysis of Major Ion and Isotope Geochemistry from Selected Wells and Springs in Dodge Flat*: in Appendix G of this study. Sampling conducted in October, 1997, and report prepared for Wateresource Consulting Engineers, Reno, Nevada, by Alan McKay and Burkhardt Bohm. Analyses performed by the Desert Research Institute, University of Nevada, Reno, Nevada. Available upon request from the Fernley Town Utilities' Manager.
- McKenna, S. A., 1990, *Examination of Water Quality and Groundwater/Surface Water Interaction During Drought Periods, Truckee River California/Nevada*: M.S. Thesis, University of Nevada, Reno.
- Melhorn, M. N., 1978, Log of Standard-Amoco S. P. Land Co. No. 1, S. 33, T. 24 N., R. 33 E., unpublished data at Nevada Bureau of Mines, Reno, Nevada.
- Morrison, R. B., 1964, Lake Lahontan: Geology of Southern Carson Desert, Nevada: *U.S. Geological Survey Professional Paper 401*, 156 pp.
- Morrison, R. B., and Davis, J. O., 1984a, Field Trip Notes, *Western Geological Excursions v. 1*, pp. 258 - 263.
- Morrison, R. B., and Davis, J. O., 1984b, Quaternary Stratigraphy and Archeology of the Lake Lahontan Area: A Reassessment, Supplemental Guidebook for Trip 13, 1984 Meeting, Geological Society of America, Reno, Nevada: *Desert Research Institute Social Sciences Center Technical Report 41*, University of Nevada, Reno, 50 pp.
- Morrison, R. B., and Frye, J. C., 1965, Correlation of the Middle and Late Quaternary Succession of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), Southern Great Plains, and Eastern Mid-West Areas; *Nevada Bureau of Mines Report 9*, 45 pp.
- NACSN, 1983, (North American Commission on Stratigraphic Nomenclature), North American Stratigraphic Code: *American Association of Petroleum Geologists Bulletin*, v. 67 No. 5, pp. 841 - 875.
- NDEP, 1997, Sample results from the Truckee River monitoring program, 1980-1997, spreadsheet containing data reported to the Nevada Division of Environmental Protection by the Desert Research Institute, Reno, Nevada.
- NLRC, 1997, Nevada Land and Resource Co., (formerly Southern Pacific Land Company), miscellaneous data supplied by Ted Fitzpatrick containing: borehole deviation, self-potential, gamma, resistance, and temperature geophysical logs of the old Olinghouse production well (SPW-6, or Butcher Boy Well, # 23581) by Century Geophysical Corp. (10/16/81); and a letter summarizing drawdown tests conducted by William E. Nork, Inc., of Reno, NV (2/28/84).

- Norris, R. M., and Webb, R. W., 1990, *Geology of California*, 2nd edition, John Wiley & Sons, Inc., New York, 541 pp.
- Plummer, C.N., Prestermon, E.C., and Parkhurst, D.L., 1991, An Interactive Code (NETPATH) for Modeling Net Geochemical Reactions along a Flow Path: *U.S. Geological Survey, Water Resources Investigations Report 91-4078*, 70 pp.
- Prudic, D. E., 1989, Documentation of a Computer Program to Simulate Stream-Aquifer Relations Using a Modular, Finite-Difference, Ground Water Flow Model: *U.S. Geological Survey Open-File Report 88-0725*, 113 p.
- PTI, 1997, *Effects of Pumping the Proposed Olinghouse Mine Supply Well on Dodge Flat and the Truckee River, Washoe County, Nevada*: Report for the Bureau of Land Management, Carson City, Nevada, by PTI Environmental Services, Pearl 4949 East Circle, Suite 300, Boulder, Colorado, 19 pp.
- Reichard, E. G., and Bredehoeft, J. D., 1984, Engineering Economic Analyses of a Program for Artificial Groundwater Recharge: *American Water Resources Association Bulletin*, V. 20, pp. 929-939
- Robyn, T. L., 1994, Geology and Ore Controls of the Lower Olinghouse Placer Gold Mine, Nevada: *Economic Geology* v. 89, pp. 1614 - 1622.
- Rowe, T. G., Lico, M. S., Hallock, R. J., Maest, A. S., Hoffman, R. J., 1991, Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in and near Stillwater, Fernley, and Humboldt Wildlife Management Areas and Carson Lake, West-Central Nevada, 1987 - 89: *U. S. Geological Survey Open-File Report 91-185*.
- Rush, Eugene F., and S.A. Kazmi, 1965. *Water Resources Appraisal of Spring Valley, White Pine and Lincoln Counties, Nevada*, Department of Conservation and Natural Resources, Water Resources-Reconnaissance Series Report 33, 36 p.
- Russell, I. C., 1895, Present and Extinct Lakes of Nevada: *National Geographical Magazine Monographs*, v. 1, No. 4, p. 101-132.
- Sanders, C. O., and Slemmons, D. B., 1979, Recent Crustal Movements in the Central Sierra Nevada-Walker Lane Region of California-Nevada: Part III, the Olinghouse Fault Zone: *Tectonophysics* v. 52, pp. 585 - 597.
- Schulke, D. F., editor, 1987: Great Basin Recharge Studies, *Desert Research Institute Water Resources Center Publication No. 41104*, Desert Research Institute, University of Nevada, Reno, Nevada, 126 pp.
- SEA, Inc., 1994, *Preliminary Ground Water Flow and Nitrate Transport Modeling, Stampmill Estates Subdivision near Wadsworth, Washoe County, Nevada*: report by SEA, Inc., Consulting Engineers, 930 Industrial Way, Sparks, Nevada, for Dunmore Homes, 10 pp., 16 plates, one appendix.
- Sheperd Miller, Inc., 1997a, *Aquifer Testing at the Proposed Alta Gold Olinghouse Open Pit Gold Mine, Washoe County, Nevada*: Consultants report for Alta Gold Company, 14 pp.

- Shepherd Miller, Inc., 1997b, *Monitoring Well and Piezometer Installation Report, Proposed Alta Gold Olinghouse Mine, Washoe County, Nevada*: Consultants report for Alta Gold Company, 11 pp.
- Shepherd Miller, Inc., 1997c, *General Hydrology and Water-Balance Model of the Proposed Alta Gold Olinghouse Mine Area, Washoe County, Nevada*: Consultants report for Alta Gold Company, 13 pp.
- Shepherd Miller, Inc., 1997d, *Water and Chemistry Mass Balance proposed Alta Gold Olinghouse Open Pit Mine, Washoe County, Nevada*: Consultants report for Alta Gold Company, 19 pp.
- Sinclair, W. C., and Loeltz, O. J., 1963, Ground-Water Conditions in the Fernley-Wadsworth area, Churchill, Lyon, Storey and Washoe Counties, Nevada: *U. S. Geological Survey Water-Supply Paper 1619-AA*, 22 pp.
- Smith, G. I., 1979, Subsurface Stratigraphy and Geochemistry of Late Quaternary Evaporites, Searles Lake, California: *U. S. Geological Survey Professional Paper 1043*, 130 p.
- Smith, G. I., Barczak, V. J., Moulton, G. F., and Liddicoat, J. C., 1983, Core KM-3, a Surface-to-Bedrock Record of Late Cenozoic Sedimentation in Searles Valley, California: *U. S. Geological Survey Professional Paper 1256*, 24 p.
- Tabaei, H. A., 1991, *Water Quality of Shallow Groundwater Reused for Irrigation*: M. S. Thesis, University of Nevada, Reno.
- TCID, 1997, Tables Showing Calculations of Historical Canal Losses for the Period 1967-1995: Supplied by the U.S. Department of the Interior, Bureau of Reclamation, Lahontan Projects Office 7/1/97.
- Thomas, J. M., J. L. Mason, and J. D. Crabtree, 1986. *Groundwater Levels in the Great Basin Region of Nevada, Utah, and Adjacent States*, U.S. Geological Survey, Hydrologic Investigations Atlas HA-694-B.
- Todd, D. K., 1965, Economics of Groundwater Recharge; Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division, V. 91, no. Hy4, pp. 249-270.
- Tschanz, C. M., and Pampeyan, E. H., 1970, Geology and Mineral Deposits of Lincoln County, Nevada: *Nevada Bureau of Mines and Geology Bulletin 73*.
- Van Denburgh, A. S., and Arteaga, F. E., 1985, Revised Water Budget for the Fernley Area, West-Central Nevada, 1979: *U. S. Geological Survey Open-File Report 84-712*, 17 pp.
- Van Denburgh, A. S., Lamke, R. D., and Hughes, J. L., 1973, A Brief Water-Resources Appraisal of the Truckee River Basin, Western Nevada: *U.S. Geological Survey Water Resources Reconnaissance Series, Report 57*, 122 pp.
- USGS, 1997, Truckee River flow measurements reported at different stations for the years 1918-1997: spreadsheet containing data acquired by the U.S. Geological Survey, Carson City, Nevada.
- U.S. Soil Conservation Service, 1975, Soil Survey, Parts of Churchill, Lyon, Storey, and Washoe Counties, Fallon-Fernley Area, Nevada: U.S. Department of Agriculture.

U.S. Soil Conservation Service, 1975, 1980, Soil Survey of Washoe County, Nevada, South Part: U.S. Department of Agriculture, 608 p.

Washoe County Utilities, 1992, Stampmill Estates Pump Tests and Water Analysis: letter dated 16 April, 1992, from Dan Dragan of the Washoe County Utility Division, Department of Public Works to Terri Svetich.

Watson, Phil, Sinclair, Peter, and Waggoner, Ray, 1976, *Quantitative Evaluation of a Method for Estimating Recharge to the Desert Basins of Nevada*, Journal of Hydrology, Vol. 31, pp. 335-357.



APPENDIX A
INTERPRETIVE GEOLOGIC
CROSS-SECTIONS

NOTE: SEE FIGURE 2.2 FOR
LOCATION OF CROSS-SECTIONS

A

A'

S 82 W
UTM NORTH 4390850
UTM EAST 297900

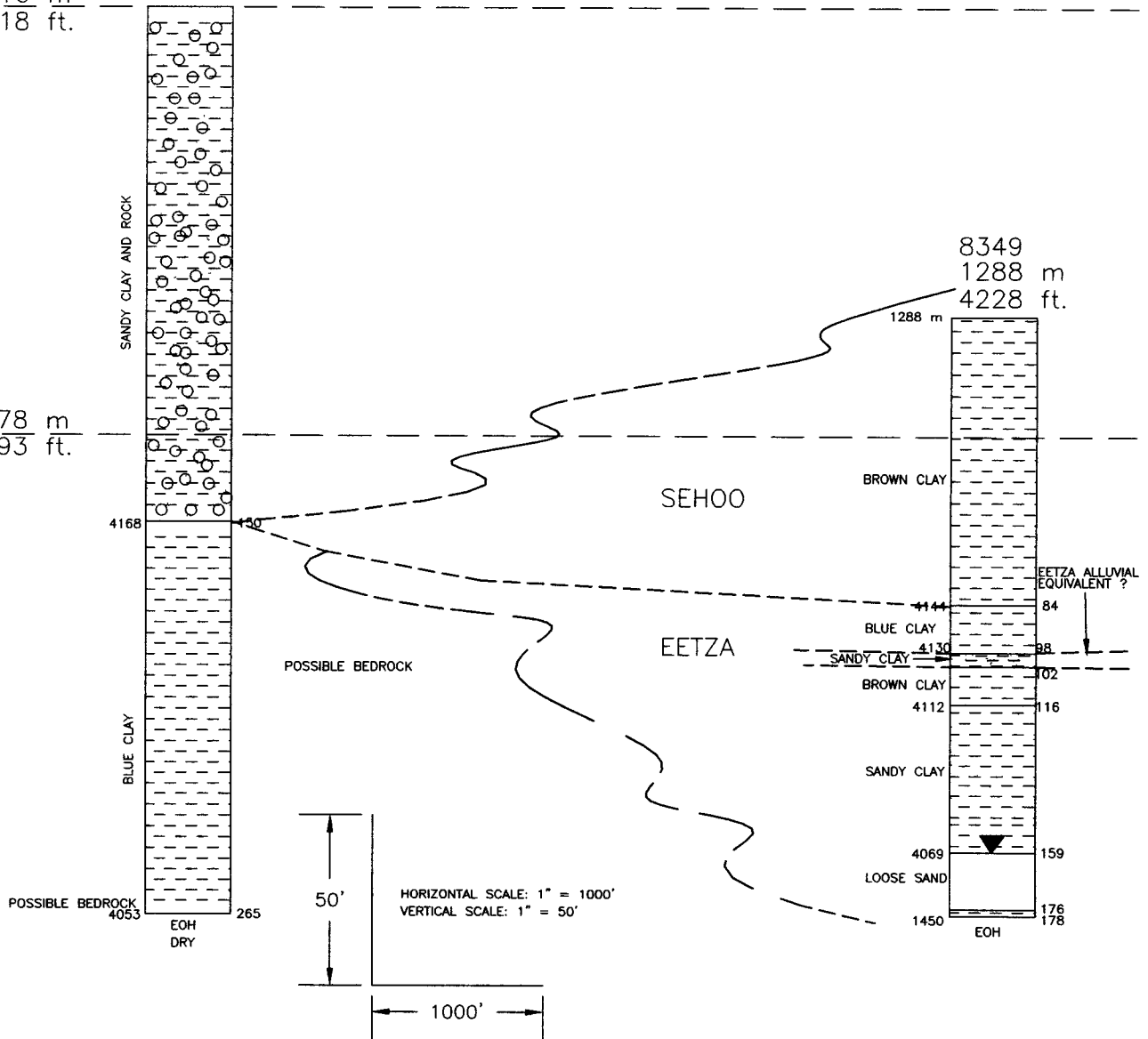
N 82 E
UTM NORTH 4391150
UTM EAST 300300

15819
1316 m
4318 ft.

1316 m
4318 ft.

1278 m
4193 ft.

8349
1288 m
4228 ft.



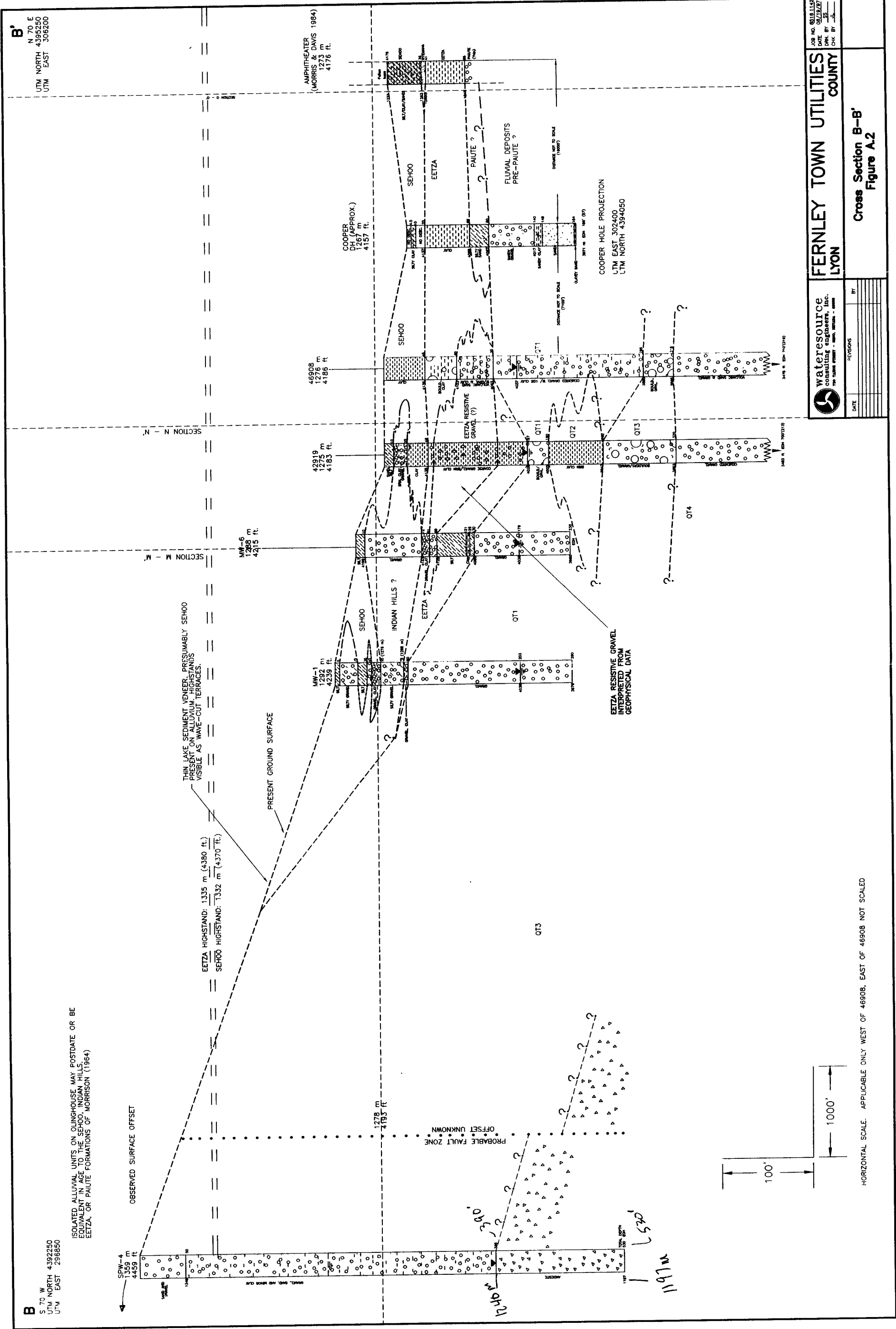
waterresource
consulting engineers, inc.
730 TAILORE STREET - RENO, NEVADA - 89505

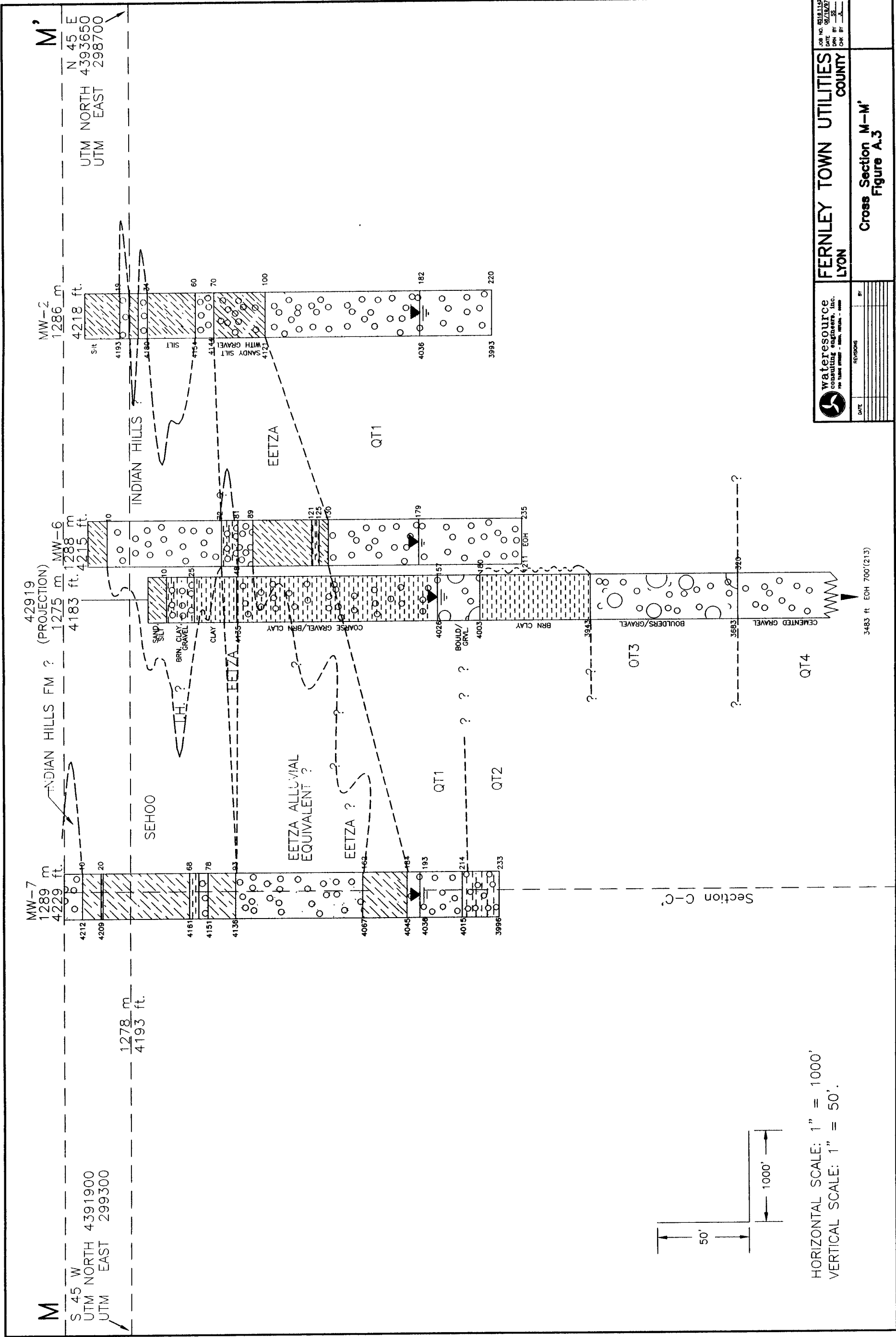
FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8516.1142
DATE 12/03/97
DRN. BY SS
CHK BY JL

DATE	REVISIONS	BY

Cross Section A-A'
Figure A.1





HORIZONTAL SCALE: 1" = 1000'
VERTICAL SCALE: 1" = 50'

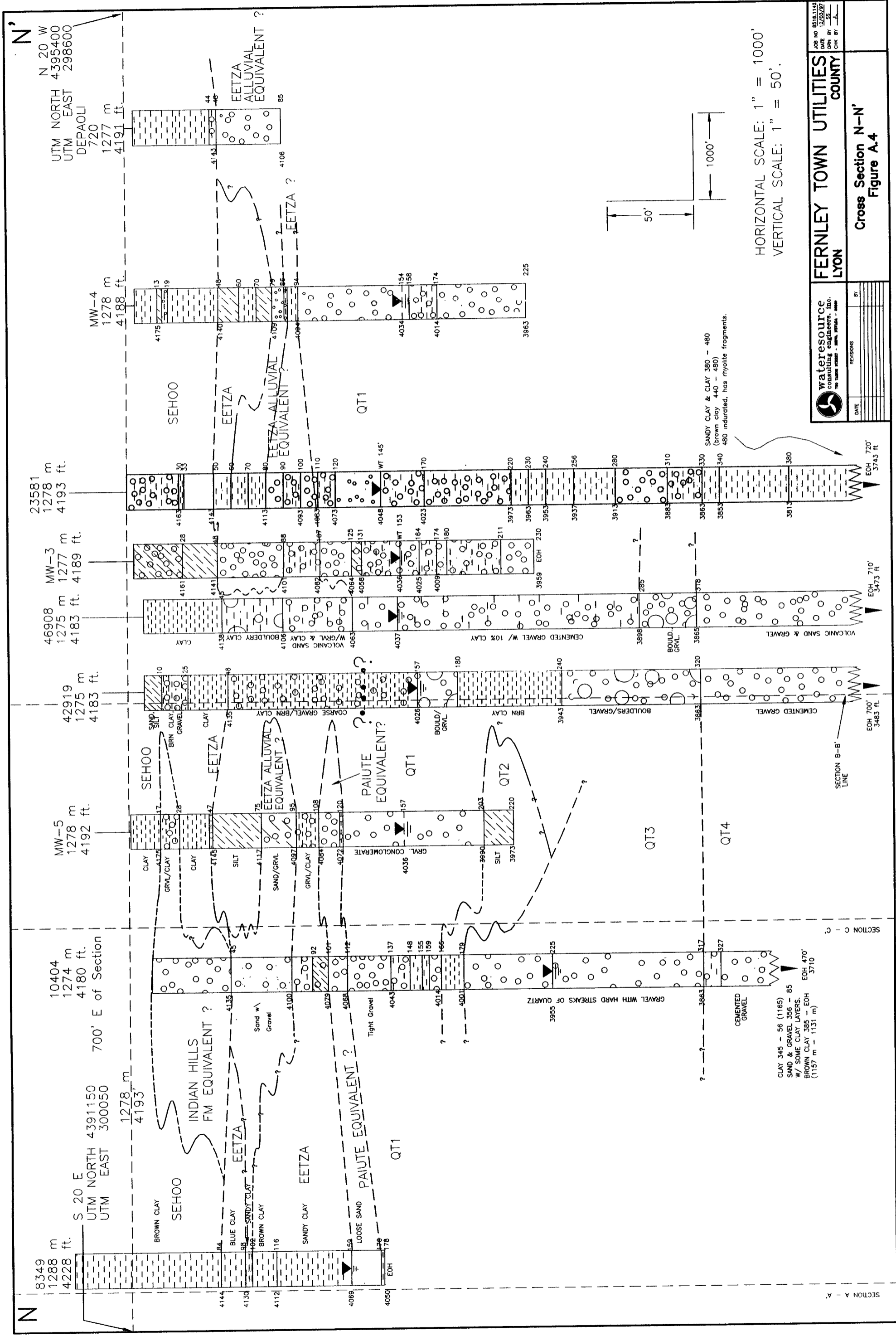
water resource
consulting engineers, inc.
FOR TOWN ENGINEERING - DESIGN - CONSTRUCTION - MAINTENANCE

