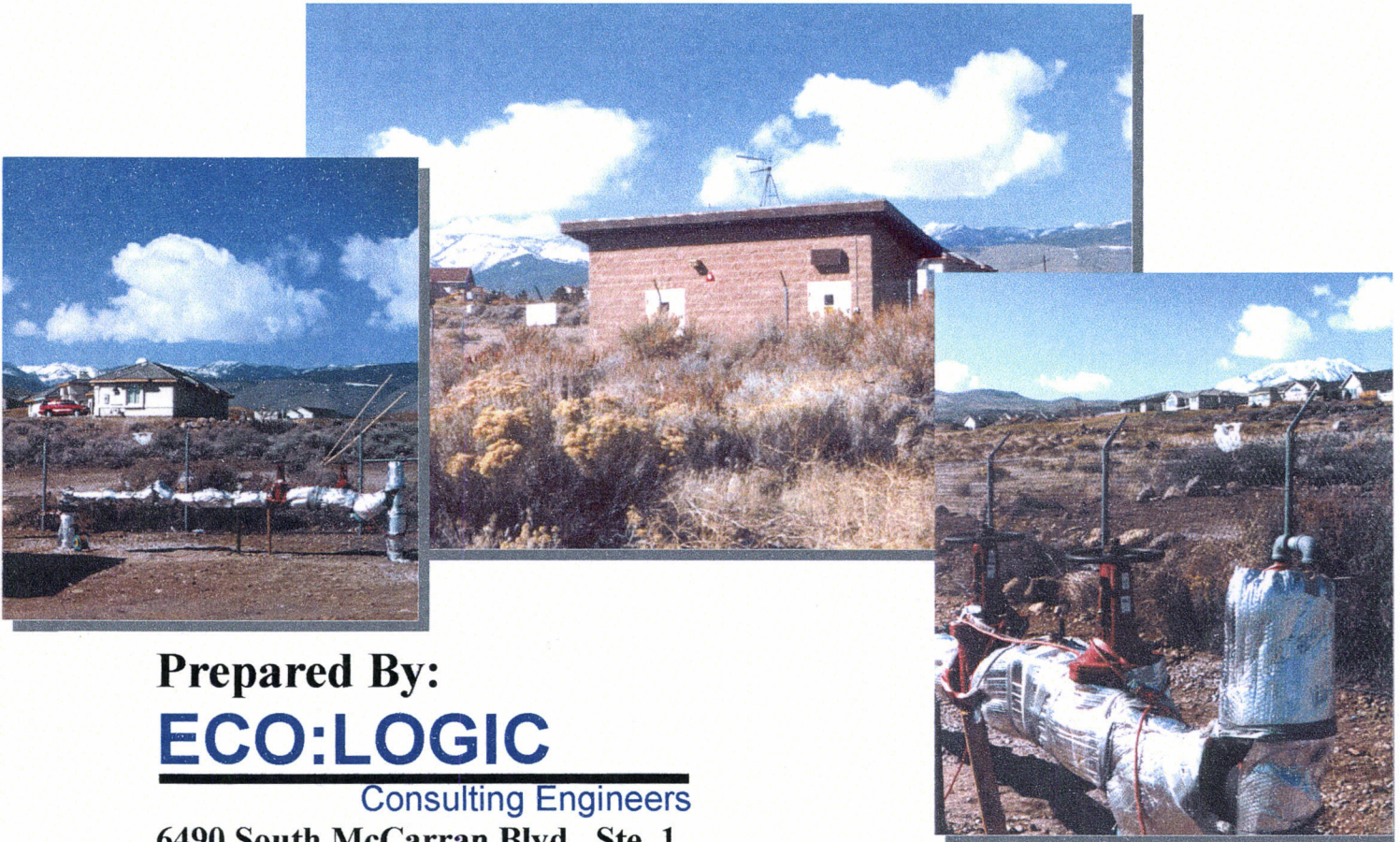


DRAFT
Pilot Aquifer Storage and Recovery Test
STMGID Well No. 1

Washoe County Regional Water Planning Commission
South Truckee Meadows General Improvement District



Prepared By:

ECO:LOGIC

Consulting Engineers

6490 South McCarran Blvd., Ste. 1

Reno, NV 89509

Tel. 775-827-2311

Fax 775-827-2316

and

Plumas Geohydrology

P.O. Box 1922

Portola, California 96122

Telephone: 530-836-2208

530-836-0959

Under subcontract to:

AMEC

Infrastructure Unit

9450 Double R Blvd.

Reno, Nevada 89511

Project Number: 01300

Draft

**PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1**

Prepared for:

Washoe County Regional Water Planning Commission
South Truckee Meadows General Improvement District

May 24, 2001

Prepared by:

Dale C. Bugenig
Senior Hydrogeologist
bugenig@ecologic-eng.com

Burkhard Bohm. Ph.D.
Principal Geochemist
pgh@psln.com

Reviewed by:

Plumas Geo-Hydrology
P.O. Box 1922
Portola, California 96122
Telephone: 530-836-2208
Fax: 530-836-0959

John P. Enloe, P.E.
Principal
Enloe@ecologic-eng.com

ECO:LOGIC Engineering, LLC
6490 South McCarran Blvd., Ste. 1
Reno, Nevada 89509

TABLE OF CONTENTS

1.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	1-1
1.1 Summary	1-1
1.2 Conclusions	1-2
1.3 Recommendations	1-3
2.0 Introduction.....	2-1
2.1 Project Description And Objectives.....	2-1
2.2 Study Area	2-4
2.3 Project Team	2-4
3.0 Hydrogeology	3-1
3.1 Physical Setting	3-1
3.2 Conceptual Model Of The Groundwater Flow System.....	3-1
4.0 STMGID-1 Injection Test.....	4-1
4.1 Well Selection & Instrumentation	4-1
4.1.1 Injection Well and Recovery Well	4-1
4.1.2 Observation Well Network	4-1
4.1.3 Instrumentation.....	4-5
4.2 Pre-Test Water-Level Data Collection.....	4-6
4.3 Injection Test Summary	4-8
4.3.1 Water Supply And Flow Control Equipment.....	4-8
4.3.2 Test Chronology	4-9
4.4 Analysis Of Injection Test Data.....	4-9
4.4.1 Injection Well and STMGID-1	4-10
4.4.2 Dible Well	4-13
4.5 Suspended Solids and Plugging Potential	4-15
5.0 Analysis Of Water Storage And Recovery Efficiency.....	5-1
5.1 Model Features	5-1
5.2 Results Of The Simulation	5-4
5.3 Simulated Water Level Rise Due To Injecting Larger Quantities of Water.....	5-10
6.0 Geochemical Tracers And Particle Loads ^(a)	6-1
6.1 Water Samples And Chemical Measurements	6-1
6.1.1 General.....	6-1
6.1.2 Environmental Isotopes And Major Ions	6-2
6.2 Changes In STMGID-1 And The Dible Monitoring Well.....	6-4
6.2.1 Isotopes	6-4
6.2.2 Field Water Quality Parameter Data	6-4
6.3 Mixing Processes Evident In Isotopes, Major Ions And Total Trihalomethanes.....	6-7
6.4 Subsurface Mixing And Mineral Deposition Potential.....	6-8
6.4.1 Mixing Calculations.....	6-9
6.4.2 Chemical Equilibria During Mixing	6-10
6.5 Suspended Matter Loads.....	6-11
6.5.1 Data Collection	6-11
6.5.2 Suspended Solids Concentrations.....	6-11
7.0 Sources Of Information.....	1

TABLE OF CONTENTS

LIST OF FIGURES

- Figure 1. Location Map
Figure 2. STMGID-1 ASR Pilot Test Study Area
Figure 3. Water-Level Contour Map
Figure 4a. Geologic Map
Figure 4b. Geologic Map Explanation
Figure 5. Construction Summary And Lithology For STMGID-1 And The Injection Well
Figure 6. Detail Of Flow Control Equipment At The Injection Well, MW-1
Figure 7. Map Of Monitoring Well Network
Figure 8. Water Level Data For Dible Well, MW-2 And MW-3
Figure 9. Historical Water-Level Data For MW-2.
Figure 10. Water Level Data For The Injection Well And STMGID-1
Figure 11. Injection Test Data For The Injection Well And STMGID-1
Figure 12. Injection Test Recovery Data For The Injection Well And STMGID-1
Figure 13. Injection Test Recovery Data For STMGID-1
Figure 14. Injection Test Data For The Dible Well (Semi-Log Plot)
Figure 15. Injection Test Data For The Dible Well (Arithmetic Plot)
Figure 16. Injection Test Data For The Dible Well (Log-Log Plot)
Figure 17. Model Domain
Figure 18. Comparison Of Observed And Simulated Water Levels For The Injection Well.
Figure 19. Comparison Of Observed And Simulated Water Levels For STMGID-1.
Figure 20. Comparison Of Observed And Simulated Water Levels For The Dible Well
Figure 21. Map Of Simulated Residual Water Level Rise 3 Months After Injecting 65 Acre-Feet Of Water
Figure 22. Map Of Simulated Residual Water-Level Rise 3 Months After Injecting 325 Acre-Feet Of Water
Figure 23. Stable Isotope Data, South Truckee Meadows Area, Reno, Nevada
Figure 24. Well Water Level Changes And Isotopes In The Dible Domestic Well, ASR Pilot Test, South Truckee Meadows.
Figure 25. Temperature, EC And DO In Injected Water And Pumped Water, STMGID-1 ASR Pilot Project
Figure 26. Levels Of pH In Injected Water And Pumped Water, STM ASR Pilot Project

LIST OF TABLES

- Table 1: Percent Injected Water Contained In Recovered Water STMGID-1 ASR Pilot Test
Table 2: Water Chemistry Data Collected In August 1999, South Truckee Meadows, ASR Pilot Project
Table 3. Suspended Solid Loads In Injection Water, STMGID-1 ASR Pilot Injection Test.

1.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

A total of approximately 65.1 acre-feet of treated surface water from the Chalk Bluff Water Treatment Plant was injected via Monitoring Well 1 at the STMGID-1 well site in the southern Truckee Meadows as part of a pilot Aquifer Storage and Recovery test. The injection phase of the test commenced January 20, 2000 and concluded March 27, 2000. The recovery portion of the test commenced April 4, 2000 and was concluded May 2, 2000 once the volume of water injected was extracted.

Water-level data prior to and during the pilot test were collected from the Injection Well (MW-1), STMGID-1, and three other observation wells. These included a nearby residential water-supply well (the Dible Well) that was converted to a monitoring well and two monitoring wells maintained by the Washoe County Department of Water Resources, referred to as MW-2 and MW-3. Data collection commenced in October 1999 and continued through the completion of the recovery portion of the test.

The injection test water-level data were analyzed to determine the hydrologic parameters of the aquifer in the vicinity of STMGID-1. Transmissivity, the overall ability of the aquifer to transmit groundwater, was calculated to be in the range of 1,340 to 1,400 feet²/day. Taking into consideration the thickness of the aquifer, the average Horizontal Hydraulic Conductivity was determined to be approximately 3.4 feet/day. The aquifer was found to be vertically anisotropic. That is, the Vertical Hydraulic Conductivity was determined to be less than the Horizontal Hydraulic Conductivity and was calculated to range between 10⁻⁴ and 0.5 feet/day. Delayed yield conditions were found to pre-dominate in the aquifer. Values for the Coefficient of Storage ranged from approximately 6x10⁻⁴ early in the test to 3x10⁻² late in the test.

Two parallel impermeable boundaries – one west of STMGID-1 and one east of STMGID-1 - were suggested by the test data from the Dible Well. This may represent one of the few occurrences where geologic faults have been recognized in pumping test data from wells completed in the alluvial deposits of the Mt Rose fan.

A simplified numerical model of the aquifer near STMGID-1 was constructed. The model was used to evaluate whether or not the groundwater mound resulting from injection would remain long enough so that the injected water could be recovered at a later date.

Water chemistry data were collected from the water injected into the aquifer via MW-1 at the STMGID-1 site during the injection phase and from the water recovered via pumping STMGID-1 during the recovery phase of the pilot study. Water chemistry data were also collected from the Dible Well throughout the test. The chemical data were examined in order to analyze the potential for adverse chemical reactions that might plug the aquifer with chemical precipitates. The data were also examined to determine how much of the injected water was recovered. In addition, the injected water was analyzed to determine the concentration and size distribution of suspended particulate matter in the injected treated surface water from Chalk Bluff. The purpose was to determine the potential for well deterioration due to plugging with suspended solids.

1.2 Conclusions

No response to injection was noted in the more distant observation wells (MW-2 and MW-3). However, these wells were useful for distinguishing regional or seasonal water-level trends in the aquifer and comparison with long-term trends that might have influenced the data from the test.

Seasonal water-level trends were significant during the ASR Pilot Study. These trends needed to be removed from the data from the Injection Well (MW-1), STMGID-1 (an observation well during the injection phase and the recovery well during the extraction phase), and the Dible Well (the nearest observation well).

Water levels in the shallower part of the aquifer near the Dible Well, located approximately 380 feet from the Injection Well, rose 1.5 feet by the end of the injection test. Approximately one week after injection ceased, and before the recovery portion of the test commenced, the residual groundwater mound near the Dible Well resulting from injection was approximately 0.7 feet.

Geologic faults appear to impede groundwater flow in the alluvial deposits. Displacement along the faults is believed to smear the fault plane with the finer grained fraction of the heterogeneous alluvial deposits. The presence of these faults is key to an ASR program in this area. The faults are expected to help retain the stored water and prevent it from moving rapidly down-gradient beyond the influence of recovery wells.

Analysis of the fate of the groundwater mound resulting from injection of 65.1 acre-feet during the test indicates that it will remain for at least several months after injection ceases. This translates to a volume of water that can be stored in the aquifer for extraction at a later date.

Electrical conductivity (EC), temperature and dissolved oxygen (DO) data suggest that most of the injected water's solute load was retrieved during extraction. However, a small percentage of total dissolved solids (TDS) and total trihalomethanes (TTHMs) were still in the aquifer by the time the extracted volume equaled the injected volume. As expected, these solutes were apparently dispersed by groundwater flow.

An evaluation of mineral precipitation potential due to injection (and subsurface mixing) resulted in finding no conceivable potential adverse impacts. This is due to the excellent quality of both ground water and injection water.

The data from this pilot study adds significantly to the understanding of recharge in the South Truckee Meadows (STM) area and will help define the direction for future groundwater recharge investigations. The isotope data suggests that groundwater pumped from the deep wells in the STM is not necessarily water recharged solely by stream bed infiltration. It maybe a mixture of deeper groundwater recharged in the Carson Range to the west, and recharge from the irrigation ditches. The shallow domestic wells (like the Dible Well) are pumping a mixture of deep aquifer water and water recharged by ditch infiltration, though the proportion of irrigation water is significantly higher.

Injection resulted in significant chemical changes in the aquifer. The resulting chemistry is an indication of subsurface mixing between ambient groundwater and injected water. Although water levels in the Dible domestic well, located about 380 feet west of the injection well, responded markedly to the injection event, isotope tracers changes were insignificant. This

information suggests that the injection plume did not reach this well. EC data from the Dible well showed no significant variation and supports this conclusion.

The surface water injected at MW-1 contained measurable suspended particulate matter in the range of 3 to 8 microns in size. These materials plugged the pore space in the aquifer in the vicinity of the borehole / formation interface. The potential for plugging underscores the need to filter even high-quality treated surface water that is injected at this locale.

The pilot Aquifer Storage and Recovery (ASR) study yielded positive results. That is, it appears that water can be successfully stored in the southwest Truckee Meadows / Mt. Rose alluvial fan aquifer for recovery at a later date. However, only a small volume of water equivalent to four percent of the annual groundwater withdrawals via wells was stored in the aquifer during the pilot study. As a consequence, the water level mound was relatively small in extent and was nearly obscured by regional or seasonal water-level fluctuations.

While seasonal ASR appears to be feasible, the available information does not conclusively indicate whether long-term water storage or water banking is a viable water-supply strategy at this locale. A larger-scale injection program is needed to further evaluate the effectiveness of water banking.

1.3 Recommendations

Future testing is recommended. Any future tests should be conducted with the aim of injecting larger volumes of water into the aquifer. By injecting larger volumes, the effect of artificial recharge will be more obvious. It may be appropriate to construct new wells for this purpose, rather than utilizing existing wells. Wells constructed for testing purposes should be completed such that they can be used for both injection and recovery. Use of the same well for injection and recovery is important in maintaining the integrity of the injection well. Plugging of the Injection Well during the Pilot Study highlighted the importance of maintaining well integrity.

Particulate matter loads in the injected water are significant and led to plugging of the Injection Well during the Pilot Study. Installation of a filter device at the injection wellhead is advisable to minimize plugging potential, particularly if the injection wells have no provision for pumping.

The STMGID-1 ASR pilot study underscores the importance of water-level data from remote water-level monitoring wells. The observed water level effects resulting from the day-to-day operation of production wells will be minimized if monitor wells are located some distance from the production facilities. This will lead to a clearer picture of the aquifer response to recharge.

2.0 Introduction

2.1 Project Description And Objectives

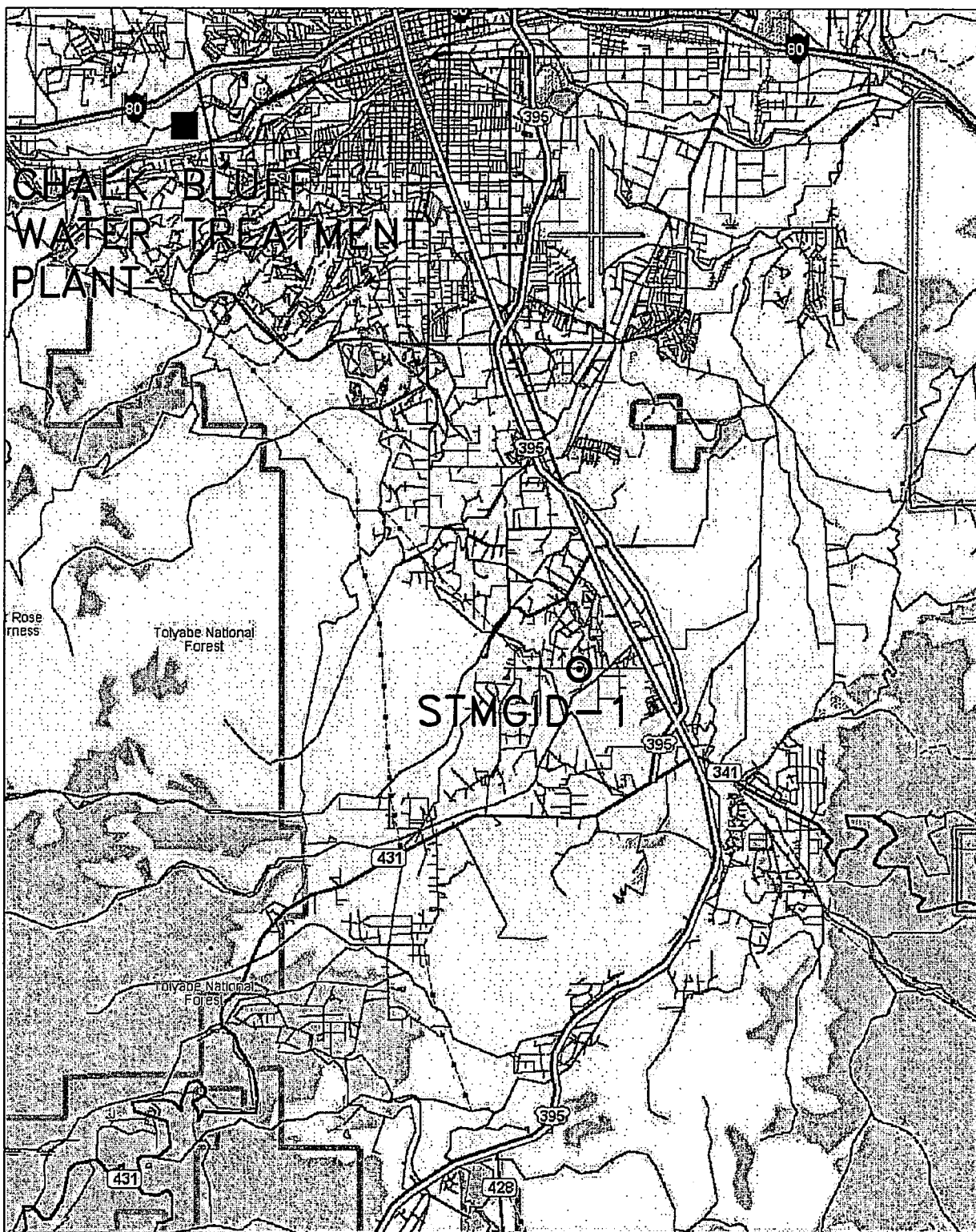
In 1997, the Water Planning Division of the Washoe County Department of Water Resources initiated an investigation of aquifer storage and recovery (ASR) in the alluvial aquifer of the southwest Truckee Meadows (Figure 1). The results of the study are provided in the report entitled Feasibility analysis of a pilot groundwater recharge project and analysis of the surface water contributions to the shallow aquifer in use by domestic well owners in the south Truckee Meadows (CES, Inc.: Plumas Geo-Hydrology; and EGR & Associates; 1998). The study examined the concept of conjunctive use of surface and groundwater. It addressed storing surface water from the Chalk Bluff water treatment plant in the aquifer during winter months when demand is low and recovering the water from wells during the summer months when demand is high. The study concluded that seasonal aquifer storage and recovery was economically and technically feasible. The study also concluded seasonal storage was more appropriate than long-term storage or water banking.

