Recharge to the Eagle Valley Ground-Water Basin by Streamflow in Vicee Canyon, West-Central Nevada

By Douglas K. Maurer and Jeffrey M. Fischer

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4158

Prepared in cooperation with the
CARSON CITY PUBLIC WORKS DEPARTMENT

Carson City, Nevada

1988

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
Room 227, Federal Building
705 North Plaza Street
Carson City, NV 89701

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CONVERSION FACTORS AND ABBREVIATIONS

"Inch-pound" units of measure used in this report may be converted to metric (International System) units by using the following factors:

Multiply	By	To obtain
Acre-feet per year (acre-ft/yr)	1.233	Cubic meters per year (m^3/yr)
Cubic feet per second (ft^3/s)	0.02832	Cubic meters per second (m^3/s)
Cubic feet per day (ft^3/d)	0.02832	Cubic meters per day (m^3/d)
Feet (ft)	0.3048	Meters (m)
Feet squared (ft^2)	0.09294	Meters squared (m^2)
Inches per hour (in/h)	25.40	Millimeters per hour (mm/h)
Miles (mi)	1.609	Kilometers (km)

For temperature, degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by using the formula °C = 0.556 (°F - 32).

ALTITUDE DATUM

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), which is derived from a general adjustment of the first-order leveling networks of both the United States and Canada.

RECHARGE TO THE EAGLE VALLEY GROUND-WATER BASIN BY STREAMFLOW IN VICEE CANYON, WEST-CENTRAL NEVADA

By Douglas K. Maurer and Jeffrey M. Fischer

ABSTRACT

Recharge to ground water can be increased by adding imported water to natural surface-water flow in Vicee Canyon, located in Eagle Valley, west-central Nevada. On the west side of Eagle Valley municipal pumping for Carson City, Nevada, has caused as much as 50 feet of ground-water level decline since 1972.

Measurements of infiltration rates, percolation rates, and hydraulic conductivity indicate that the area could be suitable for artificial recharge through infiltration of augmented streamflow. Direct runoff from storms or snowmelt creates natural infiltration beds on the floor of Vicee Canyon; however, subsequent base runoff causes channelization and armoring of the stream channel, reducing infiltration rates. A water balance of the total streamflow in Vicee Canyon indicates that 60 to 70 percent becomes recharge and that the remainder is lost to evaporation from a nearby gravel pit and evapotranspiration on the canyon floor. Estimates of recharge from measurements in the unsaturated and saturated zones account for about 45 percent of the total streamflow.

Application of a ground-water flow model indicates that, at present pumping rates, water levels below Vicee Canyon and at a nearby municipal well may rise about 15 to 30 feet after 5 years as a result of infiltration from additional streamflow of about 1 cubic foot per second (720 acre-feet per year). This would increase ground-water storage by about 2,300 to 3,100 acre-feet.

INTRODUCTION

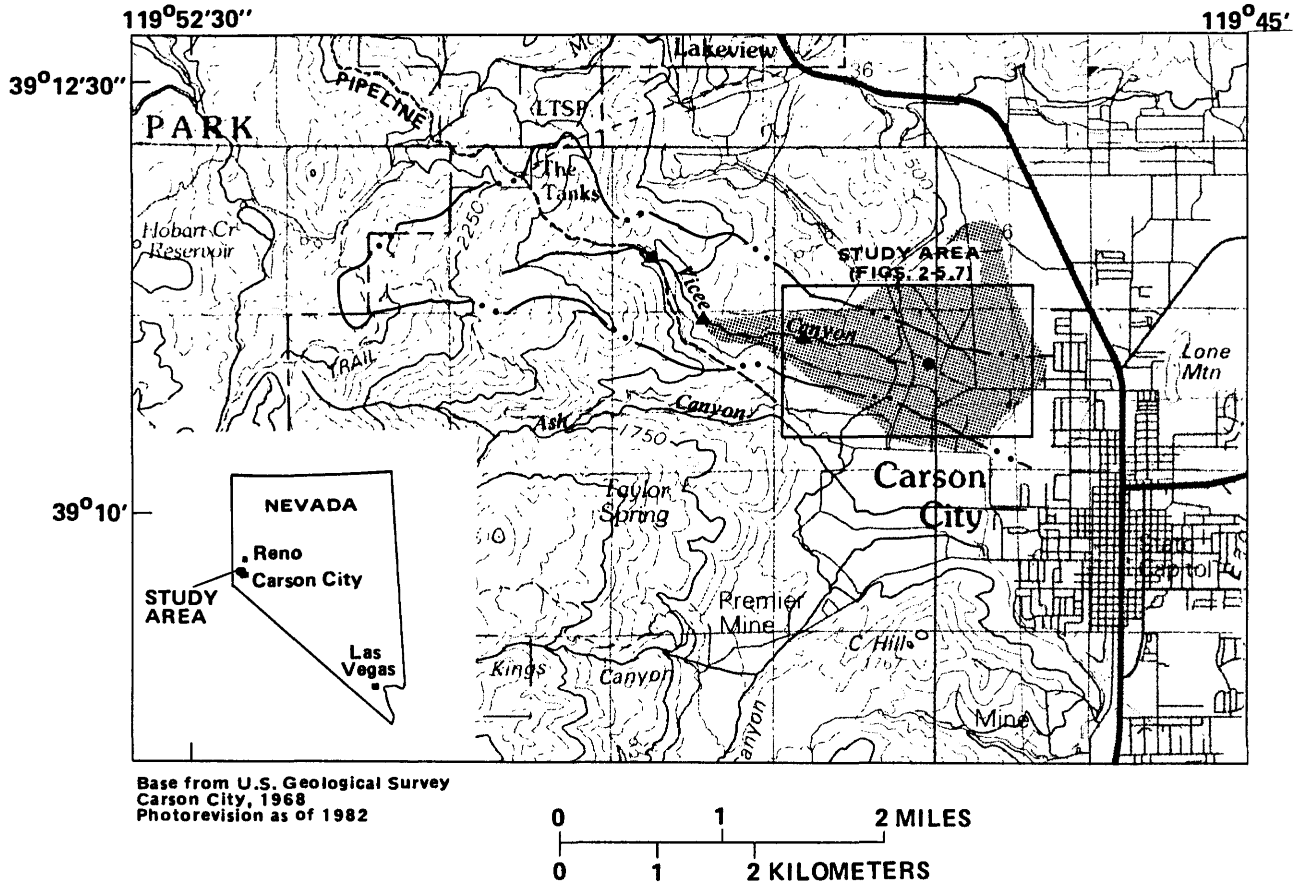
In 1983, the Carson City Public Works Department proposed a study to estimate the quantity of ground-water recharge that could be gained by augmenting streamflow in Vicee Canyon, on the west side of Eagle Valley, Nev. (fig. 1). A major storm in 1982 prompted the study by creating a natural infiltration bed in Vicee Canyon less than 2,000 feet upstream from a major city supply well where ground-water withdrawals had caused a 50-foot water-level decline since 1972. The alluvial aquifer beneath Vicee Canyon could be used as an underground reservoir to store excess runoff to be later withdrawn for municipal use.

Imported water is available to augment the natural flow of the Vicee Canyon drainage basin through an existing pipeline about 2 miles upstream from the city well (see fig. 1). The pipeline carries water from the State-owned Hobart-Marlette system, which is west of the Vicee Canyon drainage basin.

Purpose and Scope

The purposes of the report are to describe the effect of increased streamflow on existing channel characteristics and to estimate recharge to the aquifer as a result of augmented streamflow in Vicee Canyon. The unmodified stream channel was used as a percolation bed to transmit surface water to the aquifer. Arteaga and Durbin (1978, p. 14) previously estimated long-term average recharge to the underlying Eagle Valley ground-water basin from the Vicee Canyon drainage. This report presents estimates of recharge computed using three methods for augmented and natural streamflow in Vicee Canyon during the study period (1983-85).

This report summarizes the results of the study done in cooperation with the Carson City Public Works Department. Some of the data used in this report is also included in an unpublished Master's thesis (Fischer, 1988). Fischer's thesis describes in detail measurements and calculations of water movement in the unsaturated zone that will briefly be discussed in this report. This report is intended to describe results of the study for use by water managers and engineers.



EXPLANATION

- VICEE CANYON ALLUVIAL FAN
- ▲ UPPER AND LOWER STREAMFLOW GAGES
- —• •— VICEE CANYON DRAINAGE DIVIDE
- ● CITY WELL 6
- ■ POINT OF STREAMFLOW AUGMENTATION

FIGURE 1.--Location of Vicee Canyon drainage basin, stream gages, pipeline for streamflow augmentation, and study area.

Hydrologic Setting

Vicee Canyon is located about 2 miles northwest of Carson City at the head of an alluvial fan (fig. 1). The upper part of the canyon cuts through granitic bedrock of the Carson Range and debouches into Eagle Valley from the west.

Vicee Canyon incises the upper part of the fan to depths as great as 100 feet. This part of the fan is described as older fan deposits of Vicee Canyon (Quaternary age) by Trexler (1977). The older fan deposits are cut by numerous faults, some showing movement within the past 300 years (Trexler and Bell, 1979). The incised part of the fan merges with the lower fan segment about 1,000 feet upstream from Carson City Well 6 (see fig. 2) where most natural streamflow is normally lost to infiltration. The lower fan segment is described as Quaternary alluvial-fan deposits that overlie and interfinger with alluvial-plain deposits of Eagle Valley (figure 2; Trexler, 1977).

The width of the canyon floor ranges from 40 feet near the lower stream gage to about 700 feet where the canyon merges with the fan surface. Streamflow meanders across the relatively flat canyon floor through reworked alluvial fan sediments and sand and gravel recently derived from the Carson Range.

Alluvial fan deposits consist of unconsolidated sediments ranging in grain size from silt and clay to boulders. However, coarse sand derived from decomposition of the granitic bedrock of the Carson Range compose most of the fan deposit. Lithologic logs of holes drilled for this study and for Carson City Well 6 describe alternating units of medium sand, coarse sand, and boulders with occasional thin layers (2-5 feet) of clayey sand from land surface to depths of 300-500 feet. Bedrock outcrops near the upper gage and lies about 800 feet below land surface near the mouth of the canyon (Arteaga, 1981, p. 26).

Precipitation in the Vicee Canyon drainage area decreases from 32 in/yr at the top of the drainage to about 11 in/yr near the base of the fan. Most of the precipitation falls as rain and snow during winter months. Winter temperatures average about 32 °F, and summer temperatures average about 80 °F. The steep southern side of the east-west trending canyon shades the canyon floor from December through February. During this time freezing streamflow creates a thick ice canopy over much of the canyon floor and streamflow is confined beneath this canopy.

Natural streamflow in Vicee Canyon persists throughout the year; however, the length of channel with active flow depends on the season. A peak flow estimated at about 100 ft^3/s occurred in April 1982, during a period of snowmelt caused by rainfall (Otto Moosburner, U.S. Geological Survey, oral commun., 1983). During this period, flow extended down-fan to Winnie Lane (fig. 1) depositing layers of sand and gravel 2 to 3 feet thick on the canyon floor. During normal spring snowmelt periods, however, peak flows of 2 to 5 ft^3/s rarely extend beyond the mouth of the incised canyon. Flow decreases during summer months to about 0.5 ft^3/s, and may cease altogether at the lower stream gage in August or September of dry years.

Ground-water flow in the saturated zone beneath Vicee Canyon is generally in the same direction as streamflow, from west to east. Depth to the saturated zone (water table) ranges from more than 200 feet near the lower stream gage to about 80 feet near the intersection of Winnie Lane and Ormsby Boulevard (fig. 3). Piezometers installed in Vicee Canyon show that intermittent zones of saturation (perched zones) exist within the unsaturated zone between the canyon floor and the water table (table 1).

Water-table contours for the study area in spring 1984, before municipal pumping for the summer began, are shown in figure 3. A trough of depressed ground-water levels surrounds the three city wells and indicates that they divert ground-water flow from Coombs Canyon, Vicee Canyon, and probably part of Ash Canyon drainage basin. Water levels declined rapidly from the early 1970's until 1978, when the declining trend decreased. Water levels changed less than 5 feet from 1981 to 1983, a very wet water year, which caused water levels to rise through 1984. The total water-level decline from 1973 to 1981 was about 50 feet.

Definition of Hydrologic Terms

The aquifer beneath Vicee Canyon is composed mostly of unconsolidated sands and gravels. Between the individual grains of sand and gravel are pore spaces through which air and water move. The volume of pore space per unit volume of sediment is called porosity which is usually reported as a percent or decimal fraction.

The water table beneath Vicee Canyon is about 200 feet below land surface. The upper 200 feet of sediment is called the unsaturated zone. In this zone, air partially fills pore spaces, and capillary and adsorptive forces hold water in pore spaces. The amount of water in the unsaturated zone is commonly called the moisture content and is defined as the volume of water per unit volume of sediment. At saturation, the moisture content equals the porosity of the sediment. Moisture content, like porosity, is usually reported as a percent or decimal fraction.

Water flows in response to differences in hydraulic head: from areas of high hydraulic head to areas of lower hydraulic head. Hydraulic head is the sum of the elevation at a point and the pressure head at that point. The pressure head at the surface of the water table is zero; a positive value exists below the water table, and a negative value (suction) exists above the water table in the unsaturated zone. The negative pressure head in the unsaturated zone increases as the moisture content decreases and represents the capillary and adsorptive forces holding water in the pore spaces.

The difference in hydraulic head between two points determines the hydraulic gradient. Hydraulic conductivity is that property of an aquifer, together with the hydraulic gradient, that determines the volume of water moving through a cross-sectional area of aquifer materials. Hydraulic conductivity in the unsaturated zone is less than in the saturated zone for the same sediment and is a function of both the moisture content and the negative pressure head. Unsaturated hydraulic conductivity increases as moisture content increases and equals the saturated conductivity when moisture content equals the porosity (at saturation).