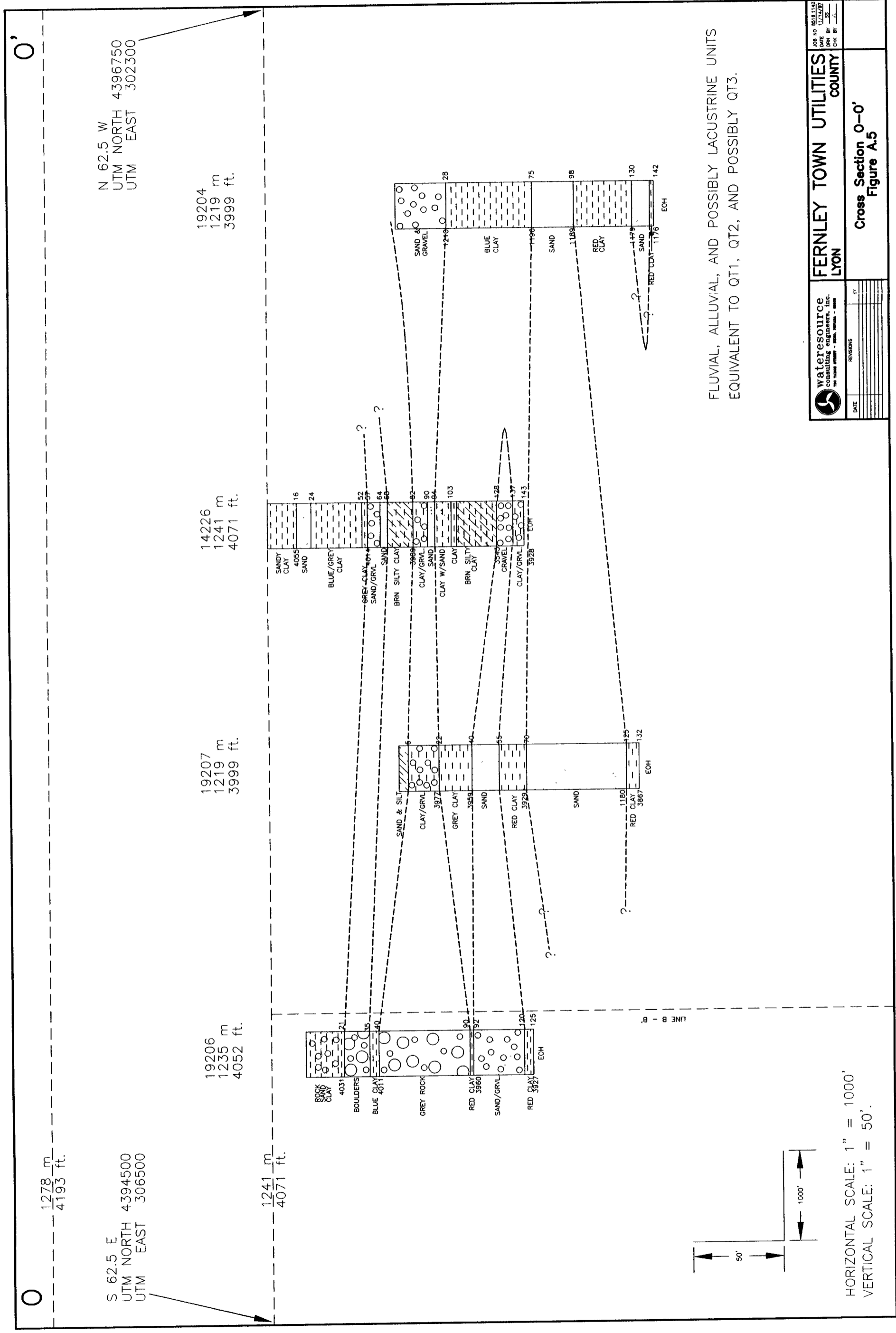
DATE: _____ BY: _____
REVISIONS: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____
DATE: _____ BY: _____

FERNLEY TOWN UTILITIES
LYON COUNTY

Cross Section M-M'
Figure A.3

JOB NO. 081112
DATE: 08/18/07
DRAWN BY: SS
CHECKED BY: JA







A vertical dashed line on the left side of the page, consisting of a series of short, thick black horizontal dashes.

APPENDIX B

SOLUTE MASS BALANCE ESTIMATES – DODGE FLAT

APPENDIX B

SOLUTE MASS BALANCE ESTIMATES – DODGE FLAT

Part 1: Equivalent Stratigraphic Thickness of Evaporite

Mass balance estimates were used in the present study to test various concepts regarding the source of groundwater solute on Dodge Flat and to gauge the impact of artificial injection on water quality. Some of these estimates, particularly average width and depth, required knowledge of basin dimensions, approximations for which were obtained using a variety of simplifying geometric assumptions.

Dodge Flat Basin Area

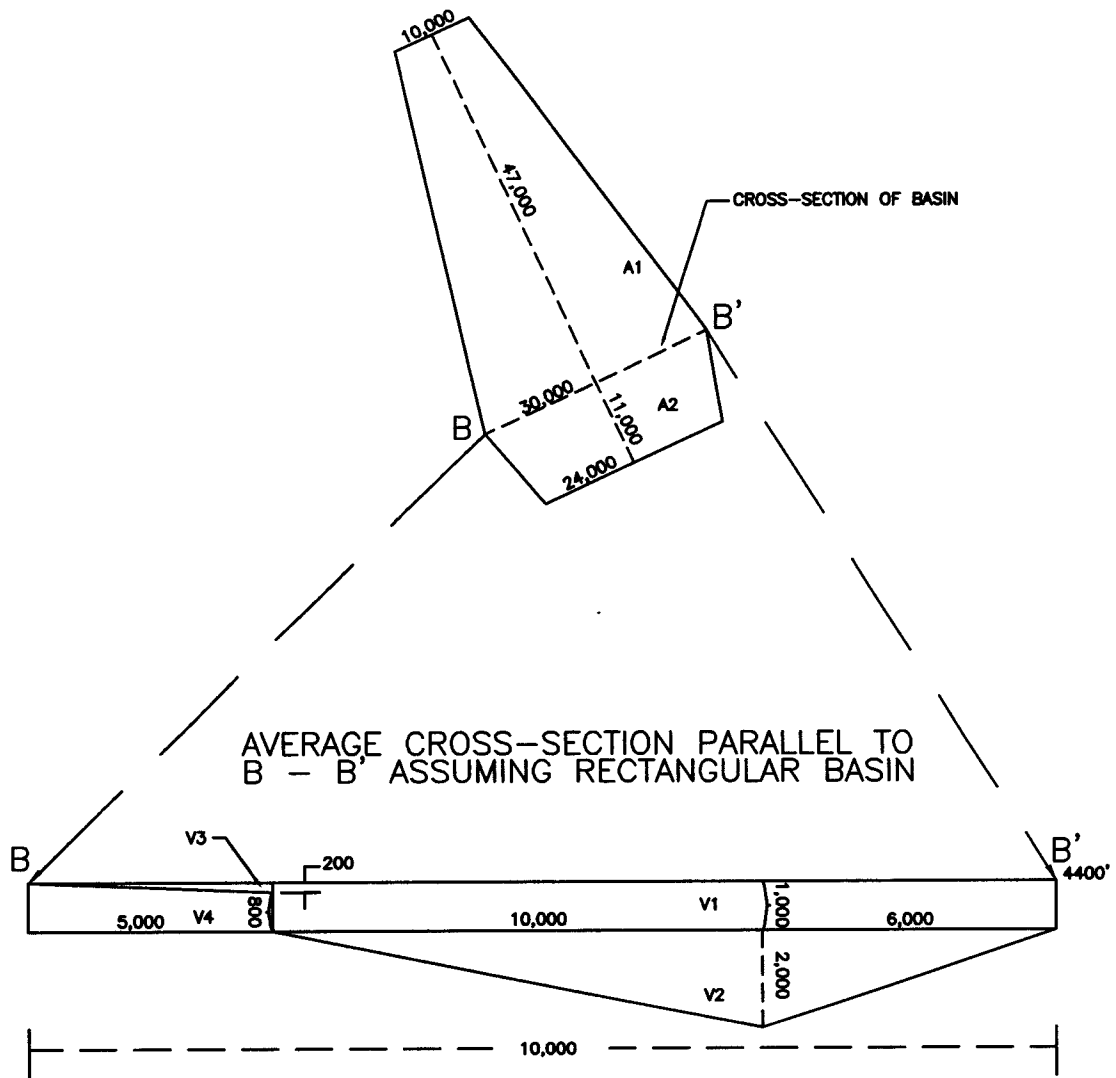
For the purpose of calculation, it was assumed that the part of the Dodge Flat basin underlain by lacustrine sediments coincides with groundwater that contains high solute concentrations. This spatial relationship is evident from geochemical analyses on and near the Olinghouse fan, which is the only information presently available (CH2MHill, 1990; McKay and Bohm, 1998). The maximum elevation of lacustrine deposition was approximated from aerial photographs to be the 4400-foot elevation contour, about 75 feet below the Sehoo Alloformation highstand.

That part of the Dodge Flat study area below this elevation is represented in Figure B.1 by two trapezoids (A1 and A2) with a common baseline and dimensions scaled from 7.5' USGS topographic maps. The combined area of these trapezoids ($\sim 1.2 \times 10^9$ ft²) agrees within $\sim 5\%$ of that obtained from ArcView data sets. The common baseline coincides roughly with geologic cross-section B-B'; the height of the trapezoids is perpendicular to the baseline and is oriented approximately N 70 W.

Average Basin Section

An average basin width (W') of $\sim 21,000$ feet was computed by dividing the total area by a length of equal to the sum of the two trapezoid heights (58,000 feet). Figure B.1 illustrates an average basin cross-section and the geometric simplifications used to represent the position and thickness of its component lithologies. Alluvial deposits form a blunt trapezoidal wedge ~ 5000 feet long on the west side of the section overlain by a thin veneer of lake beds; the remaining 16,000 feet of section is assumed to be comprised of a mixture of lacustrine and fluvial sediments. Elevation differences are ignored since the maximum relief along the section line is only ~ 340 feet. Based on inferred stratigraphic relationships, the depth to the base of Lahontan age sediments (D₁) is assumed to be ~ 200 feet. The eastern end of the alluvial wedge is thus ~ 800 feet thick (D₂), since geophysical interpretations for the present study (Hartley, 1998) suggest a total depth to bedrock of ~ 900 feet at the base of the Olinghouse fan. Eastward, the basin deepens to ~ 2700 feet (Carpenter, 1998; Hartley, 1998). For purposes of calculation, these numbers have been rounded to 1000 feet and 3000 feet, respectively.

For the section east of the alluvial wedge, the volume of a unit thickness along the 1000-foot deep upper portion (V₁) is $1 \times 1000 \times 16,000 = 16 \times 10^6$ ft³ (Table B.1). The triangular deep portion (V₂) is $0.5 \times 1 \times 16,000 \times 2,000 = 16 \times 10^6$ ft³. Similar computations give volume estimates of 0.5×10^6 ft³ for the western lacustrine sediment wedge (V₃) and 4.5×10^6 ft³ for the alluvial trapezoid (V₄). Assuming saturation and a porosity (ϕ) of $\sim 25\%$ suggests pore water volumes of 4×10^6 , 4×10^6 , 0.125×10^6 , and 1.125×10^6 ft³ respectively. An average depth (D' = 2000 ft) for the section east of the alluvial fan is obtained by summing V₁ and V₂ and dividing by a width of 16,000 ft. Analogous calculations give average depths of 100 ft for V₃ and 900 ft for V₄.



FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/28/98
DRN. BY LCS
CHK. BY JL

DATE	REVISIONS	BY

Simplified Basin Area and
Avg. at Cross Section - Figure B.1

The volume of contained water per lineal foot of section for each segment is the product of its volume and the porosity. The volume of a unit width and north-south thickness of section equals its average depth. Thus, a 1 ft² column of sediment in the eastern segment of the section ($V_1 + V_2$) contains an average of $(1 \times 1 \times 2000 \text{ ft}^3) \times 0.25 = 500 \text{ ft}^3$ of pore water. In a vertical column, the western lacustrine wedge (V_3) averages 25 ft³ of pore water, and the alluvial trapezoid, 225 ft³.

TABLE B.1
BASIN VOLUME CALCULATIONS, DODGE FLAT

Trapezoids of Figure C.1		Area	Height	Base 1	Base 2					
A1		9E+08	47000	10000	30000					
A2		3E+08	11000	30000	24000					
Total		1E+09	58000							
Average Width		21328								

Tables show estimated basin volumes; volume of contained water within the saturated zone; volume of water that lies within the saturated zone and is readily accessible by wells (depth <800 ft); and the volume of possible fresh water flanking the Pah Rah range within the northern portion of the Dodge Flat depositional basin (Trapezoid A1 of Figure B.1). Volume estimates are based on average widths and areas shown in Figure B.1. Areas shown agree with those obtained from GIS measurements within about 10%. Depth estimates are based on a maximum basin depth of 2700 feet inferred from gravity data by Hartley (1998). For purposes of calculation, this has been rounded to 3000 feet.

Contained Solute

From the top to the base of the Olinghouse fan, groundwater gains between ~300 and ~400 mg/kg TDS (CH2MHill, 1990; McKay and Bohm, 1998). Converting units, the latter figure equates to 4×10^{-4} lb/lb water or 0.025 lb. of solid/ft³ of solution using a density for water of 62.4 lb/ft³. Densities for gypsum, halite, thenardite, and trona are between ~2100 and 2600 kg/m³ (Gaines, *et al.*, 1997). A mid-range density value of 2300 kg/m³ corresponds to ~143 lb/ft³. For a 1 ft³ volume of solute laden water, the 0.025 lb. of solids gained therefore corresponds to a volume of dissolved solids of $0.025/143 = 0.00017 \text{ ft}^3$, or ~0.02% of the fluid volume.

Equivalent Thickness within Lake Beds in Eastern Part of Section

For the lacustrine sediments (V_1+V_2), the fluid volume in a unit width of section is 500 ft^3 , corresponding to $500 \times \sim 0.02\%$ or $\sim 0.1 \text{ ft}^3$ of evaporite. Therefore, in the entire sediment column averaging 2000 feet deep, there needs to have been only $\sim 0.1 \text{ ft}$ of evaporite deposited to account for the solute loading gained by groundwater as it moves from the Olinghouse fan onto Dodge Flat. If the evaporite were laterally discontinuous such that it were found on only 10% of a given stratigraphic horizon, its thickness would be $\sim 1 \text{ foot}$; for 1% continuity, $\sim 10 \text{ ft}$. The above calculations presume constant spatial distribution of solute within the groundwater. They indicate that dissolution of too small a quantity of evaporite to be mappable could account for the solute loading beneath Dodge Flat, provided the groundwater is unmoving.

Sourcing from Lake Sediment Wedge (V_3)

The total contained solute mass in the eastern portion of the section is $(V_1+V_2) \times \phi \times 0.025 = 3.2 \times 10^7 \times 0.25 \times 0.025 = 0.2 \times 10^6 \text{ lb}$. To source this from the lacustrine sediment wedge ($V_3 = 0.5 \times 10^6 \text{ ft}^3 \times \phi$) would require evaporite in the amount of $\sim 1.6 \text{ lb/ft}^3$, or $\sim 0.016 \text{ ft}^3/\text{ft}^3$. This equates to $\sim 1.6 \text{ ft}$ of evaporite in a 100 foot average vertical section if laterally continuous, or $\sim 16 \text{ ft}$ if only 10% laterally continuous. This thick an evaporite section might be recognizable in outcrop, but difficult to notice if dispersed.

Estimated Groundwater Movement

The issue of leaching by moving groundwater is far more complex and requires additional assumptions. Among these are that evaporite dissolution is kinetically rapid compared to groundwater movement, that flow through the section is uniform, and that groundwater chemistry as seen in the Olinghouse fan area is representative of Dodge Flat as a whole. To assess groundwater and solute flux requires knowledge of aquifer thickness, hydraulic conductivity, piezometric gradient, and solute concentration. Order of magnitude estimates are all that is possible at this time, but these serve to test the concept of a sedimentary solute source.

For the purposes of calculation, aquifer thickness is assumed to be that of the Lahontan age lake beds ($\sim 200 \text{ ft}$), homogeneous, and confined. However, these particular sediments actually lie within the vadose zone. The following calculations additionally assume that the characteristics and spatial distribution of these deposits are comparable to those of the saturated sediments immediately beneath them.

A second assumption is that the climate of the past 50,000 years as inferred by Benson and Thompson (1987) is representative of the preceding time period though geologic evidence suggests that this may not be precisely correct (Morrison, 1964). Groundwater gradients are presumed to be comparable to those of today, and, additionally, to have operated only during those periods when lake levels fell below the base of the Lahontan section ($\sim 4050 \text{ ft}$ elevation). According to Benson and Thompson (1987), this was the situation for roughly 28,000 out of the last 45,000 years, or $\sim 62\%$ of the time. For calculation purposes, groundwater flow is presumed to have been zero at higher lake stands. The piezometric gradient today between the Olinghouse fan and the river is $\sim 70 \text{ ft}/16,000 \text{ ft} \approx 0.0044$.

Aquifer tests for wells on Dodge Flat show high horizontal conductivity, a reasonable figure for which is $\sim 30 \text{ ft}^2/\text{day}$; estimates for the lower Truckee River aquifer are higher ($\sim 50 \text{ ft}^2/\text{day}$) (this study). Between the two areas are lacustrine deposits, which are likely to be less conductive. For purposes of calculation, a figure of $30 \text{ ft}^2/\text{day}$ was taken to represent a typical spatially averaged conductivity for all of the Dodge Flat section.

Darcy's law provides an estimate of water flux along the average cross-section (Figure B.1): $200 \text{ ft} \times 30 \text{ ft}^2/\text{day} \times 365 \text{ d/y} \times 0.0044 = \sim 9800 \text{ ft}^3/\text{y}$. One pore volume of water for the average Lahontan age section below the toe of the Olinghouse fan ($V_p = \phi V$) is $0.25 \times 200 \times 16,000 = 800,000 \text{ ft}^3$. Thus, the water flux

per year is $9800/800,000 = \sim 0.012$ pore volumes. Over a 28,000 year period, this corresponds to ~ 340 pore volumes for a 200 ft thick section, or ~ 34 pore volumes for a 2000 foot section.

These values were checked against estimated recharge from the Pah Rah range. Dividing recharge by basin length gives: $1300 \text{ af/y} \times 43560 \text{ ft}^3/\text{acre} \times (47,000 \text{ ft})^{-1} \approx 1200 \text{ ft}^3/\text{y}$. For a unit north-south distance, this corresponds to 1200 ft^3 , or ~ 0.0015 pore volumes if all flow is through a 200 ft vertical section. If flow is through the entire 2000 foot average sediment column thickness, $\sim 1.5 \times 10^{-4}$ pore volumes are flushed per year. For a 28,000 year period these equate to ~ 42 and ~ 4 pore volumes, respectively.

The precise magnitudes of subsurface flux were addressed during groundwater modeling; for the present calculation, the above estimates provide lower limits on evaporite thickness. The above calculations indicate that for unmoving groundwater (1 pore volume), a 2000 ft vertical section can contain as little as 0.1 ft of evaporite. For moving groundwater, ~ 3 ft of evaporite at 34 pore volumes, ~ 4 ft at 42 pore volumes, and ~ 0.5 ft at 4 pore volumes are required over the entire 2000 ft average basin depth. These values increase by a factor of 10 if all groundwater ions in the basin are sourced only from that 200 ft stratigraphic section, which is roughly what is exposed along the Truckee River gorge north of Big Bend. Even under those circumstances, the total evaporite proportion in the section is small. Note that the calculations suggest a minimum thickness of evaporite: slow dissolution into moving groundwater or irregular lateral distribution of evaporite would necessitate greater quantities within a given section.

In this conceptual model, the kinetics of evaporite dissolution are important. If rapid, then the entire volume of salts within the stratigraphic section would dissolve quickly. Continuing fresh-water recharge would then flush the solute-laden groundwater from the basin. Only if dissolution is fairly slow with respect to groundwater flux can evaporites act as a solute source.

Similar groundwater flux considerations suggest that sourcing solely from the lacustrine sedimentary wedge (V_3) is unlikely: the entire section must needs be evaporite at a flux of ~ 200 pore volumes, compared to ~ 20 feet of the section at 42, and ~ 2 feet at 4 pore volumes.

Sourcing from Paleosols

Studies by Cooper and Associates (1980) and by CH2MHill (1990) indicate that soil horizons in the Olinghouse fan-Dodge Flat area contain water soluble cations. Values were reported in meq/100g and vary by more than one order of magnitude. To test the concept of paleosols as solute sources, averages were taken for Na^+ and Ca^{++} , and these converted to English concentration units (lb/ft^3). In the calculations, it has been assumed that the principal cation sources were salts, so anions were present but simply not reported. To crudely account for these anions (SO_4^- , HCO_3^- , or Cl^-), the figure for total cations was multiplied by 2.5. Additionally, it was assumed that paleosols on the Olinghouse fan resemble the present-day soils tested by Cooper and Associates (1980) and CH2MHill (1990). This may not be the case, since their reports indicate that with one exception, soil borings were on the portions of Dodge Flat containing lacustrine sediments. If the sediments in fact supply solute to groundwater, then the non-representative sample distribution may cause over-estimation of the sourcing capacity of paleosols.

Reported averages in the soil analyses for Na^+ and Ca^{++} were 0.44 and 0.23 meq/100g soil, respectively. These equate to ~ 101 and $\sim 46 \text{ mg/kg}$ soil, or 10^{-4} and $4.6 \times 10^{-5} \text{ kg/kg}$ soil. Converting to English units gives 10^{-4} and $4.6 \times 10^{-5} \text{ lb solute/lb soil}$. Adding these values and multiplying by 2.5 to allow for charge balancing anions gives $\sim 3.8 \times 10^{-4} \text{ lb solute/lb soil}$ as a figure for total available solute. If a reasonable bulk density of $94 \text{ lb soil}/\text{ft}^3$ soil ($\sim 1500 \text{ kg/m}^3$), i.e., a porosity of 40% (Blake and Hartge, 1986), and complete saturation are assumed, then $94 \times 3.8 \times 10^{-4} = 0.035 \text{ lb solute}/\text{ft}^3$ soil can be released into 0.4 ft^3 of water. This is equivalent to 0.035 lb solute in $\sim 25 \text{ lb}$ of water, or $\sim 1.4 \times 10^{-3} \text{ lb/lb}$ (1400 mg/kg). Thus, by saturating a cubic foot of soil, a maximum of roughly 1400 ppm solute in its pore water could result. This figure

provides an estimate of solute availability to injected fresh water. If, for example, even 10% of the section were paleosols, ~140 ppm of dissolved solids could be produced in the newly saturated portions of the alluvial fan. The total release into injected water presumably would diminish with repetition of the process, but it is essential that tests be performed prior to designing an ASR system.

If it is conservatively assumed that the entire alluvial section (V_4) is paleosol, the maximum total solute mass available from the alluvial material is roughly $V_4 \times 0.035 \approx 158,000$ lb for a unit thickness of cross-section. For the eastern portion of the section (V_1+V_2), one pore volume of fluid $\approx 8,000,000$ ft³. This corresponds to ~ 0.02 lb/ft³ of water, or ~ 300 ppm, roughly the observed gain in solute at the base of the Olinghouse fan. In other words, even if the entire lower Olinghouse fan were paleosol, the transmission of ~ 1 (V_1+V_2) pore volume of water would have depleted it of soluble cations. Water flux estimates during only Lahontan time suggest that as many as ~ 30 pore volumes, based on hydraulic properties, or as few as four, based upon present-day recharge, may have passed through the average cross-section. It is therefore highly unlikely that paleosols were the sole source of solute to the groundwater beneath Dodge Flat.

This argument can be extended further. If one supplements the lower Olinghouse fan with a volume for the upper fan of $\sim 5 \times 10^6$ ft³ and makes the even more unrealistic additional assumption that the entirety of V_1+V_2 is paleosol, the necessary water flux to deplete salts increases to ~ 6 pore volumes during Lahontan time, quite apart from previous interpluves. If only $\sim 20\%$ of the section is paleosol, only about 1 pore volume is needed.