The 1998 feasibility study identified and ranked sites where existing facilities might be used for a pilot ASR program. A pilot study was necessary to devise a full-scale ASR program and obtain the necessary permits. The highest-ranking site for a pilot study using existing facilities was found to be South Truckee Meadows General Improvement District Well No. 1 (STMGID-1). The location of STMGID-1 is shown in Figure 2.

A subsequent and related study is described in Analysis of aquifer storage and recovery in the south Truckee Meadows utilizing a recharge well located at the TH-2 site (CES, Inc. and EGR & Associates, 1999). This study examined ASR where injection was proposed for a site located approximately 3,000 feet west of STMGID-1 and recovery of the stored water accomplished via STMGID-1. The analysis used a simplified numerical model of groundwater flow in the aquifer at this locale to evaluate changes in water levels in the aquifer due to injection and recovery. It also assessed whether or not the stored water could be recovered efficiently. The study concluded STMGID-1 had the potential to capture 85% of the water injected at the TH-2 site, but that the water level rise near STMGID-1 would be relatively small because of the distance from the injection site. Furthermore, it was expected to take up to 10 years for the water to migrate from the injection well to the recovery well, although the pressure response occurs much more quickly. The study also concluded that seasonal storage was more effective if the injection and recovery wells are either closely spaced or contained in the same facility.

In 1999, the Washoe County Regional Water Planning Commission and the South Truckee Meadows General Improvement District (STMGID) engaged Consulting Engineering Services to conduct a pilot ASR study employing existing well facilities. STMGID-1 was selected for the pilot study because of its high ranking in the original feasibility analysis. Factors influencing its selection for the pilot study included:

The site included a Washoe County monitoring well that had potential for use as an injection well. Minimal construction was needed to prepare the site for use in the pilot study. Consequently, the pilot study could be performed without the need to drill a well specifically for the test.



3-D Topo Quads Copyright © 1999 Delorme Yarmouth, ME 04096

1"=2000 ft

Detail: 11.0, Datum: WGS84

WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 2

STMGID-1 ASR PILOT TEST STUDY AREA

ECO-LOGIC
Consulting Engineers

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: 1"=2000'
Project No: 01300
File: 01300-FIG02

The facilities were close to a source of injection water (a Sierra Pacific water line situated in the right of way for Zolezzi Lane).

A nearby domestic well could function as a monitoring well to observe the effects of recharge in the relatively shallow aquifer materials tapped by domestic wells.

- The STMGID-1 site was close to numerous domestic wells that could benefit from recharge to the aquifer.

The pilot study entailed injection of treated surface water from Sierra Pacific's Chalk Bluff treatment facility delivered to the site via the Sierra Pacific distribution system. The monitoring well at STMGID-1 served as the injection well and STMGID-1 served as the recovery well. The relative locations of these two facilities are shown in Figure 2. The injection rate was limited by the injection capacity of the injection well under gravity flow conditions. That is, the well head would not be pressurized and piezometric head in the well would not extend above the land surface.

2.2 Study Area

The STMGID-1 well site is situated within an area south of Reno known locally as the Mount Rose alluvial fan. The fan occupies an area generally west of South Virginia Street, north of the Mount Rose Highway, south of Evans Creek and east of the mountain range front. The well is located south of Zolezzi Lane in the NE $\frac{1}{4}$ NE $\frac{1}{4}$ of Section 19, Township 19 North, Range 19 East, M.D.B.&M. The alluvial deposits that make up the aquifer provide a source of groundwater to municipal wells. The STMGID system operates eight wells with a combined present-day capacity of 4,646 gallons per minute (approximately 7,000 acre-feet per year) with three more wells proposed for construction. In addition to the STMGID system, as many as 650 domestic wells exploit groundwater for use as a water supply to individual residences in the southern Truckee Meadows.

As a consequence of this pumping, there have been measurable declines in the water level in the Mount Rose fan aquifer (Figure 3). These declines are significant to residential water users whose private wells are impacted. They are also significant because they indicate that a large volume of the aquifer has been dewatered.

Intuitively there is the potential to store a relatively large volume of water in the aquifer. There is also the potential to benefit individual domestic wells in the area which have experienced diminished performance or have required deepening as a consequence of the lower water levels.

2.3 Project Team

The work undertaken for this study represents a joint effort by the private and public sectors.

The Reno, Nevada office of AGRA Infrastructure, Inc. (AGRA) was contracted by the Regional Water Planning Commission and South Truckee Meadows General Improvement District (STMGID) to undertake the pilot study. AGRA is a successor to CES, Inc., the firm that had done the previous work in the area.

Project team members include:

Dale Bugenig and Raymond Kruth, P.E. of Eco:Logic, contracted through AGRA Infrastructure. Dale and Ray were the principal investigators for the project.

Dr. Burkhard Bohm, Ph.D. of Plumas Geo-Hydrology. Dr. Bohm was responsible for analysis of chemical data obtained from the study.

Randy Van Hoozer of the Washoe County Department of Water Resources Utility Division completed the project team. Randy implemented and maintained the network of data loggers utilized for the study, was responsible for collecting field water-quality data and water samples, and reviewed the data analyses performed by the other members of the project team.

3.0 Hydrogeology

The conditions in the aquifer beneath the Mount Rose fan are described in the previous reports dealing with the feasibility of aquifer storage and recovery in the south Truckee Meadows (CES, *et al.*, 1998 & 1999). For convenience, the discussions of the physical setting and the conceptual model of groundwater flow in the aquifer provided in these prior reports are summarized below.

3.1 Physical Setting

"The study area lies within the southwest Truckee Meadows. The Truckee meadows is situated at the juncture of two different physiographic provinces; the Sierra Nevada Batholith to the west and the Basin and Range to the east. Truckee Meadows is a structural depression that is bounded on the east and west by faults. The downward movement of the valley relative to the mountains along these faults has created a structural depression which has filled with detritus that has been eroded from the mountains, transported by streams and deposited in the valley."

"The elevation of the floor of the Truckee Meadows is approximately 4,400 feet above sea level. The surrounding mountains include the Carson Range of the Sierra Nevada to the west and the Virginia Range to the east. Elevations range from over 10,000 feet at Mount Rose in the Carson Range and 7,000 feet in the Virginia Range."

"The principal stream in the Truckee Meadows is the Truckee River. It is located approximately six miles north of the study area and traverses the valley from west to east. Tributary streams include Whites, Thomas, Evans and Steamboat Creeks. Although the Truckee River does not influence the study area directly, irrigation diversions from the river are transported to it via a series of ditches – the Steamboat, Last Chance, and Lake Ditches. Whites and Thomas Creeks are the streams that most affect the study area."

3.2 Conceptual Model Of The Groundwater Flow System

"Beneath the study area and vicinity, with minor exceptions, groundwater pumped from wells is obtained from unconsolidated to weakly consolidated alluvial deposits. These alluvial deposits comprise a mix of sand, gravel, silt and clay that were eroded from the mountains of the Carson Range to the west of the Truckee Meadows, transported by streams and deposited in the valley. The moderately sloping land surface that extends from the valley floor to range front west of the study area is referred to as the Mount Rose alluvial-fan complex. These saturated geologic materials that make up the fan are an important aquifer in the study area."

"Groundwater flows from areas of higher elevation to areas of lower elevation. The water table (or potentiometric surface) can be depicted by contour lines of equal water-level elevation. A water-level contour map of the Mount Rose fan

area is provided in Figure [3]. The water level contours clearly show that groundwater in the fan flows in a more or less easterly direction beneath the study area."

The geologic map of the southwest Truckee Meadows (Figure 4a) depicts a large number of northerly-trending faults. These faults are hypothesized to exert an influence on groundwater flow. Primarily, they are expected to impede groundwater flow because they tend to "smear" the finer-grained portion of heterogeneous alluvial deposits and effectively reduce the horizontal hydraulic conductivity along the fault plane. This premise is supported by water level data from wells on the fan that indicate abrupt vertical displacements in the piezometric surface that appear to be related to the faults.

Despite the indications that faults impede groundwater flow, the presence of classical impermeable boundaries is rare in pumping test data for wells completed within the fan. The reason that faults (impermeable boundaries) have not manifested themselves in pumping tests is probably a consequence of the relatively short duration of most aquifer-stress tests (pumping tests) performed to date. For example, in a moderately transmissive, unconfined or semi-confined aquifer, a test may need to be run for several weeks before the presence of a fault as close as 1,000 feet away can be detected. Most tests completed to date have been limited to a few days.



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 3

WATER LEVEL CONTOUR MAP

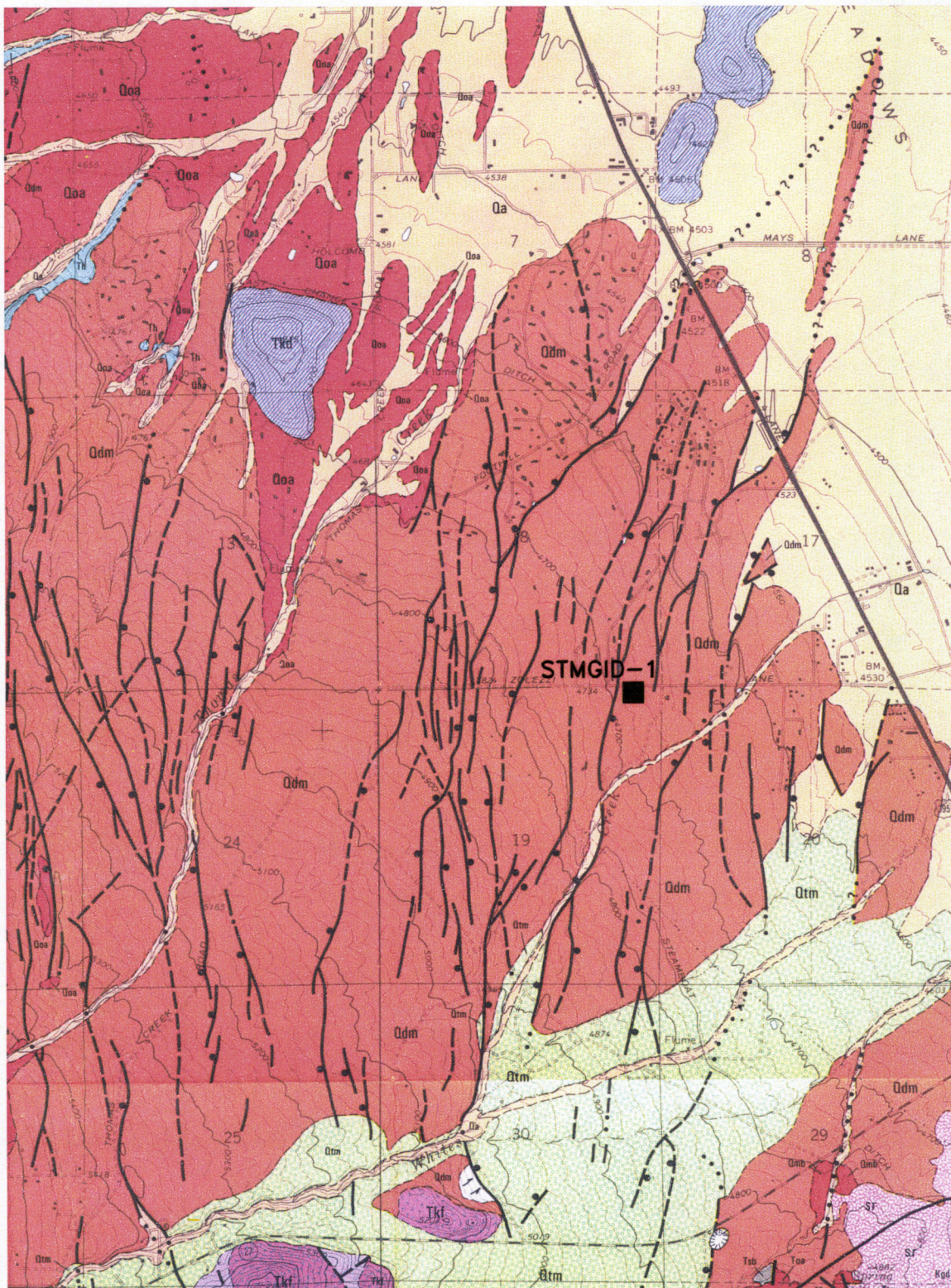
ECO-LOGIC

Consulting Engineers

REF: WCUD AND CES, 1998

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: 1"=3000'
Project No: 01300
File: 01300-FIG03



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

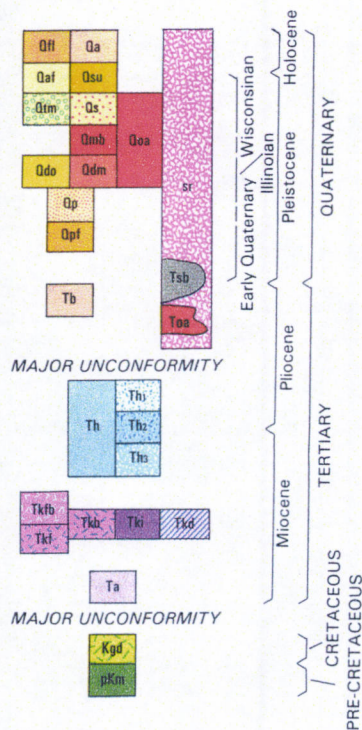
FIGURE 4a

GEOLOGIC MAP

ECO-LOGIC
Consulting Engineers

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: 1"=3000'
Project No: 01300
File: 01300-FIG04a



- Qfl** Floodplain and lake deposits. Interbedded gray to pale grayish-yellow silt and fine sand; contains thin lenses of peat; fluvial and lacustrine deposits up to 7 m (23 ft) thick. Little or no soil development (entisols)
- Qa** Alluvial bajada deposits. Thin sheet-like aprons of fine- to medium-grained clayey sand and intercalated muddy, medium pebble gravel; deposits of low gradient streams that reworked older gravelly outwash and alluvial fan deposits; weakly weathered and largely undissected. Little or no soil development (entisols)
- Qaf** Alluvial fan of Windy Hill. Locally derived silty to muddy, medium pebble gravel transported from the large Evans Creek drainage area; engulfs high-standing remnants of Donner Lake Outwash. These fan deposits intertongue with and become part of the alluvial bajada, Qa. Generally undissected, but contains scattered remnants of older alluvium
- Qsu** Sand, undifferentiated. Local deposits of fine to medium sand; eolian, alluvial outwash, and colluvial slope wash deposits
- Qtm** Tahoe Outwash—Mount Rose Fan Complex. Glacial outwash stream deposits of volcanic and granitic composition; light yellowish- to orange-brown; sandy large cobble to boulder gravel containing characteristically fresh granitic lag gravel. Strongly developed 1-m (3 ft) thick soil profile; dark yellowish-brown, prismatic argillic B-horizon; typically no siliceous or calcic duripan development; granitic boulders partly to thoroughly decomposed where buried in soil. Deposits locally only thin veneers; some undifferentiated areas
- Qoa** Older alluvium. Highly dissected remnants of muddy, sandy small pebble gravel in alluvial deposits transported from Thomas Creek; soil profile 1-2 m (3-6 ft) thick with strongly developed argillic B-horizon; local duripan development. Also includes areas of older alluvium in Steamboat Hills
- sr** Hot-spring sinter. Siliceous sinter ranging in age from late Pliocene to present. Older sinter is white to gray chalcedony; locally contains mercury sulfides; younger sinter is light gray to tan porous opal
- Tsb** Basaltic andesite of Steamboat Hills. Dark gray flows with phenocrysts of plagioclase and olivine in intergranular matrix of pyroxene, plagioclase, Fe-Ti oxides. Source of flows is cinder cone in SW/4 S32,T18N,R20E. K-Ar age: 2.53 ± 0.1 m.y.
- Toa** Old alluvium of Steamboat Hills. Pediment deposits underlying Tsb. Pebble to cobble gravel consisting of angular to subangular granitic, volcanic, and metamorphic clasts and arkosic sands. Locally well cemented and/or strongly hydrothermally altered
- Tb** Basalt and basaltic andesite of Carson Range. Dark gray basaltic-appearing flows with prominent platy flow jointing; mineralogically similar to Tsb
- Th** Sandstone of Hunter Creek. Th: Undifferentiated. Th₁: Brown to gray, medium- to thick-bedded, sub-angular coarse sand; intercalated tuff and sub-rounded andesite pebble to cobble conglomerate; grades upward into thin-bedded silt and diatomaceous silt. Th₂: White to light gray, massive to thin-bedded diatomaceous siltstone with minor beds of yellowish-tan medium sand; iron oxide staining of fractures in siltstone common. Th₃: Tan, gray to reddish-brown, thin- to thick-bedded, alternating layers of fine to coarse sand; intercalated layers of well rounded pebbles; cross-bedding common in sand fractions; basal contact conformable with Th₂
- Tkf** Kate Peak Formation. Tkf: Hornblende-pyroxene andesite and dacite flows with minor breccia
- Tkfb** and volcanic conglomerate. Tkfb: Hydrothermally

- Qs** Sidestream deposits. Fluvial silt and medium sand associated with Tahoe Outwash deposits along the Truckee River; soil profile similar to Qtm
- Qmb** Mud-volcanic breccia. Heterogeneous mixture of bleached and iron-stained boulders and fragments of volcanic rocks, opaline and chalcedonic sinter, and disintegrated granitic debris
- Qdo** Donner Lake Outwash. Boulder outwash forming strath terraces on bedrock; extensive mantle thickening eastward; unconsolidated small cobble gravel and interbedded coarse sand. Highly rounded clasts; unit locally contains very large, deeply weathered boulders of basalt and quartz monzonite more than 2 m (6 ft) in diameter. Strongly developed soil profile 2-3 m (6-10 ft) thick; prismatic argillic B-horizon; weakly to strongly developed siliceous and calcic duripan 1-2 m (3-6 ft) thick; granitic clasts thoroughly disintegrated in weathered profile
- Qdm** Donner Lake Outwash—Mount Rose Fan Complex. Pediment and thin fan deposits from major streams draining alpine glaciers on Mount Rose; brown to brownish-gray, sandy, muddy, poorly sorted large pebble gravel; cobbles and small boulders common. Clasts dominantly volcanic (porphyritic andesite and latite); surface granitic clasts rare. Deeply weathered, strongly developed soil profile similar to Qdo; locally overlain by undifferentiated veneer of Qtm; well cemented and/or hydrothermally altered in Steamboat Hills area
- Qp** Pediment gravel. Veneers of moderately to poorly sorted medium pebble to cobble gravel < 3 m (10 ft) thick; commonly occurs as gravel sheet < 1 m (3 ft) thick over bedrock and older pediment and alluvial fan gravels; clast content dominantly volcanic. Strongly developed soil profile; thick argillic B-horizon locally overlying siliceous and calcic duripan
- Qpf** Alluvial fan deposits of Peavine Mountain. Yellowish-brown gravel and gravelly muddy sand consisting of angular pebbles to small cobble-sized clasts of
- Tki** bleached Tkf. Tkfb: Hornblende-pyroxene dacite and andesite lahars, pyroclastic breccia, volcanic conglomerate, and sandstone with minor flows. Tki: Intrusive hornblende-pyroxene-biotite dacite. Tkfb: Flow-dome complexes of hornblende-biotite rhyodacite porphyry
- Ta** Alta Formation. Flows of dark, fine-grained soda trachyte; occurs in Steamboat Hills area
- Kgd** Biotite-hornblende granodiorite
- pKm** Metasedimentary and metavolcanic rocks. Graywacke, argillite, slate, phyllite, hornfels, metatuff and breccia, volcanic conglomerate, and marble

Contact. Dashed where approximately located; dotted where concealed

Fault. Dashed where approximately located; dotted where concealed; queried where presence uncertain

- Undifferentiated landslide deposits
- Artificial fill. Not all fill areas shown
- Strike and dip of beds
- Strike and dip of flow layering
- Phreatic explosion crater. (Steamboat Hills)

WASHOE COUNTY REGIONAL WATER PLANNING COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D. PILOT AQUIFER STORAGE AND RECOVERY TEST STMGID WELL NO. 1

FIGURE 4b

GEOLOGIC MAP EXPLANATION

ECO:LOGIC
Consulting Engineers

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: NONE
Project No: 01300
File: 01300-FIG04b

4.0 STMGID-1 Injection Test

4.1 Well Selection & Instrumentation

4.1.1 Injection Well and Recovery Well

The monitoring well at the STMGID-1 site (also referred to as Monitoring Well 1 or MW-1) was selected for use as the Injection Well for the ASR pilot test. The primary reasons were:

- Minimal modifications to the well were needed for it to function as an injection well. The principal change to the well structure involved installing the injection tubing and the miscellaneous valves and other control equipment. These modifications were significantly less than those needed to equip STMGID-1 for use as the injection well.
- The available data suggested the monitoring well at STMGID-1 might be capable of injection rates as high as 600 gallons per minute.