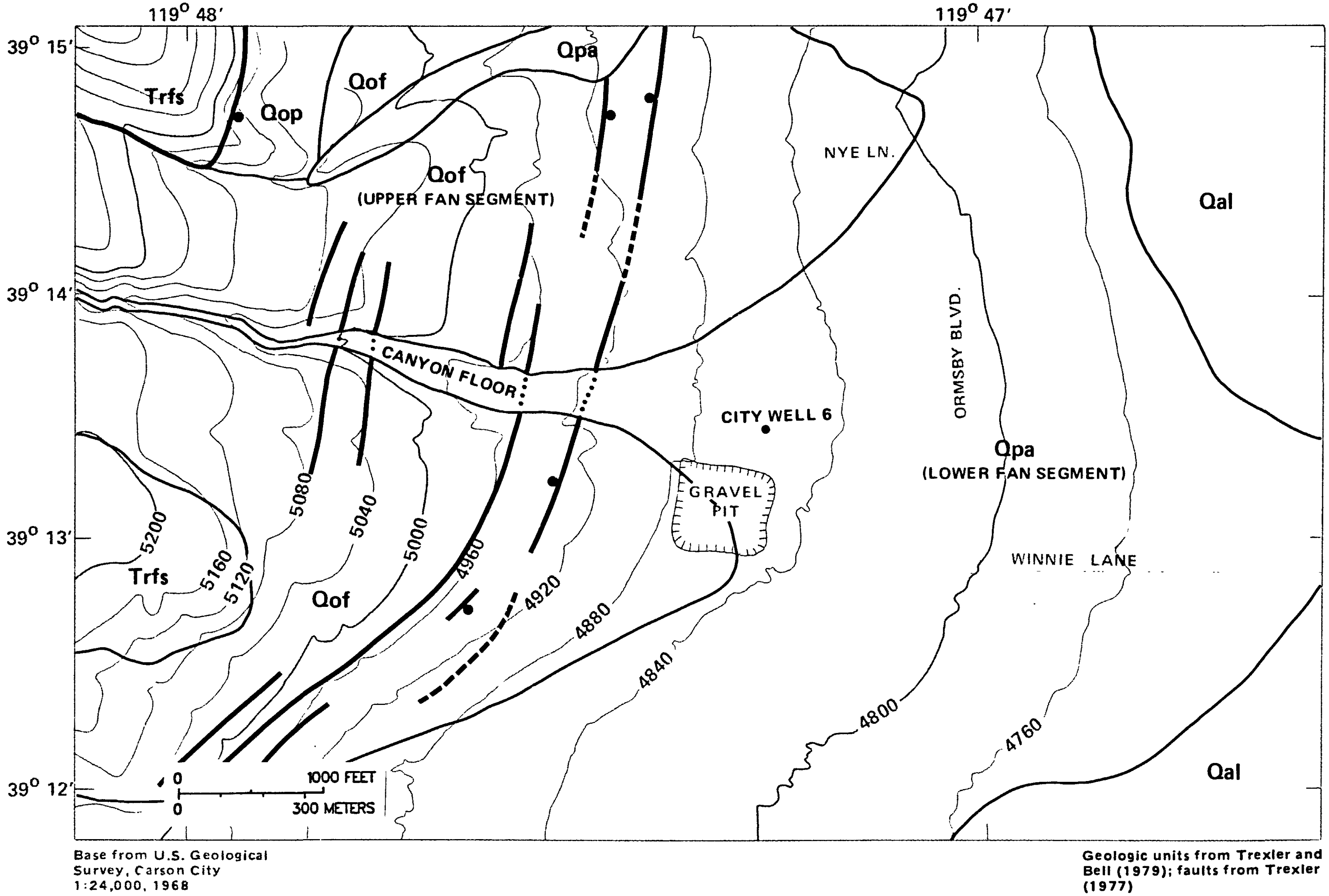
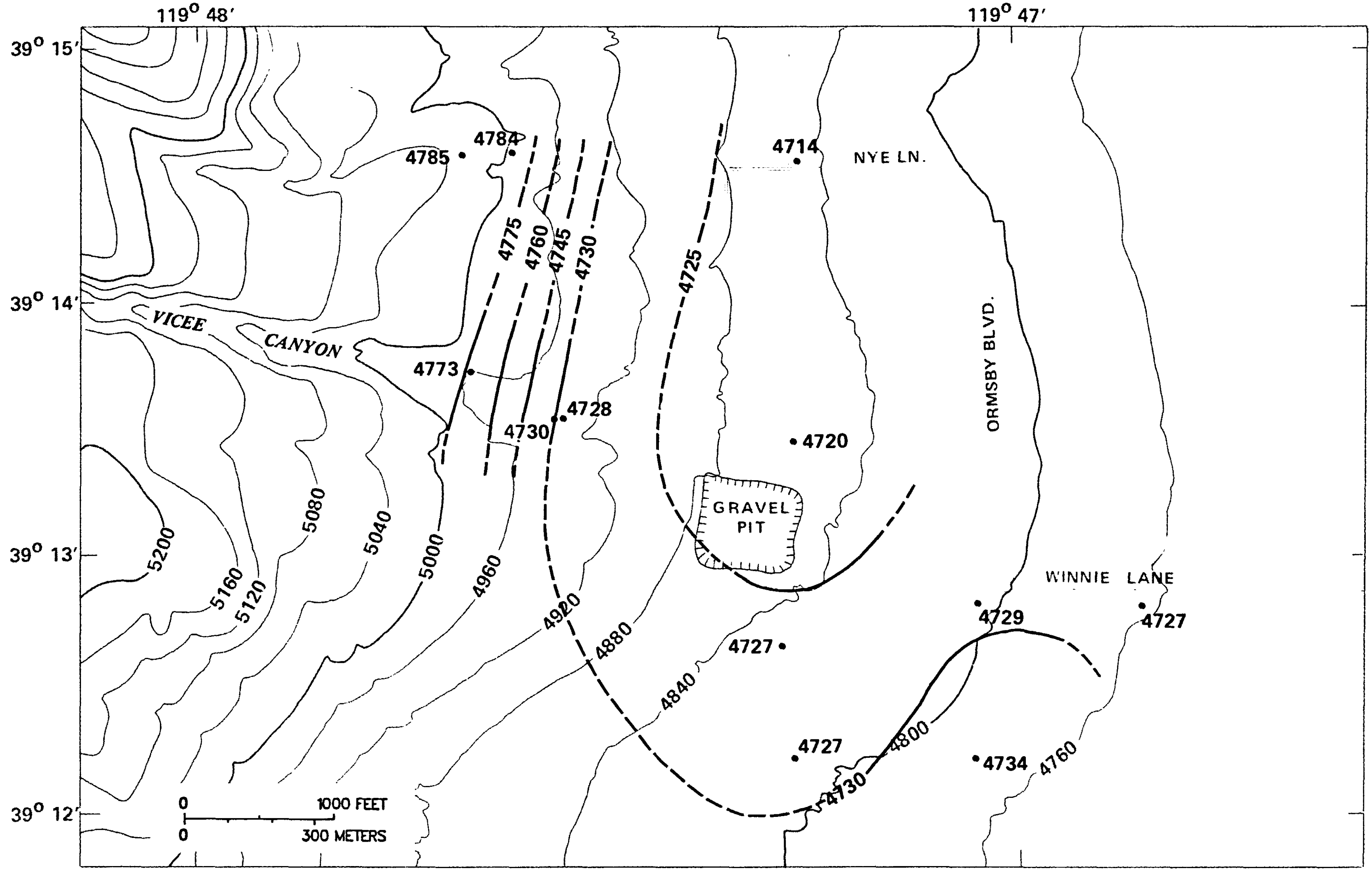


FIGURE 2.--Hydrogeologic features. Topographic contour interval 40 feet; datum is sea level.

FIGURE 2 EXPLANATION

Qpa	PEDIMENT AND ALLUVIAL-FAN DEPOSITS--Grayish-orange, tan and gray-brown granular muddy coarse sand and sandy gravel in small fans, bajadas, and minor pediment veneers
Qal	ALLUVIAL-PLAIN DEPOSITS OF EAGLE VALLEY--Yellowish-brown to gray, unbedded to poorly bedded, poorly to moderately sorted, fine silty sand, sandy silt, granular muddy coarse sand, and minor sandy gravel. Underlies broad surfaces of low gradient
Qof	OLDER FAN DEPOSITS OF VICEE CANYON--Medium-brown to light-brown, moderately to poorly sorted sandy large cobble gravel and slightly gravelly medium sand. Weathered. Moderately well-developed soil profile
Qop	OLDER PEDIMENT GRAVEL--Grayish-orange to dark yellow-brown small cobble to muddy sandy pebble gravel. Composition similar to nearby bedrock. Deposits slightly eroded, weakly to moderately weathered
Trfs	FELSIC SCHIST, UNDIFFERENTIATED--Gray-white to pale bluish-gray, siliceous, fine-grained, dense and flinty flaser schist and banded flaser gneiss. Rocks in this group represent metamorphosed rhyodacitic/andesitic tuffs, welded tuffs, and breccia
———	CONTACT--Approximately located
—•— — ...	FAULT--Dashed where approximately located; dotted where concealed. Ball on downthrown side



Base from U.S. Geological Survey, Carson City 1:24,000, 1968

EXPLANATION

—4730— — WATER-TABLE CONTOUR--Shows altitude of water table. Dashed where approximately located. Contour intervals 5 and 15 feet. Datum is sea level

4727 • OBSERVATION WELL, WITH WATER-LEVEL ALTITUDE, IN FEET--Datum is sea level

FIGURE 3.--Altitude of water table in alluvial-fan deposits, June 22, 1984. Topographic contour interval 40 feet; datum is sea level.

Flow of water through both the unsaturated and saturated zones is governed by Darcy's Law:

$$Q = KIA,$$

where Q = ground water flow volume;
K = hydraulic conductivity (saturated or unsaturated);
I = hydraulic gradient; and
A = cross-sectional area through which flow takes place.

Infiltration is the process where water moves into the subsurface; the rate of infiltration is defined as the volume of water flowing into the subsurface per unit of wetted surface area per unit of time, reported in units of length per time. Percolation is herein called the flow of water through the unsaturated zone; the rate of percolation is reported in units of length per time. Recharge is the process of water flowing into the saturated zone; the rate of recharge is the total volume of water per unit of time that reaches the saturated zone beneath Vicee Canyon.

Streamflow on the floor of Vicee Canyon is confined to a single channel, braided into a myriad of channels, or covers broad areas as sheetflow. Usually a well-defined location exists, herein called the braid point, where flow upstream is confined to a single channel, and flow downstream is braided or sheetflow.

Approach

The volume of recharge from streamflow was estimated by three methods: (1) the volume of streamflow lost to infiltration minus the estimated volume of water lost to evapotranspiration (water balance), (2) the calculated flow of water through the upper 60 feet of unsaturated zone, and (3) the volume of water required to cause measured ground-water level rises following a period of infiltration. Recharge estimates calculated by the three methods were compared to assess their accuracy. In addition, infiltration rates, hydraulic conductivities, and estimates of storage properties of the alluvial fan deposits were used in a finite-difference model (McDonald and Harbaugh, 1984) to estimate the rise in ground-water level that might be expected at the pumped wells from infiltration of additional surface-water flow.

Data used to obtain the recharge estimates were collected from 1983 to 1985. The location of data-collection sites near Vicee Canyon are shown collectively in figures 1, 4, and 5. Two recording stream gages were installed to measure stream losses between the augmentation point and the lower canyon where most infiltration was measured. Streamflow measurements, at 500-foot intervals from the lower stream gage to a distance of 4,500 feet downstream from the lower stream gage, and a double-cap infiltrometer were used to estimate the volume of streamflow lost to infiltration along the stream channel. Surveyed cross sections and measurements of streambed elevation were used to determine changes in streambed characteristics.

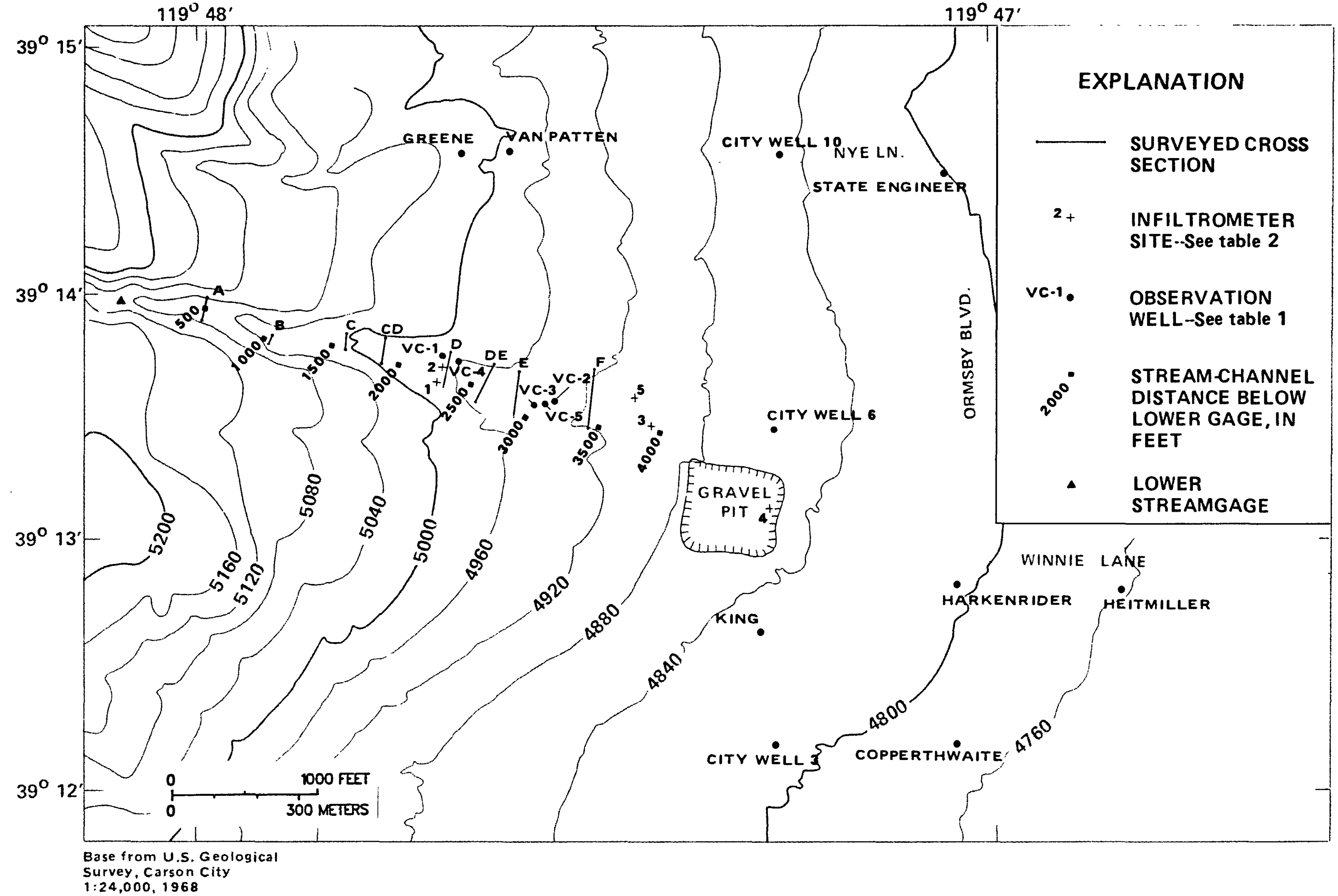


FIGURE 4.--Location of lower stream gage, observation wells, infiltrometer sites, and surveyed cross sections. Topographic contour interval 40 feet; datum is sea level.

A short pipeline was constructed to divert water for streamflow augmentation from an existing pipeline. The existing pipeline conveys water for municipal use to Carson City and Virginia City from a reservoir in the Carson Range. The diversion pipeline is equipped with a totalizing flow meter and empties directly into Vicee Canyon about 2,500 feet upstream from the upper stream gage.

Four piezometer nests and a well (table 1, fig. 4) were installed in Vicee Canyon to monitor fluctuations of hydraulic head in the saturated zones beneath Vicee Canyon. Existing wells in the area also were measured periodically during the study to obtain water-level data on a more regional scale.

Fischer (1988) provides a detailed discussion of laboratory and field methods and calculations of flow in the unsaturated zone. Moisture content was measured at 24 neutron access tubes; 16 tubes were 5-10 feet deep and 8 were 40-60 feet deep. Heat dissipation probes, tensiometers, and shallow piezometers were used to measure pressure head at 6 sites at depths ranging from 5 to 60 feet below land surface. Location of unsaturated zone instrumentation is shown in figure 5.