Concentrations in Geothermal Fluid

Measured solute concentrations in geothermal fluids in the Dodge Flat region range from $< \sim 400$ to as much as ~ 7500 ppm TDS (Garside and Schilling, 1979). Taking ~ 4000 ppm ($4 \text{ kg/m}^3 \approx .25 \text{ lb/ft}^3 \text{ fluid}$) as a rough average, and disallowing for compositional differences, geothermal water contains ~ 10 times as much solute per unit volume as is gained by groundwater moving down the Olinghouse fan. Since the flux of that water essentially equals recharge, a geothermal component of only $\sim 10\%$ of recharge could account for the entire observed solute gain.

Concentrations in Playa Waters

Similar computations can be made for playa and agricultural recharge waters in the region. Electrical conductivity measurements by Rowe, *et al.* (1991), indicate that such waters in the Fernley area contain from < 1000 to $> \sim 10,000$ ppm TDS. Although these do not discharge into Dodge Flat, they are a potentially important source of ions to the Truckee River, and even small volumes entering the Truckee system can carry significant quantities of solute.

Part 2: Lake Mass Balances

The previous discussion provided order of magnitude estimates as to the requisite minimum stratigraphic thickness of evaporite minerals to account for present-day groundwater compositions on Dodge Flat. This portion of the appendix considers another approach as to whether lacustrine sediments can plausibly supply that solute. Order of magnitude calculations have been made of the solute mass contained within an ancient lake overlying Dodge Flat, and estimates made of the number of lake volumes required to supply that mass. The first section determines whether present-day atmospheric infall above Dodge Flat suffices to supply the salts. The second section estimates the number of lake volumes needed, and the third section uses present-day ET measurements to calculate the number of lake volumes of water lost since the peak of the last pluvial interval. It should be cautioned that many simplifying assumptions were necessary to perform these calculations. Apart from geometric simplifications, chief among them are the persistence of current climatic and hydrologic

conditions into the past. Another important assumption is the lack of strong interaction between lake waters and submerged sediments: salts contained within the sediments are assumed not to re-enter the overlying waters.

The first question concerns whether present infall could account for observed solute concentrations. Junge (1958) provides contour maps indicating major ion concentrations in present-day precipitation. Based on those maps, precipitation above Dodge Flat contains an estimated TDS load of $\sim 10^{-4}$ lb solute/ft³ of solution (~ 1.6 ppm). At a precipitation rate of ~ 0.3 ft/y, this gives a solute mass flux of $\sim 3 \times 10^{-5}$ lb/ft²-y.

In the previous section, a 1 ft² column of sediment 2000 ft thick containing ~ 400 ppm TDS was estimated to contain ~ 7.5 lb of solute. Dividing this figure by the flux gives $\sim 210,000$ years as the minimum time required to account for those salts. Note that this presumes no flushing of salts by moving groundwater. If, since the last glaciation, 4 pore volumes have passed through the sediments, the requisite infall duration increases to $\sim 900,000$ y; at 30 pore volumes, $\sim 6.4 \times 10^6$ y, and at 42 pore volumes, $\sim 9 \times 10^6$ y. Because the time since the last highstand is $\sim 13,000$ y, clearly direct precipitation onto Dodge Flat is insufficient to account for the dissolved salts.

The second question addresses the mass of solute contained within a lake. For purposes of calculation it is assumed that the solute concentration of lacustrine water was similar to the median Truckee River concentration between high- and medium-flow conditions, *i.e.*, $\sim 10^{-4}$ lb/ft³ (~ 160 ppm). In that case, a 300 ft water column contains ~ 0.3 lb. TDS. This water depth was obtained from the difference in elevation between the Seho highstand and that of the typical Dodge Flat valley floor. To account for 7.5 lbs. of solute therefore requires ~ 25 lake volumes, assuming no lateral solute transport as the lake desiccated, and no subsequent flushing by fresh recharge water. This figure increases to ~ 100 lake volumes if recharge amounted to 4 pore volumes, ~ 200 at 30 pore volumes, and ~ 250 at 42 pore volumes.

These results suggest the third question: how many lake volumes might reasonably have been lost since the last glaciation. Applying present-day evaporation rates for Pyramid Lake (~ 3 ft/y; Hostetler and Benson, 1990) to a 300 ft water column suggests that roughly one lake volume is lost per century. At that loss rate, during the $\sim 13,000$ y since the last Lahontan highstand (Benson and Thompson, 1987), ~ 130 lake volumes may have been lost to evaporation, and during the past 20,000 y, ~ 200 volumes.

These figures are of the same order as those required to produce and maintain the groundwater solute concentrations found beneath Dodge Flat today. However, the question as to the ultimate source of dissolved salts remains open. If precipitation infall (at present-day rates) were the only solute source, simple mass balance suggests it must have been gathered from an area hundreds of times that of the Lahontan Basin to supply what is presently observed.

Part 3: Conclusion

Mass balance estimates suggest that a proportion of evaporite undetectable in wells on field examination potentially could source the solutes present in groundwater beneath Dodge Flat, provided there is some kinetic, transport, or other constraint on dissolution rate. The evaporation of lakes that existed during previous pluvial intervals could plausibly have supplied those solutes, if it is assumed that they gained salts from large drainage basins. Paleosols alone, even under conservative assumptions, probably could not supply all of the observed solute, though their contribution may be significant.

APPENDIX C

TRUCKEE RIVER
SOLUTE MASS BALANCES

APPENDIX C

TRUCKEE RIVER SOLUTE MASS BALANCES

C.1 Truckee River Median Flows

Table C.1 lists the means, standard deviations, and median values of monthly flow at each station for the regressed data set (Table C.2). Also included are the differences in the arithmetic average mean and median flows between the stations. At Wadsworth, the mean flow is ~440 cfs (318,000 af/y), the median is ~62 cfs (~44,800 af/y), and the standard deviation is ~815 cfs (~590,000 af/y), giving ~1.9 as the coefficient of variance. Figures for Nixon are: mean, ~444 cfs (~321,000 af/y) ; median, 71.5 cfs (~5200 af/y), standard deviation, ~789 cfs (~571,000 af/y); and coefficient of variance ~1.8. Because of their irregularity, the difference of the mean between the Nixon and Wadsworth flows is ~1.9 cfs (~1380 af/y), while the difference of the median is ~9.6 cfs (~6950 af/y).

TABLE C.1
MONTHLY TRUCKEE RIVER FLOW STATISTICS

	All Months				Months of November And December Only			
	Median	Mean	Standard Deviation	Coefficient of Variance	Median	Mean	Standard Deviation	Coefficient of Variance
Derby	47.5	401.3	756.5	1.9	24.1	247.9	562.5	2.3
Wadsworth	61.9	441.9	814.6	1.8	37.1	277.2	600.0	2.2
Nixon	72.1	443.9	789.1	1.8	52.0	284.6	585.9	2.1
Differences between flows at the stations:								
	Medians	Means			Medians	Means		
Derby- Wadsworth	14.4	40.6			13.1	29.3		
Wadsworth- Nixon	10.2	2.0			14.9	7.4		

Truckee River flow statistics derived from the regressed data set, in cfs.
Data source: U.S.G.S. monthly average flow data, 1918-1997

For the months of November and December, the respective differences are more irregular. At Wadsworth, the mean is ~277 cfs (~200,000 af/y), the standard deviation is ~600 cfs (~434,000 af/y), the coefficient of variance is ~2.2, and the median is ~37 cfs (~26,800 af/y), while for Nixon the corresponding values are ~285 cfs (~206,000 af/y), ~586 cfs (~424,000 af/y), ~2.1, and ~52 cfs (~37,700 af/y). Between Wadsworth and Nixon, the difference between means is ~2 cfs (~1500 af/y) and the medians, 14.9 cfs (~10,900 af/y).

Under all conditions, flows are markedly irregular, as indicated by high coefficients of variance. They are not normally distributed since the flow determined from the arithmetic average of logs of the flows differs significantly from the median. The mean of the logs of flows, however, is reasonably close to the log of the median, which initially suggested that flows might be a lognormally

TABLE C. 2
TRUCKEE RIVER FLOWS, REGRESSED DATASET

Basis = Derby Flows												
	AVG	Derby	Wadsworth	Nixon		Derby	Wadsworth	Nixon		Derby	Wadsworth	Nixon
	St Dv	401.292	441.9	443.9								
	Max	756.526	814.6	789.1								
	MEDIAN	47.5	61.9	72.1								
	Max	6493	7231.0	6160.0								
	Water Year											
JAN	1918	357	394.4	397.8	OCT	1926	21	33.4	48.4	OCT	1934	3.94
FEB		222	249.4	257.4	NOV		21	33.4	48.4	NOV		1.3
MAR		403	443.8	445.6	DEC		21.9	34.4	49.3	DEC		1.84
APR		1162	1259.1	1235.0	JAN		28.1	41.1	55.7	JAN		2
MAY		493	540.5	539.2	FEB		23.5	36.1	51.0	FEB		2.64
JUN		77.4	94.0	107.0	MAR		87	104.3	117.0	MAR		77.1
JUL		18.9	31.2	46.2	APR		434	477.1	477.9	APR		26.6
AUG		17.7	29.9	44.9	MAY		147	168.8	179.4	MAY		20.5
SEP		98.9	117.1	129.4	JUN		13	24.8	40.0	JUN		16.9
OCT		246	275.1	282.4	JUL		24.2	36.9	51.7	JUL		16.9
NOV		185	209.6	218.9	AUG		25	37.7	52.5	AUG		18.5
DEC		226	253.6	261.6	SEP		25	37.7	52.5	SEP		13.3
JAN		190	215.0	224.1	OCT	1927	13.3	25.2	40.4	OCT	1935	2.32
FEB		279	310.6	316.7	NOV		60.4	75.8	89.3	NOV		2
MAR		270	300.9	307.3	DEC		17.2	29.4	44.4	DEC		1.45
APR		1655	1788.6	1747.7	JAN		22.2	34.7	49.6	JAN		1
MAY		1526	1650.1	1613.6	FEB		489	536.2	535.1	FEB		2.43
JUN		60.1	75.4	89.0	MAR		586	640.3	636.0	MAR		2.48
JUL		11.3	23.0	38.3	APR		1291	1397.6	1369.2	APR		761
AUG		11	22.7	38.0	MAY		1804	1948.7	1902.7	MAY		936
SEP		12.6	24.4	39.6	JUN		1234	1336.4	1309.9	JUN		284
OCT		20.9	33.3	48.3	JUL		32.4	45.7	60.2	JUL		17.1
NOV		17.8	30.0	45.0	AUG		27.7	40.6	55.3	AUG		12.9
DEC		187	211.8	221.0	SEP		38.9	52.7	67.0	SEP		8.5
JAN		101	119.4	131.6	OCT	1928	47.6	62.0	76.0	OCT	1936	6.87
FEB		14	25.9	41.1	NOV		18	30.2	45.2	NOV		5.73
MAR		31.9	45.2	59.7	DEC		124	144.1	155.5	DEC		5.48
APR		391	430.9	433.2	JAN		415	456.7	458.1	JAN		16.5
MAY		568	621.0	617.2	FEB		272	303.1	309.4	FEB		68.3
JUN		30.2	43.3	57.9	MAR		2195	2368.7	2309.3	MAR		205
JUL		16.6	28.7	43.8	APR		1068	1158.1	1137.2	APR		1113
AUG		13.7	25.6	40.8	MAY		561	613.5	610.0	MAY		918
SEP		12	23.8	39.0	JUN		23.4	36.0	50.9	JUN		330
OCT		12	23.8	39.0	JUL		25.8	38.6	53.4	JUL		27.8
NOV		31.5	44.7	59.3	AUG		25.1	37.8	52.6	AUG		20
DEC		12.3	24.1	39.3	SEP	1929	19.9	32.3	47.2	SEP		49.6
JAN		301	334.2	339.6	OCT		23	35.6	50.4	OCT	1937	30.6
FEB		266	296.6	303.2	NOV		10	21.6	36.9	NOV		7.6
MAR		943	1023.8	1007.2	DEC		41	54.9	69.2	DEC		8
APR		364	401.9	405.1	JAN		100	118.3	130.5	JAN		12.1
MAY		823	894.9	882.4	FEB		14.6	26.6	41.7	FEB		591
JUN		559	611.3	607.9	MAR		17.1	29.3	44.3	MAR		568
JUL		15.9	28.0	43.1	APR		11	22.7	38.0	APR		932
AUG		15	27.0	42.1	MAY		31.3	44.5	59.1	MAY		609
SEP		19.9	32.3	47.2	JUN		26.6	39.5	54.2	JUN		37.2
OCT		18.2	30.4	45.4	JUL		17.8	30.0	45.0	JUL		23.7
NOV		17.5	29.7	44.7	AUG		20	32.4	47.3	AUG		18.1
DEC		40.5	54.4	68.6	SEP	1930	4.65	15.9	31.4	SEP	1938	70.5
JAN		153	175.2	185.6	OCT		2.2	13.2	28.8	OCT		14.8
FEB		426	468.5	469.6	NOV		89	106.5	119.1	NOV		1068
MAR		469	514.7	514.3	DEC		2	13.0	28.6	DEC		175
APR		856	930.4	916.8	JAN		2.32	13.4	28.9	JAN		574
MAY		2670	2878.9	2803.3	FEB		102	120.5	132.6	FEB		857
JUN		1839	1986.3	1939.1	MAR		314	348.2	353.1	MAR		2499
JUL		105	123.7	135.7	APR		55.9	70.9	84.7	APR		4093
AUG		21.6	34.1	49.0	MAY		16.2	28.3	43.4	MAY		2315
SEP		31.4	44.6	59.2	JUN		14.3	26.2	41.4	JUN		233
OCT		34.6	48.1	62.5	JUL		12.5	24.3	39.5	JUL		26.5
NOV		174	197.8	207.5	AUG	1931	8.6	20.1	35.5	AUG		32.5
DEC		423	465.3	466.4	SEP		1.84	12.9	28.4	SEP	1939	161
JAN		258	288.0	294.8	OCT		2.5	13.6	29.1	OCT		468
FEB		322	356.8	361.4	NOV		3	14.1	29.6	NOV		497
MAR		618	674.7	669.2	DEC		3	14.1	29.6	DEC		203
APR		1324	1433.1	1403.5	JAN		7.19	18.6	34.0	JAN		372
MAY		1394	1508.3	1476.3	FEB		6.93	18.3	33.7	FEB		372
JUN		319	353.5	358.3	MAR		16.6	28.7	43.8	MAR		162
JUL		20.7	33.1	48.0	APR		13	24.8	40.0	APR		21.3
AUG		20.3	32.7	47.6	MAY		6.87	18.3	33.7	MAY		22.5
SEP		25.7	38.5	53.2	JUN		5.39	16.7	32.1	JUN		21.2
OCT		24.5	37.2	52.0	JUL	1932	4.37	15.6	31.1	JUL		22
NOV		24.2	36.9	51.7	AUG		3.06	14.2	29.7	AUG	1940	11.2
DEC		143	164.5	175.2	SEP		2	13.0	28.6	SEP		5.73
JAN		214	240.8	249.1	OCT		2.1	13.1	28.7	OCT		5
FEB		287	319.2	325.0	NOV		2.48	13.5	29.1	NOV		67.4
MAR		136	157.0	168.0	DEC		2.83	13.9	29.5	DEC		77.5
APR		21.1	33.5	48.5	JAN		70.8	86.9	100.2	JAN		792
MAY		21	33.4	48.4	FEB		441	484.6	485.2	FEB		1764
JUN		11.6	23.3	38.6	MAR		867	942.2	928.2	MAR		1424
JUL		10	21.6	36.9	APR		380	419.1	421.7	APR		263
AUG		6.61	18.0	33.4	MAY		15.4	27.4	42.5	MAY		25.9
SEP		10.7	22.4	37.6	JUN	1933	15.5	27.5	42.6	JUN		24.6
OCT		11.6	23.3	38.6	JUL		8.4	19.9	35.3	JUL		24
NOV		10.7	22.4	37.6	AUG		4.65	15.9	31.4	AUG	1941	43.1
DEC		12.3	24.1	39.3	SEP		4	15.2	30.7	SEP		356
JAN		10.5	22.2	37.4	OCT		4	15.2	30.7	OCT		602
FEB		327	362.1	366.6	NOV		4	15.2	30.7	NOV		515
MAR		105	123.7	135.7	DEC		4.21	15.4	30.9	DEC		363
APR		374	412.6	415.5	JAN		5.84	17.2	32.6	JAN		13.5
MAY		647	705.9	699.4	FEB		9.97	21.6	36.9	FEB		29.1
JUN		25.6	38.4	53.1	MAR		98.1	116.3	128.5	MAR		599
JUL		21.5	34.0	48.9	APR		216	242.9	251.2	APR		402
AUG		21	33.4	48.4	MAY		12.5	24.3	39.5	MAY		27.7
SEP		21	33.4	48.4	JUN		8.48	20.0	35.3	JUN		27.6
					JUL		8.93	20.5	35.8	JUL		20.6
					AUG					AUG		21.7
					SEP					SEP		151
										OCT	1942	736
										NOV		173.1
										DEC		801.5
												792.0

	Derby	Wadsworth	Nixon			Derby	Wadsworth	Nixon			Derby	Wadsworth	Nixon
JAN	860	934.7	920.9	SEP	1951	6.4	17.8	33.2	APR	1960	7.1	18.5	21.0
FEB	1257	1361.1	1333.8	OCT		11.4	23.1	38.4	MAY		22.2	34.7	26.3
MAR	697	759.6	751.4	NOV		1572	1699.5	1661.4	JUN		19.8	32.2	19.0
APR	1484	1605.0	1569.9	DEC		3224	3474.0	3379.5	JUL		24.6	37.3	20.8
MAY	1451	1569.5	1535.6	JAN		1803	1947.6	1901.6	AUG		25.1	37.8	25.5
JUN	2250	2427.8	2366.5	FEB	1123	1217.2	1194.4	SEP	17.3	29.5	29.9		
JUL	210	236.5	244.9	MAR	633	690.8	684.8	OCT	4.64	15.9	23.5		
AUG	28.7	41.7	56.4	APR	154	176.3	186.7	NOV	4.72	16.0	24.2		
SEP	38.4	52.1	66.5	MAY	127	147.3	158.6	DEC	4.73	16.0	25.5		
OCT	17.1	29.3	44.3	JUN	61	76.4	90.0	JAN	3.09	14.2	26.7		
NOV	110	129.0	140.9	JUL	14	25.9	41.1	FEB	62.4	77.9	79.6		
DEC	449	493.2	493.5	AUG	14	25.9	41.1	MAR	18.7	31.0	41.0		
JAN	1472	1592.1	1557.4	SEP	12.3	24.1	39.3	APR	18.7	31.0	33.2		
FEB	2624	2829.5	2755.5	OCT	1952	9.74	21.3	36.6	MAY	32.3	45.6	65.5	
MAR	2246	2423.5	2362.4	NOV		2	13.0	28.6	JUN	11.4	23.1	14.8	
APR	2860	3083.0	3000.9	DEC		2	13.0	28.6	JUL	26.5	39.4	20.2	
MAY	1368	1480.3	1449.2	JAN		851	925.0	911.6	AUG	31.8	45.0	31.3	
JUN	509	557.6	555.9	FEB		2013	2173.2	2120.0	SEP	21.3	33.8	35.2	
JUL	47.8	62.2	76.2	MAR	1784	1927.2	1881.9	OCT	6.98	18.4	27.9		
AUG	42	56.0	70.2	APR	3395	3657.7	3557.3	NOV	3.7	14.9	29.0		
SEP	43.8	57.9	72.1	MAY	4587	4938.1	4797.0	DEC	4.9	16.1	29.0		
OCT	173	196.7	206.4	JUN	2552	2752.2	2680.6	JAN	0.75	11.7	22.5		
NOV	149	170.9	181.5	JUL	330	365.4	369.7	FEB	1.22	12.2	24.2		
DEC	48.9	63.4	77.4	AUG	15	27.0	42.1	MAR	1.67	12.7	22.4		
JAN	47.5	61.9	75.9	SEP	43	57.1	71.2	APR	9.51	21.1	19.8		
FEB	40.4	54.3	68.5	OCT	1953	15	27.0	42.1	MAY	17.4	29.6	27.2	
MAR	462	507.2	507.0	NOV		15	27.0	42.1	JUN	18.8	31.1	23.6	
APR	175	198.9	208.5	DEC		278	309.5	315.6	JUL	18.5	30.8	16.6	
MAY	112	131.2	143.0	JAN		685	746.7	738.9	AUG	25	37.7	36.0	
JUN	33.5	46.9	61.4	FEB		791	860.6	849.2	SEP	14.2	26.1	24.2	
JUL	30.2	43.3	57.9	MAR	50.4	65.0	78.9	OCT	1.46	12.5	16.1		
AUG	20.8	33.2	48.2	APR	264	294.5	301.1	NOV	0.15	11.0	19.2		
SEP	17.4	29.6	44.6	MAY	877	952.9	938.6	DEC	0.22	11.1	18.2		
OCT	3.03	14.1	29.7	JUN	1671	1805.8	1764.4	JAN	0.24	11.1	18.5		
NOV	39.6	53.4	67.7	JUL	286	318.1	324.0	FEB	26.2	39.0	48.4		
DEC	8.26	19.8	35.1	AUG	15	27.0	42.1	MAR	0.57	11.5	24.7		
JAN	3	14.1	29.6	SEP	15	27.0	42.1	APR	279	310.6	315.0		
FEB	167	190.3	200.2	OCT	1954	15	27.0	42.1	MAY	187	211.8	229.0	
MAR	80.5	97.4	110.2	NOV		15	27.0	42.1	JUN	23.6	36.2	31.3	
APR	409	450.2	451.9	DEC		15	27.0	42.1	JUL	21	33.4	18.8	
MAY	1168	1265.5	1241.2	JAN		5	16.3	31.7	AUG	22	34.5	16.4	
JUN	291	323.5	329.2	FEB		5	16.3	31.7	SEP	20.2	32.6	26.7	
JUL	26.8	39.7	54.4	MAR	205	231.1	239.7	OCT	1963	251	280.5	228.0	
AUG	21.7	34.2	49.1	APR	213	239.7	248.0	NOV		2.78	13.9	34.1	
SEP	14.1	26.0	41.2	MAY	236	264.4	272.0	DEC		6.63	18.0	40.7	
OCT	34.3	47.7	62.2	JUN	12	23.8	39.0	JAN		143	164.5	69.1	
NOV	87.9	105.3	117.9	JUL	12	23.8	39.0	FEB		2327	2510.5	2316.0	
DEC	365	403.0	406.1	AUG	12	23.8	39.0	MAR	82.3	99.3	146.0		
JAN	357	394.4	397.8	SEP	12	23.8	39.0	APR	155	177.4	183.0		
FEB	493	540.5	539.2	OCT	1955	9.81	21.4	36.7	MAY	1414	1529.8	1391.0	
MAR	287	319.2	325.0	NOV		6	17.3	32.8	JUN	812	883.1	926.0	
APR	930	1009.9	993.7	DEC		5.32	16.6	32.1	JUL	27.3	40.2	53.7	
MAY	727	791.8	782.6	JAN		5	16.3	31.7	AUG	26.2	39.0	35.0	
JUN	72.1	88.3	101.5	FEB		5	16.3	31.7	SEP	25.5	38.3	42.3	
JUL	24.3	37.0	51.8	MAR	5	16.3	31.7	OCT	1964	24.2	36.9	42.8	
AUG	21.7	34.2	49.1	APR	11.2	22.9	38.2	NOV		41.4	55.4	62.8	
SEP	17.3	29.5	44.5	MAY	18.3	30.5	45.6	DEC		9.36	20.9	36.3	
OCT	7.55	19.0	34.4	JUN	25.5	38.3	53.0	JAN		4.33	15.5	31.4	
NOV	25.7	38.5	53.2	JUL	23.3	35.9	50.8	FEB		2.42	13.5	26.5	
DEC	260	290.2	296.9	AUG	21.7	34.2	49.1	MAR	1.85	12.9	207.0		
JAN	340	376.1	380.1	SEP	17.3	29.5	44.5	APR	39.6	53.4	53.4		
FEB	91.9	109.6	122.1	OCT	1956	4.26	15.5	31.0	MAY	83.5	100.6	93.2	
MAR	2.65	13.7	29.3	NOV		0.13	11.0	26.7	JUN	27.5	40.4	48.3	
APR	7.77	19.2	34.6	DEC		1058	1147.4	1126.8	JUL	30	43.1	26.2	
MAY	44.4	58.6	72.7	JAN		853	927.2	913.6	AUG	21.4	33.9	34.4	
JUN	18.1	30.3	45.3	FEB		964	1046.4	1029.1	SEP	18.2	30.4	30.4	
JUL	15	27.0	42.1	MAR	1048	1136.6	1116.4	OCT	1965	15.9	28.0	32.4	
AUG	15	27.0	42.1	APR	1256	1360.0	1332.8	NOV		11.5	23.2	34.2	
SEP	14.9	26.9	42.0	MAY	1713	1850.9	1808.0	DEC		1646	1779.0	1547.0	
OCT	4.71	15.9	31.4	JUN	1624	1755.3	1715.5	JAN		1140	1235.4	1191.0	
NOV	1	12.0	27.6	JUL	36	49.6	64.0	FEB		934	1014.2	999.0	
DEC	1	12.0	27.6	AUG	14	25.9	41.1	MAR	493	540.5	573.0		
JAN	2	13.0	28.6	SEP	9.53	21.1	36.4	APR	492	539.4	580.0		
FEB	2	13.0	28.6	OCT	1957	13.7	25.6	40.8	MAY	1279	1296.0	1325.0	
MAR	2	13.0	28.6	NOV		12.6	24.4	39.6	JUN	505	503.0	515.0	
APR	21.7	34.2	49.1	DEC		12.7	24.5	39.7	JUL	47.5	53.3	62.2	
MAY	54.6	69.5	83.3	JAN		11.4	23.1	38.4	AUG	240	314.0	316.0	
JUN	192	217.1	226.2	FEB		113	132.3	144.0	SEP	39.2	47.8	67.0	
JUL	16	28.1	43.2	MAR	551	602.8	599.6	OCT	1966	28.4	48.0	60.4	
AUG	16	28.1	43.2	APR	25.7	38.5	53.2	NOV		274	346.0	290.0	
SEP	16	28.1	43.2	MAY	260	290.2	296.9	DEC		652	710.0	737.0	
OCT	4.32	15.5	31.0	JUN	581	635.0	630.8	JAN		558	567.0	591.0	
NOV	1	12.0	27.6	JUL	16.8	28.9	44.0	FEB		363	356.0	361.0	
DEC	7.48	18.9	34.3	AUG	15.1	27.1	42.2	MAR	87.1	172.0	211.0		
JAN	2	13.0	28.6	SEP	27.8	40.7	55.4	APR	29.9	36.7	64.6		
FEB	2	13.0	28.6	OCT	1958	8.82724	20.4	35.7	MAY	46.6	46.4	61.4	
MAR	2	13.0	28.6	NOV		12.3	24.1	38.9	JUN	25.1	26.9	47.0	
APR	9.07	20.6	36.0	DEC		22.5	35.1	52.3	JUL	27.6	22.3	33.2	
MAY	76.4	93.0	106.0	JAN		12	23.8	33.2	AUG	28.6	31.1	37.5	
JUN	13	24.8	40.0	FEB		119	138.7	125.0	SEP	28.5	35.0	49.0	
JUL	14	25.9	41.1	MAR	23.4	36.0	74.7	OCT	1967	21.9	37.0	41.5	
AUG	14	25.9	41.1	APR	2427	2617.9	2605.0	NOV		23.9	35.6	49.8	
SEP	11	22.7	38.0	MAY	3305	3561.0	4289.0	DEC		23	37.4	58.9	
OCT	5.48	16.8	32.2	JUN	1132	1226.8	1168.0	JAN		144	196.0	157.0	
NOV	2	13.0	28.6	JUL	15	27.0	47.2	FEB		35.8	56.3	79.4	
DEC	2	13.0	28.6	AUG	80.2696	97.1	110.0	MAR	1074	12			