The Injection Well also functioned as an observation well during the recovery phase of the test.

STMGID-1 functioned as the recovery well for the ASR pilot test. It also functioned as an observation well during the injection portion of the test.

Basic construction details and abbreviated lithologic logs for these wells are provided in Figure 5. The above-ground flow control equipment at the Injection Well is illustrated in Figure 6.

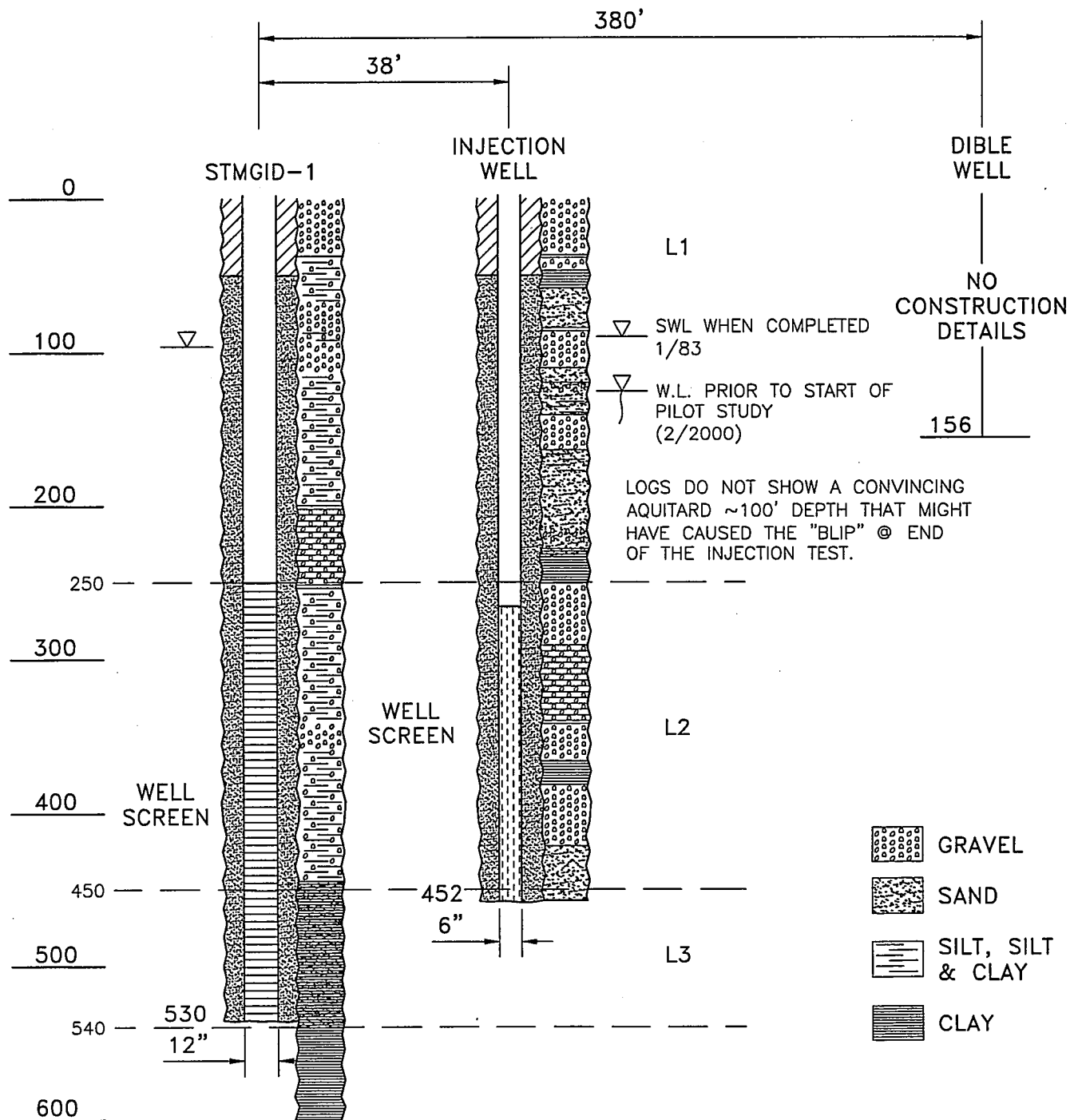
4.1.2 Observation Well Network

In addition to the Injection Well and STMGID-1, the observation well network for the ASR pilot test included three other wells; the Dible residential well, Washoe County Monitoring Well 2 (MW-2), and Washoe County Monitoring Well 3 (MW-3). STMGID-2 was monitored for a brief period prior to the test, but data collection was suspended when monitoring equipment was transferred to STMGID-1. The locations of the observation wells are indicated on Figure 7.

The Dible Well is an "unused" residential water supply well located approximately 380 feet northwest of STMGID-1. Little is known about the construction of the well other than that it is relatively shallow (approximately 150 feet deep). Because the piezometric level at this locale is more than 100 feet below the land surface, the well penetrates only the uppermost saturated thickness of the aquifer.

Monitoring Well 2 (MW-2) is a 2-inch diameter 441 feet deep monitoring well. It was completed at the site of a test well drilled by Washoe County located approximately 3,300 feet west of STMGID-1. A new production well has recently been completed at this site and may limit MW-2's usefulness as a monitoring well for future studies. The influence of the nearby production well may overshadow regional water-level trends in MW-2.

Monitoring Well 3 (MW-3) is a 3-inch diameter 286 feet deep monitoring well. It was completed at the site of a test well drilled by Washoe County located approximately 4,000 feet south of STMGID-1.



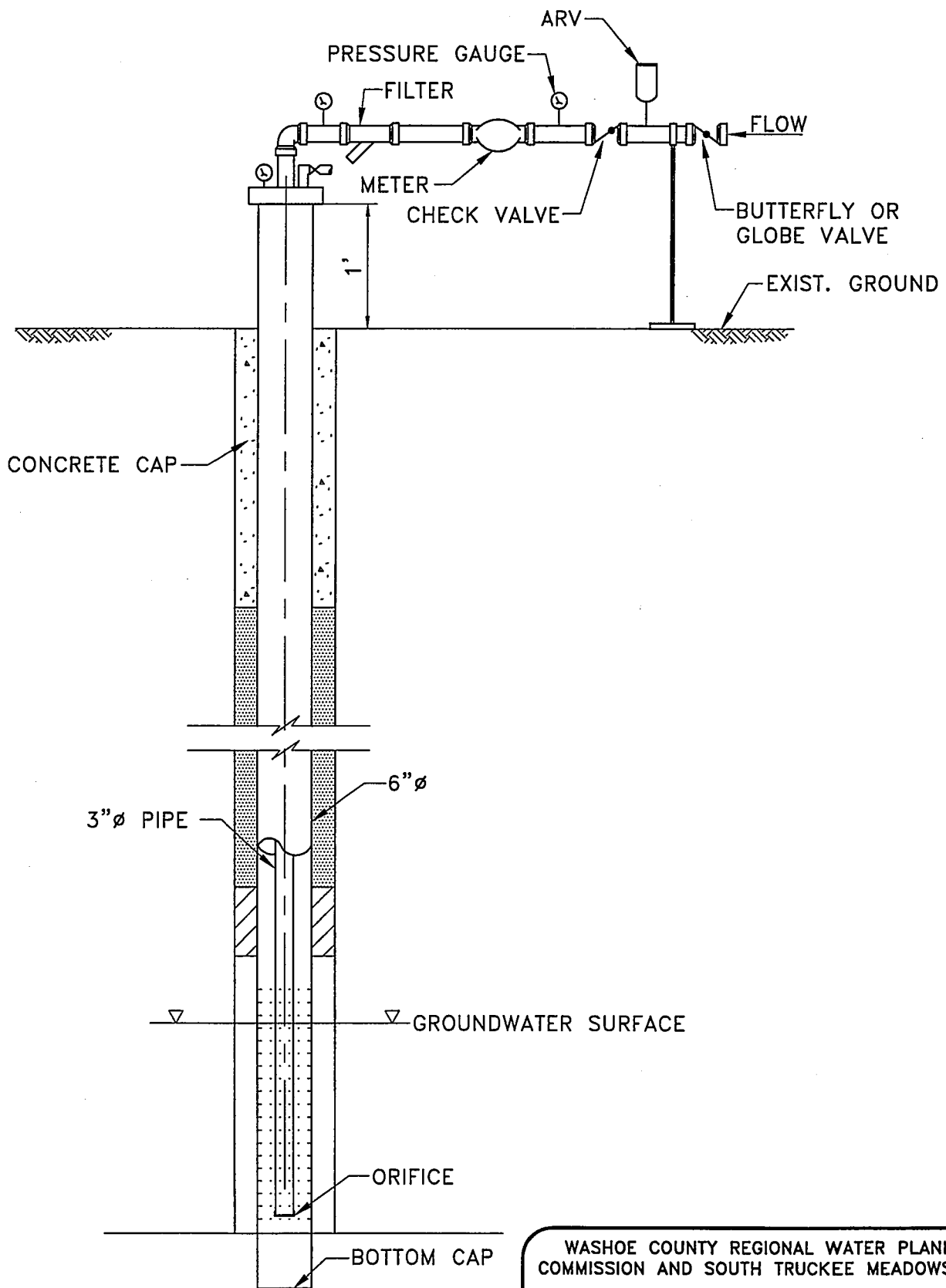
WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 5
CONSTRUCTION SUMMARY AND LITHOLOGY FOR
STMGID-1 AND THE INJECTION WELL

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: None
Project No: 01300
File: 01300-FIG05

ECO-LOGIC
Consulting Engineers



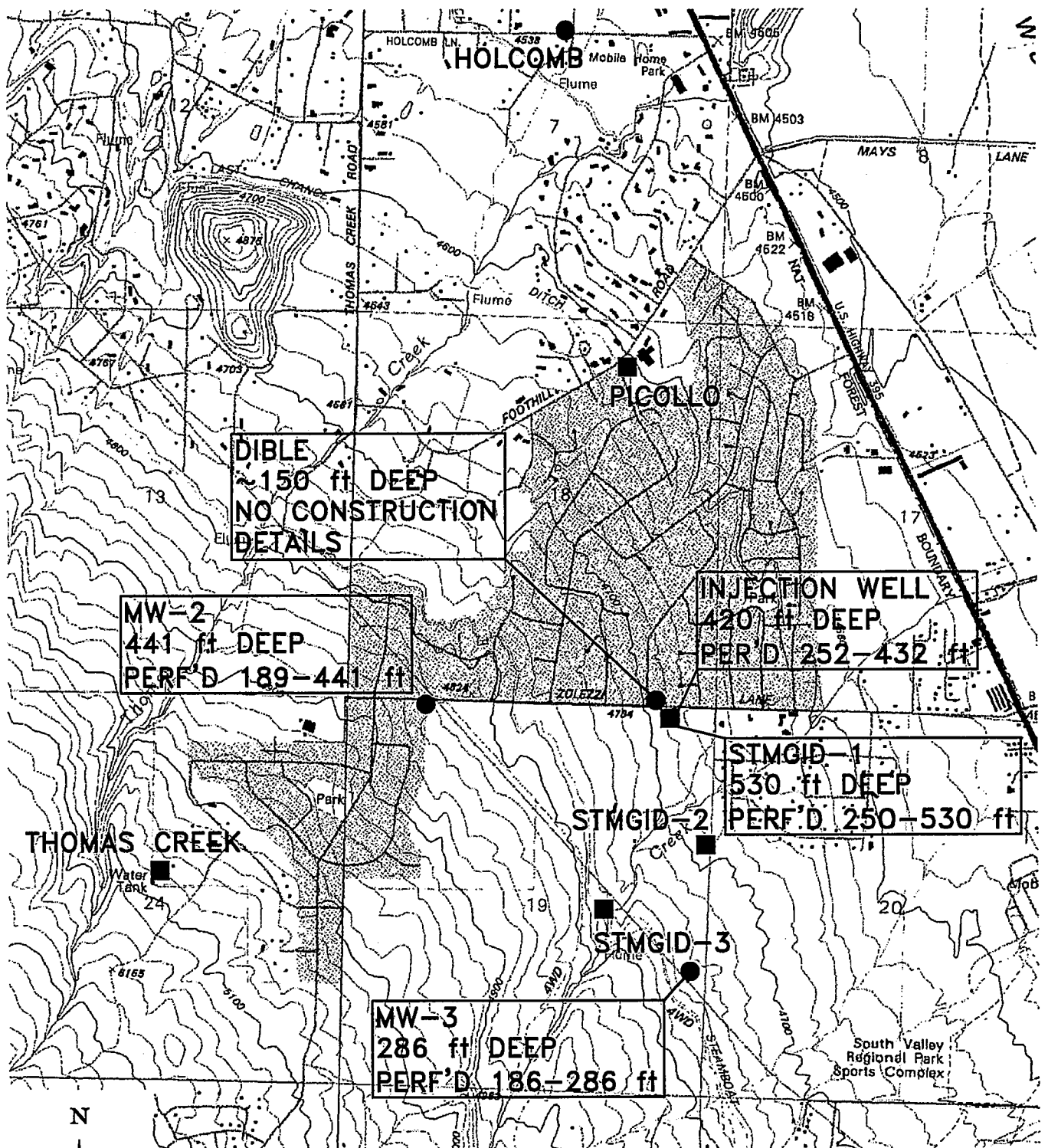
WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 6
DETAIL OF THE FLOW CONTROL EQUIPMENT
AT THE INJECTION WELL, MW-1

ECO·LOGIC
Consulting Engineers

Date: 5/10/01
Designed By: DCB
Drawn By: LKB

Scale: None
Project No: 01300
File: 01300-FIG06



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 7

MAP OF THE WATER LEVEL MONITORING NETWORK

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: 1"=2000'
Project No: 01300
File: 01300-FIG07

ECO-LOGIC

Consulting Engineers

4.1.3 Instrumentation

Water level measurements

Water levels were measured by pressure transducers and data loggers manufactured by In-Situ, Inc. of Laramie, Wyoming. Data from STMGID-1 and the Injection Well were logged with a single Hermit 1000C two-channel data logger. For the Injection Well, a 100-psi Druck quartz-crystal transducer was placed in the well inside a stilling well. A 100-psi Druck transducer was also utilized for STMGID-1. A bend in the stilling well in STMGID-1 prevented installation of the 5/8-inch diameter transducer in this well, the logging equipment installation was modified to use a 1/8-inch diameter seamless, annealed stainless steel capillary tube that was threaded down the stilling well. An adapter was custom-fabricated by the Gadgeteer of Reno to mate the transducer to the capillary tube assembly. The capillary tube was continuously charged with dry nitrogen gas regulated by a bubbler assembly custom-fabricated by the Slope Indicator Company of Bellevue, Washington.

The Dible Well was initially equipped with an In-Situ Troll 8000 self-contained pressure transducer and multi-parameter water-quality data logger. It experienced repeated problems with the dissolved oxygen probe and was supplanted by a Troll 4000 water level data logger.

Water levels in Washoe County Monitoring Well 2 and Monitoring Well 3 were individually monitored with individual Troll 4000 data loggers.

Water levels in STMGID-2 were monitored with a Hermit 3000 data logger equipped with a 100-psi pressure transducer in the early days of the project. This ceased when the transducer was moved to the Injection Well after its pressure transducer malfunctioned.

Water chemistry

During the injection test, field water chemistry parameters of the injectate were continuously monitored with a Yellow Springs, Inc. (YSI) multi-parameter water-quality data logger. Field parameters included temperature, electrical conductivity, pH, and dissolved oxygen. The instrument probes were placed in a cell that diverted a continuous flow of the injected water past the probes.

Following the injection test, the flow-through cell and YSI water-chemistry data logger were moved to STMGID-1 to monitor the field chemical parameters of the water recovered from it.

Samples of the injected water were periodically collected from the injection stream. These were analyzed for major anions and cations, trace metals, and stable isotopes of oxygen and hydrogen, and total Trihalomethanes (TTHMs). Additional samples were collected and specifically analyzed for very low concentrations of trace metals. Trace metals were anticipated to be useful in differentiating injected water from the ambient groundwater. The chemical data are detailed in Section 6 of this report.

Suspended Solids

The suspended solids in the injectate were continuously monitored during the injection test. This was accomplished by diverting a small portion of the injection stream through a series of filters. The mass of accumulated solids and flow rate through the filter assembly yielded a concentration of suspended solids in the injected water. The suspended solids data and potential consequences are addressed in Section 6 of this report.

4.2 Pre-Test Water-Level Data Collection

Hourly water-level measurements were collected from the monitoring network prior to the start of the injection test. This sampling frequency was maintained throughout the test program. The pre-test or background water-level data collection was done to document any significant pre-test trends in water levels that might influence the interpretation of the test data. If trends due to outside influences such as recharge, pumping cycles of nearby wells, *etc.* could be identified, the test data would be corrected to remove these influences.

Data collection for the Dible Well started 10/07/99. Data collection for MW-3 started 11/04/99. Data collection for MW-2 started 12/16/99. The water-level data for these three wells are provided in Figure 8.

From Figure 8, it can be seen that water levels in the Dible Well rose at a uniformly linear rate prior to the start of testing. Conversely, water levels in MW-2 declined at a uniform rate throughout the test program. Water levels in MW-3 rose initially, peaked near the end of December 1999, and then declined through the end of the injection test. The data from MW-2 and MW-3 are noteworthy because they suggest a lag between recharge to the aquifer and water level changes in the aquifer. A comparison of the pre-test data with historical data for MW-2 (Figure 9) shows the pre-test data trend is consistent with historical seasonal trends for this well. That is, it is common for water levels in the aquifer at that locale to decline during the winter months. Data for 1984 through 1987, prior to large-scale groundwater exploitation on the fan, show that water levels reach their highest elevation in November and December and decline prior to the onset of summer pumping. Likewise, the historical data show water levels start to rise during the summer months when pumping is greatest. The water levels in the aquifer appear to lag behind annual recharge from precipitation and the seasonal stresses due to pumping. The cause of this lag warrants further study because it may provide further insight into recharge to the fan area, but is beyond the scope of this study.

A portion of the water-level decline shown in Figure 9 is almost certainly a response to the protracted period of lower-than-normal precipitation from 1987 through 1992. However, this dry period was followed by average or above average precipitation and the water levels did not recover to previous levels. Consequently, some of the decline must be related to increased groundwater extractions in this area.

The differences in water-level trends for the three monitoring wells may be an indicator that the aquifer is somewhat compartmentalized due to faulting. However, more analysis is needed to evaluate this premise.