Samples of unsaturated-zone sediments were collected wherever instrumentation was installed with 57 cores collected from the upper 10 feet of sediment and 22 cores collected from 10 to 60 feet below land surface. The cores were analyzed in the U.S. Geological Survey Laboratory in Carson City, Nev., to determine unsaturated and saturated hydraulic properties of the samples.

Porosity was determined by methods described by Gardner (1965, p. 94). Volumetric moisture content of samples was measured in the laboratory using the procedure outlined by Gardner (p. 84) and a neutron log of each sample site was made quickly after collection to calibrate following neutron measurements of moisture content. Vertical saturated hydraulic conductivities of the samples were determined in the laboratory from core samples using the constant-head method described by Klute (1965, p. 214).

The relation between moisture content and pressure head were determined by placing the samples in a pressure plate extractor, applying incremental pressures, and determining the resulting moisture contents (Hanks and Ashcroft, 1980, p. 62-98). Unsaturated hydraulic conductivities of the samples at various moisture contents were then calculated using the method of Campbell (1974, p. 311-315).

Field measurements of changing moisture contents were made using a neutron probe bi-weekly or at more frequent intervals from April 1984 to July 1985. These data, along with the pressure-head data, allowed calculations of percolation rates through the upper 60 feet of unsaturated zone sediments.

TABLE 1.--*Location, depth, and average water level for wells in study area*

Well identification[1]	Owner or well name	Perforated interval (feet below land surface)	Average depth to water (feet below land surface)[2]	Average water-level altitude (feet above sea level)[2]
N15 E19 12ABCC1	USGS-VC-1A	94-99	85	4,880
	B	112-117	Dry	--
	C	134-139	Dry	--
N15 E19 12ABCC2	USGS-VC-4A	146-166	Dry	--
	B	190-210	188	4,772
	C	230-250	200	4,760
N15 E19 12ACAC1	USGS-VC-3A	180-190	180-Dry[3]	4,755
	B	212-217	215-Dry[3]	4,720
	C	243-248	225	4,710
	D	274-279	225	4,710
N15 E19 12ACAD1	USGS-VC-5	137-273	215	4,715
N15 E19 12ACAD2	USGS-VC-2A	120-125	Dry	--
	B	140-145	Dry	--
	C	180-185	Dry	--
N15 E19 12DADD1	Carson City 3	136-285	80	4,725
N15 E19 12ADAA1	Carson City 6	295-494	150	4,720
N15 E19 01DDDD1	Carson City 10	243-392	140	4,715
N15 E20 07CACB1	Copperthwaite	60-100	52	4,735
N15 E19 12DAAD1	King	80-150	100	4,725
N15 E20 07CBAA1	Harkenrider	85-105	80	4,725
N15 E20 07CAAA1	Heitmiller	<96	50	4,725
N15 E19 01DCDC1	Greene	<314	235	4,785
N15 E19 01DCDC2	VanPatten	<268	210	4,785

[1] The well-identification system used in this report is based on the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each number consists of three units: the first unit is the township, preceded by an N or S to indicate location north or south of the base line. The second unit is the range, preceded by an E to indicate location east of the meridian. The third unit consists of the section number and letter designating the quarter section, quarter-quarter section, and so on (A, B, C, and D indicate the northeast, northwest, southwest, and south-east quarter, respectively), followed by a number indicating the sequence in which the well was recorded. For example, well N15 E19 12ACAD1 is the first well recorded in the SE 1/4 of the NE 1/4 of the SW 1/4 of the NE 1/4 of section 12, Township 15 North, Range 19 East, Mount Diablo Base line and meridian.

[2] The average is for all measurments during 1983-1985.

[3] The average is for all measurements until well goes dry.

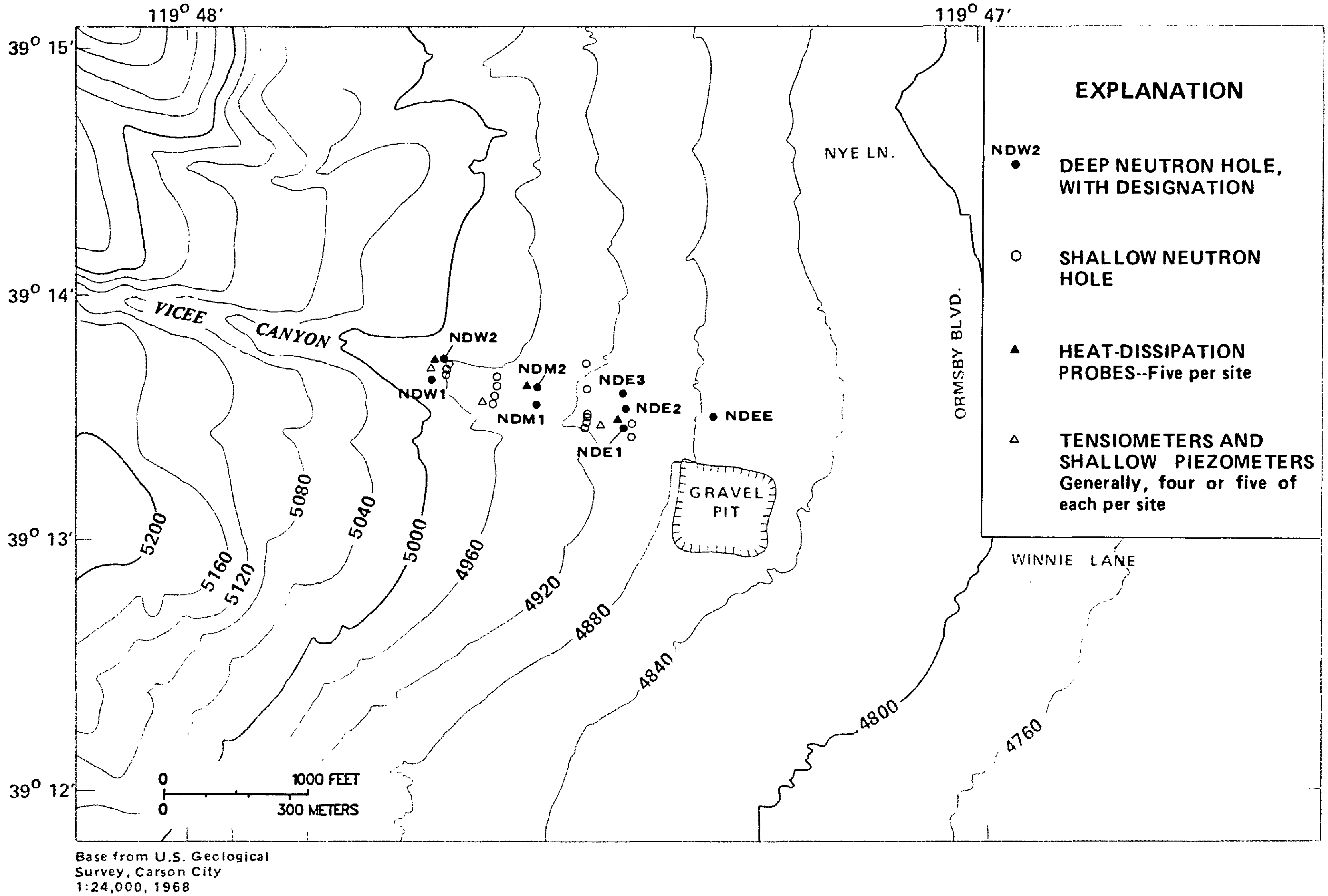


FIGURE 5.--Location of instrumentation sites for unsaturated-zone moisture content and pressure head. Topographic contour interval 40 feet; datum is sea level.

Four streamflow augmentation tests were conducted during the study period (see fig. 6). The first two tests were conducted to observe changes in channel characteristics during streamflow augmentation. During the first test on February 14, 1984, 0.7 ft^3/s was added to a base flow of 0.5 ft^3/s for 24 hours. During the second test on May 23, 1984, 1.5 ft^3/s was added to a base flow of 0.6 ft^3/s for 7 hours. Two additional tests were made at the end of the summer of 1984 during periods of low streamflow (less than 0.1 ft^3/s). These tests were designed to produce measurable changes at unsaturated- and saturated-zone instrumentation sites as a result of streamflow augmentation. During the time of the tests, only minimal infiltration had occurred near the instrumentation sites since June 1984 and stream augmentation flow produced measurable infiltration near the instrumentation sites. About 1.5 ft^3/s was added over a period of 23 hours for the third test on August 20, 1984. The last augmentation test between October 1 and October 4, 1984, lasted 74 hours. Added flow varied from 0.4 ft^3/s at the start of the test to 0.7 ft^3/s at the end of the test.

SURFACE WATER

Streamflow Characteristics

A hydrograph of daily mean streamflow recorded at gages in Vicee Canyon during the study period is shown in figure 6. Daily mean flow values and other statistics were published by Frisbie and others (1984, p. 116-118). Flow at the gages is about equal except during late summer when flow at the lower gage is slightly less, probably due to evapotranspiration from vegetation near the stream channel between the two gages. Thus, net infiltration loss between the two gages is either negligible or offset by gaining reaches below the upper gage. Net streamflow loss to infiltration generally begins downstream from the lower stream gage where the canyon floor begins to widen. Measurements at about 500-foot intervals downstream from the lower gage are listed in table 6 (Basic Data section).

Changes in Channel Characteristics

Changes in the streambed of Vicee Canyon (discussed in following sections) have a direct effect on rates of streamflow infiltration and, thus, the amount of recharge gained through streamflow augmentation. The stream channel on the floor of Vicee Canyon is characterized by flow confined to a single channel upstream, and braided or sheetflow downstream of a braid point. Where flow is in a single channel, the streambed is incised as much as 3 to 4 feet into the deposits of the canyon floor. The depth of incision decreases downstream to the braid point, where flow begins to spread into sheetflow or highly braided flow. The braid point moves up and down the axis of the canyon in response to changes in streamflow (figure 7).

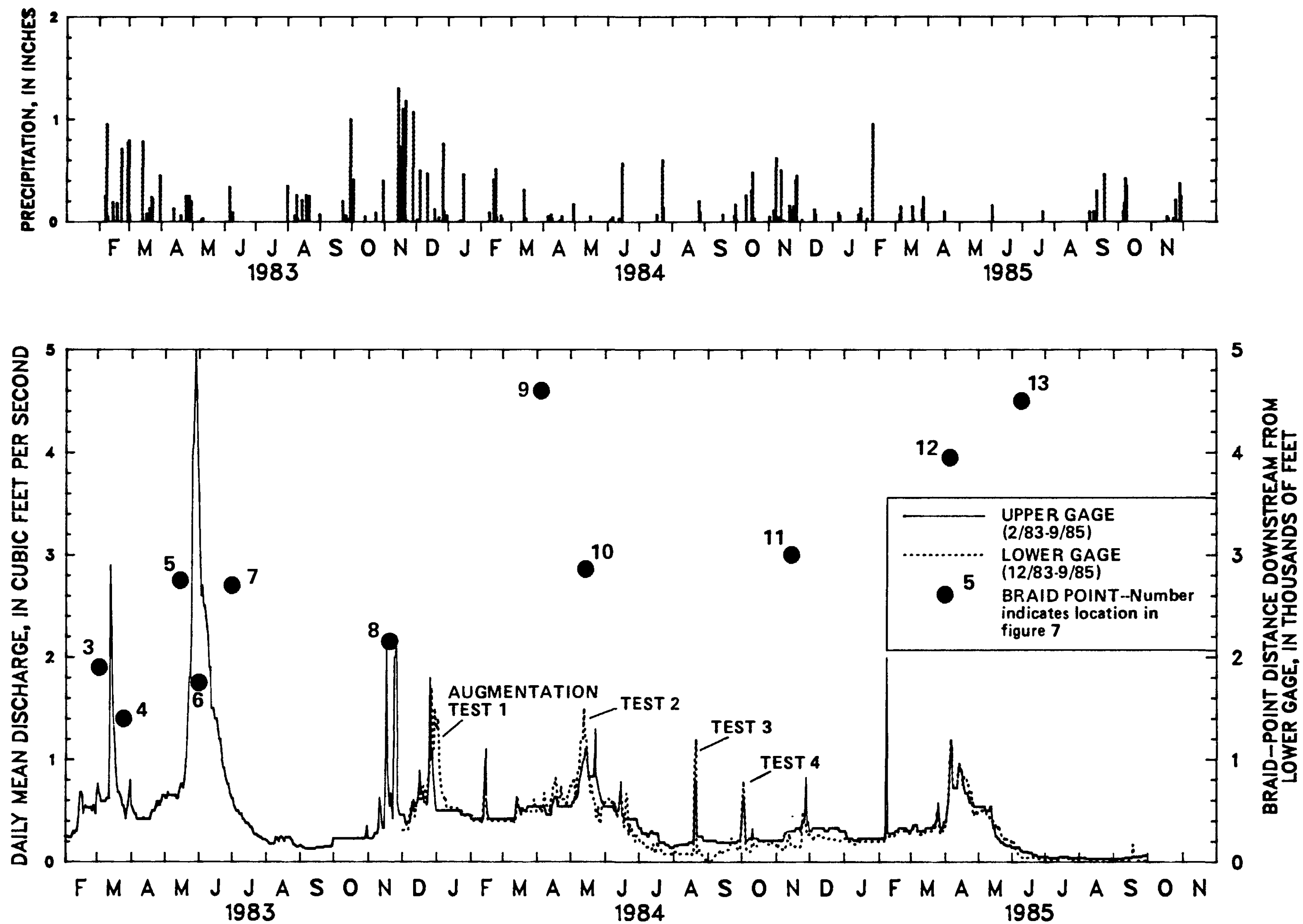


FIGURE 6.--Precipitation at Carson City weather station, stream discharge at upper and lower gages, braid-point locations, and timing of streamflow-augmentation tests, February 1983-November 1985.

Deposition of sediment during recent floods governs the location of the braid point more than the volume of flow at any particular time. The braid point moves upstream after deposition during high flows and gradually migrates downstream during downcutting from subsequent base flows. Locations of the braid point during the study period are shown in figure 7. Following the storm event in 1982, the streambed changed from braided flow over most of the canyon floor, to completely channelized flow, into a gravel pit near the mouth of the canyon by April 1984 (fig. 7). A major storm in November 1983 moved the braid point upstream and eroded a large channel into the side of the gravel pit. The gravel pit eventually captured all flow from Vicee Canyon as baseflow during winter 1984 moved the braid point back downstream and channelized the remainder of the streambed.

A rock bed was emplaced on the canyon floor in June 1984 (fig. 7) in an attempt to create an area of braided flow upstream from instrumentation emplaced for the study. This was marginally successful and a temporary infiltration bed was created until the bed filled with sediment and a channel was cut around the rock bed.

Stream losses due to infiltration are much greater when flow is braided, because the wetted surface area of the streambed is larger than when flow is confined to a single channel. Also, when flow is confined to a single channel the streambed becomes armored with cobbles embedded in a matrix of sand. This decreases the area of permeable bed material through which infiltration may take place.