	Derby	Wadsworth	Nixon		Derby	Wadsworth	Nixon		Derby	Wadsworth	Nixon
DEC	442	446.0	453.0	AUG	256	263.0	281.0	APR	774	838.0	744.0
JAN	452	509.0	537.0	SEP	220	201.0	232.0	MAY	997	1073.0	981.0
FEB	803	916.0	902.0	OCT	155	152.0	183.0	JUN	132	139.0	154.0
MAR	289	834.0	836.0	NOV	61.2	74.4	103.0	JUL	38.9	37.5	47.6
APR	124	225.0	231.0	DEC	63.5	65.9	84.4	AUG	28.3	32.1	37.8
MAY	41.6	52.4	67.9	JAN	67	71.0	84.2	SEP	57.1	64.7	74.1
JUN	37.5	38.6	52.4	FEB	62.5	69.5	83.4	OCT	49.8	42.0	71.5
JUL	33.5	28.6	38.8	MAR	29.5	33.1	47.0	NOV	103	112.0	135.0
AUG	51.5	61.0	70.0	APR	41.9	43.2	51.3	DEC	452	444.0	489.0
SEP	38.3	51.8	68.8	MAY	37.2	45.7	58.0	JAN	391	441.0	458.0
OCT	21.9	30.2	46.6	JUN	18.4	27.8	33.3	FEB	3340	3481.0	3311.0
NOV	13.8	35.4	43.3	JUL	29.1	26.3	26.9	MAR	4054	4979.0	4764.0
DEC	8.59	164.0	170.0	AUG	23.2	29.8	30.8	APR	2552	3150.0	2901.0
JAN	928	1419.0	1287.0	SEP	17.8	25.4	27.0	MAY	2055	2484.0	2424.0
FEB	1456	1799.0	1631.0	OCT	3.3	14.4	21.3	JUN	1041	1265.0	1236.0
MAR	2065	2428.0	2198.0	NOV	6.19	23.9	29.6	JUL	218	262.0	258.0
APR	3368	3595.0	3392.0	DEC	38.8	59.0	69.7	AUG	108	150.0	171.0
MAY	3715	3643.0	3454.0	JAN	44.8	61.5	69.0	SEP	120	140.0	158.0
JUN	3652	3538.0	3469.0	FEB	18.5	39.7	43.3	OCT	312	346.0	328.0
JUL	368	413.0	430.0	MAR	94.7	171.0	167.0	NOV	201	226.8	228.0
AUG	35	26.5	45.7	APR	137	155.0	164.0	DEC	65.8	81.6	89.0
SEP	30.8	38.0	54.0	MAY	846	911.0	876.0	JAN	77.2	93.8	98.4
OCT	14.9	32.0	47.2	JUN	95	100.0	112.0	FEB	94.7	112.6	112.0
NOV	3.53	21.9	36.6	JUL	36.5	25.5	44.7	MAR	207	233.2	213.0
DEC	337	336.0	345.0	AUG	34.5	18.8	37.0	APR	546	597.4	577.0
JAN	1955	2223.0	2087.0	SEP	45.2	32.3	52.5	MAY	923	1002.3	972.0
FEB	2186	2253.0	2293.0	OCT	40.2	35.3	51.8	JUN	213	239.7	222.0
MAR	1461	1464.0	1471.0	NOV	35.1	39.9	53.8	JUL	39.6	53.4	49.5
APR	411	482.0	530.0	DEC	12.6	30.0	42.4	AUG	26.1	38.9	30.5
MAY	150	169.0	212.0	JAN	148	173.0	174.0	SEP	28.3	41.3	37.0
JUN	246	271.0	291.0	FEB	233	273.0	251.0	OCT	25.3	38.1	47.9
JUL	384	435.0	445.0	MAR	26.4	26.3	30.7	NOV	23.8	36.5	48.1
AUG	39.6	77.2	89.1	APR	40.5	34.5	55.2	DEC	22.1	34.6	45.2
SEP	48.3	61.9	76.3	MAY	542	563.0	532.0	JAN	19.4	31.7	41.2
OCT	89.4	100.0	124.0	JUN	70.6	58.2	70.2	FEB	15.3	27.3	38.1
NOV	40.1	62.3	79.0	JUL	47.4	40.0	45.5	MAR	15.6	27.6	35.7
DEC	485	547.0	570.0	AUG	44.7	36.5	40.0	APR	30.9	44.1	41.0
JAN	991	954.0	969.0	SEP	55.9	17.3	43.2	MAY	40	53.9	49.3
FEB	924	902.0	929.0	OCT	93.6	75.3	90.2	JUN	28.1	41.1	39.2
MAR	852	839.0	864.0	NOV	30.1	36.1	59.3	JUL	26.7	39.6	25.7
APR	701	742.0	770.0	DEC	18.5	20.2	38.7	AUG	32.2	45.5	34.8
MAY	1204	1251.0	1234.0	JAN	1209	1154.0	1170.0	SEP	23.9	36.6	30.5
JUN	1736	1712.0	1744.0	FEB	890	806.0	884.0	OCT	14	25.9	29.7
JUL	423	432.0	451.0	MAR	587	544.0	604.0	NOV	35.4	48.9	57.4
AUG	209	224.0	239.0	APR	758	783.0	785.0	DEC	15.8	27.9	41.6
SEP	528	531.0	502.0	MAY	1597	1715.0	1689.0	JAN	17.8	30.0	38.7
OCT	647	665.0	662.0	JUN	918	978.0	1002.0	FEB	201	226.8	212.0
NOV	96.9	112.0	142.0	JUL	174	184.0	198.0	MAR	185	209.6	193.0
DEC	323	344.0	330.0	AUG	69.4	71.3	74.1	APR	66.8	82.6	118.0
JAN	529	551.0	538.0	SEP	76	75.6	84.7	MAY	49.8	64.4	61.9
FEB	526	554.0	563.0	OCT	176	160.0	181.0	JUN	36.5	50.1	37.4
MAR	681	709.0	744.0	NOV	211	229.0	259.0	JUL	41.8	55.8	47.0
APR	206	241.0	236.0	DEC	29.7	65.5	80.6	AUG	33.1	46.4	42.3
MAY	224	256.0	249.0	JAN	280	291.0	298.0	SEP	55.7	70.7	71.1
JUN	79.1	102.0	110.0	FEB	368	378.0	403.0	OCT	34	47.4	49.4
JUL	33.6	37.5	43.3	MAR	13.9	27.0	41.6	NOV	31.1	44.3	45.7
AUG	111	117.0	119.0	APR	137	128.0	140.0	DEC	24	36.7	41.6
SEP	33.6	44.5	60.3	MAY	959	1038.0	1012.0	JAN	19.4	31.7	35.8
OCT	32.3	46.0	64.5	JUN	103	112.0	126.0	FEB	13.7	25.6	33.2
NOV	104	122.0	128.0	JUL	32.2	32.4	33.1	MAR	62.8	78.3	64.7
DEC	526	532.0	579.0	AUG	26	29.3	29.5	APR	52.5	67.3	59.1
JAN	500	504.0	534.0	SEP	42.2	45.3	44.7	MAY	26.8	39.7	21.7
FEB	549	550.0	574.0	OCT	32	64.2	63.7	JUN	35	48.5	32.8
MAR	625	637.0	645.0	NOV	664	677.0	631.0	JUL	31.6	44.8	29.4
APR	733	835.0	854.0	DEC	1026	1056.0	1019.0	AUG	12.3	24.1	21.4
MAY	954	995.0	991.0	JAN	567	585.0	627.0	SEP	5.97	17.3	19.9
JUN	408	419.0	453.0	FEB	1673	1641.0	1696.0	OCT	4.34	15.5	21.2
JUL	322	310.0	321.0	MAR	997	1116.0	1115.0	NOV	5.07	16.3	21.7
AUG	332	311.0	332.0	APR	2183	2618.0	2480.0	DEC	7.51	19.0	28.7
SEP	338	341.0	346.0	MAY	3678	4164.0	4049.0	JAN	4.56	15.8	20.8
OCT	142	162.0	169.0	JUN	2254	2380.0	2565.0	FEB	21.6	34.1	38.6
NOV	295	329.0	328.0	JUL	515	565.0	600.0	MAR	41.8	55.8	47.6
DEC	491	561.0	525.0	AUG	65.1	68.2	72.9	APR	26.1	38.9	26.3
JAN	1195	1319.0	1296.0	SEP	346	427.0	436.0	MAY	35.5	49.0	21.9
FEB	704	769.0	805.0	OCT	776	905.0	917.0	JUN	26.5	39.4	27.3
MAR	1422	1558.0	1518.0	NOV	1827	2162.0	2164.0	AUG	9.61	21.2	19.7
APR	1843	2093.0	2034.0	DEC	2600	2661.0	2694.0	SEP	13.9	25.8	18.3
MAY	1822	1920.0	1875.0	JAN	1569	1715.0	1635.0	OCT	10.5	22.2	27.8
JUN	1196	1215.0	1247.0	FEB	2495	2817.0	2704.0	NOV	9.31	20.9	28.3
JUL	838	871.0	862.0	MAR	3541	3730.0	3639.0	DEC	8.63	20.2	26.4
AUG	386	398.0	409.0	APR	3219	3364.0	3380.0	JAN	7.75	19.2	24.3
SEP	290	304.0	328.0	MAY	3835	4113.0	4066.0	FEB	9	20.6	29.4
OCT	281	296.0	316.0	JUN	5099	5882.0	5398.0	MAR	26.2	39.0	39.8
NOV	320	344.0	354.0	JUL	2478	2776.0	2786.0	APR	24.5	37.2	21.9
DEC	147	156.0	179.0	AUG	710	857.0	816.0	MAY	17.7	29.9	20.8
JAN	223	267.0	291.0	SEP	1071	1218.0	1172.0	JUN	24.5	37.2	15.2
FEB	177	174.0	212.0	OCT	162	452.0	424.0	JUL	24.9	37.6	19.5
MAR	620	674.0	649.0	NOV	2629	2786.0	2659.0	AUG	18.9	31.2	17.5
APR	759	894.0	878.0	DEC	3722	3965.0	3905.0	SEP	6.97	18.4	22.8
MAY	2471	2609.0	2575.0	JAN	3205	3452.0	3430.0	OCT	2.47	13.5	18.0
JUN	1706	1820.0	1847.0	FEB	1811	2095.0	2067.0	NOV	24.1	36.8	42.4
JUL	753	786.0	760.0	MAR	1385	1613.0	1559.0	DEC	6	17.3	28.3
AUG	716	739.0	696.0	APR	969	1116.0	1106.0	JAN	381	420.1	382.0
SEP	395	462.0	436.0	MAY	1436	1608.0	1539.0	APR	624	681.2	649.0
OCT	191	209.0	225.0	JUN	1139	1277.0	1289.0	MAY	1223	1324.6	1276.0
NOV	392	463.0	463.0	JUL	166	276.0	279.0	JUN	998	1082.9	1075.0
DEC	547	518.0	546.0	AUG	43.7	85.8	98.6	JUL	248	277.3	292.0
JAN	463	490.0	535.0	SEP	55.5	140.0	148.0	AUG	94.3	112.2	99.7
FEB	450	493.0	533.0	OCT	129	395.0	403.0	SEP	72.3	88.5	79.8
MAR	439	578.0	596.0	NOV	417	634.0	573.0	OCT	40.3	59.3	106.0
APR	292	313.0	317.0	DEC	541	549.0	567.0	NOV	8.81	17.6	35.0
MAY	365	393.0	358.0	JAN	330	337.0	356.0				
JUN	214	211.0	220.0	FEB	142	162.0	173.0				
JUL	255	256.0	259.0	MAR	174	211.0	184.0				

	Derby	Wadsworth	Nixon
DEC	5.74	11.5	23.1
JAN	4.82	9.0	20.4
FEB	7.19	9.4	20.5
MAR	79.9	82.2	90.3
APR	608	604.0	598.0
MAY	1067	1114.0	1044.0
JUN	291	348.0	334.0
JUL	22.7	23.2	23.8
AUG	33.9	16.8	22.5
SEP	13.7	6.8	16.3
OCT	0.9	1.7	15.2
NOV	11.2	19.2	27.7
DEC	2.11	9.6	23.0
JAN	147	165.0	174.0
FEB	6.14	14.6	32.5
MAR	1131	1201.0	1187.0
APR	1004	1154.0	1040.0
MAY	2239	2488.0	2446.0
JUN	2092	2244.0	2332.0
JUL	1418	1477.0	1536.0
AUG	525	577.0	633.0
SEP	201	234.0	280.0
OCT	182	295.0	314.0
NOV	181	269.0	277.0
DEC	420	419.0	436.0
JAN	374	388.0	398.0
FEB	1766	1701.0	1725.0
MAR	1859	1828.0	1850.0
APR	2089	2175.0	2138.0
MAY	3283	3422.0	3642.0
JUN	1740	1718.0	1789.0
JUL	635	685.0	760.0
AUG	98.6	262.0	296.0
SEP	310	409.0	433.0
OCT	242	373.0	406.0
NOV	480	555.0	550.0
DEC	1851	1999.2	2124.0
JAN	6493	7231.0	6160.0
FEB	3682	3720.0	3960.0
MAR	2512	2512.0	2620.0
APR	1675	1776.0	1785.0
MAY	1544	1605.0	1665.0
JUN	1152	1199.0	1305.0
JUL	304	302.0	397.0
AUG	247	295.0	297.0
SEP	322	356.8	366.0

TRUCKEE RIVER FLOWS Regression Results

Derby-Wadsworth

Regression Output:

Constant	10.885
Std Err of Y Est	99.9188
R	0.99142
Squared	
No. of Observations	303
Degrees of Freedom	301
X Coefficient(s)	1.07417
Std Err of Coef.	0.00576

Derby- Nixon

Regression Output:

Constant	26.5197
Std Err of Y Est	85.6996
R	0.99131
Squared	
No. of Observations	477
Degrees of Freedom	475
X Coefficient(s)	1.04
Std Err of Coef.	0.00447

Wadsworth-Nixon Lower correlation

Regression Output:

Constant	30.0106
Std Err of Y Est	71.2396
R	0.99525
Squared	
No. of Observations	303
Degrees of Freedom	301
X Coefficient(s)	0.95571
Std Err of Coef.	0.00381

distributed. Using log-probability plots of selected data points to test this concept yielded graphs with one approximately linear trend for flows above ~50 cfs, and another with a much flatter slope for flows below that value (Figure C.1). Analogous results were obtained using only the low-ET months of November and December, but on those plots the change from shallow to steep slope took place at ~40 cfs. Because a lognormal distribution would have produced a single straight line, it is possible that Truckee River flows are best represented by some other statistical distribution. Alternatively, different processes, each giving rise to approximately lognormal flow distributions, may govern flows above and below ~40 to ~50 cfs. Whether the flow distributions derive from natural processes or from the impact of human activities such as diversions and reservoir storage is not a subject of the present investigation.

Although flows in the lower Truckee overall are not lognormally distributed, two linear segments are present on the log-probability plot, one of which describes low-flow, low ET conditions. Because the present study addresses base flow conditions, the median, rather than the mean, was therefore considered to be more advantageous in mass balance calculations since it eliminates the influence of anomalously high values when determining solute fluxes. A still more accurate result might be obtained using an alternative method described in Anderson and Meerschaert (1998), which evaluates river flows in terms of heavy-tailed rather than normal or lognormal statistical distributions. However, use of that technique is beyond the scope of the present study, so calculations were performed using median flows.

C.2 Mass Balance Expressions

Average concentrations for each major ion and TDS were determined for each station from data supplied by the Nevada Department of Environmental Protection (NDEP, 1997). These data have been acquired from a monitoring program instituted in 1980, and were combined with those presented in Bratberg (1980) for the period 1973-1980. Water quality is assessed near each flow measurement station, except Derby, for which samples are obtained at Tracy, approximately three miles upstream. However, since solute concentrations change little between Tracy and Wadsworth, there is minimal recharge along that reach, and the river flows swiftly, the Tracy data are considered applicable to Derby.

The flux of solute at a given station must equal that at the preceding station plus inputs or minus outputs between the stations:

$$[1] \quad Q_n C_n = Q_w C_w + Q_i C_i$$

where Q_n , C_n , Q_w , and C_w are respectively the flows and concentrations at Nixon and Wadsworth, while C_i and Q_i represent all concentrations and flows gained or lost between the two. From [3]:

$$[2] \quad C_i = \frac{Q_n C_n - Q_w C_w}{Q_i}$$

Input concentrations between Wadsworth and Nixon therefore can be calculated provided the solute fluxes are known at the stations and the input flows are known. Since

$$[3] \quad Q_n = Q_w - Q_i$$

Log-Probability Plot of Selected Truckee River Flows at Nixon Gage

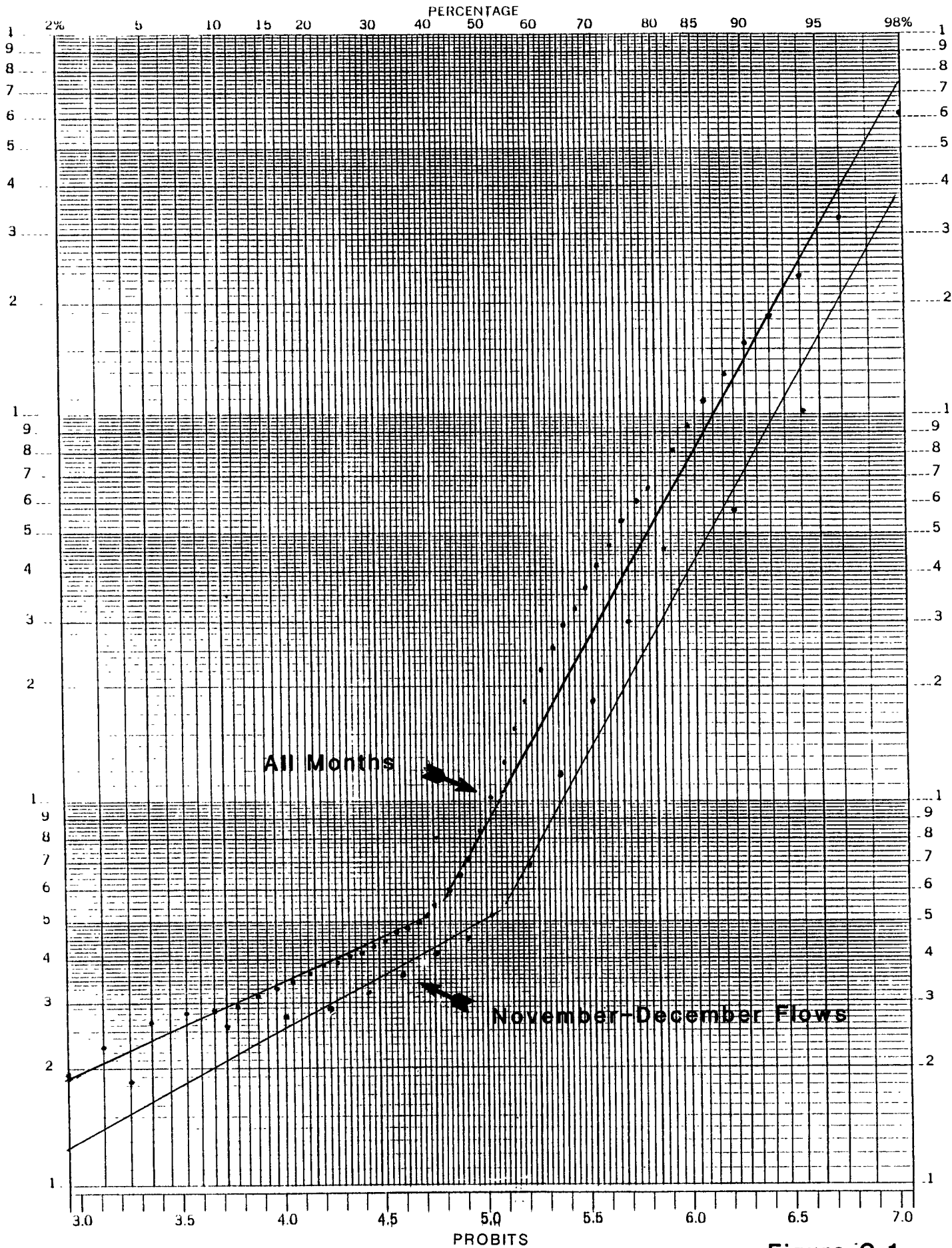


Figure C.1

water inputs between Wadsworth and Nixon (Q_{n-w}) can be determined by difference from the flows measured at those points:

$$[4] \quad Q_n - Q_w = Q_i \equiv Q_{n-w}$$

C.3 Alternative Determination of Truckee River Flows

Using the median Truckee River flows for winter months in mass balance calculations produced estimates of solute gains comparable to those of Bratberg (1980). In addition, a process-based alternative method was attempted that used the cumulative averages of flows between Wadsworth and Nixon (Appendix D). This method, though novel, produced results similar to Bratberg (1980) for both groundwater inflow and evapotranspiration (ET) along the lower Truckee corridor. Regressed monthly average flows at Wadsworth and Nixon and their difference were sorted in ascending order based on the Nixon flows. When the difference was plotted against Nixon flows, the graphs were highly irregular, so moving averages encompassing successively larger sample groups were taken to smooth the data set. The difference of the moving averages (Δ_{N-W}), was then plotted against the moving averages for the Nixon flows. As the groups became larger, the moving average graphs took on the same characteristics as cumulative averages. Plots incorporating cumulative averages were therefore selected for analysis.

Changes in the processes operating on the lower Truckee river system are indicated by changes in slope on the plots. Once the processes are identified, it is suggested that their magnitude can be determined from the plots. In the analysis, it first was assumed that groundwater input was approximately constant from month to month, and that the only other processes affecting Δ_{N-W} were ET and flows at Wadsworth. Agricultural diversions along the Wadsworth-Nixon reach exist, but are relatively minor (Bratberg, 1980). Examination of the graphs suggested the existence of an additional process that depended on the flow volume; this was eventually identified as overbank storage within the floodplain of the river. Because these three major processes – subsurface inputs, ET, and this third process – may have operated concurrently in any particular month, the next step in the analysis required identifying those months when one or more of the processes were inactive.