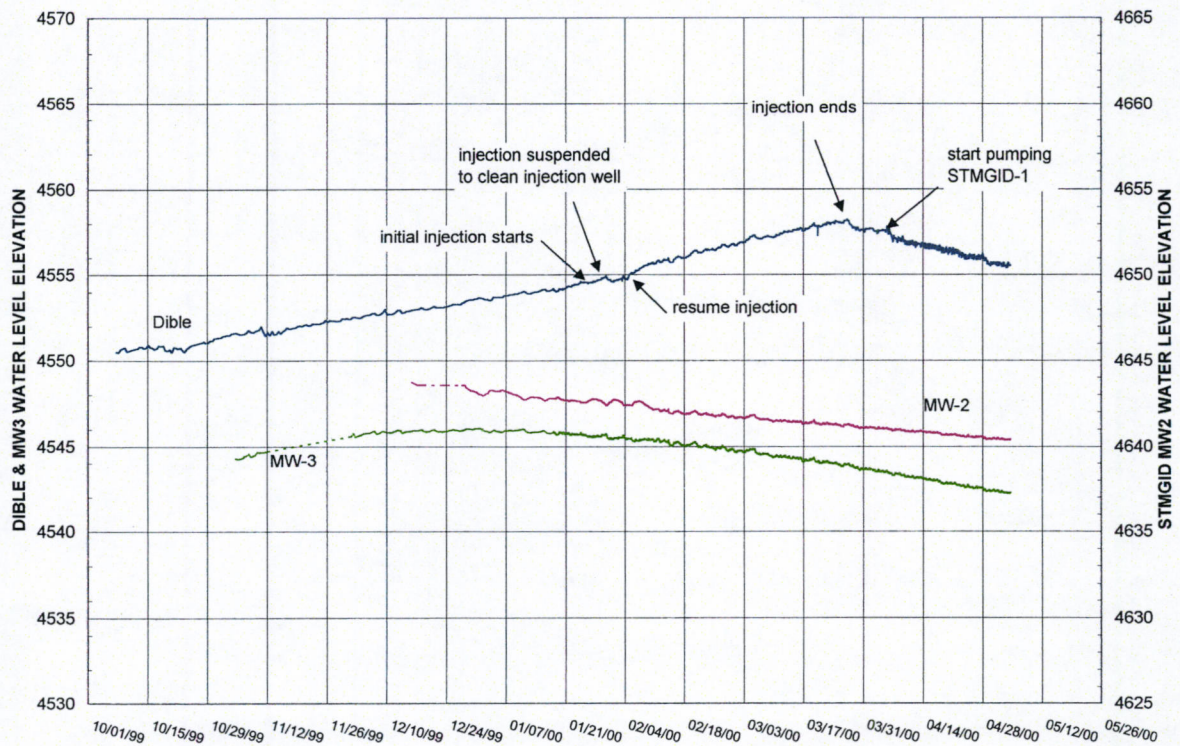


FIGURE 8. WATER-LEVEL DAT FOR DIBLE WELL, MW-2 AND MW-3

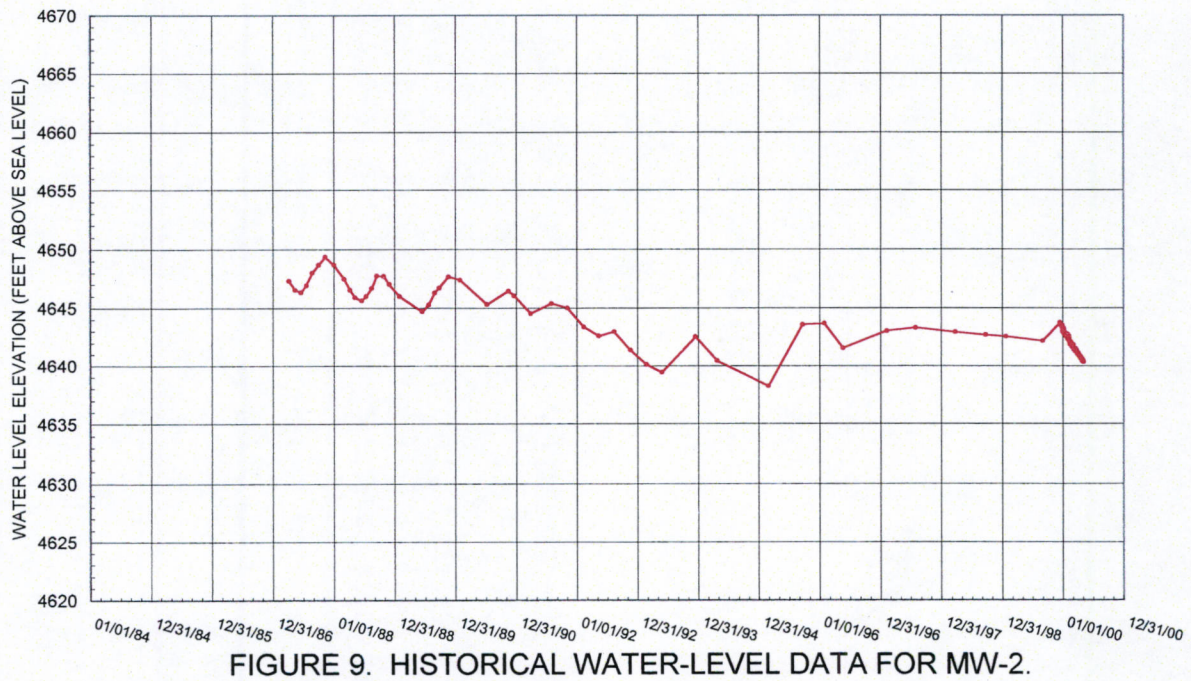


FIGURE 9. HISTORICAL WATER-LEVEL DATA FOR MW-2.

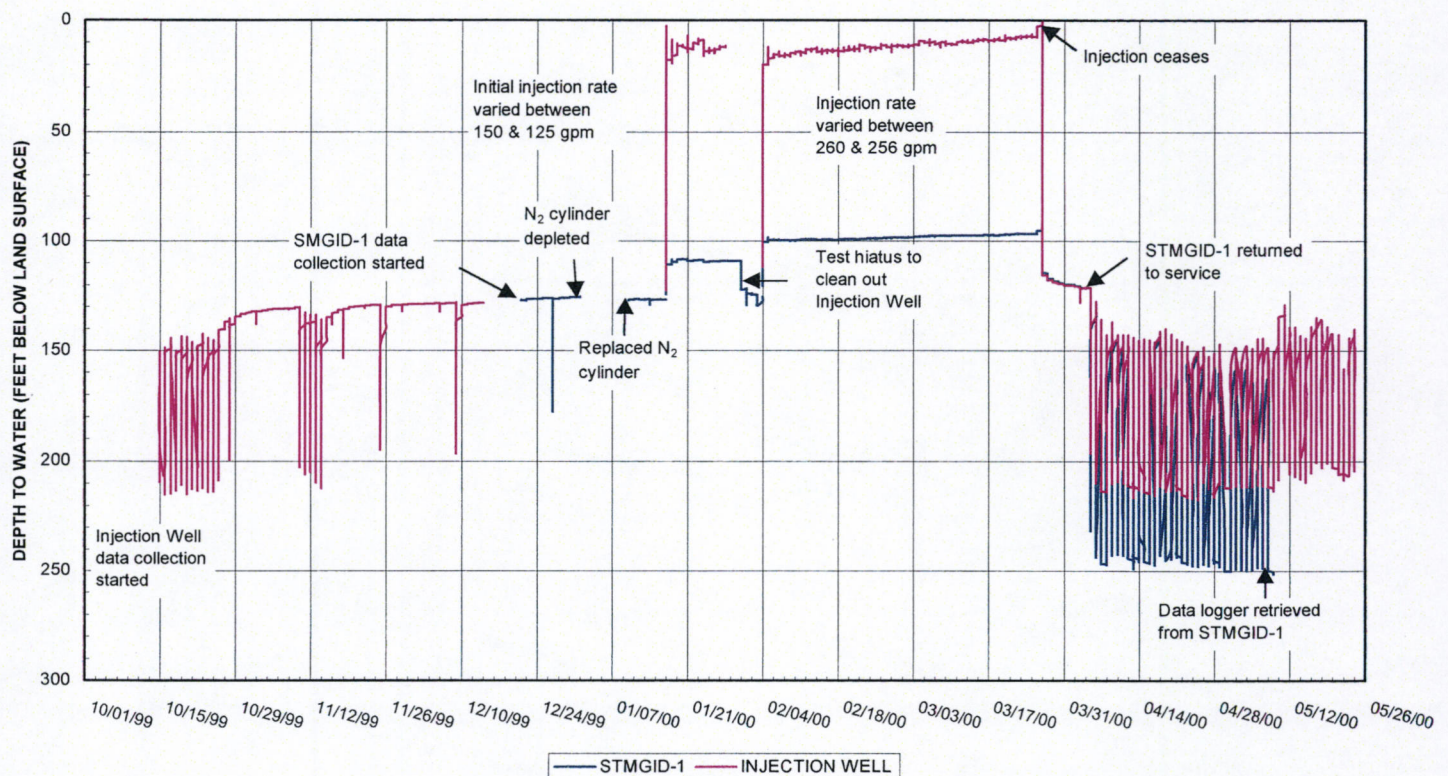


FIGURE 10. WATER-LEVEL DATA FOR THE INJECTION WELL AND STMGID-1.

In addition to the three relatively distant observation wells, pre-test background water levels were monitored in the Injection Well and STMGID-1. The collection of water levels from the Injection Well commenced October 15, 1999 and stopped May 4, 2000, with the completion of the injection test. The complete data for the Injection Well and STMGID-1 are provided in Figure 10. The data for the fall of 1999 prior to the test show fluctuations indicative of the regular usage of STMGID-1. Near the end of October 1999, pumping from the STMGID-1 was curtailed significantly and regular usage ceased in early November 1999, except for periodic readiness testing of the pump. The water levels measured in these wells also show a uniform and linear water-level rise similar to that observed in the data from the Dible well. The similarities in the water level data for these three wells suggest the aquifer conditions in the immediate vicinity of the injection test site were relatively uniform.

4.3 Injection Test Summary

4.3.1 Water Supply And Flow Control Equipment

The source of water for the injection test comprised treated surface water from Sierra Pacific's Chalk Bluff water treatment plant delivered to the site via the water main located in the road right of way north of Zolezzi Lane. The water was conveyed across Zolezzi to the injection well via an inter-tie constructed by Resource Development Company specifically for the test.

The injection rate during testing was regulated by a flow-control valve (Cla-Val). A totalizing meter recorded the injection rate and cumulative volume of water injected. Pressure gages monitored the supply line pressure up stream of the Clay valve and the injection tube backpressure. A positive pressure in the injection tubing was maintained to prevent the formation of bubbles in the injection stream that may "air bind" the aquifer and reduce its injection capacity.

4.3.2 Test Chronology

Injection commenced January 20, 2000 and was terminated March 27, 2000. Approximately one week after injection ceased, STMGID-1 was returned to service and the District started to recover the water from the well by pumping it. A longer hiatus between the end of injection and start of recovery was proposed for the pilot study, but unseasonably warm spring weather required the well be pressed into service sooner than planned.

A chronology of the test is provided below.

1/20/00	Injection commenced @ 15:51 hours.
1/31/00	Injection was stopped @ 15:00 hours.
2/1-3/00	The Injection Well, MW-1, was chemically and physically treated to improve injection efficiency.
2/4/00	Injection resumed @ 15:00 hours.
3/27/00	Injection was terminated at 13:00 hours. Recovery of water levels commenced.
4/5/00	Recovery portion of the test was completed. STMGID-1 was returned to service and pumping from the well resumed.

A total of approximately 65.1 acre-feet (21,200,000 gallons) of water were injected. By May 3, 2000, approximately 22,500,000 gallons were pumped from via STMGID-1 and data collection was terminated.

4.4 Analysis Of Injection Test Data

Before the test data could be analyzed, they were processed to remove outside influences. Processing included:

- Removing the influence of pre-test water-level trends. The data from the Dible well indicated a linear water level rise prior to the start of the test that clearly continued through the injection and recovery periods. The magnitude of this correction varied linearly from "zero" at the start of the test to 2.5 feet by the end of the injection period.
- Compensating for transducer drift. The transducer in STMGID-1 experienced drift in the magnitude of a couple of tenths of a foot. The data were corrected using a relationship between manual water-level depth measurements and transducer measurements.

Corrected data were initially analyzed by the Cooper-Jacob approximation of the Theis Equation, an analytical solution to the change in water level around a pumped well (or injection well as is the case for this test). The results of this analysis provided "seed" values for a more in-depth analysis using the computer program WHIP (Well Hydraulics Interpretation Package, ver. 3.22: Hydro-Geo Chem, 1988). WHIP utilizes numerical LaPlace inversion techniques and has the capabilities to analyze data for relatively complex well/aquifer conditions such as those thought to exist near STMGID-1.

The aquifer is heterogeneous and contains beds or lenses of fine-grained alluvial materials such as silt and clay. These fine-grained deposits are expected to impede the vertical movement of water within the aquifer and lead to a condition referred to as vertical anisotropy. Anisotropy was considered in the analysis because neither the Injection Well nor STMGID-1 fully penetrated the aquifer, nor were they completed to the same depths. In addition, the nearest observation well, the Dible Well, was completed to a much shallower depth than either the Injection Well or STMGID-1. Furthermore, the geologic map for the study area shows numerous faults. Any of these might serve as hydraulic boundaries with the potential to impede

horizontal groundwater flow. The overall hydraulic efficiency of the Injection Well was also expected to influence the water levels in this well. WHIP has the capabilities to consider all of these aquifer and well conditions.

4.4.1 Injection Well and STMGID-1

Observed and simulated water-level rise in the Injection Well and STMGID-1 are shown in Figure 11. The large fluctuation within the first 30 to 40 minutes relates to an interruption in the injection test when the injection tube orifice was changed to control the injection tube back pressure. The large difference in water level rise between the injection well and STMGID-1 is a result the distance between the two wells, (they are approximately 38 feet apart), the small diameter of the injection well and a low hydraulic efficiency in the injection well. Overall, the observed data suggest delayed-yield conditions exist in the aquifer. That is, early-time water-level rises relate to an elastic response in the aquifer to injection. This is followed by a transition period after which the injected water goes into storage in the pore spaces in the aquifer. The transition period is illustrated by the flattening of the plot of drawdown versus

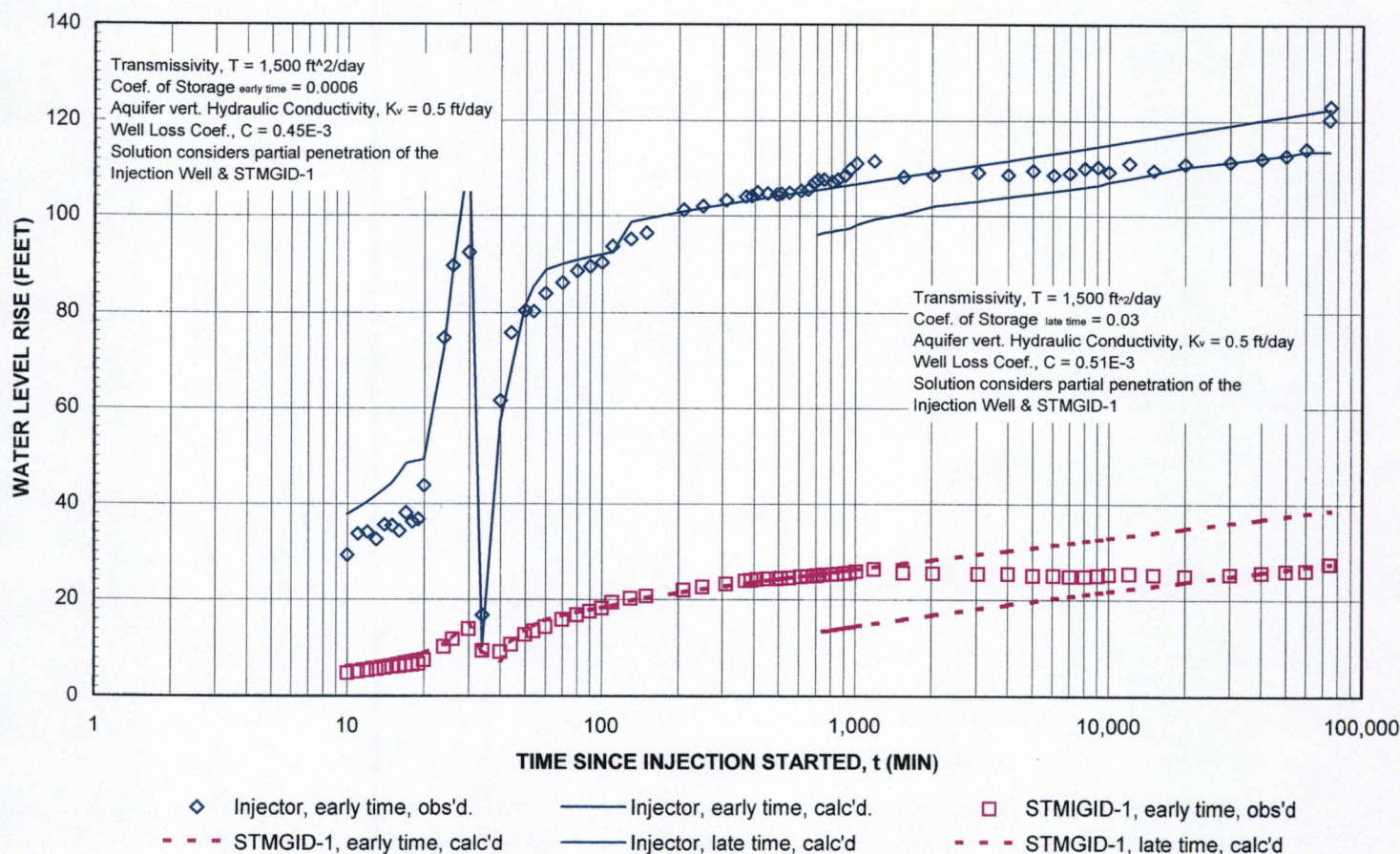


FIGURE 11. INJECTION TEST DATA FOR THE INJECTION WELL AND STMGID-1.

logarithm of time at $t \sim 1,000$ minutes, after which the plot of drawdown versus logarithm of time assumes the slope of the early-time data. The offsets between the curves for the early- and late-time data relate to the change from semi-confined to unconfined conditions in the aquifer.

Close correlation between observed and simulated water-level rise were obtained using the following aquifer properties.

Early time ($t < 1,000$ minutes)

Transmissivity – 1,500 feet²/day
Coefficient of Storage – 0.0006
Vertical Hydraulic Conductivity – 0.5 feet/day

The value for Storage Coefficient indicates semi-confined conditions prevailed in the aquifer early in the test.

Late time ($t > 15,000$ minutes)

Transmissivity – 1,500 feet²/day
Coefficient of Storage – 0.03
Vertical Hydraulic Conductivity – 0.5 feet/day

The value for Storage Coefficient indicates the aquifer is unconfined in the long term. This is consistent with previous assessments of pumping test data for the STMGID wells.

The data collected from the recovery portion of the injection test were also analyzed for the Injection Well and STMGID-1. The results of analysis of the recovery data are provided in Figures 12, and 13. Note that the data are plotted as water level decline (recovery) versus time since injection stopped and are not plotted as residual versus dimensionless time. The shape of the data plots suggest that delayed yield conditions in the aquifer are also indicated by the recovery data.

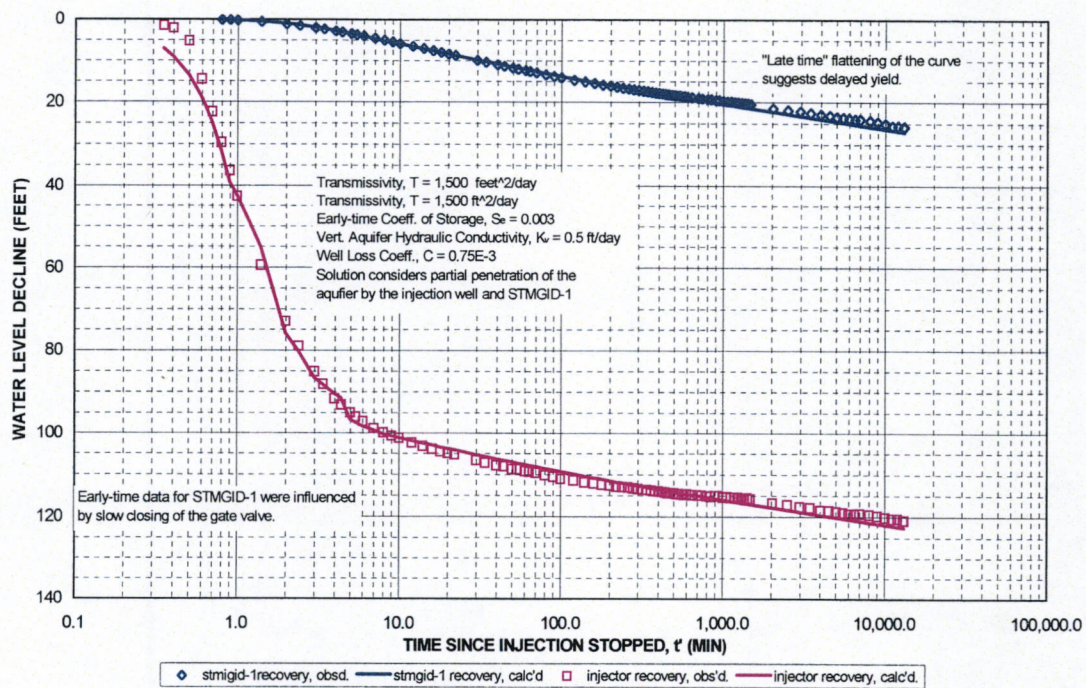


FIGURE 12. INJECTION TEST RECOVERY DATA FOR THE INJECTION WELL AND STMGID-1.