Stream-augmentation tests and observation of natural events during the study period show that sediment movement on the floor of Vicee Canyon is dynamic with up to 4 feet of scour and fill accompanying changes in streamflow. Flows greater than about 1 ft^3/s are required to move the braid point upstream. To produce deposition of a broad, thick infiltration bed covering the floor of the canyon requires a flow of about 3 ft^3/s sustained for 1 to 2 days. Depending on the extent of the infiltration bed, and rates and duration of subsequent baseflow, the streambed can become channelized within a period of 1 to 10 months. It also was observed that high flows caused erosion at the base of the unconsolidated canyon walls near the lower stream gage.

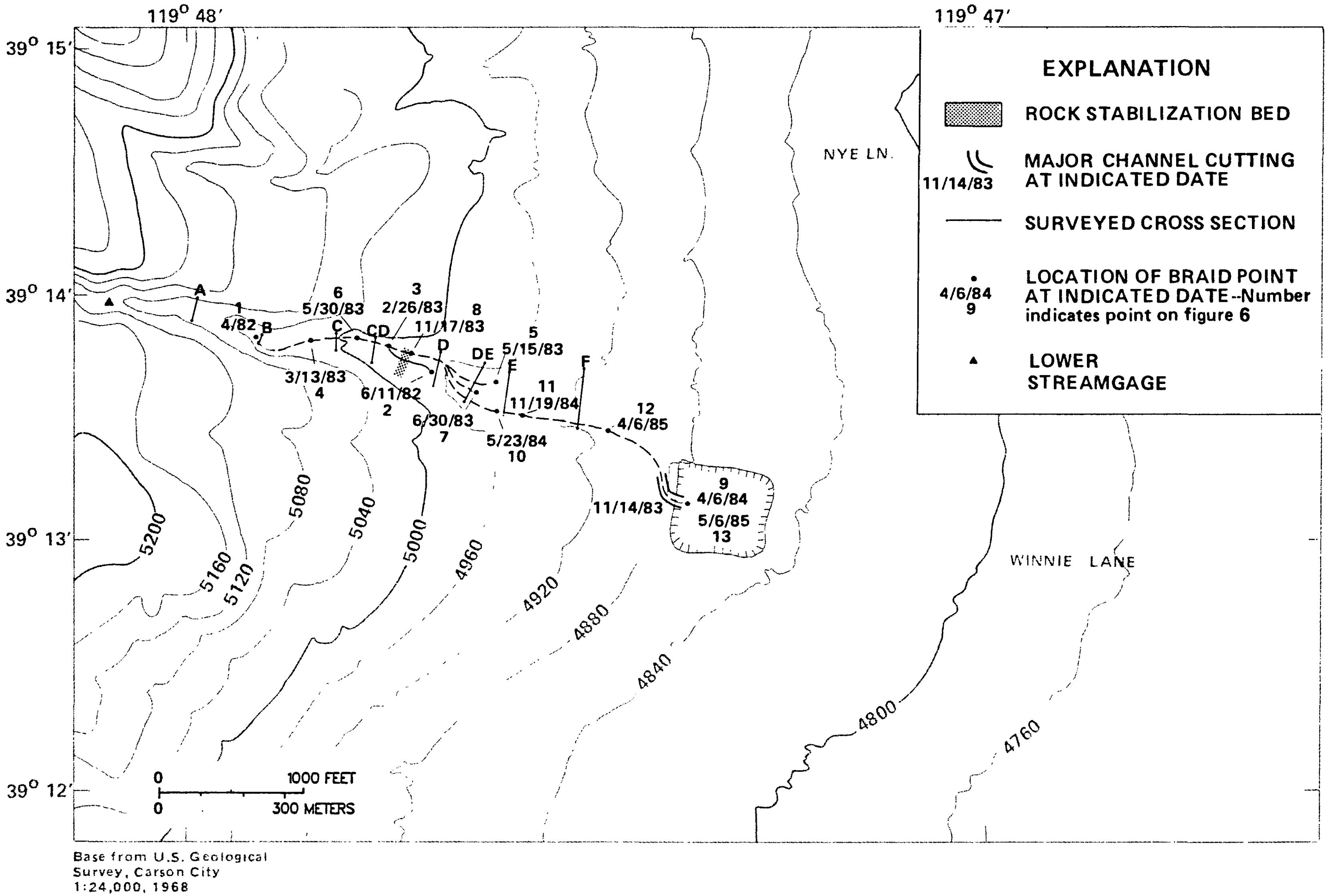


FIGURE 7.--Location of braid points and channel changes during study period. Topographic contour interval 40 feet; datum is sea level.

Infiltration Rates of Surface Water

A double-cap infiltrometer similar to the standard ASTM infiltrometer (Constantz, 1983) and measurements of stream loss over a wetted area of streambed determined infiltration rates in Vicee Canyon that ranged from 0.04 to 18 in/h (see fig. 4 and tables 2 and 6). A minimum rate of 0.04 in/h was measured on the floor of the gravel pit where a thick layer of silt and clay greatly reduced the infiltration rate. The measurements show a decrease in infiltration rates from an average of about 4 in/h in June 1984, shortly after spring runoff, to about 1 in/h or less as the streambed became more channelized and effectively armored by April 1985. Infiltration rates increased again following a period of runoff in February 1986 that created a braided channel.

GROUND WATER

Vertical Hydraulic Conductivity and Moisture Content in the Unsaturated Zone

Measurements of saturated hydraulic conductivity and porosity of samples collected in the unsaturated zone are summarized in table 3. Porosity values ranged from 0.4 to 0.5 in the upper 20 feet of sediment, and from 0.2 to 0.4 between 20 and 60 feet below land surface. Vertical saturated hydraulic conductivities decreased from an average of about 30 in/h in the upper 6 feet of sediment to about 15 in/h, 20 to 60 feet below land surface. Although highly variable, the sediments as a whole have high hydraulic conductivity.

Moisture content within 60 feet of the surface ranged from 9 to 33 percent and averaged about 20 percent. Most large changes in moisture content at sites were measured within about 15 feet of the streambed after an increase in streamflow, or a change in the braid point location. This implies predominantly vertical or downslope percolation of water infiltrating through the streambed.

Changes in moisture content at two sites adjacent to the streambed indicate that infiltration increases beneath braided parts of the streambed and decreases where the streambed becomes channelized and armored with cobbles. This is shown in figure 8 by the decrease in moisture content at neutron hole NDM1 and an increase at hole NDE1, as the braid moves downstream past the holes. Also note the lack of change at NDW2 only 20 feet from a well-armored streambed.

TABLE 2.--*Infiltration rates measured at Vicee Canyon from July 1983 to May 1986*

INFILTROMETER MEASUREMENTS

Site (figure 4)	Rate (inches per hour)	Date of measurement
1	3.3	07-14-83
2	18	07-15-83
3	17	07-20-83
4	.04	07-22-83
5	8.3	09-10-83

STREAM-LOSS MEASUREMENTS (infiltration rate, in inches per hour)

<table>
<tr><th rowspan="2">Date</th><th colspan="8">Distance below lower gage, in feet</th></tr>
<tr><th>0 - 500</th><th>500 - 1,000</th><th>1,000 - 1,500</th><th>1,500 - 2,000</th><th>2,000 - 2,500</th><th>2,500 - 3,000</th><th>3,000 - 3,500</th><th>3,500 - 4,000</th></tr>
<tr><td>02-22-84</td><td></td><td></td><td></td><td></td><td></td><td></td><td>3.0</td><td></td></tr>
<tr><td>02-23-84</td><td></td><td></td><td></td><td></td><td></td><td></td><td>3.0</td><td></td></tr>
<tr><td>02-23-84</td><td></td><td></td><td></td><td></td><td></td><td></td><td>2.8</td><td></td></tr>
<tr><td>05-31-84</td><td>1.4</td><td colspan="3">5.1</td><td colspan="2">0.9</td><td colspan="2">2.8</td></tr>
<tr><td>06-07-84</td><td>6.3</td><td>2.8</td><td>0</td><td>5.9</td><td>3.9</td><td>7.1</td><td>3.5</td><td>4.7</td></tr>
<tr><td>06-11-84</td><td colspan="4">2.3</td><td colspan="4">3.5</td></tr>
<tr><td>10-01-84[1]</td><td>0</td><td>2.1</td><td>1.5</td><td colspan="2">2.1</td><td></td><td></td><td></td></tr>
<tr><td>10-01-84[2]</td><td>5.0</td><td>1.4</td><td colspan="2">4.9</td><td>5.8</td><td></td><td></td><td></td></tr>
<tr><td>10-02-84</td><td>5.2</td><td>3.4</td><td>0</td><td>6.9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>10-03-84</td><td>1.1</td><td>1.7</td><td>0</td><td>6.2</td><td>4.8</td><td>7.0</td><td></td><td></td></tr>
<tr><td>10-03-84</td><td></td><td></td><td></td><td></td><td></td><td>5.5</td><td></td><td></td></tr>
<tr><td>10-04-84</td><td colspan="3">1.6</td><td>4.8</td><td colspan="2">6.8</td><td colspan="2">3.4</td></tr>
<tr><td>03-22-85</td><td>1.7</td><td>1.1</td><td>2.3</td><td>1.7</td><td>4.3</td><td>1.7</td><td>1.1</td><td>1.1</td></tr>
<tr><td>04-04-85</td><td>0</td><td>0</td><td>0</td><td>0.6</td><td>1.1</td><td>1.1</td><td>0.7</td><td></td></tr>
<tr><td>02-24-86</td><td></td><td></td><td></td><td colspan="4">3.0</td><td></td></tr>
<tr><td>05-02-86</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>5.9</td></tr>
</table>

[1] Before streamflow augmentation test.

[2] After streamflow augmentation test.

Table 3.--*Saturated hydraulic conductivity and porosity*

[--, no data available.]

Sample	Depth (feet)	Vertical hydraulic conductivity (inch per hour)	Porosity
NDE1	0.0	33.2	--
NDE1	.0	27.2	--
N#10(E3)	.8	--	0.42
N#6(M2)	.8	--	.52
NDW2	1.0	23.7	--
N#5A(W1)	1.0	--	.42
NDM1	1.5	27.2	--
N4B(W2)	2.0	--	.45
N4A(W2)	2.0	--	.40
NDE1	2.0	12.3	--
NDM1	2.5	4.1	--
N#4(W2)	2.5	--	.40
NDW2	3.0	17.6	--
NDM1	4.2	38.4	--
NDE1	4.5	26.9	--
NDW2	5.0	28.7	--
NDM1	5.8	71.7	--
N#5C(W1)	6.0	--	.41
NDEE	20.0	20.6	.29
NDW2	20.0	2.3	.30
NDM1	25.0	1.7	.29
NDE2	25.5	1.7	.37
NDM2	25.5	6.7	.29
NDE2	30.0	8.2	.29
NDW2	35.0	16.0	--
NDW2	40.0	37.4	.24
NDEE	40.0	4.8	.35
NDE3	42.0	16.3	.25
NDE2	45.0	8.7	--
NDE2	55.0	20.0	.31
NDEE	56.0	23.0	.24

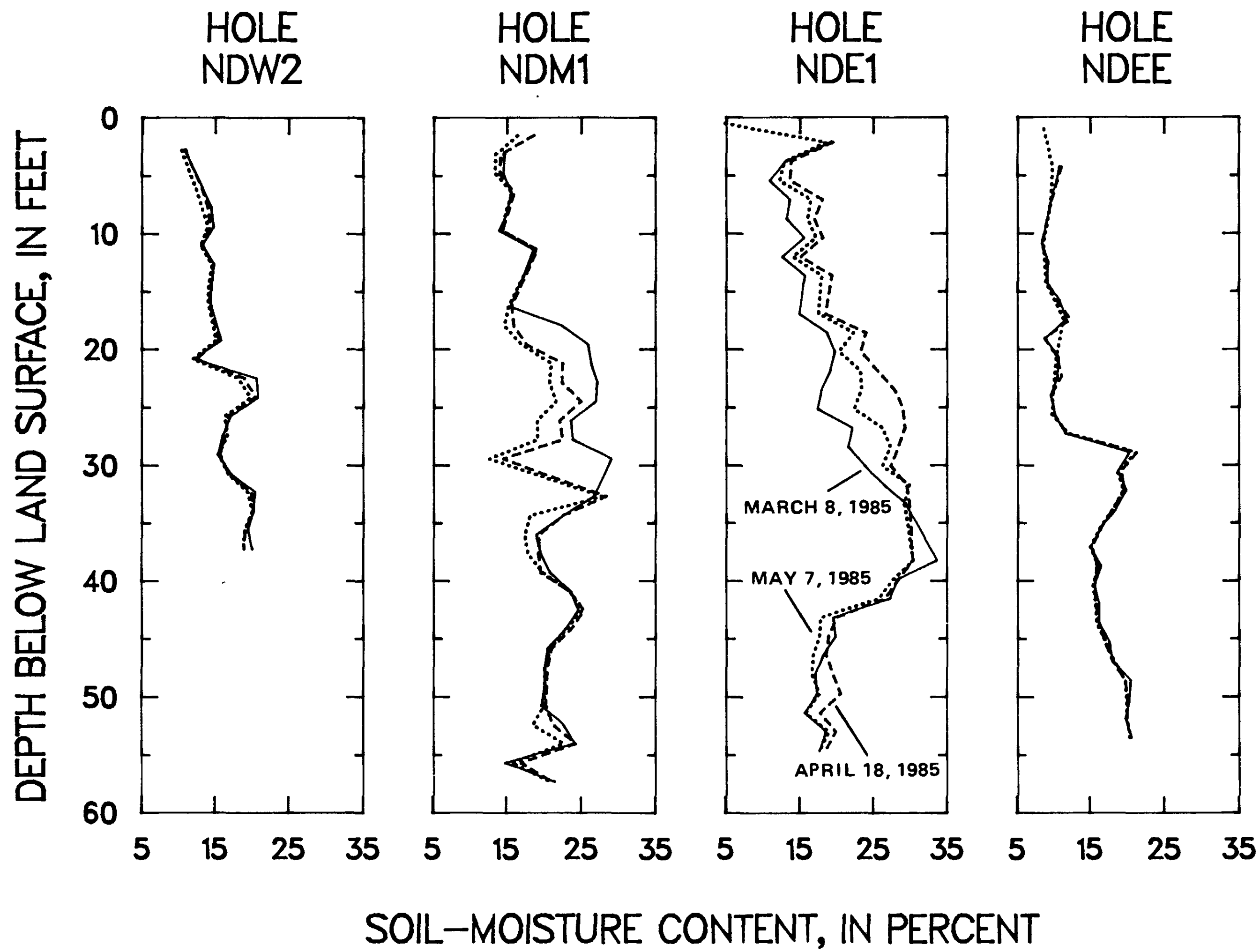


FIGURE 8.--Examples of soil-moisture changes, March to May 1985.

During increased flows, intermittent perched zones develop directly beneath the streambed between 16 and 40 feet in depth. Constant moisture contents and low water potentials at sites over 80 feet perpendicular from the axis of the streambed indicate that slow lateral flow of water may be occurring. This reduces the volume of water that reaches the water table by a small amount that was not quantified.

The unsaturated zone extends approximately 200 feet below land surface in Vicee Canyon as shown by dry piezometers (VC-3A and VC-3B) 180 to 217 feet below the land surface (table 1). Measurements at VC-1A indicate that a perched water table about 80 feet below the land surface probably formed above thin silt or clay lenses of low hydraulic conductivity.