Flows on the Truckee often are low from late summer through early winter, minimizing the influence of a flow-dependent process. Additionally, both evaporation and transpiration are minimum during the winter months, and agricultural diversions are minimal. November and December were therefore selected as months when baseflow conditions most frequently were encountered, i.e., when the sole inputs to the Wadsworth-Nixon reach were from groundwater. Nixon flows and Δ_{N-W} for November and December were extracted from the regressed data set, and a plot of cumulative averages made.

Examination of the low-flow portion of the plot suggested ~15 cfs (~10,800 af/y) of groundwater input to the Wadsworth-Nixon reach of the lower Truckee, similar to, though lower than, Bratberg's estimate of ~16 cfs (~11,600 af/y). At higher flows, the flow-dependent third process actively diminishes Δ_{N-W} until extremely high flows are reached. Since agricultural diversions were not active, this loss was attributable to a hydrologic mechanism, for which the most plausible candidates are overbank surface storage and phreatic aquifer storage induced by a rise in the water table adjoining the river. Order of magnitude calculations indicate that aquifer storage is insufficiently rapid to acquire and discharge the necessary water volumes in the appropriate timeframes, but that overbank storage plausibly could do so (Appendix D).

C.4 Mass Balance Results

Bratberg (1980) based his inflow estimate of ~16 cfs (~14,000 af/y) on hydraulic properties calculated from Fernley-Wadsworth area well tests coupled with drought flow conditions on the Truckee River, which he assumed to represent baseflow. The present study dealt with median flows and with cumulative averages derived from low-flow months, and arrived at a figure of ~15 cfs (~10,800 af/y). This value is consistent with solute fluxes along the lower Truckee. Table C.3 summarizes major ion concentrations and fluxes in the river for the Derby-Wadsworth and the Wadsworth-Nixon reaches. Fluxes and flux differences were calculated from [3] through [6], based on both median (14.9 cfs) and average (~1.9 cfs) flows for the months of November and December.

Table C.4 incorporates these solute fluxes and shows estimated groundwater solute concentrations under various input scenarios. These scenarios include flow gains based upon: (1) median flows; (2) mean flows; (3) Bratberg's (1980) inflow estimates; and (4) the assumption that all gains equal only recharge from the Pah Rah Range.

The table also lists: the average groundwater composition on Dodge Flat below the toe of the Olinghouse fan, Bratberg's (1980) average Fernley well water, and Bratberg's (1980) calculated subsurface inputs between Derby and Wadsworth, Derby and the S-S Ranch, and Wadsworth and the S-S Ranch (Table C.4 (b)). Also included is an estimate of composition for groundwater entering the Truckee from all of Dodge Flat; this derives from a weighted average of Bratberg's (1980) concentration estimates for the Wadsworth to S-S and the S-S to Nixon reaches. Note that all groundwater inflow estimates are considerably greater than recharge to Dodge Flat from the Pah Rah Range, which illustrates the significance of Fernley-Wadsworth area groundwater and possible sources east of the river to the lower Truckee system. For comparison, required groundwater input volumes are calculated based on Bratberg's (1980) solute concentration estimates (Table C.4 (c)).

Examination of Table C.4 (a), indicates that the closest approximation to the Dodge Flat groundwater composition and the average from Fernley area wells is that calculated from median flows during winter months (14.9 cfs = 10,800 af/y). Though somewhat higher than from fluxes based on Bratberg's (1980) flows, these estimates conform generally. Major ion compositions, however, suggest that flow from Dodge Flat to the river results in considerable relative Cl^- increases, some Mg^{++} and CO_3^- gains, and loss of SO_4^- and Na^+ . In all scenarios, B is anomalously low. This pattern is compatible with dissolution of halite (and B) from sediments, exchange of Na^+ for Mg^{++} and Ca^{++} , and simultaneous precipitation of gypsum or possibly the biogenic reduction of SO_4^- . A similar process without gypsum precipitation might explain Fernley flow system groundwater chemistry. However, gypsum is slightly undersaturated in the Olinghouse fan groundwater samples (see Section 8.1); but its presence within Lahontan age sediments near the S-S ranch suggests that this might not be the case elsewhere on Dodge Flat. Also, along a recharge flowline groundwater must first lose Ca^{++} and gain Na^+ on the Olinghouse fan, then lose that Na^+ (and SO_4^-) while gaining Mg^{++} and possibly Ca^{++} along its path to the river.

C.5 Evapotranspiration

In addition to providing inflow estimates, interpretation of the cumulative average flow graphs of Appendix D suggested ET losses along the lower river of between ~4 and ~5 cfs (~2900-3600 af/y). However, that portion of analysis incorporated all low-flow months, winter or summer, and, thus, implicitly assumed that ET is an important process whenever Nixon flows are relatively low. Some of those flows occurred during winter, when ET was at a minimum, and so a similar approach was attempted using only cumulative averages from months other than November and December. Analysis of these graphs assumed ~15 cfs total groundwater inflow, and suggested an ET of ~11 to ~14 cfs. This compares favorably to the ~13 cfs obtained from the phreatophyte use and cropland acreages of Van Denburgh, *et al.* (1973).

TABLE C. 3
CONCENTRATIONS, FLOWS, AND FLUXES
IN THE LOWER TRUCKEE RIVER

a) Concentrations (ppm), MEDIAN flows (cfs), and solute fluxes in the Truckee River for the months of November and December.

<i>Ion</i>	Tracy Median			Wadsworth Median			Nixon Median		
	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>
Ca	19.4	24.1	467.5	22.5	37.1	834.8	29.9	52.0	1554.8
Mg	6.7	24.1	161.5	8.4	37.1	311.6	11.7	52.0	608.4
Na	25.2	24.1	607.3	29.8	37.1	1105.6	55	52.0	2860.0
HCO ₃	101.2	24.1	2438.9	111.3	37.1	4129.2	119.2	52.0	6198.4
CO ₃	0.4	24.1	9.6	0.3	37.1	11.1	6.7	52.0	348.4
Cl	17.9	24.1	431.4	18.3	37.1	678.9	74.4	52.0	3868.8
SO ₄	23.8	24.1	573.6	29.9	37.1	1109.3	73	52.0	3796.0
B	0.286	24.1	6.9	0.3	37.1	11.4	0.31	52.0	16.1
TDS	167.2	24.1	4029.5	177.5	37.1	6585.3	358.5	52.0	18642.0

b) Flow and flux differences and calculated groundwater input concentrations to the Truckee based upon MEDIAN flows.

<i>Ion</i>	Tracy - Wadsworth Reach			Wadsworth-Nixon Reach		
	<i>Flux</i>	<i>Flow</i>	<i>Calculated Input Concentrations</i>	<i>Flux</i>	<i>Flow</i>	<i>Calculated Input Concentrations</i>
Ca	367.2	13.0	28.2	720.1	14.9	48.3
Mg	150.2	13.0	11.6	296.8	14.9	19.9
Na	498.3	13.0	38.3	1754.4	14.9	117.7
HCO ₃	1690.3	13.0	130.0	2069.2	14.9	138.9
CO ₃	1.5	13.0	0.1	337.3	14.9	22.6
Cl	247.5	13.0	19.0	3189.9	14.9	214.1
SO ₄	535.7	13.0	41.2	2686.7	14.9	180.3
B	4.5	13.0	0.3	4.8	14.9	0.3
TDS	2555.7	13.0	196.6	12056.8	14.9	809.2

c) Concentrations (ppm), MEAN flows (cfs), and solute fluxes in the Truckee River for the months of November and December.

<i>Ion</i>	Tracy Mean			Wadsworth Mean			Nixon Mean		
	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>	<i>Concentration</i>	<i>Flow</i>	<i>Flux</i>
Ca	19.4	247.9	4809	22.5	277.2	6237	29.9	284.5	8507
Mg	6.7	247.9	1661	8.4	277.2	2328	11.7	284.5	3329
Na	25.2	247.9	6247	29.8	277.2	8261	55.0	284.5	15648
HCO ₃	101.2	247.9	25087	111.3	277.2	30852	119.2	284.5	33912
CO ₃	0.4	247.9	99	0.3	277.2	83	6.7	284.5	1906
Cl	17.9	247.9	4437	18.3	277.2	5073	74.4	284.5	21167
SO ₄	23.8	247.9	5900	29.9	277.2	8288	73.0	284.5	20769
B	0.3	247.9	71	0.3	277.2	85	0.3	284.5	88
TDS	167.2	247.9	41449	177.5	277.2	49203	358.5	284.5	101993

d) Flow and flux differences and calculated groundwater input concentrations to the Truckee based upon MEAN flows.

<i>Ion</i>	Tracy - Wadsworth Reach			Wadsworth-Nixon Reach		
	<i>Flux</i>	<i>Flow</i>	<i>Calculated Input Concentrations</i>	<i>Flux</i>	<i>Flow</i>	<i>Calculated Input Concentrations</i>
Ca	1428	29.3	48.7	2270	7.3	310.9
Mg	668	29.3	22.8	1000	7.3	137.0
Na	2013	29.3	68.7	7387	7.3	1011.9
HCO ₃	5765	29.3	196.8	3060	7.3	419.2
CO ₃	-16	29.3	-0.5	1823	7.3	249.7
Cl	635	29.3	21.7	16094	7.3	2204.7
SO ₄	2388	29.3	81.5	12480	7.3	1709.6
B	14	29.3	0.5	3	7.3	0.5
TDS	7754	29.3	264.6	52790	7.3	7231.5

Concentrations, flows, and fluxes in the lower Truckee River for presumed baseflow months of November and December.
Sources: NDEP, U.S.G.S., and DRI.

TABLE C.4
SOLUTES IN GROUNDWATER ENTERING THE TRUCKEE RIVER

(a) Solute Concentrations in Groundwater, in mg/l

Calculated from Truckee River Fluxes based on

Ion	Averages of Dodge Flat Groundwater	Bratberg Flow Estimates	Median Low Flows	Mean Low Flows	Pah Rah Recharge at 1.7 cfs and Median Flows
Ca	46	45	48	311	424
Mg	4.5	19	20	137	175
Na	209	110	118	1012	1032
HCO ₃	92	129	139	419	1217
CO ₃	N.R.	21	23	249	198
Cl	71	199	214	2205	1876
SO ₄	414	168	180	1710	1580
B	1.74	0.30	0.32	0.46	2.80
TDS	844	754	809	7232	7092

**(b) Bratberg Groundwater Estimates for Various Reaches
(1980, p. 46), in mg/l**

Ion	Fernley Wells	Derby to S-S	Derby to Wadsworth	Wadsworth to S-S	All of Dodge Flat Weighted Averages
Ca	79	62	49	76	73
Mg	37	24	15	32	33
Na	138	83	84	89	156
HCO ₃	166	155	229	164	161
CO ₃	N.R.	N.R.	N.R.	N.R.	
Cl	199	100	31	121	239
SO ₄	192	143	128	211	174
B	N.R.	N.R.	N.R.	N.R.	
TDS	827	611	497	726	868

**(c) Required groundwater
input volumes (cfs) based on
Bratberg's Concentration
Estimates**

Median Flows	Mean Flows
9	44
9	46
20	126
13	23
26	206
13	91
17	111

(a) Calculated input groundwater solute concentrations into the Wadsworth-Nixon reach based upon solute flux estimates from Table 9 and various volume estimates. (b) Bratberg (1980) estimates for inputs and regional groundwaters included for Comparison. (c) Also shown are the input water volumes that are required to produce Bratberg's estimated input concentrations for the Wadsworth-Nixon reach based on median and mean Truckee River flow differences. Note that the closest approximation to the average Dodge Flat groundwater is obtained from fluxes derived using median flows. Differences between this estimate and those of Bratberg stem in part from different estimates of Truckee River baseflow.



APPENDIX D

USE OF CUMULATIVE AVERAGES TO ESTIMATE THE MAGNITUDES OF PROCESSES IMPACTING THE LOWER TRUCKEE RIVER

APPENDIX D

USE OF CUMULATIVE AVERAGES TO ESTIMATE THE MAGNITUDES OF PROCESSES IMPACTING THE LOWER TRUCKEE RIVER

Along the Truckee River east of Dodge Flat, the principal water loss mechanism is evapotranspiration (ET), while input is confined to groundwater recharge except during rare major runoff events. Surface runoff is volumetrically negligible and generally contains little solute. Since ET consumes only water, solute gains or losses must originate within groundwater, and the net water gain or loss (Δ_{a-b}) must equal the difference between ET and subsurface flow, provided no other processes impact the regional flow system.

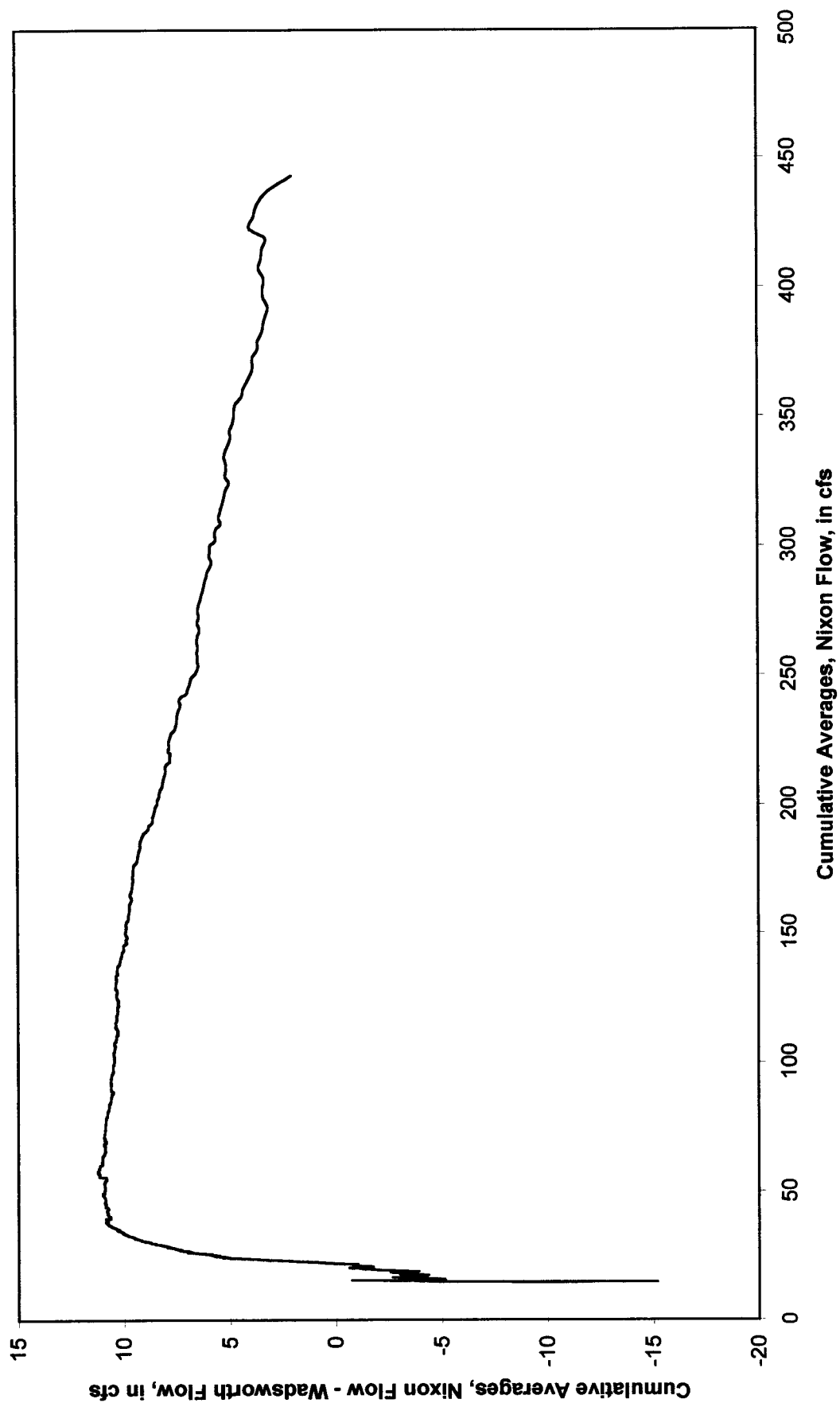
Other mechanisms, however, appear to operate that depend on the magnitude of flow. This can be seen in Figure D.1, which compares cumulative averages of the difference in monthly flows between Nixon and Wadsworth against the cumulative averages of Nixon flows. To derive the graph, average monthly flows at Wadsworth and Nixon were sorted in ascending order, with those at Nixon the sort criterion. The difference in flow (Δ_{N-W}) was obtained for each of the 956 regressed data points. To smooth the results, cumulative averages were taken beginning at low Nixon flow values. A given value at the left-hand (low flow) portion of the plot therefore derives from fewer data points than those farther to the right. Similarly, the effect of greater river flows on Δ_{N-W} becomes more pronounced from left to right along the plot. Cumulative, rather than moving, averages are reported to better smooth irregularities and to view the shape of the low-flow portion of the curve, but both produced similar results. The data from which this plot derives are presented in Appendix C.

Because Figure D.1 shows cumulative averages, the changes in system behavior should manifest themselves as changes in slope, though their precise onset may be difficult to ascertain. One such change takes place at at ~ 40 cfs, where the curve levels off after a steep rise; another can be seen at ~ 100 - 130 cfs, above which Δ_{N-W} declines in a roughly linear fashion with a slope ~ -0.02 . This suggests that a mechanism or mechanisms roughly proportional to flow are operating in this region. To characterize them requires consideration of the physical processes that dominate the lower river and its aquifer system. For time scales on the order of days to months, these are: flows from upstream; groundwater inputs; and evapotranspiration (ET).

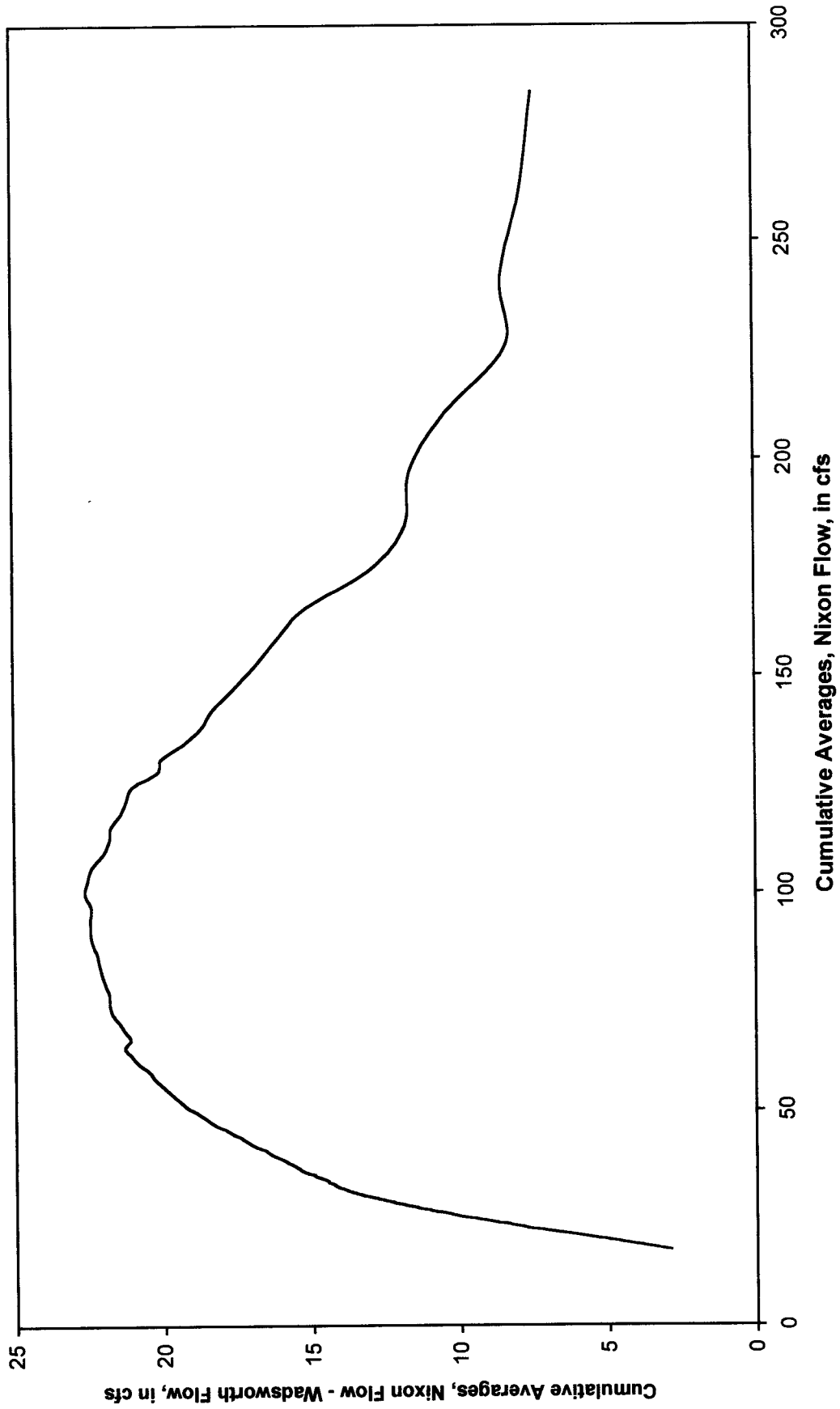
In Figure D.1, for Nixon flows between ~ 35 and ~ 130 cfs, $\Delta_{N-W} \approx 11$ cfs. This represents the combined influence of all process, including groundwater input and ET losses. The major drop in Δ_{N-W} below ~ 34 cfs suggests that as flows diminish, losses (ET) rapidly dominate the lower Truckee surface water system. However, ET is not truly independent of flow, since both are seasonal. Attempts to ascertain the magnitude of ET losses using Figure E.1 alone were unsuccessful, so a means of separating ET effects was necessary.

Along the lower Truckee corridor, plant activity diminishes beginning roughly in October, and remains low through the winter (Klotz, 1998). River flows during this period are generally also low. This suggests that the aggregated data from these months should represent baseflow conditions, and that gains or losses between Wadsworth and Nixon define river-groundwater interaction in the absence of vegetative transpiration and for low evaporation rates.

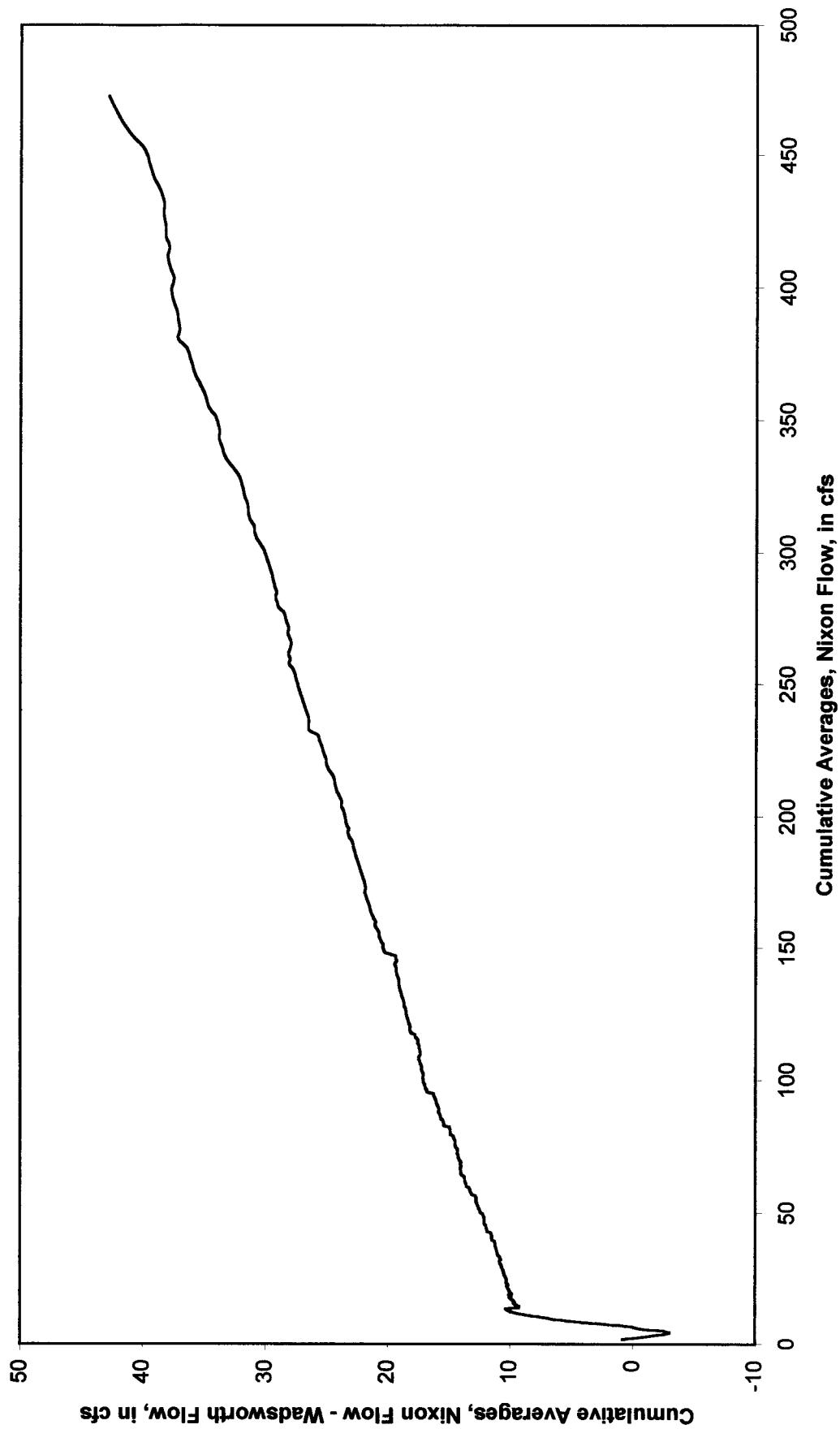
Flow data were extracted from the regressed data set for the months of November and December for each year of record and sorted in ascending order based on gage readings at Nixon (Appendix C). Cumulative averages of these are plotted in Figure D.2, against cumulative averages of corresponding Δ_{N-W} . Similarly, Figure D.3 compares cumulative averages of Nixon flows and Δ_{N-W} for the remaining months of the year.