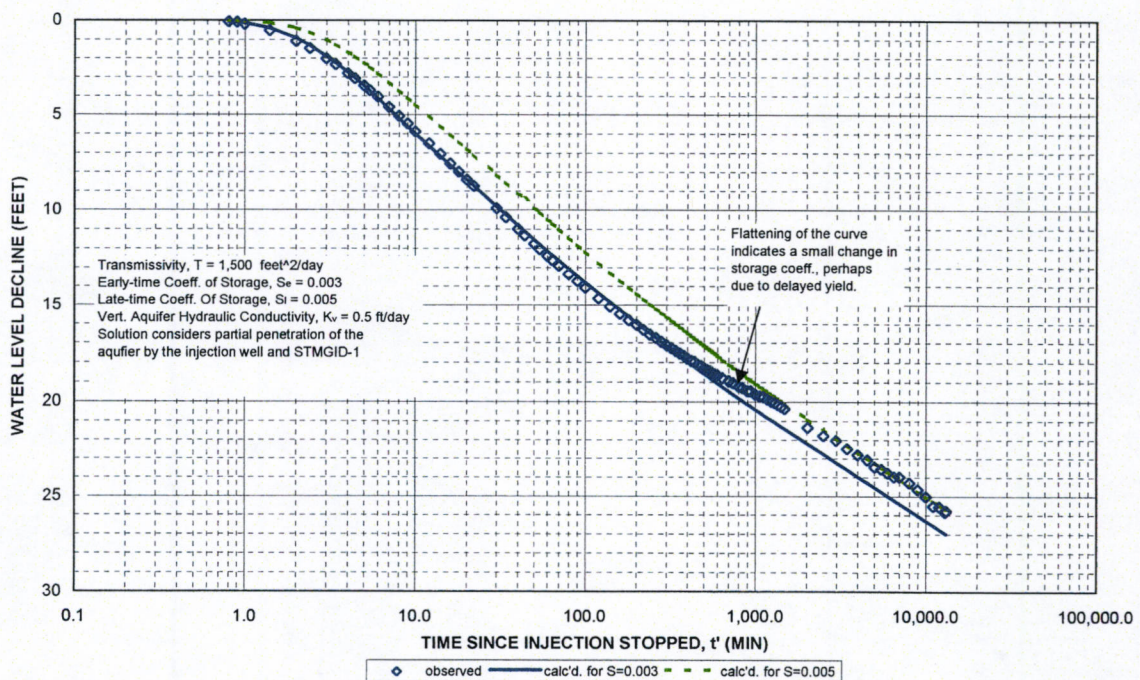


FIGURE 13. INJECTION TEST RECOVERY DATA FOR STMGID-1.

4.4.2 Dible Well

The data in Figure 8, Section 4.2, clearly indicate that the Dible Well was influenced by injection at the STMGID-1 site. The water-level data from the Dible Well during the injection test were also analyzed in detail. Prior to analysis, the data were processed to remove the pre-test trends in the water levels (refer to Section 4.4). The observed data were simulated using the following aquifer properties.

Transmissivity – 1,350 feet²/day
Coefficient of Storage – 0.017
Vertical Hydraulic Conductivity – 0.0007 feet/day

Another feature of the analysis of the Dible Well was the need to invoke two parallel boundaries located on either side of the well to satisfactorily simulate the observed data. One boundary was simulated to be 1,500 feet to the east, the other 2,000 feet to the west. Faults have long been hypothesized to influence the hydrogeology of the Mount Rose alluvial fan. These data constitute one of the few observations of a fault acting as an impermeable boundary during a pumping test performed in this area.

Observed and simulated data for the Dible Well are provided in Figures 14, 15, and 16.

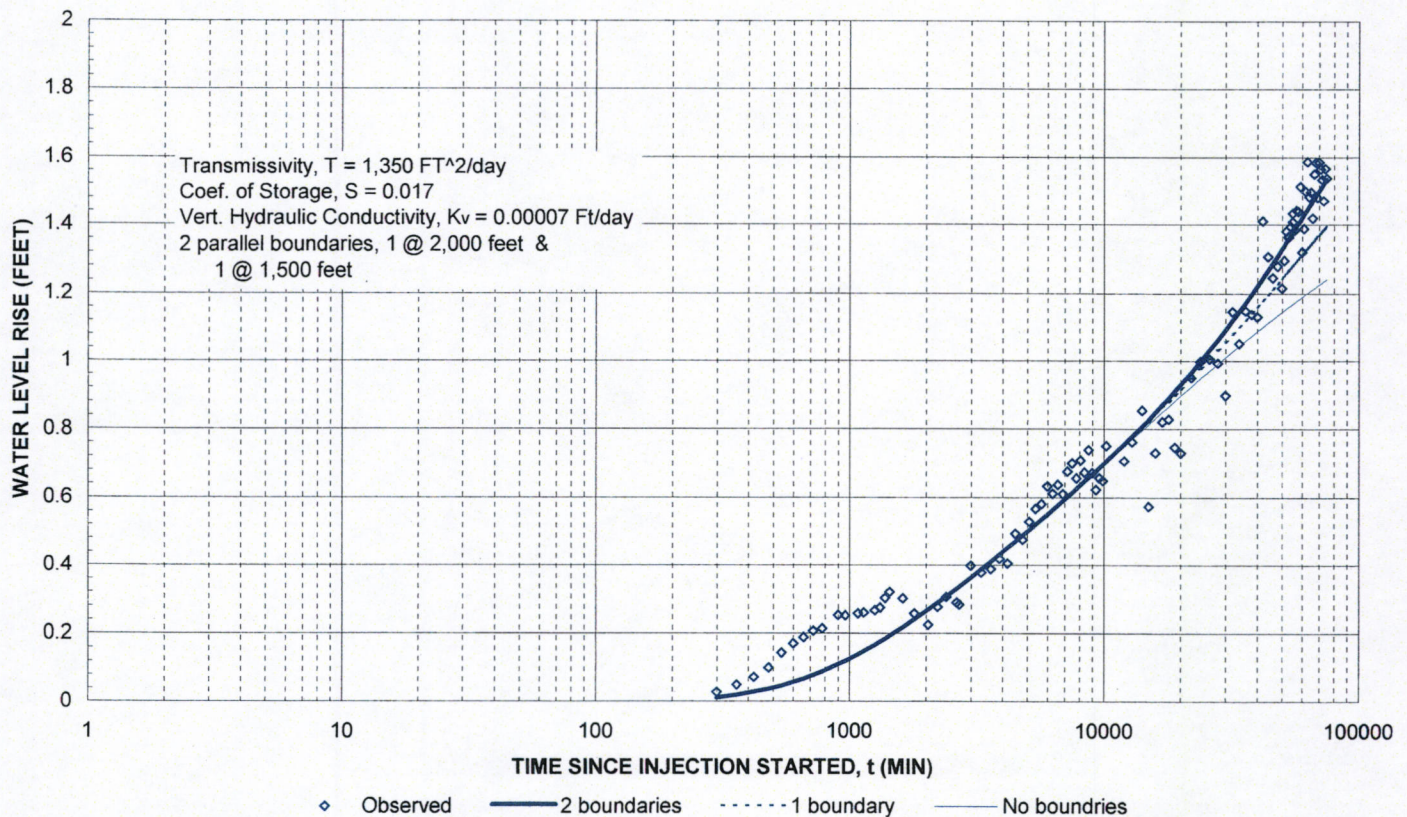


FIGURE 14. INJECTION TEST DATA FOR THE DIBLE WELL. (SEMI-LOG PLOT)

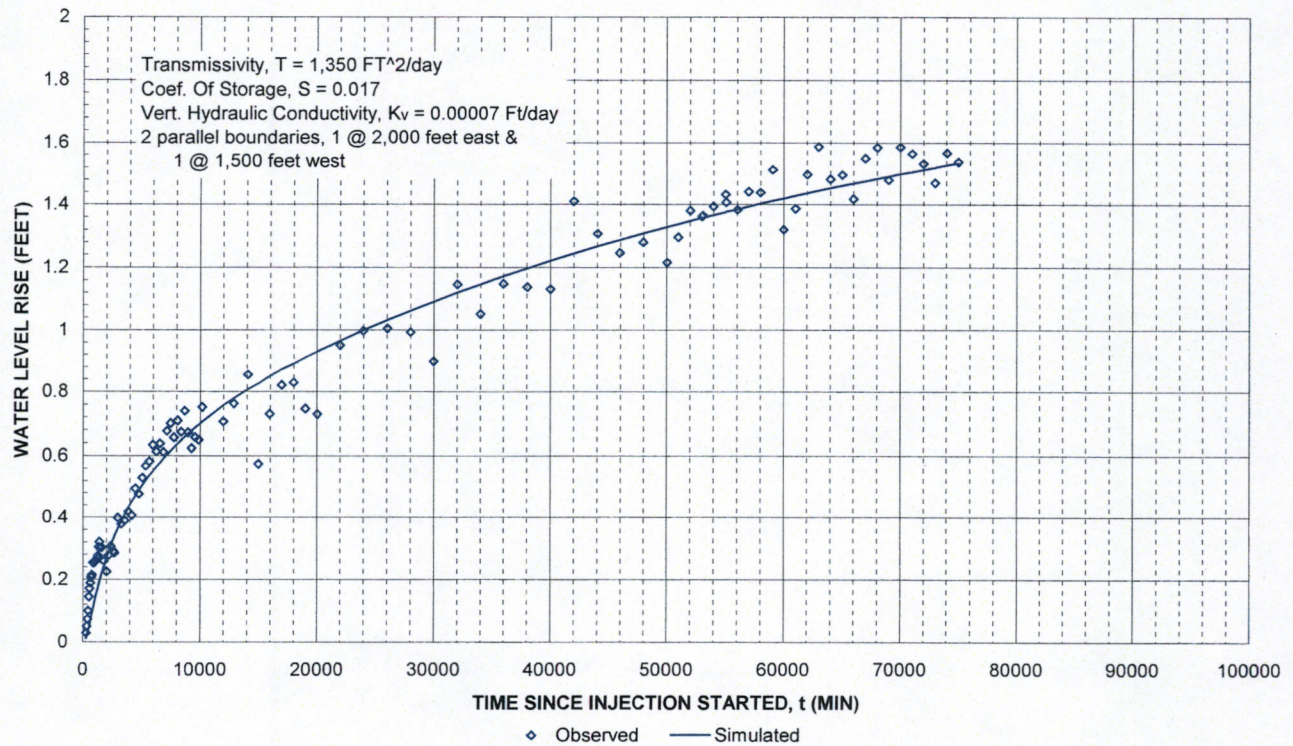


FIGURE 15. INJECTION TEST DATA FOR THE DIBLE WELL (ARITHMETIC PLOT).

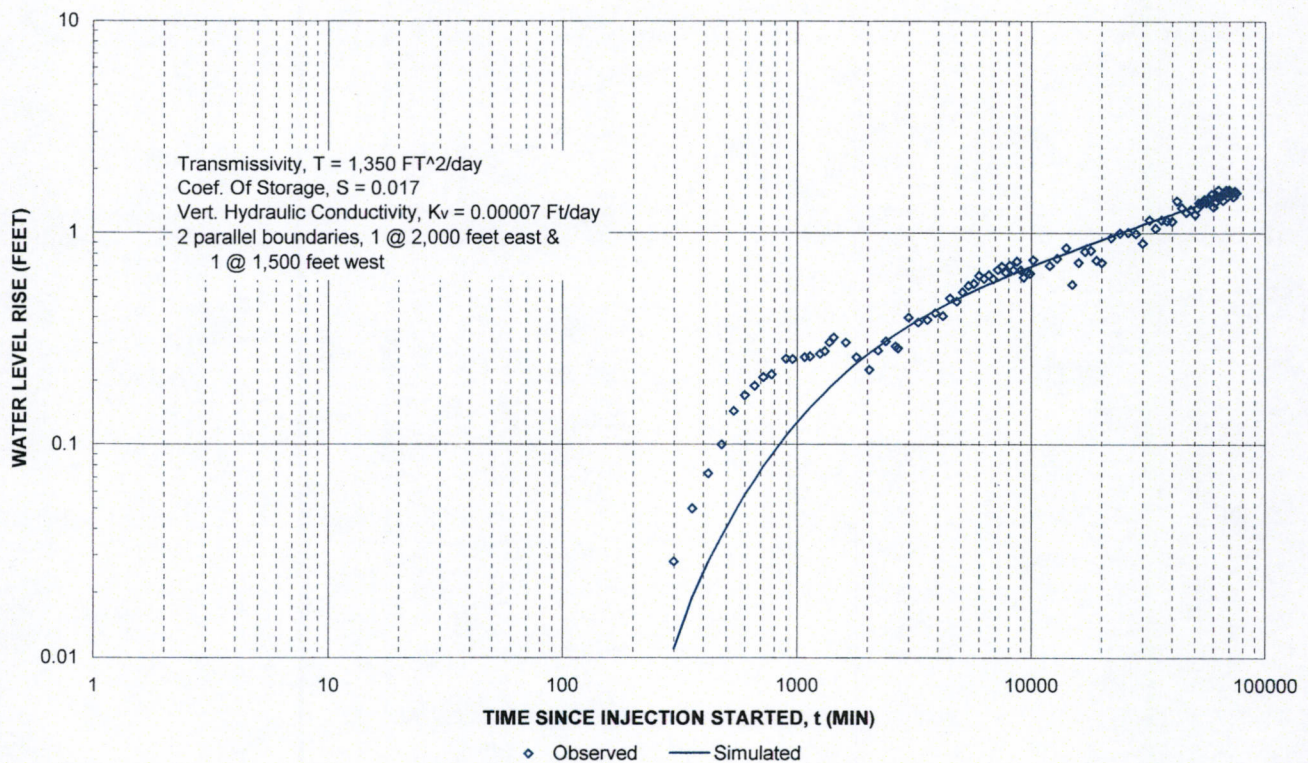


FIGURE 16. INJECTION TEST DATA FOR THE DIBLE WELL (LOG-LOG PLOT).

The values for aquifer Transmissivity and late-time Storage Coefficient for the STMIGID-1 site and the Dible Well are similar in magnitude to those calculated from the STMIGID-1 and Injection Well data, but the calculated vertical hydraulic conductivity differs by three to four orders of magnitude. This difference may be explained by the stratigraphy at the site. The lithologic logs for the Injection Well and STMIGID-1 indicate a significant proportion of silt and clay in the alluvial deposits that overlie the screened intervals for these wells. The Dible well is comparatively shallow, approximately 156 deep. The horizon in which it is completed overlies the water-bearing zones tapped by the Injection Well and STMIGID-1 and is separated from them by intervening deposits of lower vertical hydraulic conductivity. Alternatively, the vertical hydraulic conductivity of the shallower deposits may simply be much lower than that for the aquifer as a whole.

MW-2 and MW-3

The data plotted in Figure 8, Section 4.2, provide no indication of a measurable response in either of these two wells to injecting at the STMIGID-1 site. The lack of a response can be explained in terms of the aquifer properties at this locale. The calculated value for the Storage Coefficient indicates the aquifer is unconfined. Consequently, the area of influence due to pumping or injecting a well propagates outward relatively slowly and the test simply was not run long enough for either of these two sites to have been influenced by injection. Furthermore, the Dible Well data suggest a boundary west of STMIGID-1. An intervening fault would preclude, or at least retard, any effect at MW-2, which is located approximately 3,300 feet to the west of STMIGID-1.

4.5 Suspended Solids and Plugging Potential

Suspended solids were monitored by a series of filters placed in a side stream of the injected water. These data are addressed in a later section of the report. Other work by the Washoe County Department of Water Resources has provided data from two samples of the treated water from the distribution system in 2001 for suspended solids in injected water in the South Truckee Meadows. Their results indicated the concentration of suspended solids in the treated surface water is less than 1 part per million and that most of the suspended solids may be originate from the distribution system and is not an artifact of the treatment process (John Hulett, personal communication).

Near the end of the injection period, the Injection Well experienced an abrupt rise in water level. This rise is attributed to plugging of the pore spaces by material suspended in the injected water. The sudden rise in water level is suggestive of the membrane plugging effect described by Pyne. This occurs as a result of gradual deposition of suspended material near the Injection Well borehole / formation interface. No loss of efficiency due to plugging will be noticed until a critical level of plugging is reached. Once this happens, plugging occurs at an accelerated rate accompanied by a significant decrease in well efficiency that is manifested by a rise in the injection water level.

The plugging of the Injection Well appears to have been facilitated by two factors.

- The aquifer materials at this locale comprise poorly sorted mixtures of gravel, sand, silt and clay. The presence of silt and clay reduces the size of the pore spaces in the interstices between the coarser-grained deposits. The small pore spaces are more prone to plugging than the relatively large pore spaces in relatively well sorted coarse sand and gravel deposits.

- The injection well is not equipped with a pump. Suspended materials deposited in the aquifer near the well could not be periodically removed by reversing the flow of water by pumping.

In contrast to the experience at STIMGID-1, Sierra Pacific has not experienced any plugging of the aquifer materials in any of their wells as part of their on-going ASR projects (Paul Miller, personal communication). An explanation for the difference is that their wells are completed in coarser grained well-sorted alluvial deposits. These are expected to be more porous and the deposition of a small amount of suspended material in the well does not materially affect the hydraulic conductivity in the immediate vicinity of their wells.

5.0 Analysis Of Water Storage And Recovery Efficiency

A total of approximately 65 acre-feet of water was conveyed to the aquifer via the Injection Well at the STMGID-1 site during the ASR pilot study in the winter and spring of the year 2000. Injecting water into an aquifer results in a water mound more or less centered on the recharge well site. The mound will decay in a predictable fashion once injection is terminated. The rate of decay of the mound and the residual water level mound in the aquifer at some future time are primary concerns of any ASR program. This increase in water level within the aquifer after injection has ceased is indicative of the volume of stored water that can later be recovered.

In the vicinity of STMGID-1, -2 and -3, groundwater withdrawals have resulted in a decline in the head in the aquifer (Figure 3, Section 2). Intuitively, this depression of the piezometric surface constitutes a potential reservoir that can be used to store groundwater. However, aquifers are dynamic systems, and some of the stored water can be expected to move under the influence of the hydraulic gradient beyond wells that have the potential to recover the stored water.

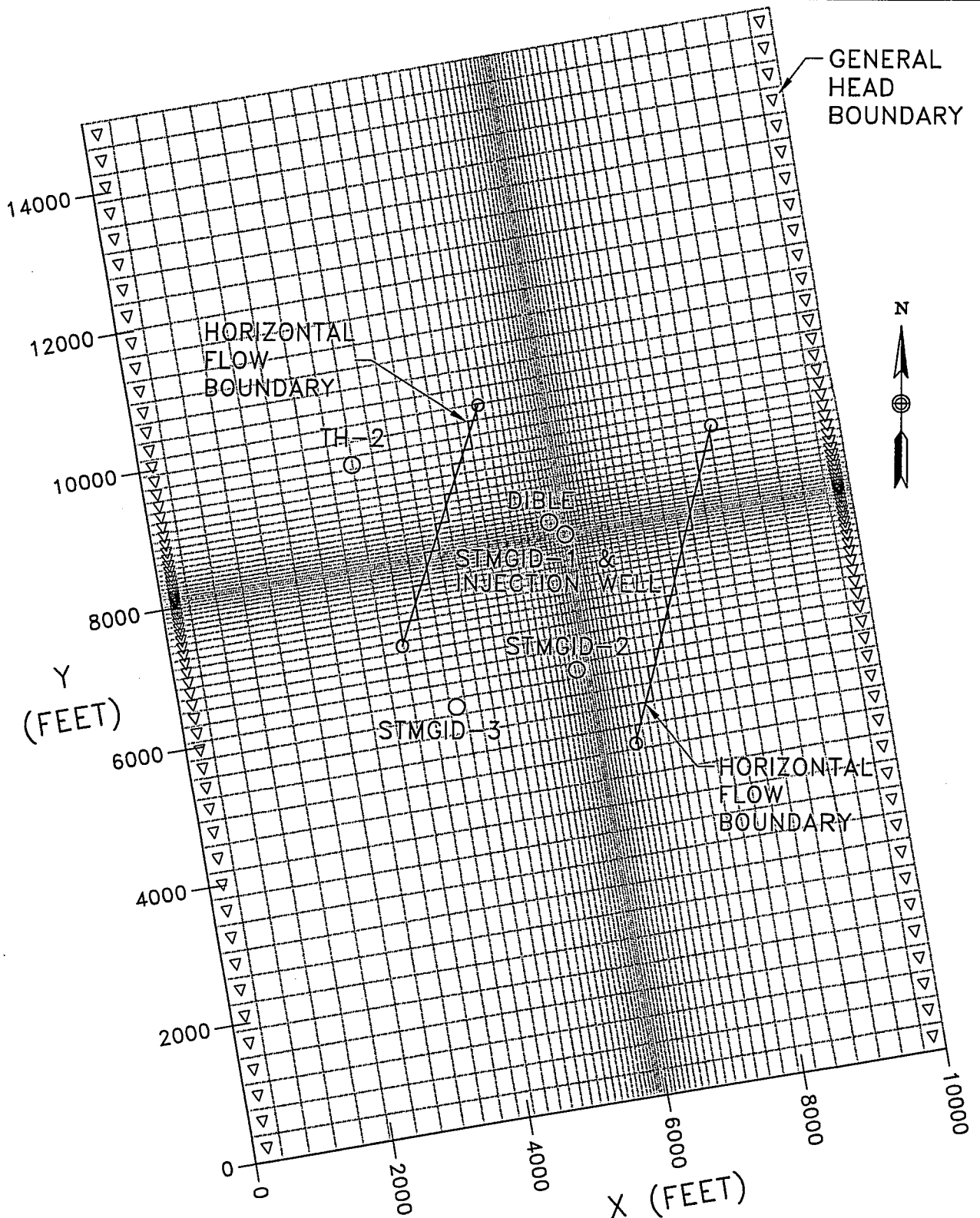
A visual inspection of the water levels for the Dible Well illustrated in Figure 8 indicates the shallow aquifer experienced a rise of approximately 1.5 feet a distance of more than 300 feet from STMGID-1 by the end of the injection period. Once injection ceased, the mound started to decay and there was approximately 0.7 foot of residual water-level rise by the time STMGID-1 was pressed back into service. Extrapolating the mound's decay beyond the recovery period suggested it might have taken months for the water levels to return to background levels. However, these graphical data do not allow for a quantitative assessment of the residual water level rise a few months into the future. Nor do the data allow for a rigorous assessment of storage in the aquifer at higher injection rates and larger stored water volumes.