Although hydraulic gradients in the upper 60 feet of the unsaturated zone were close to unity, calculated and estimated flows to the saturated zone were less than the saturated hydraulic conductivity. The main reason for this is that the sediments are not saturated and the hydraulic conductivity at the measured moisture content of about 20 percent is considerably less than the saturated hydraulic conductivity. Also, thin silt or clay lenses not detected during drilling or sampling may further reduce flow to the water table, or air trapped in the unsaturated-zone sediments below the wetting front may also reduce the flow. Entrapped air was detected during the fourth augmentation test but it was eventually driven out or dissolved. This implies that continuous stream augmentation is required to obtain the maximum hydraulic conductivity and, thus, maximum recharge efficiency. However, as shown previously, high baseflow results in channelization of the streambed, reducing the volume of infiltration.

Water Levels in the Saturated Zone

Water levels in the piezometers screened in the saturated zone indicate that hydraulic heads near the top of the water table were greater than those 40 to 50 feet below the top of the water table; this indicates a downward vertical gradient that averages about 0.35 at piezometers VC-4 and VC-3 for the study period. The horizontal water-table gradient between VC-4 and VC-3 is about 0.13. Water-level measurements made during this study were published by Frisbie and others (1984, p. 226-228; 1985 [1988], p. 230-238) and are shown in table 7 (Basic Data section).

Municipal pumping affects the water-table levels near the lower part of Vicee Canyon (piezometers VC-3C and D and water-table well VC-5) by causing water levels to decline about 20 feet (fig. 9) during summer months, followed by recovery after the pumps are turned off. Hydraulic conductivity of about 28 in/h was calculated from the response of VC-5 to pumping at City Well 6. All wells had a declining water-level trend during the study period as streamflow and infiltration volumes decreased. Piezometers indicated a temporary rise in water levels after an increase in streamflow and resultant changes in channel characteristics.

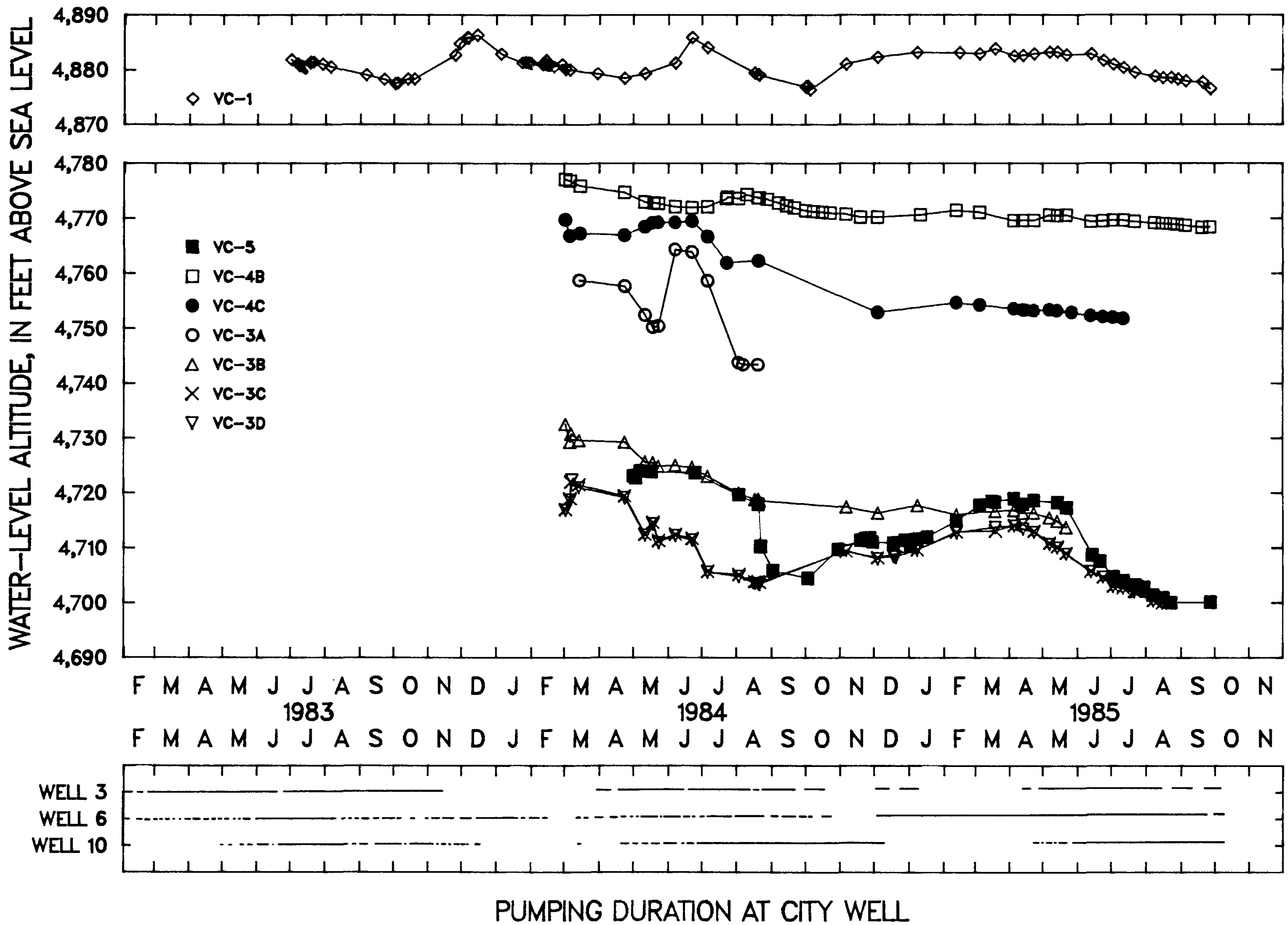


FIGURE 9.--Water levels in observation wells drilled during study, and duration of pumping at nearby city wells. Well locations are shown in figure 3.

Rates of Percolation to the Water Table

The time between infiltration and a measurable change in moisture content or water level at depth, divided by the depth of the observation point, yields the rate of percolation. Calculated rates of percolation through the unsaturated zone, which range from 0.3 in/h to as much as 8.8 in/h, and average about 2.4 in/h, are listed in table 4. Different times for the increase in moisture content measured at the same depth for different events, indicate that either the change in moisture content or water level was not a true response to infiltration, or, more likely, the percolation rate changes with changes in moisture content. Also, a pressure wave transmitted through the unsaturated zone by entrapped air could temporarily cause a rise in the water levels measured in piezometer tubes. Percolation rates show that the time of response for the wetting front through the 200-foot unsaturated zone ranges from 30 to 60 days (table 4).

ESTIMATES OF RECHARGE BY STREAMFLOW

Recharge was estimated using three different methods: (1) a water-balance method, (2) calculations based on measurements of moisture content and pressure head in the unsaturated zone using a finite-difference approach, and (3) ground-water level responses to infiltration events. Assumptions are made in all methods that deep percolation of precipitation is insignificant compared to streamflow percolation, and that ground-water inflow equals ground-water outflow. Moisture measurements before and after precipitation on the canyon floor and water-level measurements on the Van Patten and Greene wells substantiate those assumptions. Methods 2 and 3 are limited also by the distribution of data points on a relatively small part of the Vicee Canyon fan. The large depth to water allowed only minimal installation of instrumentation. Also, channelization of the streambed caused the location of stream infiltration to move downstream past most instrumentation from 1983 to 1985.

The water-balance method is used to estimate recharge by subtracting evapotranspiration and streamflow into the gravel pit from total streamflow measured at the lower gage. This method assumes that all streamflow not lost to the gravel pit or evapotranspiration becomes recharge. Evapotranspiration was estimated by applying rates measured 10 miles to the south by Pennington (1980, p. 48) to a 15,000-ft^2 area where instrumentation in the shallow unsaturated-zone indicated most lateral flow from the streambed had occurred. The flow lost to the gravel pit listed in table 5A was estimated by assuming all flow in excess of 0.4 ft^3/s did not infiltrate the streambed and was lost to evaporation. This was a close approximation for the time period of May 1984 to July 1985 based on field observations and recorded flow at the lower gage. Values of flow lost to the gravel pit listed in table 5B were estimated from measurements of streamflow above the gravel pit and duration of the high flows. Recharge estimated by the water-balance method is about 60 to 70 percent of the total streamflow (tables 5A and 5B).

TABLE 4.--*Estimated percolation rates through the unsaturated zone below Vicee Canyon*

Site	(A) Date of change in streamflow or braid-point location[1]	(B) Date of water level or soil moisture change	Depth detected (feet)	Response time (B)-(A) (hours)[2]	Percolation rate (inch per hour)
Soil-moisture measurement site					
NDM1	05-13-84	05-23-84	40	240	2.0
	08-20-84*	09-07-84	20	432	.5
	10-01-84	10-05-84	33	96	4.0
	10-11-84	11-12-84	33	768	.5
	or				
	11-08-84	11-12-84	33	96	4.0
NDE1	05-13-84	05-23-84	56	240	2.8
	06-15-84	07-03-84	56	432	1.6
	11-28-84	12-12-84	52	336	1.8
	03-26-85	04-18-85	33	552	.7
	or				
	04-06-85	04-18-85	33	288	1.3
NDW2	06-12-84*	06-26-84	36	336	1.3
	10-01-84	10-26-84	36	600	.7
	or				
	10-11-84	10-26-84	36	360	1.2
	11-08-84	11-23-84	10	360	.3
	11-28-84	12-12-84	30	336	1.1
Water-level measurement site					
VC-1A	11-17-83	12-10-83	85	552	1.7
	06-14-84*	06-22-84	85	192	5.3
	08-31-84*	10-02-84	85	768	1.2
	02-08-85	03-19-85	85	792	1.3
VC-3A	05-23-84*	06-07-84	185	360	6.1
VC-4B	06-14-84*	08-09-84	210	1368	1.8
	08-20-84	09-09-84	210	480	5.3
	10-01-84	10-13-84	210	288	8.8
	11-28-84	12-27-84	210	720	3.5
	04-06-85	05-14-85	210	888	2.8

[1] Asterisk indicates date of change in braid-point location. All others are dates of increase in streamflow.

[2] Difference between date of change in streamflow and date of water level or soil moisture change, in hours.

Recharge was calculated from unsaturated-zone data by solving the unsaturated-zone flow equation (Fischer, 1988, p. 32, equation 1.3) using a two-dimensional, finite-difference method which was developed by Fischer (appendix 3). The technique calculates vertical and downslope flow and assumes no flow perpendicular to the axis of the canyon.

The unsaturated zone beneath Vicee Canyon was divided into an array of grid cells defined by four columns and five rows. Columns represent downslope sections of the canyon floor and rows represent successively deeper layers beneath the canyon floor. Successive downslope columns have lengths of 1,000, 1,000, 500, and 500 feet. Column lengths were selected so that neutron access tubes NDW2, NDM1, NDE1, and NDEE would be near the center of each column and data on pressure head, hydraulic conductivity, and infiltration were available for each column. Rows or layers from land surface downward have thicknesses of 6.5, 5.5, 9, 20, and 20 feet.

Hydraulic heads were calculated from land-surface altitudes and pressure-head measurements. The pressure heads were measured from either the tensiometers or heat-dissipation probes. All moisture-content measurements within a given grid cell were averaged and the resulting values used to calculate unsaturated hydraulic conductivity for that cell. Storage changes for each cell were also calculated from the averaged moisture content data and an estimated width for each element (Fischer, 1988).

Grid cells ranged from 2 feet wide at land surface, representing the average stream width, to 100 feet wide at the base of the array. Widths were determined using the method described by Hanks and Ashcroft (1980, p. 87) in the shallow cells where tensiometer data was available, and on the extent of measurable moisture-content changes perpendicular to the streambed for deeper elements.

Calculations were made using data collected from May 1984 to June 1985. A total of 52 time steps were used, ranging in length from 4 hours to 17 days. Vertical and downslope flows were calculated for each grid cell. Flow leaving the base of the nodal array was assumed to be recharge to the saturated ground-water aquifer.

The calculated outflow through the upper 60 feet of unsaturated zone from May 1984 to July 1985, compared with water-balance estimates of recharge during the same period, is listed in table 5A. Recharge calculated by the water-balance method is consistently larger than that calculated by the finite-difference method because 1,500 feet of streambed downstream from the lower gage was not instrumented and, thus, flows could not be calculated beneath this stretch of streambed.

Recharge calculated from the water-balance method indicate that maximum recharge occurred during spring months; however, the maximum recharge through the upper 60 feet of unsaturated zone occurred during January and February 1985. The reason for increased recharge in January is unknown. Possibly, formation of an ice canopy during this period confined streamflow to a single location for a sufficient length of time to substantially increase hydraulic conductivity by increasing moisture content beneath the streambed.

During the study period, channelization of the streambed allowed 30 percent of the streamflow to reach the gravel pit; evapotranspiration losses from the channel on the canyon floor accounted for 7 percent of the streamflow; and about 43 percent of the streamflow percolated through the upper 60 feet of unsaturated zone and became recharge. Thus, flow to the gravel pit, evapotranspiration losses, and recharge accounted for 80 percent of the total streamflow. Recharge in the 1,500-foot reach downstream from the lower gage and upstream from the unsaturated-zone instrumentation could account for the remaining 20 percent of the total streamflow.

By use of the third method (ground-water level response to infiltration events), inspection of water-level data showed seven water-level responses that correlated with changes in the rate and location of streamflow infiltration. These events and estimates of recharge calculated by the water-balance and water-level rise methods are listed in table 5B. The area used for these estimations was obtained from the areas of cells of successively deeper layers in the finite-difference grid of the unsaturated zone. Multiplying water-level rises by the estimated area of water-level rise and 0.2, the estimated specific yield of the sediments near the water table (Fischer, 1988, p. 75), resulted in a volume of recharge.

Again, recharge volumes calculated by the water-level rise method are less than those calculated by the water-balance method, probably because observation wells are also absent 1,500 feet downstream from the lower gage. Twenty-two percent of the streamflow was lost to the gravel pit, 7 percent to evapotranspiration, and 44 percent was calculated as recharge, accounting for 73 percent of the total streamflow. Recharge in the 1,500 feet of streambed below the lowest gage could account for the remaining 27 percent.

Errors involved in recharge estimations include: (1) errors in estimation of evapotranspiration, (2) point samples and measurements used to estimate recharge that do not cover the entire area of infiltration and might not be representative, and (3) inaccurate areas used to estimate recharge volume due to limited instrumentation. These errors could be large; however, similar recharge rates calculated from both the unsaturated-zone estimates and the water-level rise estimates lends credence to the recharge estimates.