Net Gain vs. Nixon Flow
Cumulative Averages, All Months
Figure D.1



Net Gain vs. Nixon Flow
Cumulative Averages, November, December
Figure D.2



Net Gain vs. Nixon Flow
Cumulative Averages, Months Other Than November, December
Figure D.3

Table D.1 lists the mean, sample standard deviation, and median values of these 151 flows and for a subset consisting of the lowest 30 flows. The table also includes Δ_{N-W} determined from the mean and median of these low flows. As is the case with the entire data set, the arithmetic mean and standard deviation are large due to the influence of relatively few extremely high flows. Moreover, both exceed Δ_{N-W} by between one and two orders of magnitude. It should be noted that the flows at which the change in slope take place correspond approximately to those at which slope changes were observed in the log-probability plots of Appendix C. Although flows in the lower Truckee are not lognormally distributed, to eliminate the influence of anomalously high values the median, rather than the mean, was considered to be more representative and so was incorporated in mass balance calculations. Solute mass balance calculations based on this figure correspond well with major ion compositions of Dodge Flat waters.

TABLE D.1
TRUCKEE RIVER FLOW STATISTICS FOR
MONTHS OF NOVEMBER AND DECEMBER

	Derby	Wads	Nixon	Differences in Averages	
				Wadsworth- Derby	Nixon - Wadsworth
Average	247.9	277.2	284.6	29.3	7.4
Stdev	562.5	600.0	585.9		
Median	24.1	37.1	52.0	13.1	14.9

Data source: U.S.G.S., for period 1918 - 1996.

The magnitude and nature of the processes that operate between Wadsworth and Nixon during winter flows can be gauged using Figure D.2, which plots a very steep increase in Δ_{N-W} with increasing flow up to ~30 cfs, after which the rate of increase declines, peaking at ~23 cfs for Nixon flows of ~100 cfs. At still higher flows, Δ_{N-W} declines toward a possible asymptote of ~7.5 cfs above ~250 cfs. Examination of major slope changes and inflection points the graph suggests that for Nixon flows >~50 cfs a process initiates that progressively reduces the flow gain between Wadsworth and Nixon. Its influence becomes roughly constant above ~200-220 cfs. Since both agricultural diversions and plant transpiration are ~0 during these months, the process must be hydrologic as opposed to biological or anthropogenic. Two possible mechanisms, bank storage along the river and aquifer storage, were proposed for this process. Their plausibility was tested computationally.

Between ~120 and ~220 cfs, Figure D.2 exhibits a constant slope of ~9%, suggesting that the process changes relatively little under those flow conditions, and that the process consumes ~9 cfs of Δ_{N-W} for each 100 cfs of flow. At 220 cfs, this implies roughly 20 cfs of consumption. For a 1-month period, the shortest time discretization available in the flow data, this corresponds to roughly 5.2×10^8 ft³ of water stored along the river system. Dividing this by twice the bank length for a 16-mile stretch of river exclusive of meanders (~169,000 ft) indicates that ~300 ft³ of storage is required on each bank per lineal foot of channel. At a water depth of 1 foot, that volume of water can be stored within an area of about 300 ft² per foot of channel length. This figure is less than the average half-floodplain width of ~1000 ft, suggesting that overbank storage could very plausibly account for water losses between Wadsworth and Nixon during high flow periods in the absence of ET. That same mechanism would permit rapid reintroduction of the stored water to the river.

Aquifer storage appears insufficient to acquire and discharge comparable water volumes during the requisite time frames. Conservative order of magnitude calculations suggest times between ~70 and ~500 days to release a similar volume of water from aquifer storage.

TABLE D.2
AQUIFER STORAGE CALCULATION

	Conductivity Range	
	High	Low
Distance	500	500
Gradient	0.002	0.002
Conductivity	735.7	98.4 ft/day
Avg. Linear Velocity	7.4	1.0 ft/day
Time = Dist./Velocity	68.0	508.2 days to drain aquifer

Surface aquifer storage calculation for high flows using average hydraulic conductivity, 1' aquifer thickness, 1' head, 500' lateral distance of storage, effective porosity 0.2, and Darcy flow. Units: ft, ft/day, and days

These computations assumed a constant 1-foot head, confined flow, and the hydraulic conductivities estimated during this study for the Truckee River aquifer (Appendix E and Table 5.8).

In a manner analogous to Figure D.2, the constant-slope line in Figure E.3 for Nixon flows above ~15 cfs indicates that for those months and at those flows there are no changes in the hydrologic processes operating on the lower Truckee. The decline in storage seen in Figure E.1 above ~130 cfs thus derives from the inclusion of low-flow months in its data set, and indicates that ET and Δ_{N-W} are not completely independent.

Figures D.2 and D.3 may also supplement inflow estimates based on median flows. In Figure D.2, above ~250 cfs, an asymptotic Δ_{N-W} of ~7.5 cfs appears to be reached, at which point the storage/consumptive mechanism no longer changes Δ_{N-W} . The difference between this asymptote and the maximum Δ_{N-W} of ~23 cfs, which occurs when the cumulative average Nixon flows are in the vicinity of ~100 cfs, is ~15.5 cfs, close to the 14.9 cfs input obtained from median flows (Table C.1).

Figures D.1 and D.3 suggest ET estimates for the lower river. In Figure D.1, for Nixon flows between ~35 and ~130 cfs (~25000-94000 af/y), Δ_{N-W} is roughly 10-11 cfs (~7200-8000 af/y). However, this presumes that ET is an important process when Nixon flows are in that relatively low range. Some of those flows take place during winter months when ET is at a minimum.

Figure D.3 derives only from those months of the year when ET is active. The plot displays a constant slope for Nixon flows >~15 cfs, indicating that the process or processes governing Δ_{N-W} operate steadily under a wide range of flows, and only cease to do so under extremely low flow conditions. A Δ_{N-W} of between ~9 and ~10 cfs is seen at the change in slope representing the onset of low flow conditions, below which Δ_{N-W} becomes slightly negative (~2 to 4 cfs). Assuming that under these low flow conditions ET is the governing process, subtracting the two figures gives an estimate for ET of ~11 – 14 cfs. This is consistent with the values obtained from Figure D.1, and with that derived from estimates of vegetative cover by Van Denburgh, *et al.* (1973).

APPENDIX E

**HYDRAULIC CONDUCTIVITY ESTIMATES
FOR THE TRUCKEE RIVER AQUIFER**

APPENDIX E

HYDRAULIC CONDUCTIVITY ESTIMATES FOR THE TRUCKEE RIVER AQUIFER

To estimate hydraulic conductivities for each segment of the Truckee River aquifer, drillers' well logs were examined and lithologies grouped into categories. For each category, a hydraulic conductivity was assigned based upon the ranges shown in Freeze and Cherry (1979) (metric units). These were later adjusted to optimize transmissivities obtained from pump test data. Table E.1 lists the lithologic categories and the log of initial conductivity estimate. The table also shows the optimized conductivities in gpd/ft^2 and the logs of optimized conductivity as expressed in m/s and ft/day .

The average conductivity for a well or screened interval consisted of the arithmetic mean of the assigned conductivities weighted according to stratigraphic thickness. Use of this approach presumed horizontal flow in all units.

Four pump tests provided a standard against which initial conductivity assignments were adjusted. For each well, conductivities were assigned only to those units contained within the screened interval of each well. Table E.2 shows the four wells (Stampmill Estates West and East; and two Wadsworth production wells), their measured transmissivity, and the lithology and thickness of each stratigraphic interval. The average conductivity was obtained by dividing the transmissivity by the thickness of the well screen.

The optimization procedure consisted of adjusting the conductivity of each lithology until the average estimated conductivity of those wells most closely approached the average measured conductivity. These results were shown in Table 5.8.

Once conductivities were determined for each lithology, these were applied to well logs within each segment of the Truckee River aquifer (see Tables 5.8 and C.1). To obtain the average conductivity for the entire aquifer, all stratigraphic units were considered, not only those that lay within the screened interval. An average was obtained for each well, and the mean of those was designated the conductivity for that aquifer segment (Table E.3).

Aquifer thickness was based upon average depth to bedrock in those segments where it was encountered. For those wells completed entirely within the aquifer, the depth was taken as the average well depth. Since only the deeper wells were used to determine aquifer properties, this eliminated any bias that might be caused by shallow wells. Maximum well depth might provide an equally appropriate gauge; however, since the aquifer segments are as much as several miles long, the average was chosen as a more conservative measure.

An average aquifer width was also estimated for each segment (Table E.4). This was obtained from 1:24,000 scale U.S.G.S. topographic maps by measuring the floodplain width perpendicular to flow at half-mile intervals within each segment. The median of these values was then applied to the segment. This approach conservatively assumes that fluvial sediments only underlie the floodplain of the river.

Table E.5 lists transmissivities reported by CH2MHill (1990). Its intent is to enable calculated to enable comparison with the estimated transmissivity figures of Tables 5.8 and C.1. For this table, both the arithmetic and geometric means were determined.

TABLE E.1
HYDRAULIC CONDUCTIVITIES ASSIGNED TO VARIOUS LITHOLOGIC
CATEGORIES FROM DRILLERS' LOGS OF WELLS IN THE TRUCKEE RIVER AQUIFER

log K (m/s) Initial Est.	log K Best Fit m/s	log K ft/day	K gpd/ft ²		Symbol
-9	-9	-4.58	0.00020	Clay	C
-8	-7.5	-3.08	0.00621	Sandy or Silty Clay = Clayey Silt	CS
-7	-6	-1.58	0.197	Silt = Sandy Clay = Clay + Rock = Clay, Sand, Gravel = Sandy Clay + Gravel	SC
-6	-4.5	-0.08	6.2	Sand + Silt = Sandy Clay Rock	S/S
-5	-3	1.42	197	Sand = Sand+Gravel with Clay = Gravel with Clay = Boulders, Cobbles with Clay and Fine Sand = Dirt Sand and Gravel	S
-4	-2.4	2.02	782	Sand + Gravel	SG
-3	-2	2.42	1965	Gravel = Gravel + Rock + Sand + Gravel = Rock + Sand = Rock + Gravel = Sand + Boulders	G
-2	-1.5	2.92	6215	Boulders = Cobbles	B

Initial estimates from Freeze and Cherry (1979). Best fits are adjustments made to original estimates that better enabled fitting estimated conductivities to conductivities obtained from well logs.

TABLE E.2

**THICKNESS AND ESTIMATED CONDUCTIVITIES OF SCREENED
INTERVALS IN SELECTED MAJOR WADSWORTH AREA WELLS**

	<u>Stampmill Estates</u>		<u>Wads. Production</u>	
	West	East	32581	New (Leisek)
C				
CS				
Slt		12	75	
S/S	35	32		
S	35	18		
SG	10	40	25	
G				20
B				
Total thickness (ft.)	80	102	100	20
K average (ft/day)	24.9	45.9	26.2	262.9
K average (gpd/ft ²)	186.5	343.5	195.7	1965.3

TABLE E.3

THICKNESS AND ESTIMATED HYDRAULIC CONDUCTIVITIES SELECTED IN THE TRUCKEE RIVER AQUIFER

[illegible]

Estimated Segment 2 Average Depth to Bedrock = 160

Asterisk (*) denotes either a pump test or drawdown-pump rate measurement.

TABLE E.3 (CONTINUED)

Well No.	Reservation Boundary -> Wadsworth; includes Production Well												
	Aquifer Segment 3 *IHS Well	*IHS 12599	49350	*20125	32581	*40825	*8186	*14130	24223	20181	*? 19022	*17467	*IHS49305?
Clay		62		4		16	4				24	61	
Silt-Cl		2					19	24	5		8		
Silt			70		34		7	33			13		
S+Silt	2.5				171			18	60	20		14	
Sand	36		4	7				10		34	87		88
S+G	69.5	116	21	78	25		35			41	73	128	31
Gr	55			161		76	4		80	3			7
Bould													
Bedrock													
Conductivity (ft/day)	139	67	24	203	12	217	68	18	469	177	138	168	184
gpm/ft²	1040	504	181	1515	90	1624	511	134	3510	1324	1032	1253	1375
Depth to Bedrock	>163	>180	>95	>250	>230	bedrock aquifer	>69	>85	>145	>98	>205	>203	>126
Estimated Segment 3 Average Depth to Bedrock = 170													
Well No.	Wadsworth->Windmill Canyon												
	Aquifer Segment 4 33855	23589	*18081	50319	19214	19215	50317	*18079	*18078	50316			
Clay	49		32	52	20	28	77	107	72	92	55		
Silt-Cl							3						
Silt		1		38			10			5			
S+Silt					7	7	18			53			
Sand	22	22	20	82	35		40	23					
S+G	4	66	24	25		85	19	49	33	53			
Gr	27	2	19		48	15							
Bould				33			12						
Bedrock													
Conductivity (ft/day)	79	88	85	140	123	95	73	32	33	59			
gpm/ft²	593	658	632	1047	921	711	544	239	246	444			
Depth to Bedrock	>102	>91	>95	>230	>110	>135	>179	>179	>105				
Estimated Segment 4 Average Depth to Bedrock = 260													

Asterisk (*) denotes either a pump test or drawdown-pump rate measurement.

TABLE E.3 (CONTINUED)

Well No.	Aquifer Segment 5	Windmill Canyon -> Nixon Gage				
		19207	19205	19204	*14426-1	*18026
	Clay	40	46	81	128	138
	Slt-Cl				179	
	Slt		25		50	
	S+Slt	5			16	
	Sand	70	23	33	12	3
	S+G		50	28	13	30
	Gr	17			9	
	Bould					27
	Bedrock					
Conductivity (ft/day)		48	41	27	10	43
gpm/ft ²		358	303	200	75	322
Depth to Bedrock		>132	>144	>142		>165
Estimated Segment 5 Average Depth to Bedrock = 310						>35

TABLE E. 4

**TRUCKEE RIVER FLOODPLAIN WIDTHS
USED TO ESTIMATE WIDTH OF THE FLUVIAL AQUIFER**

	Segment 2	Segment 3	Segment 4	Segment 5	Segment
	800	2500	5000	1400	1600
	600	1400	6000	2400	3300
	1000	1200	4500	3600	1200
	900	1100	3200	7000	1600
	700	1000	2500	4500	2400
	1000	1400			1700
	1500	1000			2000
	1200				1300
	1000				1200
					400
					700
					400
Average of all sections	967	1371	4240	3780	1483
Average of Averages		2368			

Segment 1 is within Truckee River Canyon, upstream of Rainbow Rock, and was not included.

TABLE E. 5
AVERAGE TRANSMISSIVITIES FROM CH2MHILL DATA

	Aquifer Thickness [ft]	Transmissivity [gpd/ft]	Conductivity	
			[gpd/ft ²]	[ft/day]
	42	3000	71	10
	56	14600	261	35
	11	4000	364	49
	22	9000	409	55
	56	25000	446	60
	18	9000	500	67
	56	32000	571	76
	42	38000	905	121
	11	20000	1818	243
	11	30000	2727	365
	12	33000	2750	368
	30	90000	3000	401
	30	270000	9000	1204
With last well – Arithmetic Mean		44431	1756	235
Geo. Mean		19200	767	103
W/o last well – Arithmetic Mean		25633	1152	154
Geo. Mean		17500	700	94



A vertical dashed line on the left side of the page, consisting of a series of short, thick black horizontal bars separated by gaps.

APPENDIX F

COMPARATIVE GEOCHEMISTRY

APPENDIX F

COMPARATIVE GEOCHEMISTRY

F.1 Soluble Paleosol Cations and Ion Exchange

Between the lower Olinghouse fan and its toe, groundwater loses a small amount of Ca^{++} , but disproportionately gains Na^+ and SO_4^- , thereby increasing its TDS. Equilibrium calculations demonstrate that gypsum is undersaturated and calcite supersaturated, suggesting calcite precipitation as a possible Ca^{++} sink.

Cation exchange with Na^+ in clays may also deplete Ca^{++} . Studies by Cooper and Associates (1980) and CH2MHill (1990) tested the cation exchange capacity (CEC) and soluble ion release of typical Dodge Flat soils. For the present investigation, calculations were performed assuming that ~10% of a 1000-foot vertical cross-section is soil, that the CEC of paleosols is comparable to that found by Cooper and CH2MHill, and that present-day recharge is representative of the total water flux through the section since the latest Lake Lahontan highstand (~13,000 y.b.p.) (Benson, 1993). These show that more than sufficient CEC exists to account for the differences in Ca^{++} between the groundwaters on the upper and lower Olinghouse fan (Appendix B).

Soluble ion release from paleosols is by itself unlikely to account for the observed TDS gains beneath the base of the Olinghouse fan. Based on the Cooper and Associates (1980) and CH2MHill (1990) analyses and using water flux based upon present-day recharge, paleosols must constitute the entire stratigraphic section beneath the Olinghouse fan to account for the solute concentrations recorded in the Dodge Flat wells. This is geologically unrealistic. Moreover, the capacity of those soils to supply cations would coincidentally just now be depleted, which is implausible. Some SO_4^- and Ca^{++} could potentially derive from dissolution of gypsum in the paleosols, although there is no specific evidence for this process in the soil leach tests.

Soluble ions from paleosols could, however, potentially degrade artificially recharged fresh water, depending upon the recharge method used. Water moving through unsaturated sediment beneath infiltration basins could release unacceptable amounts of Na^+ from certain soils (CH2MHill, (1990), and groundwater mounding due to artificial injection through wells could saturate paleosols that hitherto lay within the vadose zone. The extent of that mounding depends on the volume and rate of recovery, water injected, hydraulic characteristics of the aquifer, well field geometry, and other factors relating to design and operation. Assuming that 10% of an aquifer is paleosol with a bulk density of 94 lb/ft³ (1500 kg/m³) (Blake and Hartge, 1986) and properties similar to those reported by CH2MHill (1990), saturating that soil could supply ~140 ppm of ions to fresh groundwater (Appendix B). Possible future ASR engineering efforts must establish the magnitude of this potential solute source; however, it is entirely possible that due to the confined nature of aquifer mounding may not be significant.

F.2 Surface Water Ion Sources

Except for occasional ephemeral runoff during storms, the only surface water near the ASR sites is Olinghouse Creek, which vanishes a mile or more away. Since infiltration from precipitation events is insignificant at the elevations encountered on the lower Olinghouse fan (Maxey and Eakin, 1949; Eakin, *et al.*, 1951), it can be presumed that surface waters do not impart ions to the aquifer system in that area.

F.3 Geothermal Waters

Some geothermal contribution to the Dodge Flat aquifer system is possible, not only on the Olinghouse fan but elsewhere within the hydrographic basin. Pleistocene and later faults, possible conduits, have been identified along the foot of the Pah Rah Range and within the central portions of Dodge Flat (Sanders and Slemmons, 1979; Bell, 1984; Hartley, 1998; and photographic interpretation for the present study). At present, the volume of water that might derive from such sources is unquantifiable, but examination of ionic and isotopic composition, as well as temperature data suggests some geothermal influence on Dodge Flat groundwater chemistry (McKay and Bohm, 1998).

The trilinear plot (Figure F.1) shows the composition of selected geothermal waters from Dodge Flat and surrounding regions. Chemical data were obtained from Garside and Shilling (1979) for sites that include: Well 272, a low temperature borehole near the Pyramid Highway; Needle Rocks, which represents the averages from a group of springs and geothermal wells from around Pyramid Lake; Eagle Salt Works Spring, situated adjacent to Interstate 80 about 15 miles NE of Fernley; Patua Hot Springs, located about 5 miles east of Fernley near Hazen; and averages from a number of measurements taken at the Moana and Steamboat springs geothermal fields near Reno.

The trilinear diagram shows that Na^+ is by far the dominant cation and Cl^- the dominant anion in these waters; $\text{SO}_4^{=}$ and HCO_3^- occur in varying amounts. Only two areas, Needle Rocks and Moana, match the Olinghouse fan well samples (Figure 8.16) at all closely in anion proportions, and both of these show somewhat higher HCO_3^- . No pure mixing of these with Olinghouse fan source waters will give the precise composition of that found at the toe of the fan, though in some cases the differences are not large. However, it must be remembered that neither $\text{SO}_4^{=}$ nor HCO_3^- are conservative. The latter in particular is sensitive to the presence of CO_2 and to pH, which varies within the geothermal waters from which the averages were made. Furthermore, the TDS of these geothermal waters can exceed by an order of magnitude that in the Dodge Flat wells. Qualitatively, it would therefore require a relatively small input of saline geothermal water to account for the solute concentrations observed on Dodge Flat. Whether this has in fact occurred can not be determined based solely on major ion analyses.

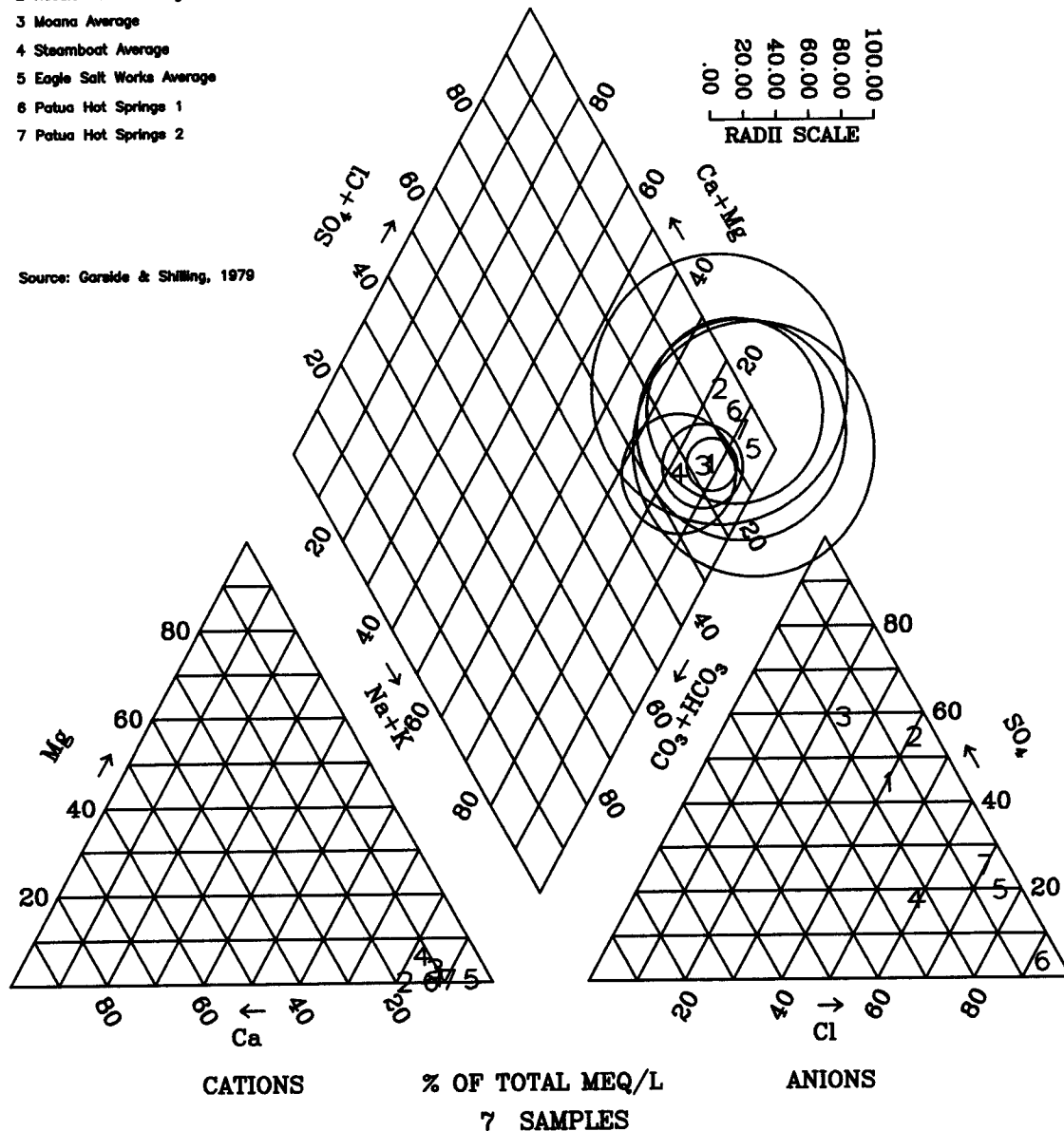
Available data for minor ions also cannot resolve this issue. Silica, for example, averages ~30 mg/kg at the Alta Gold mine and in all of the Olinghouse fan wells except MW-4, where it is ~48 mg/kg. Typical of many near-surface groundwaters, these are supersaturated with respect to quartz and under-saturated as regards amorphous silica (Drever, 1988). The consistency of observed concentrations suggests that the silica observed in these wells is probably not geothermal in origin, since geothermal input of other solutes would also add SiO_2 . Supporting evidence was obtained from the mass balance calculations in Appendix C; though because reactions involving aqueous silica are governed largely by kinetics and are strongly temperature-dependent (Drever, 1988), any conclusions are at best tenuous.