The fate of the stored water and the volume of water that might be later recovered at this locale were examined by employing a relatively simple model of groundwater flow in the aquifer in the vicinity of STMGID-1. The model analysis employed the computer code MODFLOW (MacDonald and Harbaugh, 1988). Even though the model is relatively simplistic, it appears to have simulated the ASR test with some degree of confidence and may have some use for evaluating the effectiveness of an ASR program at higher injection rates. In essence, the model generated a local groundwater velocity distribution upon which injection and subsequent recovery of water could be superimposed. It should not be construed as a virtual representation of groundwater flow in the entire Mt. Rose fan aquifer.

5.1 Model Features

Model Domain

The model domain is depicted in Figure 17. It is represented by 56 columns and 69 rows. The grid spacing is variable, ranging from 33 feet in the vicinity of STMGID-1 up to a maximum of 400 feet along the margins. The variable grid spacing was selected to allow greater accuracy in the vicinity of the Injection Well site while allowing the model to be more computationally efficient than if the entire model was made up of a uniform fine grid.



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 17

MODEL DOMAIN

ECO-LOGIC
Consulting Engineers

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: None
Project No: 01300
File: 01300-FIG22

The model is bounded on the east and west by general head boundaries. The use of general head boundaries in these areas reduces the potential for the boundaries to influence the model solution. Flow lines represent northern and southern boundaries and no flow crosses these boundaries. The southern boundary approximately corresponds with the Steamboat Hills. Groundwater flux through the consolidated rocks that make up the Steamboat Hills is believed to be relatively small, rendering this boundary more or less correct. The northern no flow boundary is far from the injection site and does not represent any natural feature of the aquifer. It was selected primarily for convenience.

Model Layers

The model utilized three layers.

- Layer 1 represents the uppermost-saturated aquifer materials in the aquifer. The bottom of this unit is approximately 250 feet below the land surface. The top of Layer 1 is the water table. The Dible Well is completed solely in Layer 1.
- Layer 2 represents the aquifer deposits 250 to 450 feet below the land surface that correspond to the depths of the perforated portion of the Injection Well casing. STMGID-1 is also completed with perforations in Layer 2.
- Layer 3 represents the aquifer materials from 450 to 540 feet. At 540 feet, the borehole for STMGID-1 bottomed in a clay unit that for modeling purposes is assumed to be the base of the aquifer. STMGID-1 is completed with perforations in the portion of the aquifer represented by Layer 3 of the model as well as Layer 2.

The elevations of the bottoms of each layer were calculated from the difference between the elevation of the land surface (estimated from elevations determined from topographic map coverage of the study area) and the assumed uniform thickness of each layer. The top of Layer 1 was equal to the water table. The tops of Layers 2 and 3 are coincidental with the bottoms of Layer 1 and 2, respectively.

Aquifer Properties

The model utilized the true-layer approach, not the standard MODFLOW approach. Aquifer properties required for the model using this approach include vertical and horizontal Hydraulic Conductivity, Coefficient of Storage, and Specific Storage. Aquifer properties were initially assumed to be uniform throughout the model layers, but were modified slightly in order to simulate the hydraulic gradient in the aquifer.

Hydraulic Conductivity

Horizontal Hydraulic Conductivity was calculated on the basis of the Transmissivity of 1,500 feet²/day from the injection test and an aquifer thickness of 440 feet, or 3.4 feet/day. The horizontal Hydraulic Conductivity of the model was assumed to be the same for all three layers

Vertical Hydraulic Conductivity of Layer 1 was assumed to be 0.00007 feet/day based on the analysis of the Dible Well data. For Layers 2 and 3, the vertical Hydraulic Conductivity was assumed to be 0.5 feet/day on the basis of the analysis of the Injection Well and STMGID-1 data.

Storage Coefficient

Layer 1 is presumed to be unconfined. The Specific Yield of Layer 1 was initially assumed to be 0.017 based on the late-time value for Storage Coefficient calculated from the Dible Well data from the injection test. This value is relatively low for an unconfined aquifer that can approach 0.25 for well-sorted sands and gravels. This initial low value was selected to reflect the poorly sorted nature of the alluvial-fan deposits where the fine-grained portion of the alluvium limits the proportion of groundwater in the pore spaces that can drain under the influence of gravity. During calibration of the transient model, the Coefficient of Storage for Layer 1 was increased to 0.24, which is consistent with typical values for unconfined aquifers.

Layer 2 was assumed to be confined, but de-watering was permitted. The Specific Storage (Storage Coefficient divided by layer thickness) of Layer 2 was initially assumed to be approximately 0.000075, based on the late-time value for Coefficient of Storage of 0.03 calculated from the pilot study test and the thickness of the aquifer. During model calibration, the Specific Storage was increased to 0.00024. This translates to a Coefficient of Storage for Layer 2 of 0.045, which is similar the late-time Coefficient of Storage calculated from the injection well and STMGID-1 I data.

Layer 3 is confined and utilized the same initial value for Specific Storage as Layer 2.

Model Calibration

The initial steady-state model was considered to be calibrated in a broad sense once it reproduced the generalized hydraulic gradient in the aquifer, particularly in the vicinity of STMGID-1. It was not formally verified for the entire model domain by simulating specific historical events that have affected the aquifer as a whole.

The initial steady-state model resulted in a uniform groundwater gradient through the model domain that replicated the general gradient in the vicinity of STMGID-1 as suggested by the piezometric head data in Figure 3 (Section 2). However, the original uniform hydraulic conductivity distribution required modification to reproduce the gradient west and east of STMGID-1. The Hydraulic Conductivity value west of STMGID-1 was reduced to 1.85 feet/day in order to increase the gradient in this area. East of STMGID-1, the Hydraulic Conductivity was increased to 4.9 feet/day to flatten the hydraulic gradient in this area.

Two parallel horizontal flow barriers (one west and one east of STMGID-1) were inserted into the steady-state model to simulate the effects of the faults suggested by the Dible Well data. Initially, the faults were assumed to be impermeable, but their hydraulic conductivity was increased to 0.5 feet per day to better simulate the gradient near STMGID-1. Consequently, the faults impede east-west groundwater flow, but do not prevent it.

The steady-state model formed the basis of a transient model that was used to simulate the results of the injection test. As indicated above, the original estimates of Specific Yield and the Specific Storage required modification in order to reasonably reproduce the observed results of the injection test.

5.2 Results Of The Simulation

A limitation of the model is its inability to rigorously simulate delayed yield conditions that are known to exist in the aquifer. Consequently, only the late-time effects of injection and recovery

could be simulated with a level of confidence. Another limitation is its inability to simulate water level changes in a production or injection well because of the effect of the grid spacing.

Figures 18, 19 and 20 illustrate the results of the numerical simulation of the injection test. The best correlation between simulated and observed water levels for late-time conditions are found for the Dible Well and STMGID-1.

Figure 18 illustrates the water level changes for the Injection Well. The model simulated the shape of the curve for the Injection Well, including the abrupt rise near the end of the test, but the magnitude of the simulated water-level rise is less than half of that which was observed. The difference can be explained by the size of the model cell that represents the injection well. The cell is 33 feet square and the model is incapable of depicting the water level in a nominal 6-inch diameter injection well. In essence, the model simulates the water level for an injection well approximately 11 feet in diameter.

Figure 19 illustrates the water level changes for STMGID-1. The early-time data are not reproduced very well because the model cannot take into account the early-time coefficient of storage that is related to delayed yield. However, for late times (greater than 20 days) the model does reproduce the observed water-level rise, including the abrupt rise near the end of the test.

The model reproduced the elevation of the water levels in the Dible Well (Figure 20) within the one-foot calibration target for all but the earliest times. The results indicate approximately one foot of residual water-level rise could be expected at that location three months after injection was terminated. The inference that can be drawn from this result is that the volume of water that was injected created a mound that represents water stored in the aquifer. At the least, this water represents seasonal storage that can be recovered at a later date.

The 65 acre feet of water from the Chalk Bluff water treatment plant injected during the ASR pilot test at STMGID-1 in the year 2000 represents less than 4 per cent of the total water pumped from quasi-municipal wells in the southern Truckee Meadows. However, it yielded a benefit by causing a localized rise in water level that translates to water that can be recovered at a later date. The increase in water levels resulting from the test is depicted in Figure 21.