TABLE 5.--*Estimates of streamflow lost to gravel pit, evapotranspiration, and recharge*

[Values in thousands of cubic feet]

A. Comparison of recharge estimates based on water-balance and unsaturated-zone calculations.

Date		Total flow[1] (A)	Flow lost to gravel pit (B)	Stream infiltration (C)=(A)-(B)	Evapotranspiration (D)	Recharge calculated by water balance[2] (E)=(C)-(D)	Recharge calculated through upper 60 feet of unsaturated zone (F)
1984	May	2,100	1,280	820	95	725	140
	Jun	1,230	465	765	95	670	260
	Jul	355	0	355	105	250	220
	Aug	390	0	390	90	300	200
	Sep	270	0	270	70	200	190
	Oct	590	0	590	30	560	150
	Nov	520	50	470	8	460	215
	Dec	620	50	570	3	565	430
1985	Jan	535	0	535	2	530	1,130
	Feb	650	120	530	2	525	520
	Mar	835	105	730	9	720	310
	Apr	1,690	1,010	680	35	645	470
	May	875	140	735	95	640	215
	Jun	160	0	160	95	65	170
Total		10,820	3,220	7,600	734	6,855	4,620
Percent of total flow[3]		100	30	70	7	63	43
			(B) +		(D) +		(F) = 80

[1] Flow at lower stream gage.

[2] Rounded to nearest 5,000 ft^3.

[3] Water-balance method accounts for 100 percent of flow downstream from lower gage (that is, the sum of columns B, D, and E). Recharge calculated from unsaturated-zone measurements (column F), plus estimated gravel-pit and evapotranspiration losses (columns B and D), account for 80 percent of flow downstream from lower gage.

TABLE 5.--*Estimates of streamflow lost to gravel pit, evapotranspiration, and recharge*--Continued.

B. Comparison of recharge estimates based on water-balance and water-level calculations.

Cause of water-level rise	Date of event; date of rise	Site	Total streamflow[1] (A)	Flow lost to gravel pit (B)	Stream infiltration (C)=(A)-(B)	Evapotranspiration (D)	Recharge calculated by water balance[2] (E)=(C)-(D)	Recharge calculated from water-level responses (F)
High streamflow	Nov. 17, 1983; Nov. 29, 1983	VC-1	1,565	700	865	3	860	335
Augmentation test 2	May 23, 1984; Jun. 07, 1984	VC-3A	855	335	520	40	480	365
Installation of rock dam	Jun. 14, 1984; Jun. 22, 1984	VC-1	385	0	385	25	360	335
Installation of rock dam	Jun. 14, 1984; Aug. 09, 1984	VC-4B	915	0	915	180	735	355
Augmentation test 3	Aug. 20, 1984; Sep. 09, 1984	VC-4B	115	0	115	50	65	80
Augmentation test 4	Oct. 1, 1984; Oct. 13, 1984	VC-4B	180	0	180	12	170	60
High streamflow	Nov. 27, 1984; Dec. 27, 1984	VC-4B	650	0	650	3	645	540
		Total	4,665	1,035	3,630	313	3,315	2,070
Percent of total streamflow[3]			100	22	78	7	71	44
				(B) +		(D) +		(F) = 73

[1] Flow at lower stream gage.

[2] Rounded to nearest 5,000 ft^3.

[3] Water-balance method accounts for 100 percent of flow downstream from lower gage (that is, the sum of columns B, D, and E). Recharge calculated from water-level response (column F), plus estimated gravel-pit and evapotranspiration losses (columns B and D), account for 73 percent of flow downstream from lower gage.

SIMULATION OF POSSIBLE GROUND-WATER LEVEL CHANGES CAUSED BY STREAM AUGMENTATION

The purpose of stream augmentation is to store excess runoff in the alluvial aquifer beneath Vicee Canyon, increasing the amount of ground water that could later be pumped for municipal use. The effect of stream augmentation on ground-water levels beneath Vicee Canyon and at City Well 6 was evaluated using a simplified ground-water flow model.

A finite-difference ground-water flow model written by McDonald and Harbaugh (1984) was used for the simulations. A grid consisting of 1 row and 16 columns was superimposed on the Vicee Canyon drainage basin below the lower stream gage (fig. 10). Grid cells are 3,000 feet wide, representing the average width of the lower part of the drainage basin. Cell length ranged from 100 feet for cells 8 and 9 to 1,725 feet for cells 1 and 16. The shorter cell lengths near the center of the grid were used to more accurately represent water levels near the cone of depression of City Well 6.

One layer was used to represent the alluvial-fan materials overlying bedrock, which was assumed to be impermeable. Cell thicknesses were estimated from a thickness map of valley-fill deposits developed by Arteaga (1981, p. 26). The estimated saturated thickness for columns 1 and 2 was about 80 feet, increasing to about 800 feet in columns 9-16.

Saturated hydraulic conductivity assigned to cells 1-12 was 28 in/h determined from values determined from laboratory tests of core samples from Vicee Canyon, and the response of water level in well VC-5 to pumping at City Well 6. Hydraulic conductivity assigned to cells 13-16 was 6 in/hr. This value was used in a calibrated ground-water flow model of Eagle Valley developed by Arteaga (1981, plate 5) and represents finer grained sediments of the Eagle Valley alluvial plain.

Two values for specific yield were used for the the model simulations to account for its uncertainty at the water table beneath Vicee Canyon. Specific yield for the upper 60 feet of sediment is estimated to be about 0.20 on the basis of porosity and water-retention measurements of samples (Fischer, 1988, p. 75). Arteaga (1981, p. 35) used a value of 0.15 in his model simulations for the upper 100 feet of saturated sediments throughout Eagle Valley. Typically, specific yield ranges from about 0.15 to 0.30 for subsurface alluvium (Johnson, 1967, table 6). For this reason, specific yields of 0.15 and 0.30 were used in these simulations to provide a range of possible water-level changes that might occur beneath the canyon floor.

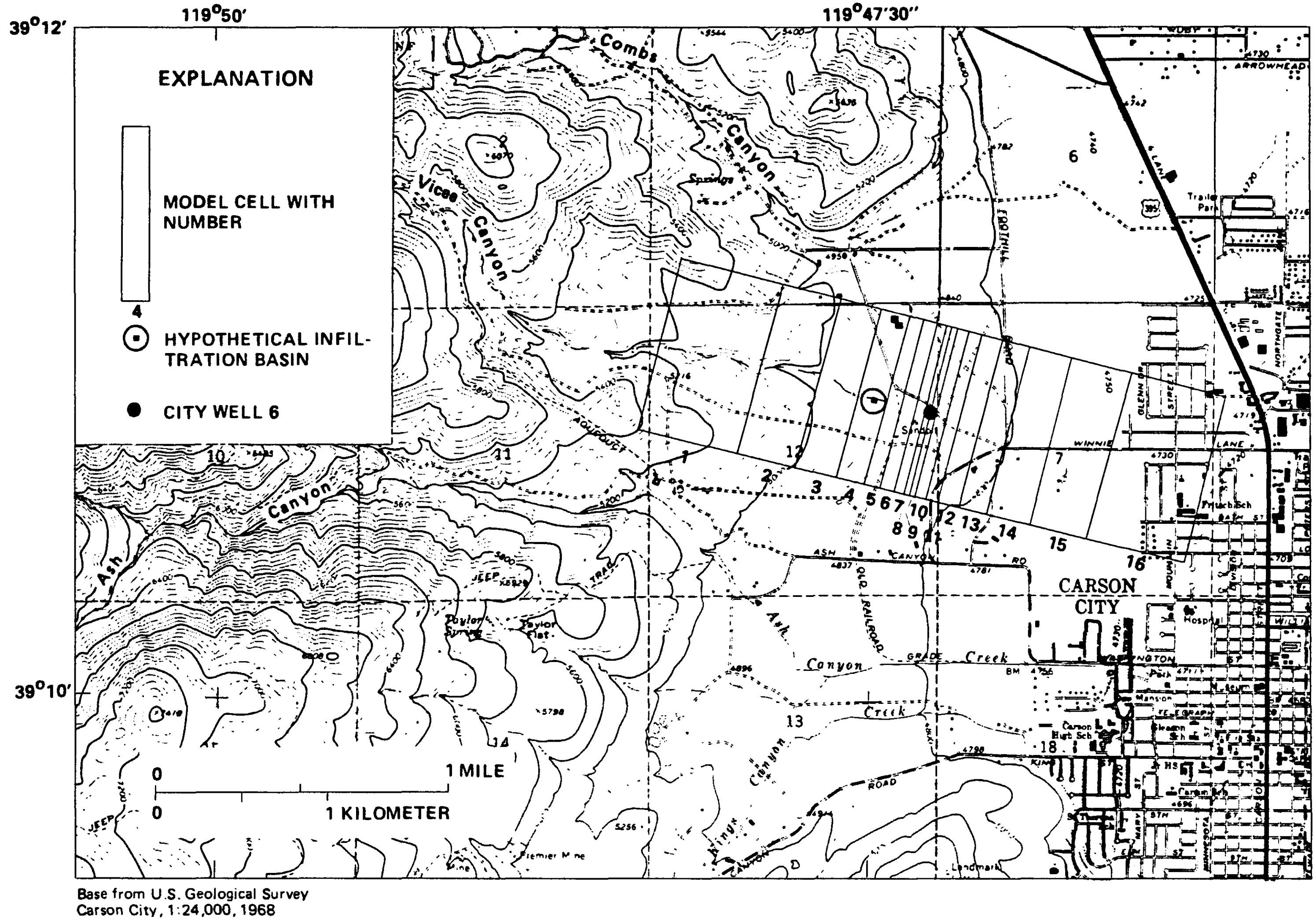


FIGURE 10.--Location of grid for finite-difference ground-water flow model.

The first simulations assumed steady-state (equilibrium) conditions for the period 1981-83, a period when water levels in observation wells near Vicee Canyon varied less than 5 feet and showed little net change. A constant recharge rate totaling 0.5 ft^3/s was applied to model cells 2, 3, and 4, representing the estimate of average natural streamflow generally lost along that reach. In addition, a pumping rate of 1.3 ft^3/s, equal to the average annual rate of City Well 6, was assigned to model cell 8. Ground-water inflow at the upper cell of the grid was estimated by applying Darcy's Law (see section on Definition of Hydrologic Terms). A horizontal hydraulic gradient of about 0.02 ft/ft was estimated from observation wells near the canyon (fig. 3). The hydraulic conductivity was assumed to be 28 in/hr, and an average cross-sectional area of about 80 feet thick by 1,400 feet wide was used for the calculation. The total cell width of 3,000 feet was not used because bedrock outcrops restrict the western end of cell 1. The estimated ground-water inflow was about 1.5 ft^3/s. Ground-water outflow at the lower cell was simulated by assigning a constant head at that cell.

The heads computed from the steady-state simulation approximated the observed configuration of the water table in figure 3. The computed water levels were then used as initial water levels in a transient model. The initial transient simulations used the same conditions as the steady-state simulation except a specific yield of 0.15 and 0.30 was applied for a 5-year period. The computed water levels from the initial transient simulations were the same as the steady-state simulation with only small amounts of water moving in and out of storage.

An idealized infiltration basin shown in figure 10 was then superimposed onto the initial transient simulations. The infiltration basin was assumed to cover 10,000 ft^2 in grid cell 4, and was supplied with sufficient water to maintain a constant water depth of 1 foot. The river package in McDonald and Harbaugh (1984, chapter 6) was used to simulate the infiltration basin. A hydraulic conductivity of 5 in/hr, equal to the average infiltration rate measured on the canyon floor, was used in the simulation and the infiltration bed thickness was assumed to be 1 foot. The time for infiltration from the basin to the water table was neglected in the simulations as were changes in storage in the unsaturated zone. These assumptions may affect the model results for initial times as results from the unsaturated zone studies suggest flow through the unsaturated zone may take 30 to 60 days (see section on Rates of Percolation), but probably have little effect for the 5-year period used in the simulations. Water loss from evaporation was also neglected for the simulations.

The flow rate through the infiltration bed was 1.1 ft^3/s for the simulations and was the same as the infiltration rate times the area of the infiltration basin. Increasing recharge in Vicee Canyon by 1.1 ft^3/s caused water levels to rise 35 feet in cell 4 after 5 years when a specific yield of 0.15 was used and 23 feet when a specific yield of 0.30 was used. The water-level rise near City Well 6 (cell 8) after 5 years was 34 feet when the specific yield was 0.15, and 23 feet when the specific yield was 0.30.

To determine the effect of uncertainties in hydraulic conductivity beneath the canyon, the conductivity was increased by a factor of 2 in the upper cells and, correspondingly, the ground-water inflow was increased to duplicate the general configuration of the water table in figure 3. Repeating the simulation process described in the previous paragraphs, the increase in hydraulic conductivity produced simulated water-level rises in cell 4 of 21 feet after 5 years when the specific yield was 0.15 and 15 feet when the specific yield was 0.30. Corresponding water-level rises in cell 8 were about 1 foot less than those in cell 4.

Two additional simulations were made, increasing the depth of water in the infiltration bed to 2 feet and decreasing the depth to 0.5 foot. The simulated water-level rise beneath cell 4, assuming a specific yield of 0.30 and a hydraulic conductivity of 28 in/hr, was 46 feet and 12 feet, respectively. Also, the flow rate of water required for simulated water depths of 2 and 0.5 feet were 2.2 and 0.6 ft^3/s, respectively. Thus, the required flow of water to the infiltration basin and the corresponding water-level rise is directly proportional to the depth of water maintained in the basin. This is consistent with the findings of Walton and others (1967, p. 4) who found infiltration loss from rivers was proportional to river stage.

The model results can only be considered approximate because of uncertainties in the hydraulic properties of sediments beneath Vicee Canyon. However, on the basis of the model simulations, increasing the infiltration in the canyon by about 1 ft^3/s at grid cell 4 would likely result in water-level rises of about 15 to 30 feet beneath the basin after 5 years and similar rises at City Well 6. For the simulations where hydraulic conductivity was equal to measured values, the amount of water added to ground-water storage after the 5-year period was 2,300 acre-feet using a specific yield of 0.15 and 3,100 acre-feet using a specific yield of 0.30. However, under high rates of infiltration, water levels in shallow, perched zones could approach land surface, resulting in loss of ground water to evapotranspiration and surface seepage downslope.

SUMMARY AND CONCLUSIONS

Changes in the streambed of Vicee Canyon have a direct effect on rates of streamflow infiltration and, thus, the amount of recharge gained through streamflow augmentation. Sediment movement on the floor of Vicee Canyon is dynamic with as much as 4 feet of scour and fill accompanying major changes in streamflow. Periodic high flows are important in producing natural infiltration beds on the floor of Vicee Canyon; without these flows, base flow results in channelization and armoring of the streambed, greatly reducing infiltration. On the basis of observations during natural runoff events and streamflow augmentation tests, deposition of a broad, thick infiltration bed requires streamflows greater than 3 ft^3/s sustained for a period of 1 to 2 days. However, base flow following the high flows can cause channelization of the bed over a period of 1 to 10 months, indicating that periodic high-flows are needed to maintain an effective infiltration bed. Also, infiltration during high flows drives out air entrapped in the unsaturated zone, increasing unsaturated hydraulic conductivities and, thus, the volume of recharge from subsequent streamflow infiltration.

During the study period channelization of the streambed, combined with a major erosional event above a gravel pit near the mouth of Vicee Canyon, caused the point where most streamflow is lost to infiltration to move downstream past observation wells and unsaturated-zone instrumentation. These changes caused streamflow in excess of infiltration to be captured completely by the gravel pit. Streamflow that does not infiltrate the canyon floor flows to the pit and is lost to evaporation.