It would require the addition of ~500 mg/kg TDS to upper Olinghouse fan waters to reach a TDS comparable to those at its base. To acquire this loading from saline geothermal waters would require ~10%-20% of the estimated recharge. In regional low-temperature geothermal waters, silica concentrations range from ~30 to ~150 mg/kg, while TDS varies between ~300-4000 mg/kg (Garside and Schilling, 1979). If silica were added proportionally to the TDS gain shown on the Olinghouse fan, geothermal waters would provide between ~3 and ~50 mg/kg SiO_2 . Because more saline thermal waters generally contain more dissolved silica, the upper figure is perhaps more likely

Pyramid Lake-Fernley-Reno Region

- 1 Well 272
- 2 Needle Rocks Average
- 3 Moana Average
- 4 Steamboat Average
- 5 Eagle Salt Works Average
- 6 Patua Hot Springs 1
- 7 Patua Hot Springs 2

Source: Garalde & Shilling, 1979



 waterresource consulting engineers, inc. <small>700 TOWN CENTER - SUITE 100, RENO, NEVADA - 89502</small>		
DATE	REVISIONS	BY

FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/28/99
DRN. BY LCS
CHK. BY JL

Selected Geothermal Water
Analyses - Figure F.1

for water derived from high-TDS geothermal inputs. The addition of that quantity of silica would result in higher concentrations than those seen in most waters beneath Dodge Flat. Only in MW-4 is the silica concentration within a range suggestive of possible geothermal input.

Boron, another minor element, can derive from evaporite minerals or geothermally. Its highest concentrations in the Dodge Flat wells (~0.3 mg/kg) are comparable to those in Steamboat Creek near Reno, which receives some geothermal flow (NDEP, 1997). However, a concentration of 0.3 mg/kg is below that typical of many geothermal, ground, and evaporated surface runoff waters in the region (Garside and Schilling, 1979; McKenna, 1990; Rowe, *et al.*, 1991) and so does not permit distinction between these possible sources at Dodge Flat. If boron is assumed to be conservative and to originate solely from geothermal input, its increase from ~50 µg/kg to ~1700 µg/kg down the Olinghouse fan suggests that the maximum volume of these waters is roughly 3% of total recharge.

Like boron, fluorine is common in geothermal waters. Concentrations in regional hot springs average ~3 mg/kg, about twice that found in seawater (Garside and Schilling, 1979; Drever, 1988). This exceeds by a factor of ~50 the maximum values for the Olinghouse fan monitor wells reported in CH2MHill (1990), but is of the same order as that found by McKay and Bohm (1998). Fluorine is highly reactive; but if it is assumed to be conservative and to derive solely from hot springs, its observed concentrations suggest a lower limit on possible geothermal input to Dodge Flat of ~2% of recharge and a maximum approximately equal to recharge.

Water compositions on the Olinghouse fan enable order of magnitude limits to be placed on possible geothermal inputs to the aquifer system. Ignoring silica and fluoride, an upper limit on the order of ~10% of recharge can be estimated by assuming all TDS is geothermal. Similarly, the lower limit suggested by fluoride concentrations is on the order of 1%. The water volumes for the entirety of Dodge Flat (~130 - ~13 af/y) associated with these numbers are well within the error limits of recharge estimates, and as such would be undetectable in a regional water balance. It is therefore possible for a volumetrically small geothermal input to account for a relatively large proportion of the dissolved salts. Methods other than comparing major ions are required to discern whether this is the case.

McKay and Bohm (1998) performed D-¹⁸O isotopic analyses during the present study to test solute sourcing alternatives for Dodge Flat. Their results show waters isotopically heavier in δ¹⁸O than the global or local meteoric water lines (Schulke, 1987) and with considerably lower δD and δ¹⁸O values than those of the Truckee River, but which are consistent with the δD-δ¹⁸O line established for the Truckee drainage system by McKenna, *et al.* (1992). McKay and Bohm (1998) conclude that the Dodge Flat results are consistent with the presence of geothermal waters, which suggests a geothermal solute contribution. However, based on presently available information, they do not rule out sediment solute sources, since δD-δ¹⁸O lines for evaporation-dominated environments can show relative enrichment in ¹⁸O (Clark and Fritz, 1997).

F.4 Evaporite Mineral Ion Sources

Previous studies, rather than considering a geothermal contribution, presumed instead that the dominant solute sources to the Dodge Flat aquifer are lacustrine sediments, within which salts would have been concentrated during periods of desiccation (Sinclair and Loeltz, 1963). This is quite plausible, and many subsequent works have cited the earlier investigations (*e.g.*, Van Denburg, *et al.*, 1973; Bratberg, 1980) without actually testing that assumption. However, its validity is relevant to the present study.

Two subordinate objectives of the current investigation are to propose an ASR site on or near the Olinghouse fan and to assess its impact on groundwater resources in that area. Selection of that site must consider water quality degradation due to solute input as well as increased downgradient solute movement. Moreover, regional water planning objectives propose reducing irrigation to lessen solute loading in the Truckee River between Fernley and Nixon. Identifying the source of ions garnered by agricultural runoff and infiltration is crucial in that regard.

Three approaches were attempted during the present study to test the concept of sediment-derived solutes. Each provides circumstantial evidence consistent with that concept, though none demonstrate it unquestionably. It should be cautioned that the calculations involve a great many simplifying assumptions and should not be interpreted too rigidly. The intent of this section is to provide order of magnitude concept tests. The first approach compares groundwater ionic compositions to that generated by stoichiometric dissolution of selected common evaporite minerals. The second tests whether the presence of the requisite volume of those phases is geologically reasonable. A third method used mass balance to assess qualitatively whether several desiccation cycles would have sufficed to source the observed TDS levels.

F.4.1 Stoichiometric Mineral Dissolution

A realistic mixture of minerals commonly associated with evaporite deposits can provide water chemistries similar to those observed on Dodge Flat. As a test, phases typical of evaporites and arid climate soils were chosen to exemplify possible major ion sources. These were: gypsum ($\text{CaSO}_4 \cdot 5\text{H}_2\text{O}$), trona ($\text{Na}_3[\text{CO}_3][\text{HCO}_3] \cdot 2\text{H}_2\text{O}$), thenardite (Na_2SO_4), and halite (NaCl) (Gaines, *et al.*, 1997). Calcite, though an early-formed precipitate in many evaporating lake systems (Hardie and Eugster, 1970; Eugster and Hardie, 1978), is ubiquitous in the Dodge Flat region and supersaturated in the groundwaters on the Olinghouse fan. Under present conditions, it could buffer the concentration of Ca^{++} through precipitation but not dissolution. However, its ability to supply Ca^{++} is controlled by pH, P_{CO_2} , and $\text{HCO}_3^- - \text{CO}_3^{--}$ activity. To account for present concentrations requires either assuming significant changes in groundwater pH or independent sourcing of Ca^{++} and CO_3^{--} . Because gypsum is undersaturated in Olinghouse fan waters, and because of the high solubility of trona and thenardite, these minerals rather than calcite were chosen to represent the sources of Ca^{++} and CO_3^{--} .

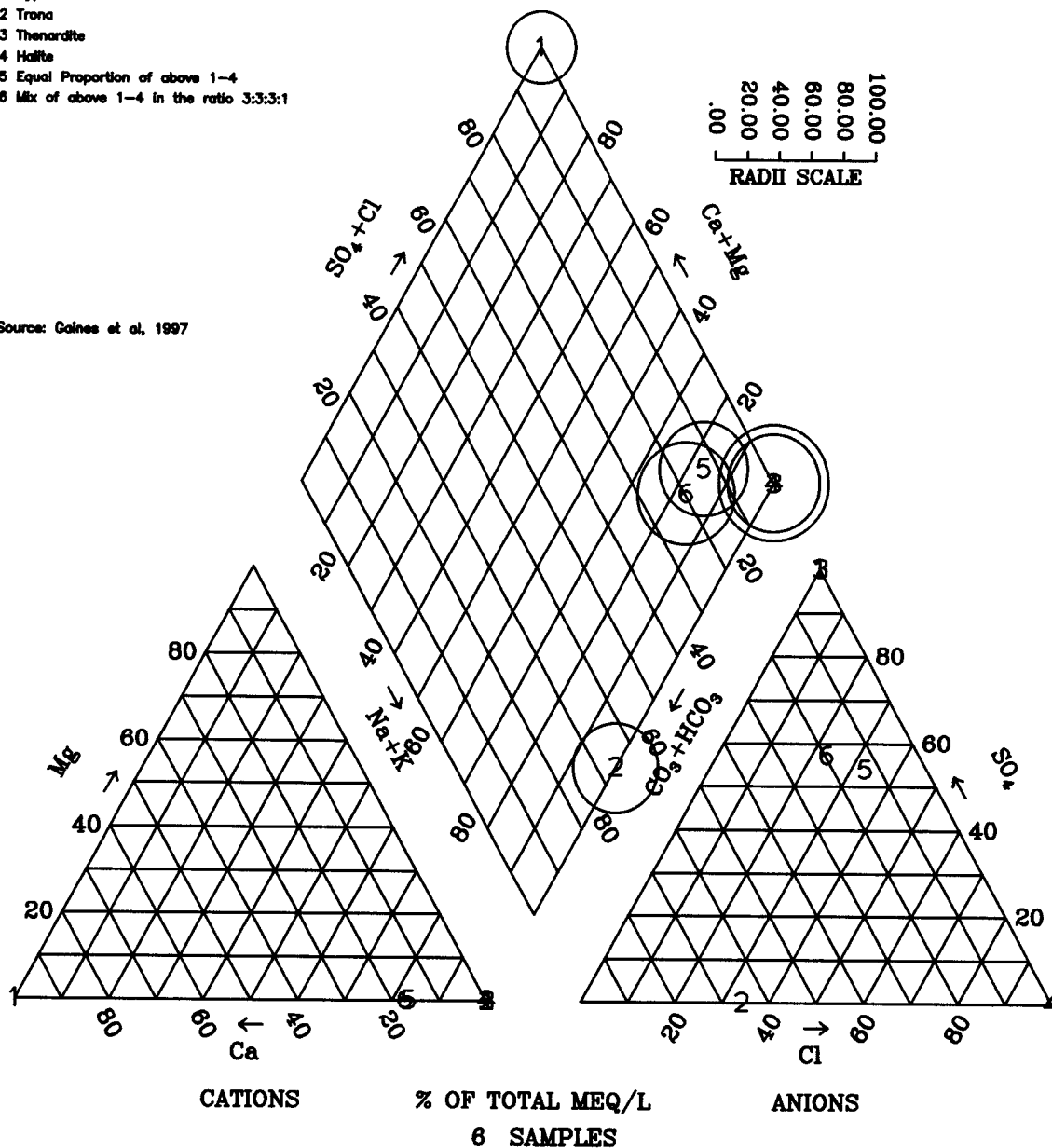
Each phase was assumed to dissolve stoichiometrically, rapidly, and without reaction to provide 100 mg/kg TDS in the resultant water. Results were plotted on a trilinear diagram (Figure F.2). Also shown are waters derived from arbitrary mixtures of these minerals at ratios of 1:1:1 and 3:3:3:1. These ion ratios are reasonable for some lacustrine evaporite deposits, depending upon the evolutionary history of their predecessor lakes (*e.g.* Lake Magadi, Searles Lake) (Eugster and Hardie, 1978; Smith, 1979). Similar ratios are found in some saline lake waters, though most are higher in Cl (*e.g.*, Jones, 1965; Hardie and Eugster, 1970; Eugster and Hardie, 1978; Hardie, *et al.*, 1978).

While it is possible to obtain a wide range of water compositions simply by adjusting the proportions of the dissolved minerals, those ratios depicted in Figure F.2 nonetheless correspond to waters on the lower Olinghouse fan (Figure 8.16). Additionally, these show considerable similarity to the average for Fernley area wells (Sinclair and Loeltz, 1963) (Figure F.3) and to surface waters near the terminus of the Fernley Drain system (Rowe, *et al.*, 1991) (Figure F.4). It is therefore plausible that dissolution of evaporite phases provides solutes to the Dodge Flat aquifers, and possibly those near Wadsworth and Fernley.

Mineral Species

- 1 Gypsum
- 2 Trona
- 3 Thenardite
- 4 Halite
- 5 Equal Proportion of above 1-4
- 6 Mix of above 1-4 in the ratio 3:3:3:1

Source: Gaines et al, 1997



700 TOWN STREET - BIRMINGHAM, ALABAMA - 35203		
DATE	REVISIONS	BY

FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 9518.1142
DATE 10/28/98
DRN. BY LCS
CHK. BY JL

Waters from Stoichiometric Dissolution
of Evaporite Minerals - Figure F.2

However, it should be re-emphasized that the waters derived from hypothetical mineral mixtures also fall within the compositional range typical of some geothermal areas (Figure F.1).

F.4.2 Proportion of Evaporites Within the Stratigraphic Column

Order of magnitude mass balance computations indicate that to provide the observed solute concentrations, mineral salts would constitute a small to a negligible portion of the stratigraphic column: from $<0.01\%$ $\sim 0.2\%$ depending upon continuity of evaporite beds, the kinetics of mineral dissolution, and water flux through the section. This proportion represents $\sim 0.2\sim 5$ feet total of evaporite in a 2000-foot vertical section, and if dispersed would be undetectable in water well drill cuttings and nearly so in outcrop.

To perform these calculations, simplifying assumptions were made regarding basin geometry, water flux, sediment hydraulic properties, and mineralogy. Details are discussed in Appendix B. Many of these same assumptions were applied when estimating total CEC and ion release from paleosols, and in estimating the maximum possible solute contribution from ancient lakes.

F.4.3 Mass Flux from Ancient Lakes

If groundwater solute originated within sediments, and if salts therein resulted from desiccation of ancient lakes, then the evaporite mass within the sediments should equate to the solute mass within the lakes themselves. Moreover, the total evaporite mass derived from the lakes must exceed that leached from the sediments by flowing groundwater during interpluves. Order of magnitude calculations were performed to estimate the mass flux of salt into ancient lakes and that leached by present-day moving groundwater. These required significant assumptions regarding solute conservation within the basin, hydraulic properties, lake water volumes, input solute fluxes, and duration of pluvial intervals, which also are discussed more fully in Appendix B. Within the constraints imposed by those assumptions, sufficient solute to account for present-day groundwater concentrations could have been imparted by lacustrine cycles and subsequent desiccation to Dodge Flat, provided the duration of pluvial intervals comprised at least $\sim 7\%$ of its depositional history.

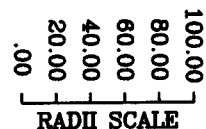
F.4.4 Conclusions Regarding Evaporite Mineral Solute Sources

The three approaches: comparison of solute compositions, establishment of minimum evaporite thickness, and mass fluxes to ancient lakes – indicate that lacustrine sediments plausibly could supply a sufficient quantity of salts to account for the present-day groundwater at the base of the Olinghouse fan. The presence of gypsum, calcite, and efflorescent minerals in Lahontan-age lacustrine sediments has been verified for the present study during field activities. Subsequent EDS microchemical investigation showed that the efflorescent contains Na, Ca, K, Al, Fe, S, and O, possibly indicating some Na-sulfate species and a phase compositionally similar to alunite-jarosite (M. C. Jensen, personal communication 3/27/98). The latter is unusual in that the presence of carbonate species suggest alkaline vadose waters, rather than acid one more typically associated with alunite group minerals (Long, *et al.*, 1992).

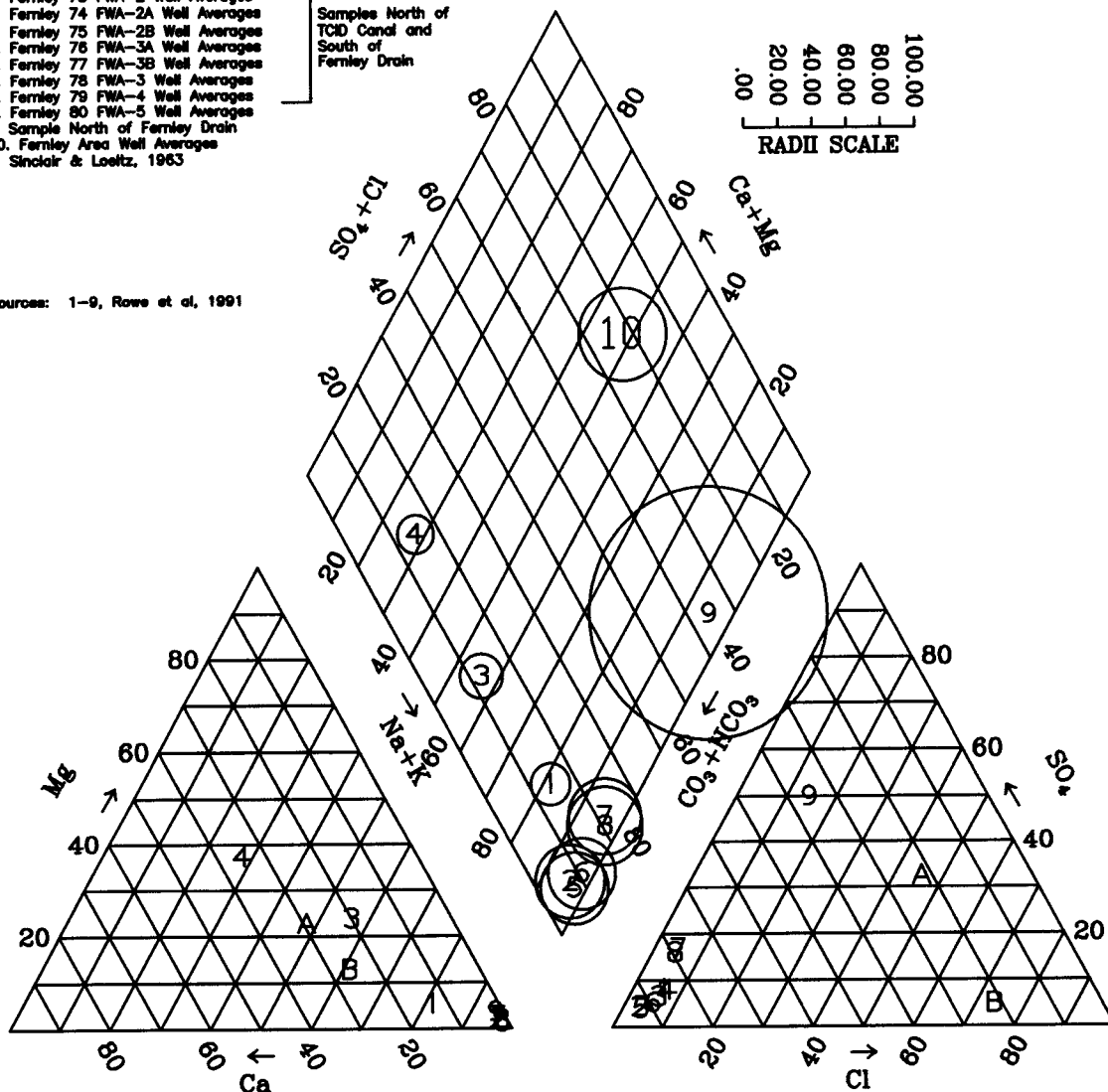
Sample Sites N. of TCID Canal 1987-9

1. Fernley 72 FWA-1 Well Averages
2. Fernley 73 FWA-2 Well Averages
3. Fernley 74 FWA-2A Well Averages
4. Fernley 75 FWA-2B Well Averages
5. Fernley 76 FWA-3A Well Averages
6. Fernley 77 FWA-3B Well Averages
7. Fernley 78 FWA-3 Well Averages
8. Fernley 79 FWA-4 Well Averages
9. Fernley 80 FWA-5 Well Averages
- Sample North of Fernley Drain
10. Fernley Area Well Averages
Sinclair & Loeltz, 1963

Samples North of
TCID Canal and
South of
Fernley Drain



Sources: 1-9, Rowe et al, 1991



CATIONS

% OF TOTAL MEQ/L

ANIONS

11 SAMPLES



waterresource
consulting engineers, inc.
700 THREE STREET - BIRMINGHAM, ALABAMA - 35203

FERNLEY TOWN UTILITIES
LYON COUNTY

JOB NO. 8518.1142
DATE 10/28/99
DRN. BY LCS
CHK. BY JL

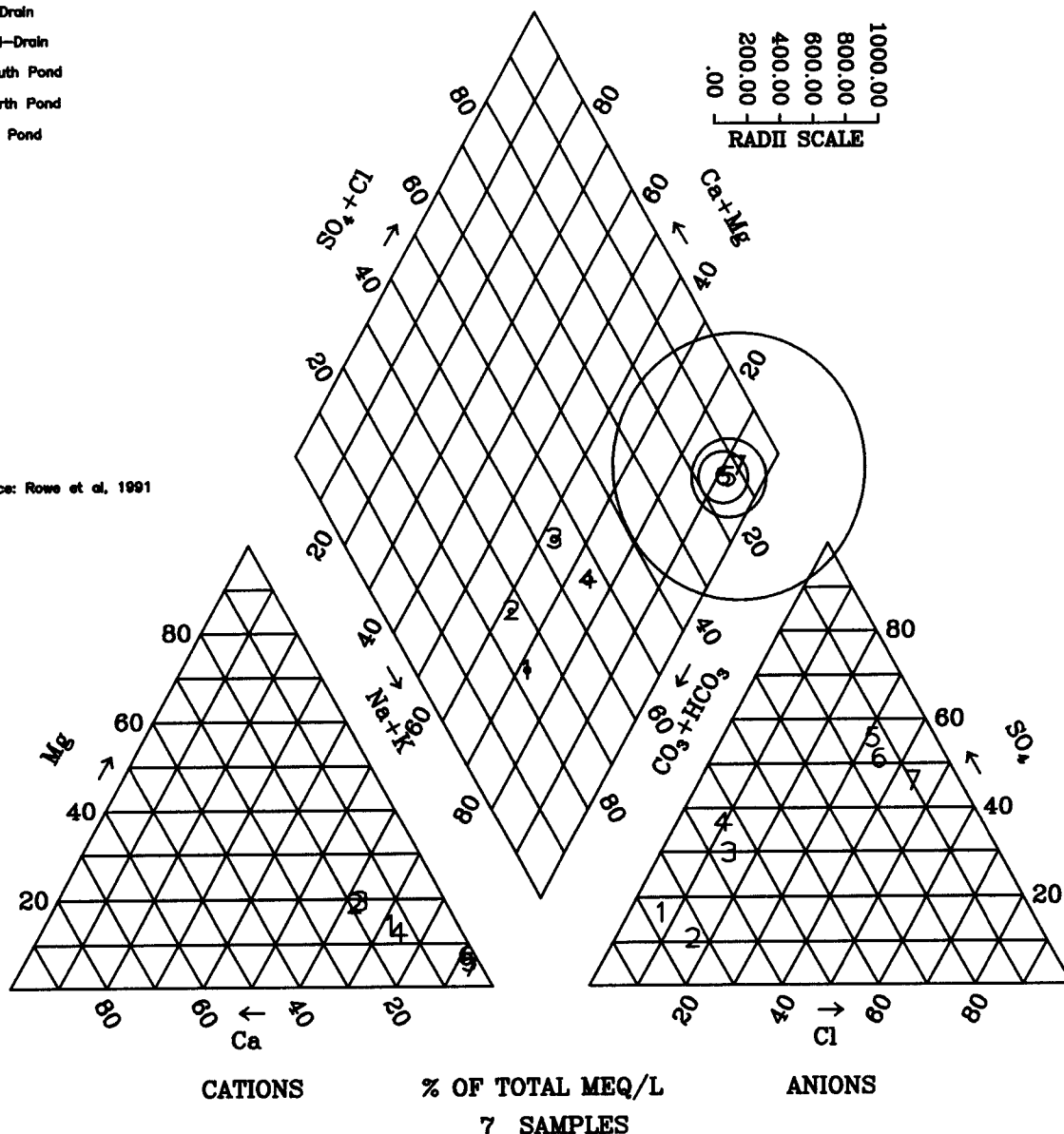
DATE	REVISIONS	BY


Major Groundwater Constituents - Sample
Sites N of TCID Canal - Figure F.3

Sites Along Fernley Drain To Fernley Wildlife Management Area

- 1 Streiff Drain
- 2 Fernley Drain
- 3 A-Drain
- 4 Mid-Drain
- 5 South Pond
- 6 North Pond
- 7 NE Pond

Source: Rowe et al. 1991



 waterresource consulting engineers, inc. <small>THE TOWN OF LYON - BUREAU, KENTON - 00000</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/28/99 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Major Surface Water Constituents Along Fernley Drain System - Figure F.4		

F.5 Fernley Area Waters

Poor quality groundwater from the base of the Olinghouse fan (Figure 8.16) resembles that of selected geothermal waters (Figure F.1) and that derived from a hypothetical mixture of evaporite minerals (Figure F.2). How closely the Dodge Flat waters resemble recharge to the Truckee between Wadsworth and Nixon must be addressed for ASR design.