STMGID-1 ASR PILOT STUDY **SIMULATED WATER LEVELS FOR THE INJECTION WELL**

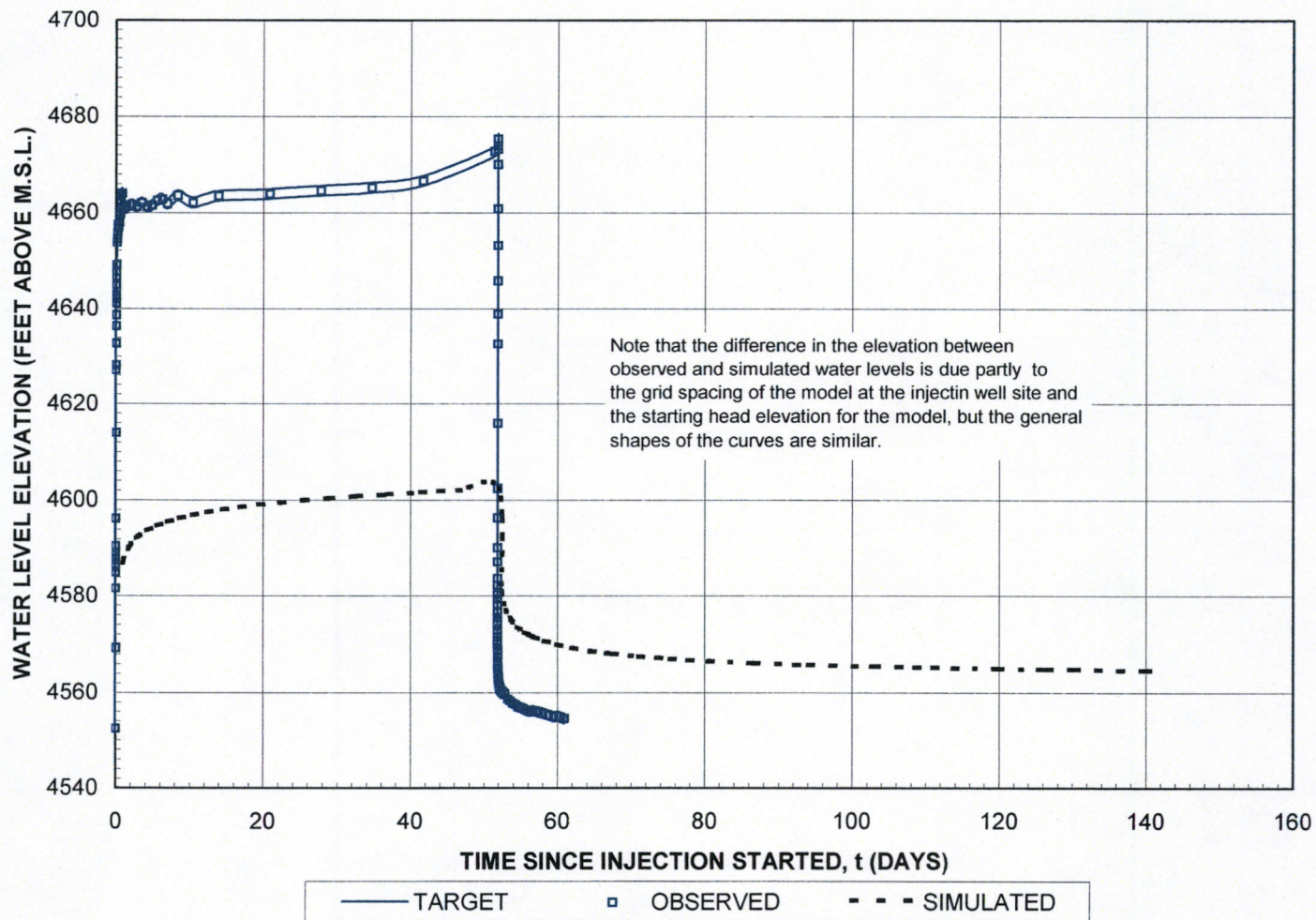


FIGURE 18. COMPARISON OF OBSERVED AND SIMULATED WATER LEVELS FOR THE INJECTION WELL

STMGID-1 ASR PILOT STUDY SIMULATED WATER LEVELS FOR STMGID-1

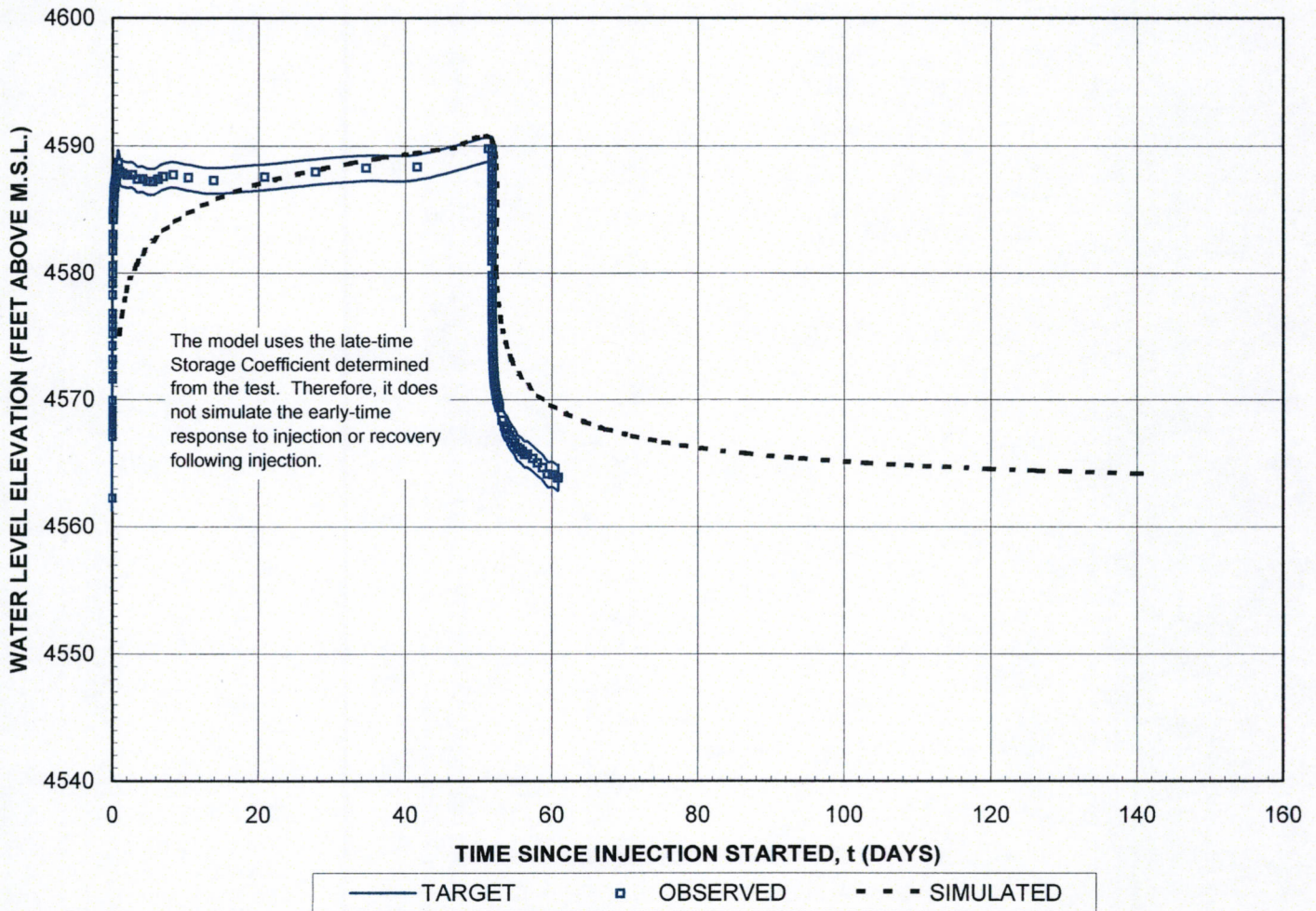


FIGURE 19. COMPARISON OF OBSERVED AND SIMULATED WATER LEVELS FOR STMGID-1

**STMGID-1 ASR PILOT STUDY
SIMULATED WATER LEVELS FOR THE DIBLE WELL**

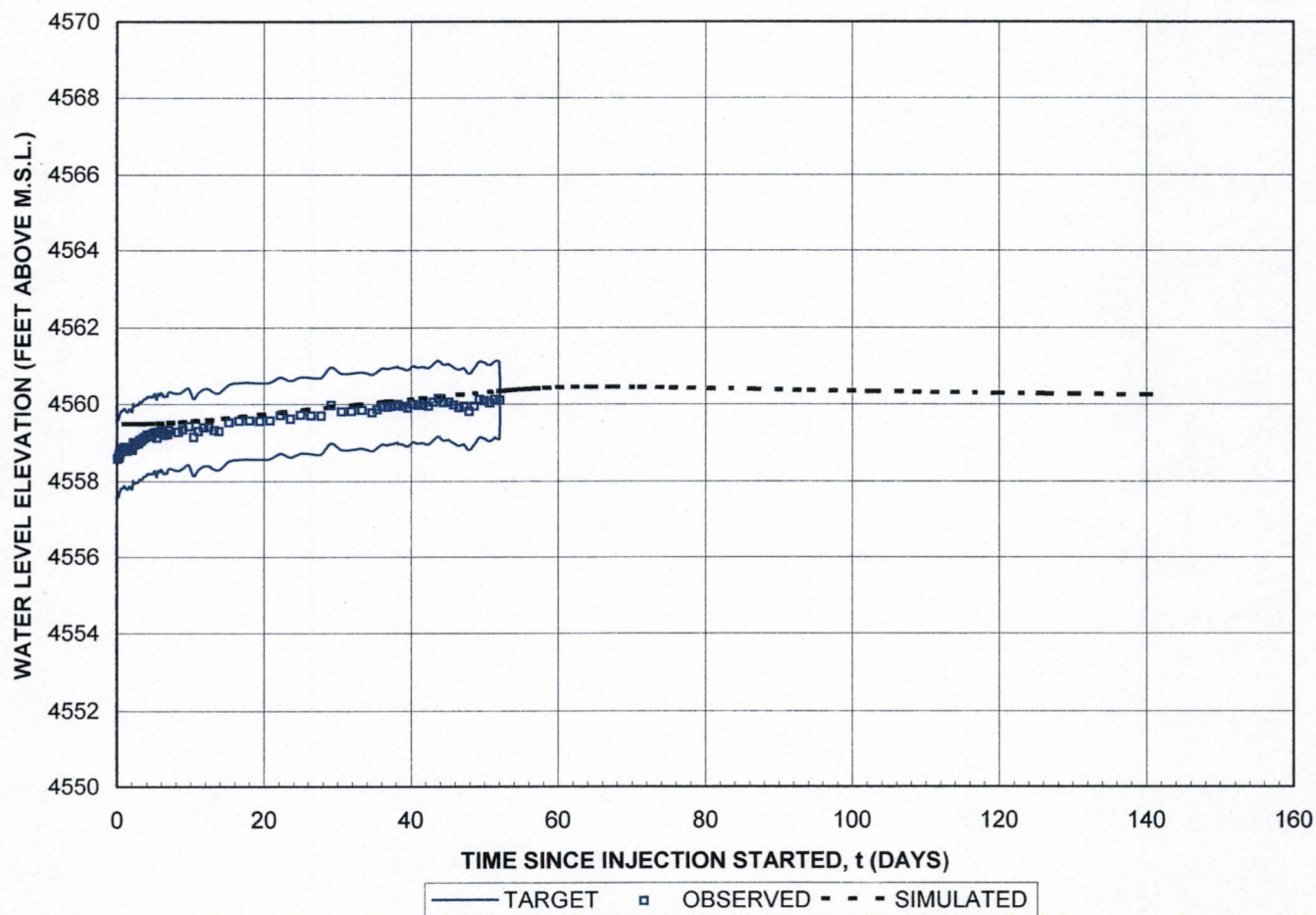
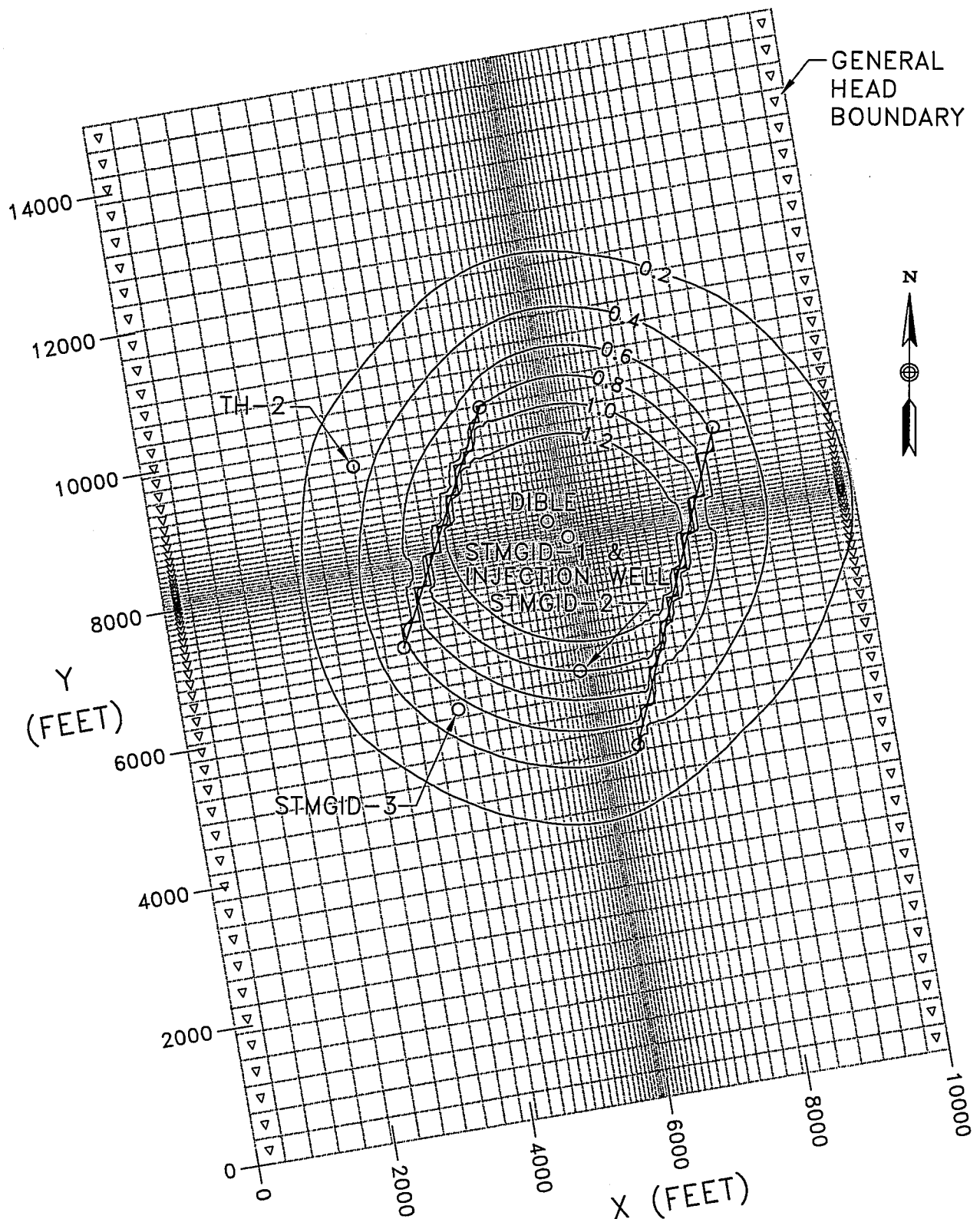


FIGURE 20. COMPARISON OF OBSERVED AND SIMULATED WATER LEVELS FOR THE DIBLE WELL



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 21

MAP OF SIMULATED RESIDUAL WATER LEVEL RISE
3 MONTHS AFTER INJECTING 65 ACRE-FEET OF WATER

Date: 5/22/01
Designed By: DCB
Drawn By: LKB

Scale: None
Project No: 01300
File: 01300-FIG21

ECOLOGIC
Consulting Engineers

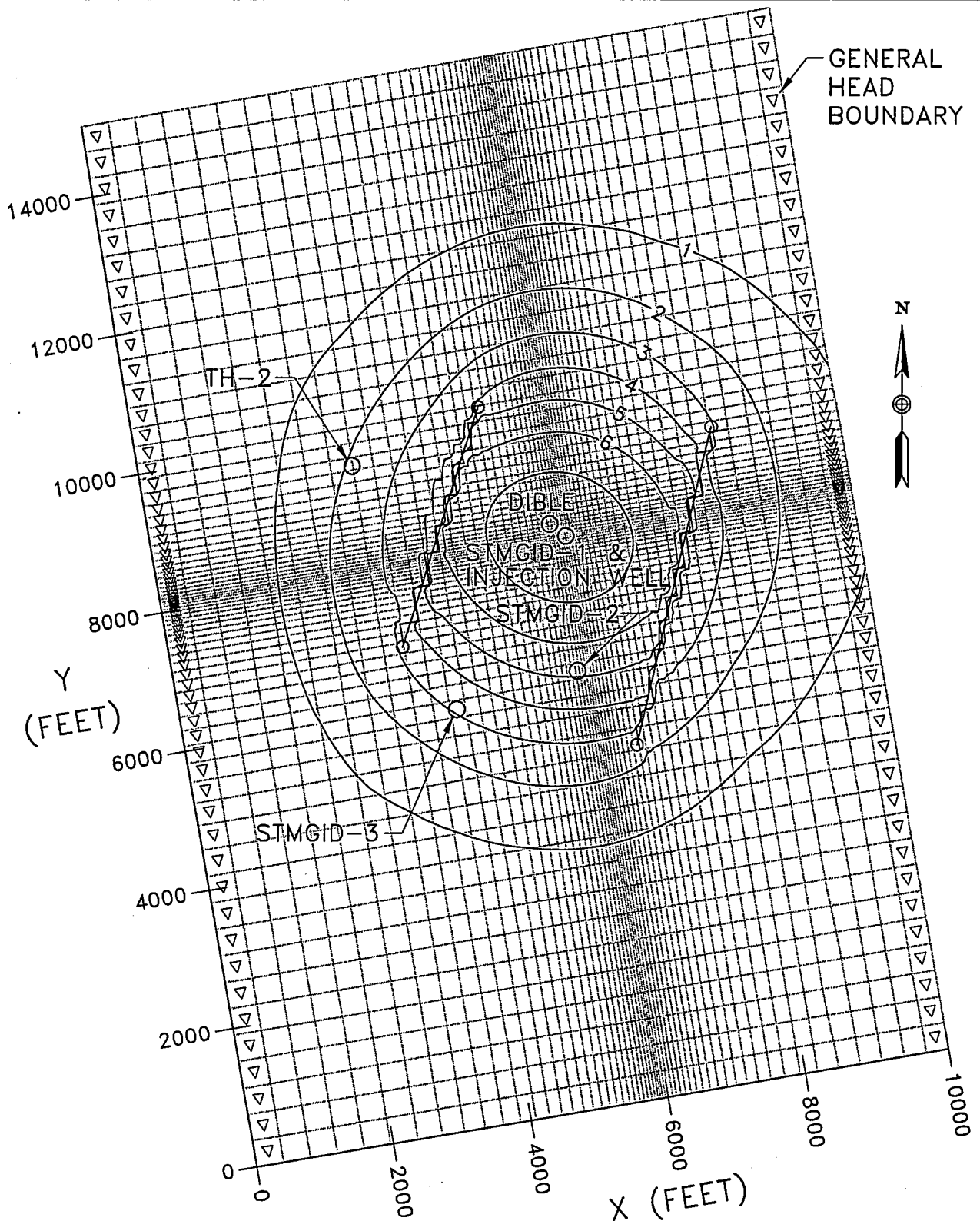
5.3 Simulated Water Level Rise Due To Injecting Larger Quantities of Water

Because aquifers are dynamic systems, it is not always possible to extrapolate upward the results of a small-scale test with a high degree of accuracy. For this reason a simulation of injection at STMGID-1 was run at a greater injection rate for a longer period of time. The injection rate for this simulation was assumed to be 325 acre-feet, or five times the injection rate for the pilot study and equates to approximately 880 gpm for a period of four months. The Injection Well at STMGID-1 is not capable of injecting water at this rate and the simulation assumes that the well head equipment in STMGID-1 can be modified to permit injection at this rate. The injection period is 120 days, presumably from December 1st through the following March 31st.

All model parameters for this simulation remained the same as those for the model of the pilot injection test. The only differences entailed increasing the injection rate to 880 gpm and increasing the injection period to 120 days to simulate injection from December 1st through March 31st. Following the end of injection, no pumping was assumed for a period of 90 days. The result is the simulation of a groundwater mound in the aquifer due to injection that would exist as of July 1st.

The simulated water mound is depicted in Figure 22. Within 1,000 feet of STMGID-1, the anticipated rise in water level 90 days after injection ceases is at least seven feet. At a distance of approximately 4,000 feet from STMGID-1, the simulated rise in water level is one foot. The area of the mound covers a large portion of the south Truckee Meadows where water level declines have been observed in individual domestic wells. Given this result, it is apparent that these homeowners are expected to benefit from a larger scale ASR program as well as the South Truckee Meadows General Improvement District.

The results of the pilot test and the subsequent simulation are compelling enough to launch the obvious next phase of Aquifer Storage and Recovery in this area, namely a larger scale program that enables storing larger quantities of groundwater in the aquifer.



WASHOE COUNTY REGIONAL WATER PLANNING
COMMISSION AND SOUTH TRUCKEE MEADOWS G.I.D.
PILOT AQUIFER STORAGE AND RECOVERY TEST
STMGID WELL NO. 1

FIGURE 22

MAP OF SIMULATED RESIDUAL WATER LEVEL RISE
3 MONTHS AFTER INJECTING 325 ACRE-FEET OF WATER

ECO-LOGIC

Consulting Engineers

Date: 5/22/01

Designed By: DCB

Drawn By: LKB

Scale: None

Project No: 01300

File: 01300-FIG22

6.0 Geochemical Tracers And Particle Loads ^(a.)

Data sets obtained during the injection phase of the pilot study were collected from the Injection Well (MW-1). Data obtained during the pumping or recovery phase were collected from the recovery well (STMGID-1). Furthermore, data were collected during both phases from the Dible Monitoring Well, located about 380 ft northwest of STMGID-1.

Besides well water-level data, other field data collected included electrical conductivity (EC), dissolved oxygen (DO), temperature, and pH. These data were collected with a Yellow Springs, Inc. (YSI) water chemistry probe and data logger installed and maintained by Washoe County Utility Division (WCUD). The YSI data record was continuous with the exception of several breaks, caused by instrument malfunction or problems with operating the equipment.

Furthermore, WCUD collected water samples that were analyzed for general chemistry, trace metals, stable isotopes (deuterium and oxygen-18) and total trihalomethanes (TTHMs). Data were also collected to determine suspended particle loads.

6.1 Water Samples And Chemical Measurements

6.1.1 General

Water quality data were collected for the following two purposes:

- Injection permit requirements.
- Scientific and engineering evaluation to help optimize the injection process and to improve our understanding of the hydrologic system.

Samples and measurements were taken at the following locations:

- a. At the injection wellhead, sampling for injection water.
- b. At the STMGID-1 wellhead, for water recovered after injection.
- c. At the Dible Well wellhead, for ambient groundwater quality and to document any variations in chemistry that might be attributable to the injection test.

Permit requirements

These samples were required as a condition of the Underground Injection Control (UIC) permit issued by the Nevada Division of Environmental Protection to Washoe County (Randy Van Hoozer, personal communication). For this purpose the following samples were collected:

1. Gross Alpha and Beta radiation/particles:
 - a. Sampled at all three locations, STMGID-1, Dible Well, and injection wellhead, before the injection test began.
2. Routine Domestic analysis, including analysis for TDS, hardness, Ca, Mg, Na, K, SO₄, Cl, NO₃, Alkalinity, F, As, Fe, Mn, Cu, Zn, Ba, B, SiO₂, pH, EC.

- a. Sampled during the injection phase: Dible Well and at injection wellhead. Sampled during the pumping phase: Dible Well and STMGID-1 well.

3. Total Trihalomethanes:

- a. Sampled during the injection phase from the Dible Monitoring Well and the injection well head.
- b. Sampled during the pumping phase from the Dible Monitoring Well and the STMGID-1 well.

Scientific and engineering evaluation

These data were collected to be able to better understand the injection process and its impact on aquifer permeability. Before and during the test general chemistry and isotope data were collected at the following locations.

- a. The Dible well, to characterize the ambient ground water.
- b. Injection well, to characterize the injected water.
- c. The STMGID-1 pumping well, to characterize the recovered (pumped) water.

Continuous recording devices (YSI probes) were installed in the injection line, the pumping wellhead (STMGID-1), and in Dible Well.

Particulate matter samples were collected from the injection line to quantify average suspended particulate loads.

All of the data mentioned above were analyzed to help in better understanding the injection process and assist in hydraulic data interpretation.

6.1.2 Environmental Isotopes And Major Ions

General Observations

The isotope database gathered for this project was augmented with other data available from the South Truckee Meadows area, including historical data from the STMGID-1 well, the irrigation ditches (Steamboat, Last Chance and Lake Street Ditches), Thomas and Whites Creeks, and three other wells in the South Truckee Meadows (STMGID-5 & 7, and Double Diamond Well No. 2). The isotope data collected so far substantiate the conceptual model of ditch infiltration, as proposed in the Feasibility Analysis of this ASR (CES, *et al.*; 1998). However, the currently available data also further complicate the interpretation of South Truckee Meadows aquifer system, and open up further questions about its recharge mechanisms.

All available isotope data are plotted in Figure 23. Also shown is the range of composition of snow (Szecsody 1982) from the Carson Range (indicated as a line), as a

The foregoing interpretation, stipulating the significance of surface water infiltration into the STM aquifer system, is strongly supported by the unusually high dissolved oxygen levels in these groundwaters (see Table 2, and the discussion below). The significance of surface water infiltration was hypothesized earlier, suggesting the potential feasibility of passive artificial recharge by various means, and implying the aquifer's high vulnerability to surface contamination (CES, 1998).

Although the new data significantly improved our understanding of STM hydrology, it is recommended to develop a more thorough isotope database, to be able to better quantify irrigation ditch recharge and recharge from the Carson Range.

6.2 Changes In STMGID-1 And The Dible Monitoring Well

6.2.1 Isotopes

Also shown in Figure 23 is the injection water isotopic composition. This is actually treated Truckee River water, with varying composition affected by changing river conditions during the winter months January through March 2000. The post-injection composition of water recovered from STMGID-1 ("Pumping Well" sample collected 4/03/00) is clearly similar to injection water immediately after injection ceased. The chemistry of water recovered from STMGID-1 ("Pumping Well" sample collected 4/28/00) gradually returns to the typical groundwater composition in the aquifer by the end of the recovery phase (these data plot in the lower left hand corner of the graph).

The chemical composition of the Dible Monitoring Well (depth approximately 150 ft) represents shallow groundwater. This is apparently a mixture of deeper groundwater as represented by the 530 ft deep STMGID-1 well and infiltrated irrigation ditch water. Throughout the test, the Dible Monitoring Well maintained an isotope composition close to its original composition. However, a detailed analysis suggests that slight changes in response to injection and pumping did occur. In Figure 24, water level elevations in the Dible well are plotted versus time. The water levels responded to injection within a short time and declined when injection was disrupted temporarily, although only five isotope samples were collected from the Dible Monitoring Well, and isotopic changes are rather small, Figure 24 indicates deuterium levels closely followed the water level trends. Similar trends are evident in the oxygen-18 and in-situ temperature data. These data suggest that deeper water is being forced upward into the shallower zones. They do not indicate migration of the injected water from STMGID-1.

6.2.2 Field Water Quality Parameter Data

The field water quality parameter data collected with the continuous recording device (YSI data) also provide some useful indications of aquifer response to injection and subsequent pumping. In Figure 25 continuously recorded water temperature, EC and DO are plotted versus time relative to the end of injection / start of recovery. The data plotted to the left of the line representing the end of injection / start of recovery are from the injected water, the data plotted to the right are from the water recovered by pumping STMGID-1.

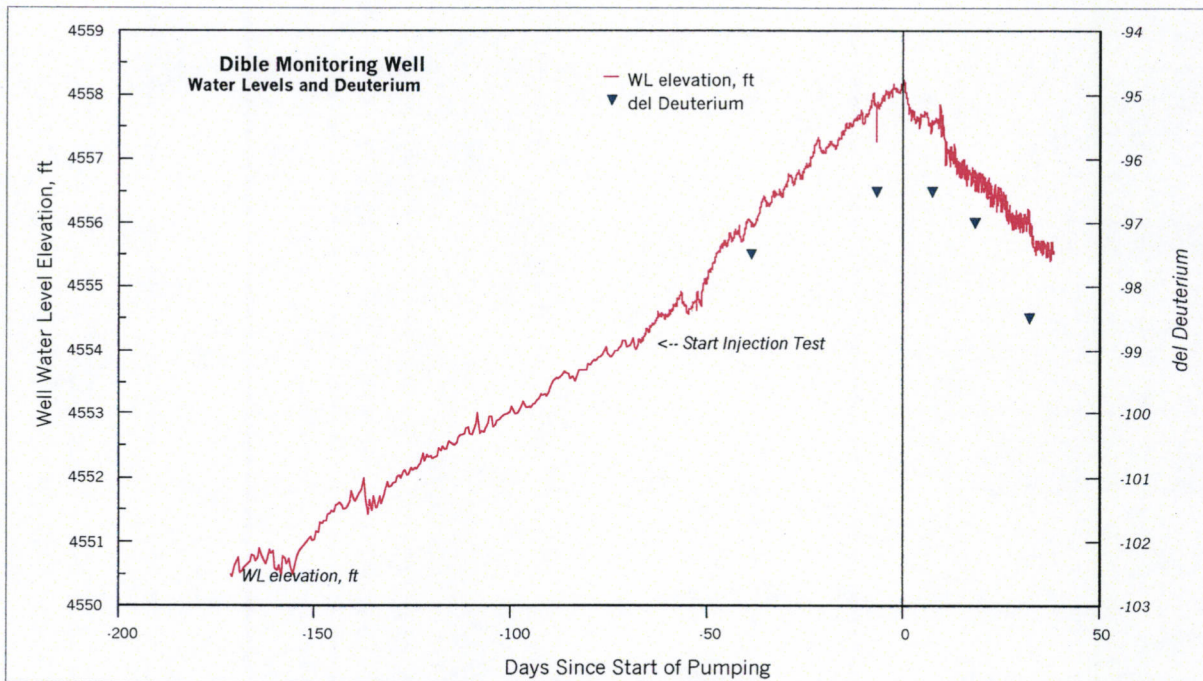


FIGURE 24. WELL WATER LEVEL CHANGES AND ISOTOPES IN THE DIBLE DOMESTIC WELL, ASR PILOT TEST, SOUTH TRUCKEE MEADOWS.