Infiltration rates, percolation rates, and saturated hydraulic conductivity measured during the study indicate that recharge can be artificially increased to the aquifer underlying the floor of Vicee Canyon. However, streambed armoring, low moisture content, and thin silt and clay lenses can reduce the infiltration rates. For artificial recharge through streamflow augmentation to be most effective, a clean, wet infiltration bed must be maintained. Assuming an average infiltration rate of 5.0 in/h, an infiltration bed of 10,000 ft^2 would transmit about 1 ft^3/s (720 acre-ft/yr) to the water table. Laboratory measurements and aquifer-test data indicate that saturated hydraulic conductivities average about 28 in/h, suggesting that greater percolation rates occur in the alluvial sediments as saturation is approached.

Estimates of recharge from streamflow to alluvial sediments beneath Vicee Canyon during the study period were obtained from three different methods: (1) a water-balance method, (2) calculations based on unsaturated-zone measurements of moisture content and pressure head using a finite-difference approach, and (3) ground-water level responses to infiltration events.

The water-balance method estimates that about 20 to 30 percent of the total streamflow is lost to the gravel pit, about 7 percent to evapotranspiration, and about 60 to 70 percent infiltrates as recharge. Recharge estimated from unsaturated-zone data accounts for 43 percent of the total streamflow, agreeing closely with recharge estimated from water-level responses to infiltration events which accounts for 44 percent. A 1,500-foot stretch of streambed downstream from the lowest stream gage was not instrumented, and recharge beneath this stretch probably accounts for the discrepancy between the estimates for the water-balance method and methods 2 and 3.

Estimates using a ground-water flow model indicate that water-level rises below a hypothetical infiltration bed in Vicee Canyon and at City Well 6 may range from 15 to 30 feet. The model assumes a constant recharge rate of 1.1 ft^3/s from a 100-by-100-foot infiltration bed maintained on the canyon floor for 5 years and no loss of flow to evapotranspiration. The amount of ground water added to storage artificially after the 5-year period would be about 2,300 to 3,100 acre-feet. The computed water-level rises and estimated additions to storage depend on hydraulic properties near the water table beneath Vicee Canyon and are proportional to the depth of water maintained in the infiltration basin.

Low infiltration rates measured in the gravel pit suggest that, in conjunction with an infiltration bed, a settling pond where fine sediments could be removed periodically from the system would prevent reduction in infiltration rates. An alternative would be a pipeline from which clear water could be added directly to an infiltration bed.

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BASIC DATA

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TABLE 6.--*Miscellaneous streamflow measurements*

(--, no time recorded)

Date	Time	Distance below lower stream gage (feet)	Streamflow (cubic feet per second)
02-22-84	15:48	3,000	0.04
		3,200	.00
02-23-84	15:29	3,100	.03
		3,240	.00
02-23-84	15:48	3,100	.03
		3,220	.00
05-29-84	09:00	0	.50
		4,700	.10
	15:45	0	.40
		4,500	.00
05-30-84	14:53	0	.28
		2,500	.20
05-31-84	15:00	0	.43
		1,000	.38
		2,000	.20
		3,000	.17
		4,000	.07
		4,500	.06
		4,570	.00
06-07-84	10:00	0	.57
		500	.46
		1,000	.41
		1,500	.43
		2,000	.33
		2,500	.26
		3,000	.14
		3,500	.08
		4,000	.004
		4,400	.00
06-11-84	07:50	0	.61
		2,500	.41
		4,000	.26
06-12-84	--	2,000	.38
		2,200	.24

TABLE 6.--*Miscellaneous streamflow measurements*--Continued

Date	Time	Distance below lower stream gage (feet)	Streamflow (cubic feet per second)
06-13-84	08:00	2,000	0.41
		2,200	.26
	15:40	0	.35
		2,000	.20
06-14-84	08:25	0	.52
		2,000	.38
06-15-84	07:50	0	.67
		2,000	.64
06-26-84	13:20	0	.24
		2,000	.15
		2,300	.00
07-03-84	07:20	0	.29
		2,000	.14
		2,300	.00
07-31-84	12:35	0	.10
		2,000	.02
		2,200	.00
08-31-84	10:00	0	.12
		2,000	.04
		2,300	.00
08-20-84	09:50	0	.09
		2,000	.03
	14:30	0	1.83
		2,000	1.69
		2,500	.52
		3,500	.35
10-01-84	10:30	0	.12
		500	.12
		1,000	.08
		1,500	.05
		2,000	.00

TABLE 6.--*Miscellaneous streamflow measurements*--Continued

Date	Time	Distance below lower stream gage (feet)	Streamflow (cubic feet per second)
10-01-84	14:10	0	0.52
		500	.43
		1,500	.38
		2,500	.04
		2,600	.00
10-02-84	11:40	0	.62
		500	.52
		1,000	.46
		1,500	.46
		1,700	.33
		2,000	.22
		2,600	.00
10-03-84	14:50	0	.76
		500	.74
		1,000	.71
		1,500	.73
		2,200	.43
		2,500	.38
		3,000	.00
	16:30	2,500	.33
		2,900	.00
10-04-84	08:00	0	.86
		1,500	.78
		2,200	.55
		3,000	.17
		4,000	.05
10-04-84	10:40	0	.78
		1,500	.71
		2,200	.58
		2,500	.55
		3,000	.19
		3,500	.06
10-05-84	10:55	0	.12
		500	.11
		1,000	.08
		1,500	.05

TABLE 6.--*Miscellaneous streamflow measurements*--Continued

Date	Time	Distance below lower stream gage (feet)	Streamflow (cubic feet per second)
03-29-85	--	0	0.29
		500	.26
		1,000	.24
		1,500	.20
		2,000	.17
		2,200	.14
		2,500	.11
		2,700	.09
		3,000	.07
04-04-85	12:10	0	.11
		500	.11
		1,000	.11
		1,500	.11
		2,000	.10
		2,500	.08
		3,000	.06
		3,400	.05
		3,600	.00
05-22-85	15:02	0	.13
		500	.13
		1,000	.12
		1,500	.07
		2,000	.05
		2,200	.02
		3,000	.00
05-23-85	09:40	0	.20
		1,000	.18
		2,000	.11
		2,200	.05
		3,000	.03
		3,500	.03
		4,000	.03
02-24-86	13:30	1,500	.69
		3,500	.00
05-02-86	--	3,500	.05
		4,000	.00

Table 7.--*Water-level measurements for study-area wells*

Well identification.--See table 1.
Owner.--Abbreviations: NEVADA-DWR, Nevada Division of Water Resources; USGS, U.S. Geological Survey.
Site status.--Abbreviations: D, well dry; O, obstruction in well; P, well pumping; R, well pumped recently; S, nearby well pumping.
Water-level measurement method:--Abbreviations: R, water level reported (measurement method not known); S, steel tape; T, electric tape; Z, other.

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 01DCDC1	GREENE	03-23-84	239.32		S
		03-30-84	238.91		S
		04-23-84	237.59		S
		05-11-84	236.77		S
		06-11-84	235.47		S
		06-22-84	235.24		S
		08-08-84	234.38		
		08-28-84	233.85	R	S
		09-18-84	233.82	R	S
		10-23-84	233.61		S
		12-04-84	233.68		S
		02-15-85	234.08		S
		03-19-85	236.02		S
		04-05-85	234.64		S
		04-23-85	236.25		S
		05-07-85	235.49		S
		05-14-85	235.71		S
		05-31-85	236.05		S
		06-13-85		P	
		06-24-85	237.16		S
		07-03-85		P	
		07-22-85	238.27		S
		08-09-85		P	
		08-16-85		P	
		08-29-85		P	
		10-29-85	240.75		S
		11-22-85	241.33		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 01DCDC2	VAN PATTEN	08-08-84	211.54	R	S
		08-28-84	210.95	R	S
		09-18-84	210.82	R	S
		10-23-84	210.65	R	S
		12-04-84	210.62		S
		01-08-85	210.79		S
		02-15-85	211.02		S
		03-19-85	211.52		S
		04-05-85	211.48		S
		04-23-85		P	
		05-07-85	212.14		S
		05-14-85	212.45		S
		05-31-85	212.62		S
		06-13-85	213.49	R	S
		06-24-85	213.89		S
		07-03-85	214.37		S
		07-12-85	214.78	R	S
		07-22-85	215.06		S
		08-09-85	215.78		S
		08-16-85	215.79	R	-
		08-29-85	216.20		S
104 N15 E19 01DDDD1	CARSON CITY OF (CARSON 10)	04-25-83	143.16		S
		05-03-83	142.52		S
		10-04-83	168.13		S
		12-07-83	153.07		S
		03-15-84	137.32		S
		03-30-84	136.29		S
		04-23-84		P	

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 01DDDD1 (Cont.)		05-11-84		P	
		05-18-84		P	
		06-11-84		P	
		06-22-84		P	
		08-08-84		P	
		04-13-85	136.21		S
		04-23-85	137.54		S
		10-29-85		P	
		11-22-85		P	
104 N15 E19 12ABCC1	USGS (VC-1)	07-01-83	84.2		T
		07-07-83	84.8		T
		07-08-83	85.2		T
		07-11-83	85.4		T
		07-13-83	85.6		T
		07-14-83	85.6		T
		07-18-83	84.6		T
		07-21-83	84.6		T
		07-29-83	85.0		T
		08-05-83	85.4		T
		09-06-83	86.9		T
		09-22-83	87.8		T
		10-02-83	88.5		T
		10-04-83	88.4		T
		10-13-83	87.7		T
		10-19-83	87.7		T
		11-25-83	83.3		T
		11-29-83	81.3		T
		12-06-83	80.1		T
		12-07-83	80.2		T
		12-15-83	79.7		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ABCC1 (Cont.)		01-05-84	83.1		T
		01-24-84	84.7		T
		01-27-84	84.6		T
		01-29-84	84.7		T
		01-30-84	84.7		T
		02-01-84	84.8		T
		02-11-84	85.1		T
		02-13-84	84.9		T
		02-14-84	84.3		T
		02-15-84	85.1		T
		02-16-84	85.1		T
		02-17-84	85.2		T
		02-21-84	85.5		T
		02-28-84	85.1		T
		03-02-84	82.9		T
		03-06-84	83.0		T
		03-30-84	83.7		T
		04-23-84	84.6		T
		05-11-84	83.7		T
		06-07-84	81.8		T
		06-22-84	77.1		T
		07-06-84	78.9		T
		08-17-84	83.6		T
		08-20-84	83.8		T
		08-21-84	83.9		T
		10-01-84	86.1		T
		10-02-84	86.0		T
		10-03-84	85.9		T
		10-05-84	86.6		T
		11-06-84	82.0		T
		12-04-84	80.7		T
		01-08-85	79.9		T
		02-15-85	79.9		T
		03-05-85	80.1		T
		03-19-85	79.2		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Site status	Measurement method
104 N15 E19 12ABCC1 (Cont.)		04-05-85	80.5		T
		04-13-85	80.4		T
		04-23-85	80.1		T
		05-07-85	79.8		T
		05-14-85	79.8		T
		05-22-85	80.3		T
		06-13-85	80.1		T
		06-24-85	81.3		T
		07-03-85	82.0		T
		07-12-85	82.7		T
		07-22-85	83.5		T
		08-09-85	84.2		T
		08-16-85	84.5		T
		08-23-85	84.4		T
		08-29-85	84.7		T
		09-05-85	85.1		T
		09-20-85	85.2		T
		09-27-85	86.5		T
		10-08-85	85.9		T
		10-11-85	86.2		T
		10-15-85	86.0		T
		10-18-85	85.7		T
		10-23-85	85.5		T
		10-30-85	86.0		T
		11-22-85	86.5		T
104 N15 E19 12ABCC2	USGS (VC-4A)	03-02-84	144.5		T
		03-06-84	154.5		T
		03-15-84	162.3		T
		04-23-84	162.5		T
		05-11-84		D	
		05-18-84		D	
		05-23-84		D	