Figure F.3 depicts a trilinear plot of shallow groundwater samples for an area north and downgradient from the Truckee Canal near Fernley (Rowe, *et al.*, 1991). It also includes Fernley area domestic water well averages reported by Sinclair and Loeltz (1963) and Bratberg (1980). Sample locations are recorded in Rowe, *et al.* (1991). Except for Site 80, none of those samples resemble a mixture composed of Dodge Flat water (or hypothetical waters derived from a mixture of evaporite minerals and typical Olinghouse fan recharge water). Similarly, they do not appear to derive from mixing of evaporite mineral waters with water from the Truckee River (Figure F.5).

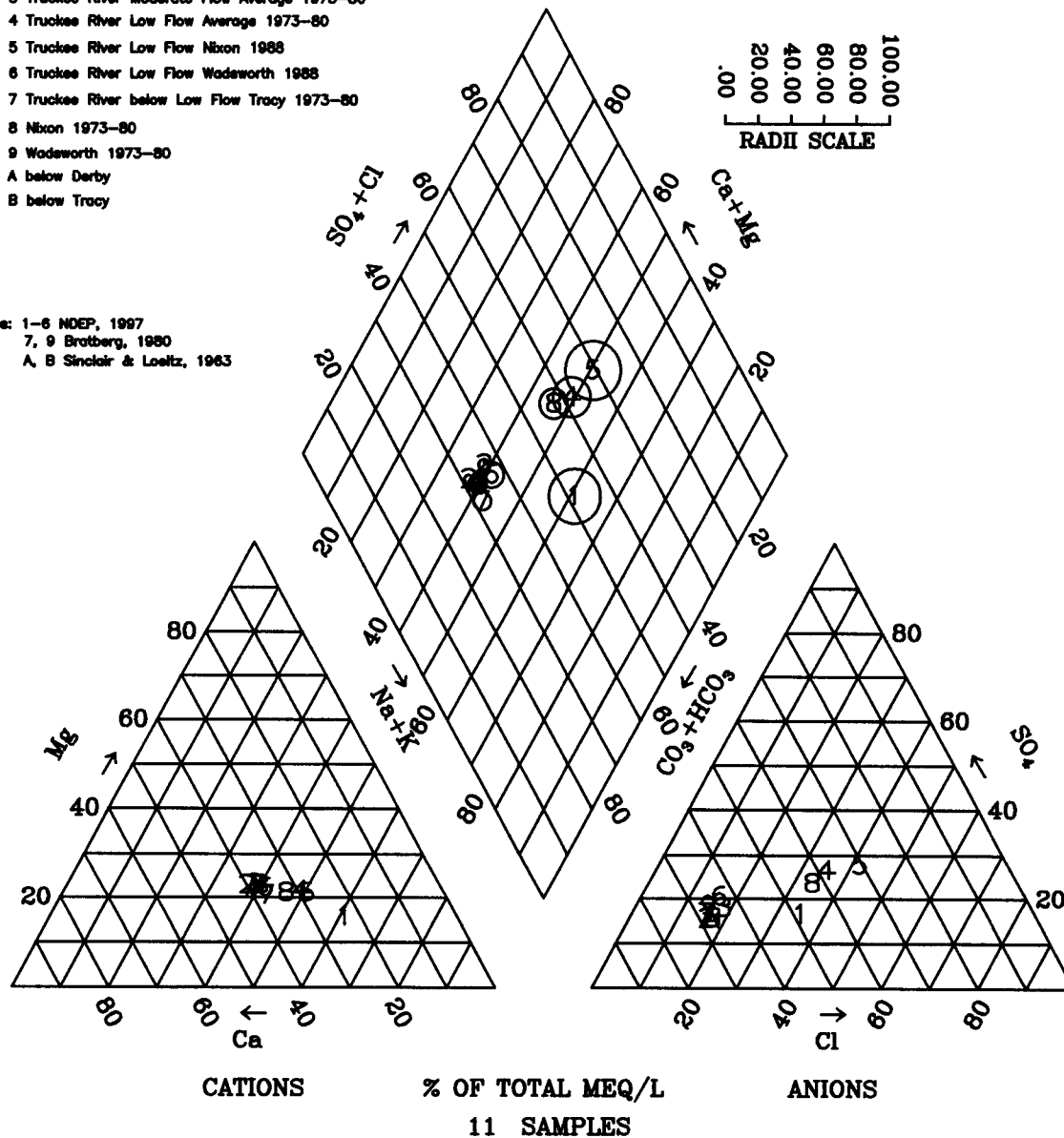
Plots conforming to average water well compositions could, however, derive from the input of high-Cl⁻ Patua-type geothermal waters to that from the Truckee. Alternatively, differing mineralogical composition within the sediments could be assumed to account for the groundwater differences, *e.g.*, excess halite between Fernley and the Truckee Canal. Agricultural impacts such as evapotranspiration and fertilization may also contribute, and should be evaluated.

The implication is that evaporite minerals in sediments may not have provided solutes to the Fernley area wells; based solely on composition, surface waters might have done so. This is evidenced by analyses from groundwater Fernley Sample Site 80 (Rowe, *et al.*, 1991), which was taken from sediment immediately underlying a saline portion of the Fernley Drain flow system. Water in that system derives from surface agricultural runoff. Ionic proportions in the downstream portions of the drains closely resemble that from the evaporites hypothesized for Dodge Flat, though concentrations are much greater (Figures F.1 and F.3). This is particularly apparent at the North and Northeast ponds, which adjoin playas. The similarity of present-day playa water to that beneath Dodge Flat supports but does not confirm the hypothesis of evaporite-derived solutes. Though it is beyond the scope of the present investigation, this resemblance also suggests that the possibility of indirect surface playa water contributions to the Truckee River near Fernley should be examined.

Surface Water Sites

- 1 Steamboat Creek
- 2 Truckee River High Flow Average 1973-80
- 3 Truckee River Moderate Flow Average 1973-80
- 4 Truckee River Low Flow Average 1973-80
- 5 Truckee River Low Flow Nixon 1988
- 6 Truckee River Low Flow Wadsworth 1988
- 7 Truckee River below Low Flow Tracy 1973-80
- 8 Nixon 1973-80
- 9 Wadsworth 1973-80
- A below Derby
- B below Tracy

Sources: 1-6 NDEP, 1997
7, 9 Bratberg, 1980
A, B Sinclair & Loeltz, 1963



waterresource consulting engineers, inc. <small>700 THREE STREET - DENVER, COLORADO - 80202</small>			FERNLEY TOWN UTILITIES LYON COUNTY		JOB NO. 8516.1142 DATE 10/28/98 DRN. BY LCS CHK. BY JL
DATE	REVISIONS	BY	Major Constituents, Truckee River and Steamboat Creek - Figure F.5		



APPENDIX G

**FERNLEY CREDIT STORAGE
WATER SUPPLY ANALYSIS
SIERRA HYDROTECH**

FAX NOTE

To: George Ball
Subject: Fernley Water Supply Analysis
Date: May 5, 1997
From: Rod Hall

This is a brief transmittal with some discussion of the investigation that you and Rebecca Harold have requested. Maybe this will provide something to discuss. A more complete description of the analyses can be provided later.

Basic Assumptions

Basic assumptions for the investigation are those used for the TROA EIS/EIR analysis and for the February 1997 analysis of Fernley and TCID credit storage. A few characteristics of this approach are as follows:

1. Analysis was conducted with the Truckee monthly operation model used for EIS/EIR studies. Modifications necessary to incorporate items to be analyzed for these studies were made.
2. Analysis period was 95 years representing the historic climatic conditions of 1901 through 1995.
3. Tahoe basin fully utilized the California and Nevada water allocations provided in PL101-618.
4. California Truckee basin utilized 1,500 acre-feet of surface water (M&I storage 300 acre-feet and diversion supply 1,200 acre-feet) plus 7,300 acre-feet of surface water for recreation and instream flow (from Joint Program Fish Credit). These two when combined with 1,200 acre-feet of current surface water use represent the 10,000 acre-feet allocated to California.
5. California Truckee basin utilized 17,600 acre-feet of groundwater, which is 12,800 acre-feet more than the 4,800 acre-feet of groundwater assumed to represent current use.

6. Sierra Pacific normal year demand is 119,000 acre-feet.
7. TMWRF production is 67,070 acre-feet per year.
8. Newlands Project is operated in accordance with the 1988 OCAP and Carson Division annual demand is 264,500 acre-feet. The Truckee Division annual demand before being reduced by acquisition of water rights for water quality and Fernley is 23,000 acre-feet.
9. The Water Quality Agreement is fully implemented and 24,000 acre-feet of water rights have been assigned to water quality (12,000 from the Truckee Division of Newlands).
10. Sierra's Orr Ditch hydrogeneration water rights were assumed to be waived for these studies.

Fernley Supply and Demand Assumptions

Fernley is assumed to acquire 4,500 acre-feet of Truckee Division water rights and Fernley is allowed to use the 4,500 acre-feet provided from the rights directly plus the assumed 1,500 acre-feet of reduction in (TCID) distribution system losses. These losses do not include any losses in the Truckee Canal.

The normal year water supply provided by the water right acquisition and the normal year Fernley water demand assumptions are tabulated below. The Fernley water demand is provided for two schedules, one that matches the Truckee Division agricultural demand schedule and one that is an assumed M&I demand schedule.

Table No. 1			
Month	Water Supply	Demand on Agricul. Schedule	Demand on M&I Schedule
	(ac-ft)	(ac-ft)	(ac-ft)
January	0	0	260
February	0	0	240
March	30	20	260
April	400	300	340
May	1110	830	450
June	1160	870	520
July	1200	900	580
August	1050	790	550

Table No. 1 continued			
September	670	500	450
October	330	250	340
November	50	40	260
December	<u>0</u>	<u>0</u>	<u>250</u>
Annual	6000	4500	4500

The M&I schedule is estimated based upon the assumed demand schedule of Sierra. It may have a somewhat smaller month to month variation that should be applicable to Fernley. To the extent that is the case, the Fernley water supplies calculated in this analysis may be a bit conservative.

General Description of Analyses

Seven analyses were conducted. The first analysis has no supply for Fernley. That was run so that some of the results could be compared.

Six analyses were run to provide a Fernley water supply. Fernley water supply was provided by first using any water that would have been diverted to the Truckee Division to supply water rights Fernley is assumed to acquire. That is, any water supplies associated with water acquisition listed in the second column would be used to supply Fernley demand (as identified using either column three or four).

When the water supply provided by the column two acquisition exceeds current month Fernley demand, that water may be stored in a Truckee reservoir (Tahoe, Prosser, Stampede or Boca) if allowed by physical conditions and operation criteria.

When the column two water supply would not supply Fernley demand (columns three or four), Fernley storage in a Truckee reservoir was released.

Results of the analyses are summarized in Table 2 (attached). The six analyses are briefly described as follows:

Basic (Ag Demand Sched) #1

This study is comparable to Fernley studies presented in February that included limitations on Fernley storage whenever Truckee River flow was less than necessary for water quality purposes. These supplies are somewhat less than presented in the February report. This occurs primarily because of changes in storage priority that have

been negotiated since those studies were started. As the tabulation indicates, the least annual supply is 2,105 acre-feet and there are four years when the full 4,500 acre-feet would not be provided.

M&I Demand Sched #2

This applies the same criteria as study #1 except the Fernley demand schedule is that listed in column four (M&I schedule) of the above Table 1. The dry year supply is slightly better than calculated for the agricultural demand schedule (study #1). But, the number of short supply years increases dramatically. The primary water supply problem occurs in the winter. Attached is a table showing the monthly supply for the 1901-1995 analysis period. Shortage occurs in the winter because either storage spills during wet years, leaving no supply for Fernley, or because summer water quality restrictions prevent accumulation of enough storage for Fernley to a supply during November through March.

Wat. Exch. & M&I Dmd Sch. #2m

This analysis applies the same (M&I) demand and criteria as study #2 except for one very important modification. In this analysis, there is a seasonal exchange of water supply among Fernley, TCID, and Pyramid Lake.

Review of conditions during which the Truckee Division can receive a water supply indicates that the minimum Truckee Division water supply can be related to Pooled Water storage in Lake Tahoe and Boca. If one assumes that such information is used in an operation, then it could be possible for Fernley to divert and store water during the winter based upon the assurance that water for Truckee Division rights would be available during the upcoming irrigation season. Using such seasonal exchange, water was borrowed from either the Carson Division (of TCID) or from Pyramid Lake. The water was either diverted to serve Fernley's winter demand or put into Fernley storage during the winter. Then, during the summer, an equivalent amount of water was turned over either to the Carson Division or Pyramid Lake, as appropriate. This provided a dramatic improvement in Fernley water supply, as is indicated by the attached Table 2. This is also illustrated by the attached table showing monthly Fernley supply for study #2m.

Unfortunately, November frequently ran short of water in this analysis. I believe much of this problem could have

been avoided by a little better operation. Rather than make additional analysis, that observation is offered for consideration.

It can be noted from the attached table that the least annual supply occurs in 1993. All storage is used during 1992 and by December (1992 calendar or 1993 water year) there is no Fernley water supply.

W.Q. Crit. Relax. & M&I Sch #3

This analysis is the same as study #2 except Fernley is allowed to store (during June through September) as long as Truckee flow at Sparks is 200 cfs or more. (Several runs were made using greater Sparks flow as a limit, but they provided significantly less benefit to Fernley.)

This analysis shows improvement in Fernley water supply when compared to study #2. Although, there continue to be many winter periods when storage is not sufficient and Fernley runs out of water.

The Fernley 1992 and 1993 water supplies are similar to those for study #2m except this study (#3) has a bit less water than study #2m.

Wat. Exch. & WQ Rlx & M&I S #3m

This study is the same as study #3 except it applies the criteria that allow winter diversion and storage, as described for study #2m. The supply is essentially the same as that calculated for study #2m. The November-March Fernley supply is much better than study #3's supply because study #3 does not include the seasonal exchange of water.

No W.Q. Crit & M&I Dmd. Sch #4

To look for the limit of Fernley water supply that could be obtained if there were to be no water quality related limits, this study was run. The water supply is slightly better than calculated for study #3.

Limits on Fernley Storage

All studies were run using a limit of 10,000 acre-feet upon the total Fernley storage in Truckee reservoirs. I was asked to look at the impact of raising the limit on total Fernley storage. As the attached tabulation indicates no study accumulated more than 6,500 acre-feet, so it did not seem necessary to study a greater limit.

Impacts on Newlands Project, Carson Division

There is essentially no impact of these operations upon the Carson Division. Average annual shortage is reduced slightly when Fernley acquires water and uses it as an M&I supply. That occurs because reduction in Truckee Division demand during dry years can result in slightly greater water supply being available for the Carson Division.

Impacts on Pyramid Lake and Cui-ui

The Pyramid Lake inflows are modestly increased by the Fernley supply operation. This occurs because some of the water acquired by Fernley is not used and there is a reduction in Truckee Canal loss associated with reduced supply to the Truckee Division. These waters flow into Pyramid Lake. Also, the cui-ui index is slightly improved. But, my judgment would be that the cui-ui index calculation is too subject to computational factors that may not accurately reflect very small changes in cui-ui habitat. and no conclusions should be drawn. (I need to add that I have no expertise in cui-ui biology or habitat.)

Table No. 2
SUMMARY OF IMPACTS FROM ANALYSIS OF FERNLEY WATER SUPPLY OPERATION
(May 5, 1997)

	Fernley Supply Summary						Pyramid Summary		Newlands Average Carson Div. Shortage (1000 A-F) 6.19
	Average Annual Supply (1000 A-F)	Least Annual Supply (1000 A-F)	1992 Cal. Yr. Supply (1000 A-F)	No. Short Years Included	Novembr Not Incl.	Maximum Reservior Storage (1000 A-F)	Average Pyramid Inflow (1000 A-F)	Cui-Ui Index (1000 A-F)	
No Fernley Supply	0	-----	-----	-----	-----	-----	487.60	434.39	6.19
Base (Ag Demand Sched)	1	4.425	2.105	4	4	1.82	490.76	463.93	6.16
M&I Demand Sched	2	3.792	2.250	69	69	1.37	491.23	461.78	6.16
Wat. Exch. & M&I Dmd Sch.	2m	4.417	3.717	33	2	5.46	490.65	458.89	6.16
W.Q. Crit. Relax. & M&I Sch	3	4.082	3.300	41	41	5.88	491.21	461.91	6.16
Wat. Exch & WQ Rlx & M&I S	3m	4.418	3.717	33	2	6.41	490.67	458.90	6.16
No W.Q. Crit & M&I Dmd. Sch	4	4.088	3.300	41	41	5.88	491.21	461.91	6.17

FERNLEY WATER SUPPLY

Run No. 2

R. Harold, in. 2 -- M&I Demand Schedule for Fernley Investig.

Page No. 1

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Jaary	Febry	March	April	May	June	July	Augst	Septb	Annual
1901	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1902	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1903	.340	.210	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.470
1904	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1905	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1906	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1907	.340	.141	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.401
1908	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1909	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1910	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1911	.340	.260	.250	.155	.000	.030	.340	.450	.520	.580	.550	.450	3.925
1912	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1913	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1914	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1915	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1916	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1917	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1918	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1919	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1920	.340	.260	.250	.158	.000	.030	.340	.450	.520	.580	.550	.450	3.928
1921	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1922	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1923	.340	.260	.250	.063	.000	.030	.340	.450	.520	.580	.550	.450	3.833
1924	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1925	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1926	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1927	.340	.260	.250	.255	.000	.030	.340	.450	.520	.580	.550	.450	4.025
1928	.340	.260	.250	.163	.000	.030	.340	.450	.520	.580	.550	.450	3.933
1929	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1930	.340	.260	.250	.228	.000	.030	.340	.450	.520	.580	.550	.450	3.998
1931	.340	.260	.250	.173	.000	.030	.340	.450	.520	.328	.000	.387	3.078
1932	.331	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.301
1933	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1934	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.060	.387	3.947
1935	.332	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.302
1936	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1937	.340	.260	.250	.162	.000	.030	.340	.450	.520	.580	.550	.450	3.932
1938	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1939	.340	.053	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.313
1940	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1941	.340	.260	.250	.221	.000	.030	.340	.450	.520	.580	.550	.450	3.991
1942	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1943	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1944	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1945	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500

FERNLEY WATER SUPPLY

Run No. 2

R. Harold in 2 -- M&I Demand Schedule for Fernley Investig.

Page No. 2

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Janrg	Febry	March	April	May	June	July	Augst	Sept	Annual
1946	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1947	.340	.260	.250	.111	.000	.030	.340	.450	.520	.580	.550	.450	3.881
1948	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1949	.340	.260	.250	.219	.000	.030	.340	.450	.520	.580	.550	.450	3.989
1950	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1951	.340	.260	.250	.260	.240	.030	.340	.450	.520	.580	.550	.450	4.270
1952	.340	.260	.250	.260	.240	.083	.340	.450	.520	.580	.550	.450	4.323
1953	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1954	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1955	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1956	.340	.156	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.416
1957	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1958	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1959	.340	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.310
1960	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1961	.340	.260	.250	.222	.000	.030	.340	.450	.520	.580	.550	.450	3.992
1962	.340	.260	.250	.160	.000	.030	.340	.450	.520	.580	.550	.450	3.930
1963	.340	.260	.250	.163	.000	.030	.340	.450	.520	.580	.550	.450	3.933
1964	.340	.260	.250	.160	.000	.030	.340	.450	.520	.580	.550	.450	3.930
1965	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1966	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1967	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1968	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1969	.339	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.499
1970	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1971	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1972	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1973	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1974	.340	.260	.250	.222	.000	.030	.340	.450	.520	.580	.550	.450	3.992
1975	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1976	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1977	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1978	.340	.094	.000	.260	.240	.176	.340	.450	.520	.580	.550	.450	4.000
1979	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1980	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1981	.340	.260	.151	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.671
1982	.340	.260	.250	.260	.240	.030	.340	.450	.520	.580	.550	.450	4.270
1983	.331	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.301
1984	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1985	.340	.260	.250	.152	.000	.030	.340	.450	.520	.580	.550	.450	3.922
1986	.340	.260	.250	.260	.240	.030	.340	.450	.520	.580	.550	.450	4.270
1987	.340	.260	.250	.140	.000	.030	.340	.450	.520	.580	.550	.450	3.910
1988	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1989	.340	.231	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.491
1990	.340	.260	.250	.260	.240	.078	.340	.450	.520	.580	.550	.450	4.318

FERNLEY WATER SUPPLY

Run No. 2

R. Harold. in. 2 -- M&I Demand Schedule for Fernley Investig.

Page No. 3

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Janry	Febry	March	April	May	June	July	Augst	Septb	Annual
1991	.340	.077	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.337
1992	.340	.076	.000	.000	.000	.030	.340	.450	.520	.133	.000	.387	2.276
1993	.330	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.300
1994	.340	.260	.250	.162	.000	.030	.340	.450	.520	.310	.000	.387	3.049
1995	.331	.050	.000	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.301
Average	.336	.169	.133	.122	.081	.096	.340	.450	.520	.570	.527	.447	3.792
Minimum	.330	.050	.000	.000	.000	.030	.340	.450	.520	.133	.000	.387	2.276

FERNLEY WATER SUPPLY

Run No. 2n

R. Harold in. 2n-- N&I Demand Schedule for Fernley Investig.

Page No. 1

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Janry	Febry	March	April	May	June	July	Augst	Septb	Annual
1901	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1902	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1903	.340	.209	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.449
1904	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1905	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1906	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1907	.340	.141	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.381
1908	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1909	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1910	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1911	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1912	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1913	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1914	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1915	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1916	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1917	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1918	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1919	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1920	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1921	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1922	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1923	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1924	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1925	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1926	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1927	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1928	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1929	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1930	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1931	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1932	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1933	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1934	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1935	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1936	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1937	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1938	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1939	.340	.109	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.349
1940	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1941	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1942	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1943	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1944	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1945	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500

FERNLEY WATER SUPPLY

Run No. 2n

R. Harold. in. 2n-- M&I Demand Schedule for Fernley Investig.

Page No. 2

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Janry	Febry	March	April	May	June	July	Augst	Sept	Annual
1946	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1947	.340	.260	.250	.260	.239	.260	.340	.450	.520	.580	.550	.450	4.499
1948	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1949	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1950	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1951	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1952	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1953	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1954	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1955	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1956	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1957	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1958	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1959	.340	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.290
1960	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1961	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1962	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1963	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1964	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1965	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1966	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1967	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1968	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1969	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1970	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1971	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1972	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1973	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1974	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1975	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1976	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1977	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1978	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1979	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1980	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1981	.340	.260	.250	.260	.239	.260	.340	.450	.520	.580	.550	.450	4.499
1982	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1983	.331	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.281
1984	.330	.050	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.280
1985	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1986	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1987	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1988	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1989	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1990	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500

FERNLEY WATER SUPPLY

Run No. 2n

R. Harold. in. 2n-- M&I Demand Schedule for Fernley Investig.

Page No. 3

5 MAY 1997

(Supply in 1000 acre-feet)

Year	Octbr	Novbr	Decbr	Janry	Febry	March	April	May	June	July	Augst	Septb	Annual
1991	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1992	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1993	.340	.260	.197	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.717
1994	.340	.260	.250	.260	.240	.260	.340	.450	.520	.580	.550	.450	4.500
1995	.340	.260	.250	.260	.103	.030	.340	.450	.520	.580	.550	.450	4.133
Average	.337	.193	.249	.257	.236	.255	.340	.450	.520	.580	.550	.450	4.417
Minimum	.330	.050	.197	.000	.000	.030	.340	.450	.520	.580	.550	.450	3.717