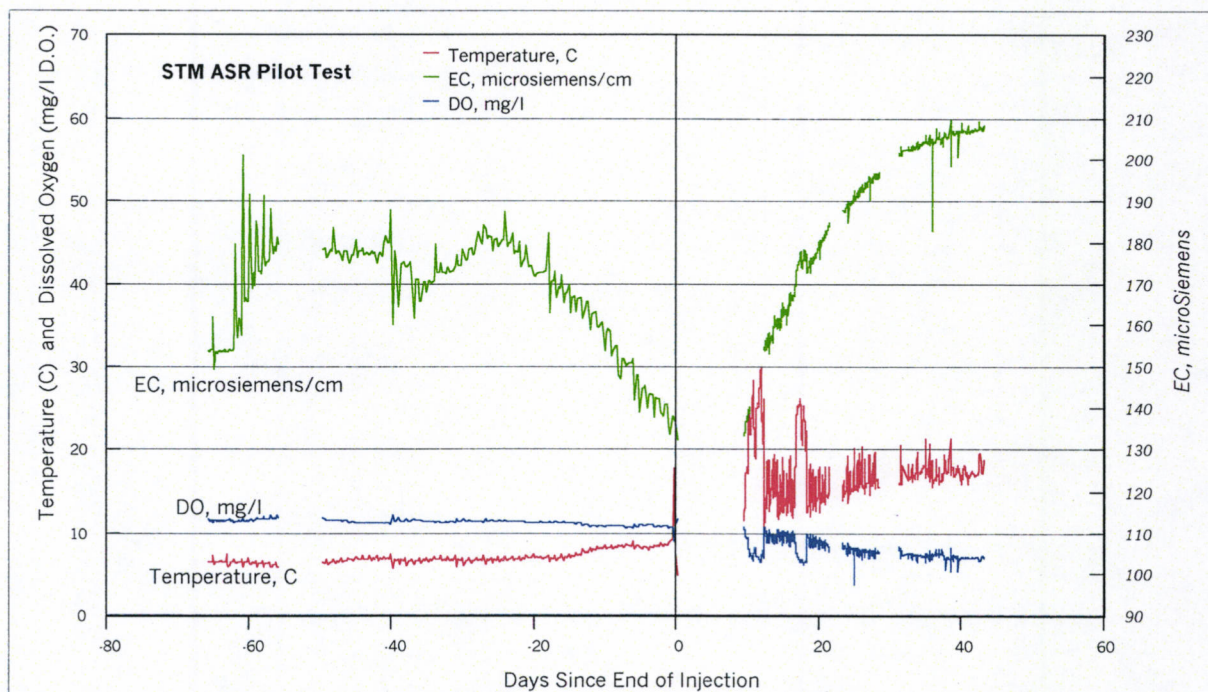


FIGURE 25. TEMPERATURE, EC AND DO IN INJECTED WATER AND PUMPED WATER, STMGID-1 ASR PILOT PROJECT

Injection water chemistry changed dramatically, as indicated by the changing EC values (in response to changing runoff conditions in the Truckee River). EC dropped from about 180 in February, down to 135 micro Siemens by the end of the injection test (March 27). The temperature increased slightly, probably due to warming weather, while dissolved oxygen in the injection water remained practically constant, at the high level expected in the oxygenated water from the Chalk Bluff Treatment Plant.

The pumping data show a gradual change of EC, DO and temperature, back to the levels of ambient ground water conditions. Clearly this indicates mixing of injected water with ambient groundwater, with increasing ambient portions throughout the pumping phase.

The pH data (plotted in Figure 26) showed a dramatic drop from injected water to pumping phase. In other words the gradual transition from injected water back to ambient groundwater is not as gradual as in the other variables. This suggests that the injected water may have been subjected to changing chemical conditions in the aquifer, resulting in a drop of about 0.8 pH units, thereby approaching the pH level of 7.2 measured at the STMGID-1 wellhead on August 23, 1999. The dramatic pH change during the pumping phase may be attributed to the injection water being subjected to increased pressure in the aquifer environment. However, with these data it is not clear if any significant chemical reactions affected water chemistry during injection.

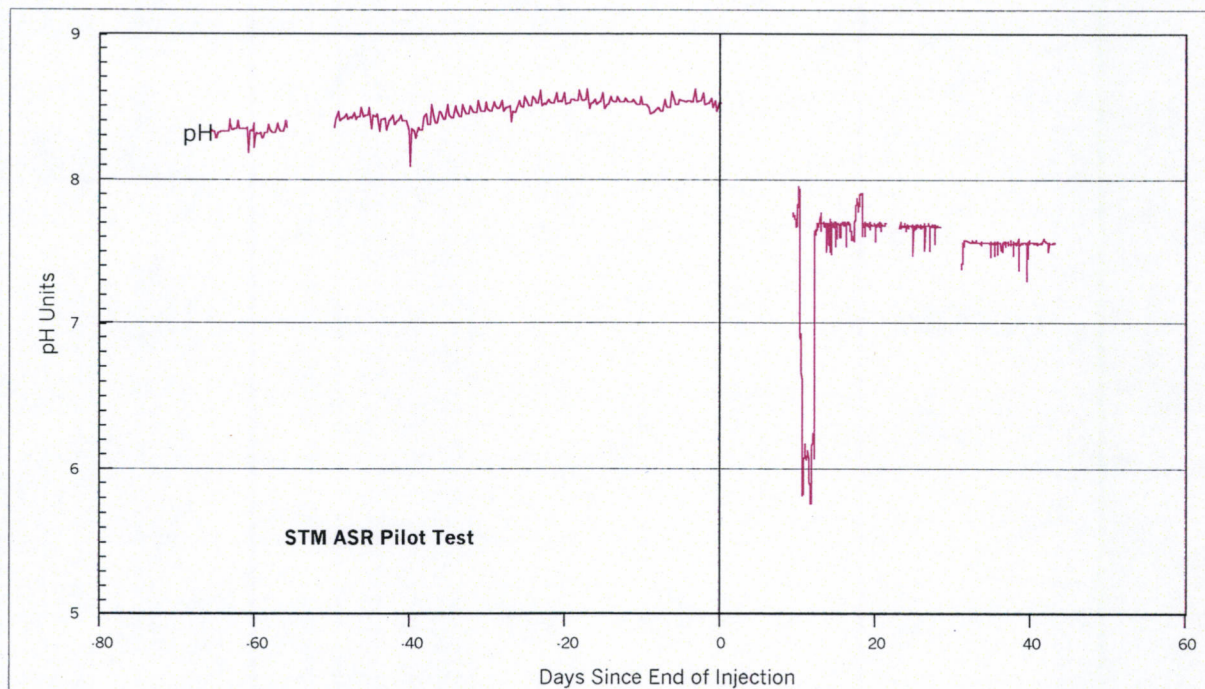


FIGURE 26: LEVELS OF pH IN INJECTED WATER AND PUMPED WATER, STM ASR PILOT PROJECT

6.3 Mixing Processes Evident In Isotopes, Major Ions And Total Trihalomethanes

By comparing concentrations of certain conservative constituents, like sulfate, chloride, and stable isotopes in pumped water with that in injected water, one can estimate how much of the original injection water was recovered and how much remained in the aquifer by the time the volume extracted equaled the volume injected. The following formula was used:

$$V_i = (C_m - C_g)/(C_i - C_g)$$

where

- V_i is the proportion of injected water pumped back out of the aquifer;
- C_m is the mixing concentration in the pumped water;
- C_g is the concentration in ambient ground water;
- C_i is the concentration in the injected water.

In Table 1, the percent injection water in the water recovered via pumping STMGID-1 is given in column 4, based on comparing total volume of injected water with pumped water. The columns to the right give the percentage of injected water estimated from each constituent, as calculated with the formula given above.

TABLE 1: PERCENT INJECTED WATER CONTAINED IN RECOVERED WATER STMGID-1 ASR PILOT TEST.									
Sampling Date	Days pumping	Volume Pumped		Estimated percent injected water in extracted water, based on the constituents shown below					
		ac-ft	% inj. water	SO4	Cl	O-18	Deuterium	TDS sum	TTHM ppb
04/03/00	7	0	100%	42%	75%	74%	77%	99%	104%
04/14/00	18	20	70%	76%	82%	51%	55%	80%	79%
04/28/00	32	54	17%	34%	30%	17%	13%	56%	22%
05/03/00	37	69	-6%						12%
06/27/00	92			4%	-3%			-19%	

As can be seen readily, by comparing the extracted volume ratios with the ratios of the tracers, there are some discrepancies. For example when looking at TDS almost 100% of injected water was recovered. This observation is supported by the YSI EC data plotted in Figure 21, i.e. the initial pumping EC was comparable to the very last injection water EC. On the other hand when looking at the isotopes deuterium and oxygen-18, it appears as if some injected water was "lost" before it could be retrieved by pumping. The first impression is that recovery of injected water may not necessarily be a molecule-by-molecule recovery. However, there are several factors that shed some uncertainty on this conclusion:

1. Due to a hiatus between injection and pumping phase some of the original injected volume may have been diluted before pumping, thereby consistently leading to lower estimates.

2. The recovery well STMIGID-1 is about 80 ft deeper than the injection well. Thereby the recovery well also pumps both from shallower (injected water) and deeper aquifer portions.
3. The percentages among the various chemicals differ markedly, which may be an indication of varying diffusion rates among constituents.
4. Chloride and sulfate values may have been inverted, i.e. the dates have been confused. This could not be verified since the original lab data sheets are not in our possession.

The differences in well construction between injection and pumping well make it somewhat uncertain which effect is truly dominating. Since the well was not sampled at the time when pumped volume equaled injected volume, it cannot be determined if the isotope ratios converged to unity at the same time the volume ratio did. The chemical data do deserve a more in-depth analysis, for example by modeling chemical processes as a result of mixing, using the USGS computer code PHREEQ. However, this exceeds the current scope of this report.

6.4 Subsurface Mixing And Mineral Deposition Potential

The following discussion identifies potential water quality effects due to injection at STMIGID-1 that could lead to mineral precipitation and its potential for well and aquifer deterioration. This analysis resorted to historical data from the STMIGID-1 well and the Chalk Bluff treatment plant, and a number of samples collected from STMIGID-1, 2 and 3 in August 1999.

STMIGID-1 data

A total of 28 historical data sets were available from STMIGID-1, covering the period from 1983 to 1999. TDS values calculated as sum total of all major ions range from 160 to 200 mg/l, not including SiO₂. SiO₂ is about 60 mg/l in all these sets, and the actual TDS is higher about by that increment.

Iron, manganese and dissolved oxygen in ground water will be discussed in a later section below.

Chalk Bluff Plant effluent data

Only four data sets were available from Chalk Bluff Water Treatment Plant. These were not adequate to determine the full range of possible chemical variations in an average year. Fortunately, more than 30 years of monthly data were available for the Truckee River at Idlewild Park. As expected, the available Chalk Bluff Effluent data correlate reasonably well with Idlewild Truckee River chemistry data of that same month.

One deficiency of the river data is that the full set of major ions is available only for January, April, July, and October. Sodium (Na) and potassium (K) had to be calculated via the epm-charge balance for the other months.

Maximum TDS by sum of the river water ranges from 83 mg/l in May to 300 mg/l in October (not including SiO₂, for which there are no data). By comparison STMIGID-1 groundwater ranges from 160 to 200 mg/l.

6.4.1 Mixing Calculations

Precipitation of carbonate minerals is a potential concern during mixing of river water with groundwater. To determine if this is a potential problem, hypothetical mixing concentrations were calculated. By sorting out the maximum values of all the major ions, it is clear that except for October and November (especially during dry years), most of the year river water concentrations are lower than groundwater near STMGID-1. Therefore, for most months of the year mixing groundwater with river water should result in improved major ion water quality parameters near STMGID-1. Since indigenous groundwater under natural conditions is already compatible with the aquifer, we do not anticipate mineral precipitation to become a problem under injection conditions. In other words, groundwater quality (major ions) would be improved during all injection months, except October and November.

Iron in ground water

Precipitation of iron carbonates and hydroxides in the aquifer during injection can be a potential concern. Groundwaters in the STM area typically have abundant bicarbonate. The pH values in

TABLE 2: WATER CHEMISTRY DATA COLLECTED IN AUGUST 1999, SOUTH TRUCKEE MEADOWS, ASR PILOT PROJECT.				
Well sampled:	STMGID-1	STMGID-2	STMGID-3	STMGID-MW-1
Date	08/23/99	08/23/99	08/23/99	08/25/99
TIME	12:00	13:06	13:50	11:30
Temperature, °C	29.3		25	20
EC, micro Siemens	209			
pH, field	7.2			
pH, lab	8.01		7.5	7.75
DO saturated, mg/l	6.44	6.9	6.92	7.61
Field DO, mg/l, YSI meter	5.96	6.7		
Lab DO, mg/l, Winkler Method	6.2	6.8	8.7	8
Calcium	16.8			
Magnesium	10.1			
Sodium	10.3			
Potassium	5.7			
Sulfate	2.8			
Chloride	1.1			
Bicarbonate	133			
Silica	69.6			
NO ₃ -N	0.69	0.52	0.59	0.42
NO ₂ -N	<.01	<.01	<.01	<.01
NH ₄ -N	<.01	<.01	<.01	<.01
Iron (total, unfiltered)	<.01	<.01	0.01	0.44
Iron (dissolved, filtered 0.4 micron)	<.01	<.01	<.01	<.01
Manganese (dissolved, filtered 0.4 micron)	<.01	<.01	<.01	<.01
Manganese (total)	<.01	<.01	<.01	0.02

the historical data are relatively high (at or above 8). The historical data at times also contain high iron values. STMGID-1 iron data show wide ranges of iron, ranging from zero to 0.69 mg/l iron.

It is suspected that the inconsistency of these data is due to particulate (if not colloidal) matter carrying iron in unfiltered water samples. To our knowledge the routine water chemistry samples from these wells are never filtered before analysis. In other words the historical iron data may very well be the sum total of dissolved and suspended iron in ground water.

To clarify this issue, we re-sampled all three STMGID wells on August 28, and had the samples filtered before analysis. The results show iron less than 0.01 mg/l in STMGID-1. The situation is similar in the other two wells sampled (STMGID 2 and 3).

On the other hand, a sample from the monitoring well next to STMGID-1 (the pilot test injection well) had significant dissolved iron due to stagnant well water (the well could not be purged adequately before sampling). This suggests that the source of the apparently high iron levels in these wells may be due to casing deterioration and/or suspended iron in the aquifer. Casing deterioration is suggested by a coating of iron on water level sounders when manual water level measurements are taken in the Injection Well.

Dissolved oxygen in ground water

The low iron levels in STM ground water can be explained by the relatively high levels of dissolved oxygen (DO) in ground water, since iron is less soluble in oxygenated water. Dissolved oxygen was measured in ground water, first at the wellhead of all three production wells, and then in-situ in the Dible well. At the wellhead DO was measured with a YSI probe, and with a preserved sample (analyzed in the lab). Much to our surprise, dissolved oxygen in the well waters was always at or above saturation. Being skeptical about these values some wells were resampled and still the results were similar. High DO values in ground water were confirmed by Washoe County Utility personnel in the Dible well by means of a down hole DO probe (Randy Van Hoozer, personal communication).

Dissolved oxygen levels at or near saturation in ground water are unusual, and demand a reasonable explanation. One explanation is that highly oxygenated surface water recharge from streams may indeed be a significant source of ground water in these wells. This is clearly supported by the stable isotope data discussed in Figure 17. Furthermore, the aquifer materials in this area were probably deposited in a very active clastic sedimentation facies (alluvial fan), with little or no organic material buried (arid climate). At least whatever little amounts of organic material accumulated is probably oxidized before it accumulates in the subsurface. This scenario would allow little room for reducing environments in the aquifer, and thereby the levels of dissolved iron (and manganese) in ground water are kept at a minimum.

In summary the data are interpreted as an indication of an aquifer subject to rapid surface water recharge in an environment with little or no ground water oxygen depleting chemical reactions.

Whatever iron data are available from the Chalk Bluff effluent, they are also low, as would be anticipated, due to the oxygenated water available from the plant (although suspended iron maybe high. Presumably treated surface water is highly oxygenated and chemical conditions are even more oxidized due to addition of chlorine. For that reason dissolved iron in the injection water will always be at a minimum.

6.4.2 Chemical Equilibria During Mixing

The effect of mixing on mineral equilibria in the aquifer due to injection was evaluated before the injection test, using the USGS computer code PHREEQE. Injection results in mixing between two waters that are chemically different, and chemical reactions can potentially result in formation of insoluble minerals. This can result in chemical clogging of pore spaces, leading to gradual reduction of aquifer permeability, thereby diminishing the injection efficiency.

Mineral saturation indices were used to determine potential of mineral precipitation in the aquifer due to mixing, etc. Saturation indices were estimated for calcite, siderite, and amorphous iron hydroxide. These were calculated for the original solutions, as well as at 20, 40, 60 and 80% mixing ratios.

The results suggest that saturation indices for all three minerals remain less than zero for all mixing scenarios. These saturation indices are also less than zero in the end member solutions. These results make sense when looking at the water chemistry and the resulting mixing compositions. Moreso, amorphous iron hydroxide remains below saturation despite the conservative iron input values (i.e. the actual concentration is lower than the values used).

Rather high saturation indices for goethite and hematite produce ambiguous results. However, it is unlikely that these minerals will form under these conditions. It must be kept in mind that even if iron is sufficient to precipitate these minerals, under oxidizing conditions in each solution, this would occur before injection, i.e. under ambient ground water and pipeline conditions (though it could show up as suspended iron).

6.5 Suspended Matter Loads

6.5.1 Data Collection

Suspended matter loads are needed to be able to determine injection water filtration requirements to avoid future aquifer and well deterioration due to subsurface mechanical clogging.

It was attempted to obtain existing (historical) data of the Chalk Bluff effluent from SPPCo. All that was available was one set of data from the Glendale Plant (for greater than 2 microns diameter). According to Todd Brewer, plant chemist, the particle counts are generally "extremely low at the plant". However, he speculated that these counts may increase with distance from the plant. The SPPCo data were used to help design a particulate filter sampling system at the injection wellhead.

Seven successful filter tests were run during the injection test. Samples were obtained for the 1.2, 5 and 8 micron diameters, by using in-line filters that were installed on a sample tap on the injection line. The filters were weighed dry before and after installation to determine the weight of particulate matter accumulated on the filters after a certain period of time. The flow through the filters was measured periodically to be able to calculate particulate loadings by integration during various stages in the test period.

6.5.2 Suspended Solids Concentrations

The results are tabulated in Table 3. From Table 3, it is apparent that approximately 50% or more of the suspended solids were larger than 8 microns.

TABLE 3: SUSPENDED SOLID LOADS IN INJECTION WATER, STMGID-1 ASR PILOT INJECTION TEST.

Concentration (mg/l for each filter size)				Concentration (lbs/ac-ft for each filter size)			
1.2 microns	3 microns	8 microns	Total	1.2 microns	3 microns	8 microns	Total
0.001	0.018	0.028	0.046	0.002	0.048	0.075	0.125
0.003	0.017	0.046	0.066	0.008	0.047	0.124	0.179
0.000	0.000	0.071	0.071	0.000	0.000	0.192	0.192
0.000	0.071	0.072	0.143	0.000	0.191	0.196	0.388
0.000	0.054	0.119	0.173	0.000	0.147	0.323	0.470
0.000	0.003	0.135	0.138	0.000	0.008	0.366	0.374
0.000	0.002	0.082	0.084	0.000	0.006	0.222	0.227

For dedicated injection wells that will not be pumped as production wells, filtration of the injected water is recommended to relieve the plugging that occurred during the injection test. Self-cleaning filter screens are available that can effectively capture suspended solids particles larger than 5 microns, but the number of suppliers is limited. For particle sizes greater than 10 microns, there are more suppliers from which to choose. It would be worthwhile to collect additional samples of water from the distribution system to determine whether a 10 micron filter would be suitable for this application.

7.0 Sources Of Information

CES, Inc., Plumas Geo-Hydrology, and EGR & Associates; 1998. Feasibility analysis of a pilot groundwater recharge project and analysis of the surface water contributions to the shallow aquifer in use by domestic well owners in the south Truckee Meadows: consulting report prepared for the Washoe County Water Planning Department.

CES, Inc. and EGR & Associates, 1999. Analysis of aquifer storage and recovery in the south Truckee Meadows utilizing a recharge well located at the TH-2 site: consulting report prepared for the Washoe County Water Planning Department

Szecsody, 1982. Use of major ion chemistry and environmental isotopes to delineate subsurface flow in Eagle Valley, Nevada. M.S. Thesis, Univ. Of Nevada, Reno, 193 pages. October 1982.