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level			
		Date	Depth (feet below land surface)	Site status	Measurement method
104 N15 E19 12ABCC3	USGS (VC-4B)	03-02-84	180.9		T
		03-06-84	181.2		T
		03-15-84	182.1		T
		04-23-84	183.3		T
		05-11-84	185.0		T
		05-19-84	185.2		T
		05-23-84	185.3		T
		06-07-84	185.9		T
		06-22-84	186.0		T
		07-06-84	185.9		T
		07-23-84	184.4		T
		07-24-84	184.1		T
		08-03-84	184.4		T
		08-10-84	183.7		T
		08-20-84	184.2		T
		08-21-84	184.2		T
		12-04-84	187.8		T
		01-11-85	187.4		T
		02-12-85	186.5		T
		03-05-85	186.9		T
		04-05-85	188.4		T
		04-13-85	188.4		T
		04-23-85	188.4		T
		05-07-85	187.4		T
		05-14-85	187.5		T
		05-22-85	187.4		T
		06-13-85	188.6		T
		06-24-85	188.5		T
		07-03-85	188.3		T
		07-12-85	188.3		T
		07-22-85	188.6		T
		08-09-85	188.8		T
		08-16-85	188.9		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ABCC3 (Cont.)		08-23-85	189.0		T
		08-29-85	189.1		T
		09-05-85	189.3		T
		09-20-85	189.6		T
		09-27-85	189.6		T
		10-08-85	190.1		T
		10-11-85	189.9		T
		10-15-85	189.9		T
		10-18-85	190.0		T
		10-23-85	190.1		T
		10-30-85	190.2		T
		11-22-85	190.6		T
104 N15 E19 12ABCC4	USGS (VC-4C)	03-02-84	188.3		T
		03-06-84	191.2		T
		03-15-84	190.8		T
		04-23-84	191.1		T
		05-11-84	189.5		T
		05-18-84	188.8		T
		05-23-84	188.8		T
		06-07-84	188.8		T
		06-22-84	188.5		T
		07-06-84	191.3		T
		07-23-84	196.1		T
		08-20-84	195.7		T
		12-04-84	205.1		T
		02-12-85	203.3		T
		03-05-85	203.7		T
		03-16-85	208.9		T
		04-05-85	204.4		T
		04-13-85	204.6		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Depth (feet below land surface)	Site status	Measure-ment method
104 N15 E19 12ABCC4 (Cont.)		04-16-85	204.7		T
		04-23-85	204.7		T
		05-07-85	204.6		T
		05-14-85	204.8		T
		05-27-85	205.1		T
		06-13-85	205.7		T
		06-24-85	205.9		T
		07-03-85	206.0		T
		07-12-85	206.2		T
		07-22-85		O	
104 N15 E19 12ACAB1	USGS (VC-5)	05-01-84	203.85		
		05-03-84	204.18		
		05-07-84	202.99		
		05-17-84	203.10		
		06-25-84	203.30		
		08-03-84	207.29		
		08-20-84	209.02		
		08-22-84	216.68		
		09-02-84	221.12		
		11-19-84	215.6		T
		12-18-84	216.07		
		12-19-84	212.42		
		01-02-85	216.6		T
		01-08-85	214.8		T
		01-17-85	215.01		S
		02-12-85	212.0		T
		03-05-85	209.21		S
		03-16-85	208.5		T
		03-19-85	208.6		T
		04-05-85	208.0		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ACAB1 (Cont.)		04-13-85	209.0		T
		04-23-85	208.4		T
		05-14-85	208.7		T
		05-22-85	209.7		T
		06-21-85	219.39		S
		07-03-85	222.25		S
		07-12-85	222.97		S
		07-22-85	223.73		S
		07-24-85	223.96		S
		07-30-85	224.19		S
		08-07-85	225.56		S
		08-16-85	226.06		S
		08-23-85	226.93		S
		08-29-85	227.44		S
		09-05-85	227.85		S
		09-20-85	227.98		S
		09-27-85	226.86		S
		10-08-85	228.40		S
		10-11-85	227.44		S
		10-15-85	226.21		S
		10-18-85	225.29		S
		10-23-85	224.24		S
		10-29-85	223.43		S
		11-22-85	221.09		S
104 N15 E19 12ACBB1	USGS (VC-3A)	03-14-84	169.3		T
		04-23-84	170.3		T
		05-11-84	175.5		T
		05-18-84	177.8		T
		05-23-84	177.5		T
		06-07-84	163.7		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Depth (feet below land surface)	Site status	Measurement method
104 N15 E19 12ACBB1 (Cont.)		06-22-84	164.1		T
		07-06-84	169.3		T
		08-03-84	184.2		T
		08-07-84	184.5		T
		08-20-84	184.6		T
		11-06-84		D	
		12-04-84		D	
		01-08-85	166.4		T
		02-12-85	183.0		T
		04-05-85		D	
104 N15 E19 12ACBB2	USGS (VC-3B)	03-02-84	195.5		T
		03-06-84	198.7		T
		03-07-84	197.2		T
		03-14-84	198.4		T
		04-23-84	198.7		T
		05-11-84	202.4		T
		05-18-84	202.5		T
		05-23-84	203.1		T
		06-07-84	202.9		T
		06-22-84	203.3		T
		07-06-84	204.9		T
		08-03-84	207.9		T
		08-17-84	209.2		T
		08-20-84	209.1		T
		08-21-84	209.4		T
		11-06-84	210.5		T
		12-04-84	211.6		T
		01-08-85	210.3		T
		02-12-85	211.9		T
		03-19-85	211.4		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ACBB2 (Cont.)		04-05-85	211.1		T
		04-13-85	211.6		T
		04-23-85	211.6		T
		05-07-85	212.5		T
		05-14-85	213.1		T
		05-22-85	214.3		T
104 N15 E19 12ACBB3	USGS (VC-3C)	03-02-84	211.0		T
		03-06-84	209.0		T
		03-07-84	206.0		T
		03-14-84	206.5		T
		04-23-84	208.5		T
		05-11-84	215.5		T
		05-18-84	213.4		T
		05-23-84	216.7		T
		06-07-84	215.55		
		06-22-84	216.3		T
		07-06-84	222.3		T
		08-03-84	222.8		T
		08-17-84	224.1		T
		08-20-84	224.0		T
		08-21-84	224.2		T
		11-06-84	218.6		T
		12-04-84	219.8		T
		01-08-85	218.3		T
		02-12-85	215.1		T
		03-19-85	214.9		T
		04-05-85	213.9		T
		04-13-85	213.6		T
		04-23-85	214.9		T
		05-07-85	217.1		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Depth (feet below land surface)	Site status	Measurement method
104 N15 E19 12ACBB3 (Cont.)		05-14-85	217.8		T
		05-22-85	218.9		T
		06-13-85	222.2		T
		06-24-85	223.3		T
		07-03-85	225.0		T
		07-12-85	225.2		T
		07-22-85	225.9		T
		07-24-85	225.9		T
		08-08-85	227.5		T
		08-16-85	228.0		T
		08-23-85	228.8		T
		08-29-85	229.9		T
		08-29-85	229.85		T
		09-05-85	229.4		T
		09-16-85	229.1		T
		09-20-85	230.0		T
		09-27-85	228.9		T
		10-08-85	230.2		T
		10-11-85	227.4		T
		10-15-85	226.3		T
		10-18-85	225.7		T
		10-23-85	225.7		T
		10-30-85	224.6		T
		11-22-85	222.8		T
104 N15 E19 12ACBB4	USGS VC-3D	03-02-84	211.1		T
		03-06-84	209.3		T
		03-08-84	205.6		T
		03-14-84	206.96		
		04-23-84	208.9		T
		05-11-84	215.7		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ACBB4 (Cont.)		05-18-84	213.6		T
		05-23-84	217.0		T
		06-07-84	215.8		T
		06-22-84	216.5		T
		07-06-84	222.4		T
		08-03-84	223.1		T
		08-17-84	224.3		T
		08-20-84	224.5		T
		08-21-84	224.6		T
		11-06-84	218.4		T
		12-04-84	220.0		T
		12-18-84	219.44		
		12-19-84	219.59		
		12-20-84	219.65		
		01-08-85	218.4		T
		02-12-85	215.2		T
		03-19-85	214.2		T
		04-05-85	214.0		T
		04-13-85	214.5		T
		04-23-85	215.1		T
		05-07-85	217.3		T
		05-14-85	218.0		T
		05-22-85	219.1		T
		06-13-85	222.3		T
		06-24-85	223.3		T
		07-03-85	225.0		T
		07-12-85	225.4		T
		07-22-85	226.0		T
		08-08-85	227.6		T
		08-16-85	228.0		T
		08-23-85	228.8		T
		08-29-85	229.3		T
		09-05-85	229.6		T
		09-20-85	230.1		T
		09-27-85	229.1		T

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ACBB4 (Cont.)		10-08-85	230.3		T
		10-11-85	227.4		T
		10-15-85	226.3		T
		10-18-85	225.8		T
		10-23-85	225.6		T
		10-30-85	224.6		T
		11-22-85	222.8		T
104 N15 E19 12ADAA1	CARSON CITY OF (CARSON 6)	05-09-83	156.67	S	S
		10-04-83	158.03	R	S
		01-24-84	149.74	R	S
		01-30-84	155.09		S
		02-11-84	149.52		S
		02-13-84	151.92		S
		02-14-84	143.81		S
		02-15-84	143.56		S
		02-16-84	143.36		S
		02-17-84	143.32		S
		02-21-84	142.52		S
		02-28-84	141.44		S
		03-15-84	140.11		S
		03-30-84	140.22		S
		04-23-84	142.26		S
		06-18-84	146.74		S
		06-21-84	146.74		S
		06-22-84		P	
		08-08-84		P	
		10-01-84	154.53		S
		10-02-84	153.72		S
		10-03-84	153.04		S
		10-16-84	152.68		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E19 12ADAA1 (Cont.)		11-19-84	148.51		S
		12-19-84		P	
		01-11-85		P	
		02-12-85		P	
		10-29-85	154.3		T
104 N15 E19 12DAAD1	KING, DR. WILLIAM R.	04-14-83	105.19	S	S
		04-25-83	105.16	S	S
		05-03-83	105.12	S	S
		05-13-83	105.07		
		05-20-83	105.06		S
		06-02-83	105.49		S
		06-09-83	105.52		S
		06-23-83	105.82		S
		07-08-83	106.12		S
		07-18-83	106.64	R	S
		07-22-83	106.84	R	S
		07-29-83	107.07	R	S
		08-12-83	106.92		S
		08-19-83	106.98	R	S
		08-26-83	107.09	R	S
		09-03-83	107.13		R
		09-11-83	107.32	R	S
		09-22-83	107.69		S
		10-06-83	107.46		S
		10-25-83	107.20		S
		12-07-83	107.38		S
		01-05-84	107.80		S
		02-01-84	106.45		S
		02-07-84	100.04		S
		03-15-84	101.73		S
		03-30-84	97.77		S
		04-23-84	97.02		S
		05-11-84	97.58		S
		06-11-84	97.49		S
		06-22-84	97.52		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Depth (feet below land surface)	Site status	Measurement method
104 N15 E19 12DAAD1 (Cont.)		07-13-84	98.53		S
		08-08-84	99.34		S
		08-28-84	100.05		S
		09-18-84	100.64		S
		10-23-84	99.43		S
		12-04-84	98.00		S
		01-08-85	98.09		S
		02-15-85	96.62		S
		03-19-85		P	
		04-05-85	96.09		S
		04-23-85	97.32		S
		05-07-85	98.04		S
		05-15-85	98.40		S
		05-31-85	99.19		S
		06-13-85	99.80		S
		06-24-85	100.30		S
		07-03-85	100.92		S
		07-12-85	101.43		S
		07-22-85	101.81		S
		08-09-85	102.69		S
		08-16-85	102.53		S
		08-29-85	103.35	R	
		10-29-85	102.15		S
		11-22-85	102.15		S
104 N15 E19 12DADD2	CARSON CITY OF (CARSON 3)	12-08-83	87.30		S
		02-21-84	79.59		S
		03-22-84	78.03		S
		03-30-84		P	
		04-23-84		P	
		05-11-84		P	
		06-11-84	81.48		S
		08-03-85	85.97		S
		10-29-85	83.90		S
		11-23-85	82.85		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Site status	Measurement method
104 N15 E20 07BBAB1	NEVADA-DWR	02-02-83	60.63		S
		02-09-83	60.64		S
		03-04-83	60.65		S
		03-16-83	60.69		S
		03-23-83	60.68		Z
		04-11-83	60.74	S	S
		04-25-83	60.73		S
		05-03-83	60.73		S
		05-09-83	60.74		S
		05-20-83	60.76		S
		06-02-83	60.79		S
		06-09-83	60.77		S
		06-16-83	60.77		S
		06-23-83	60.82		S
		07-08-83	59.81		S
		07-18-83	60.84		S
		07-22-83	60.81		S
		07-29-83	60.82		S
		08-12-83	60.82		S
		08-19-83	60.87		S
		08-26-83	60.88		S
		09-03-83	60.88		S
		09-11-83	60.90		S
		09-22-83	60.92		S
		10-04-83	60.95		S
		10-25-83	61.02		S
		11-02-83	61.01		Z
		12-07-83	61.08		S
		01-05-84	61.12		S
		02-01-84	61.13		S
		02-15-84	61.15		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Site status	Measurement method
104 N15 E20 07BBAB1 (Cont.)		02-17-84	60.74		S
		03-15-84	61.19		S
		04-23-84	61.25		S
		04-24-84	61.24		Z
		05-11-84	61.28		S
		06-11-84	61.30		S
		06-22-84	61.33		S
		07-13-84	61.37		S
		07-17-84	61.34		Z
		08-08-84	61.43		S
		08-28-84	61.39		S
		09-18-84	61.42		S
		10-23-84	61.48		S
		10-24-84	61.40		Z
		12-04-84	61.53		S
		01-08-85	61.61		S
		02-15-85	61.09		S
		03-19-85	61.70		S
		04-05-85	61.70		S
		05-07-85	61.72		S
		05-14-85	61.73		S
		05-30-85	61.7		Z
		05-31-85	61.75		S
		06-13-85	61.77		S
		06-24-85	61.77		S
		06-26-85	61.86		Z
		07-03-85	61.79		S
		07-12-85	61.82		S
		07-22-85	61.83		S
		08-09-85	61.87		S
		08-16-85	61.86		S
		08-29-85	61.90		S
		10-29-85	61.99		S
		11-22-85	62.03		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level			
		Date	Depth (feet below land surface)	Site status	Measurement method
104 N15 E20 07CAAA1	HEITMILLER, H.C.	03-07-84	50.88		S
		03-30-84	50.15		S
		04-23-84	49.48		S
		05-11-84	49.15		S
		06-11-84	49.40		S
		06-22-84	48.75		S
		07-13-84	49.39		S
		08-08-84		P	
		08-28-84	49.44		S
		09-18-84	49.03		S
		10-23-84	49.16		S
		12-04-84	48.29		S
		01-08-85	47.98		S
		02-15-85	47.28		S
		03-19-85	46.99		S
		04-05-85	46.62		S
		04-23-85	45.76		S
		05-07-85	47.00		S
		05-14-85	46.95		S
		05-31-85	47.01		S
		06-13-85		P	
		06-24-85	48.04		S
		07-03-85	48.49		S
		07-12-85		P	
		07-22-85	48.49	R	S
		08-09-85	49.31		S
		08-16-85		P	
		08-29-85	51.52		S
		10-29-85	50.23		S
		11-22-85	50.24		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E20 07CACB1	COPPERTHWAITE, MEL	03-07-84	55.31		S
		03-30-84	54.66		S
		04-23-84	56.12	R	S
		05-11-84	53.34		S
		06-11-84	52.57		S
		06-22-84	53.30	R	S
		07-13-84	52.19	R	S
		08-08-84	53.01		S
		08-28-84	53.14		S
		09-18-84	53.51		S
		10-16-84	53.57		S
		12-04-84	51.93		S
		01-08-85	51.73		S
		02-15-85	51.05		S
		03-19-85	50.66		S
		04-05-85	50.74		S
		04-23-85	51.11		S
		05-07-85	52.05		S
		05-14-85	51.35		S
		05-31-85	51.72		S
		06-13-85	52.35		S
		06-24-85	54.58		S
		07-03-85	53.06		S
		07-12-85	53.46		S
		07-22-85	53.95		S
		08-09-85	54.68		S
		08-16-85	54.43		S
		08-29-85	54.30		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E20 07CBAA1	HARKENRIDER, JAMES	04-08-83	83.13		S
		04-11-83	83.28		S
		04-25-83	82.96	S	S
		05-03-83	82.84		S
		05-09-83	82.70		S
		05-20-83	82.90		S
		06-02-83	82.87		S
		06-09-83	82.82		S
		06-23-83	83.06		S
		07-05-83	83.07		S
		07-08-83	83.04		S
		07-18-83	83.20		S
		07-22-83	83.26		S
		07-29-83	83.36		S
		08-12-83	83.45		S
		08-19-83	83.49		S
		08-26-83	83.48		S
		09-03-83	83.67		S
		09-11-83	83.74		S
		09-22-83	83.88		S
		10-06-83	83.96		S
		10-25-83	83.14		S
		12-07-83	83.82		S
		01-05-84	82.14		S
		02-01-84	82.27		S
		02-17-84	79.64		S
		03-15-84	78.38		S
		03-30-84	77.49		S
		04-23-84	76.78		S
		05-11-84	76.45		S
		06-11-84	76.10		S
		06-22-84	75.98		S
		07-13-84	76.27		S

Table 7.--*Water-level measurements for study-area wells*--Continued

Well identification	Owner (or other identifier)	Water level: Date	Water level: Depth (feet below land surface)	Water level: Site status	Water level: Measurement method
104 N15 E20 07CBAA1 (Cont.)		08-08-84	76.88		S
		08-28-84	77.22		S
		09-18-84	77.78		S
		10-23-84	77.88		S
		12-04-84	76.37		S
		01-08-85	76.41		S
		02-15-85	76.60		S
		03-19-85	74.88		S
		04-05-85	74.52		S
		04-23-85	76.14		S
		05-07-85	75.10		S
		05-14-85	75.31		S
		05-31-85	75.79		S
		06-13-85	76.26		S
		06-24-85	76.63		S
		07-03-85	77.03		S
		07-12-85	77.41		S
		07-22-85	77.80		S
		08-09-85	78.54		S
		08-16-85	78.66		S
		08-29-85	79.14		S
		10-29-85	80.02		S
		11-22-85	79.60		S