The Hydrologic Impacts From the Diversion of Winter Flows of Cordova Creek for Snowmaking Purposes

Ski Rio Resort
Amalia, New Mexico

by
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INTRODUCTION

To lure business during the early season and to establish independence from unpredictable winter precipitation, many northern New Mexico ski areas have turned to artificial snowmaking to cover their slopes. The various owners (under three names since 1983) of Ski Rio Ski Area have acquired storage rights from nearby Costilla Reservoir, purchased snowmaking equipment and buried three water lines adjacent to their major ski runs with the intention of carrying out this process.

Ski Rio is located on the north flank of Latir Peak, situated on the western slope of the Sangre de Cristo Mountains 6.5 miles south of Amalia, New Mexico. Temperatures of the area range from a mean winter low of 21 degrees (F) to a mean summer high of 65 degrees (F). The average precipitation for the area is 20-28 inches per year and most of the annual precipitation (55-70%) falls from May through October in the form of thundershowers (Wilson, 1978).

Rio Costilla Recreational Development Corporation filed application RG-37787 & RG-37787-S thru S-3 to divert 159 acre-feet of ground water with 17 acre-feet of consumptive use (CU) in 1982. In January, 1983 the State Engineer Office approved the application for 17 acre-feet/annum of diversion. Attached to the permit were the conditions that: 1) up to 159 acre-feet/annum (maximum of 17 acre-feet/annum of CU) could be diverted if the applicant could prove return flow and 2) the resort has to release 10.6 acre-feet of storage right (from 159 acre-feet/year of their storage right in Costilla Reservoir) and 6.4 acre-feet of direct flow in Costilla Creek to offset the 17 acre-feet/year of CU.

The ski area encompasses the Cordova Creek (fka Rito Ballegos) watershed. Because production from nine ski area wells is so poor the third owner, Miracle Mountain Inc., filed application 4149 & RG-37787 thru RG-37787-S-3 in December 1986 to capture flows of the creek to supplement groundwater use. The application proposed to include snow-making in addition to the permitted use for construction, commercial, domestic, and recreational purposes.

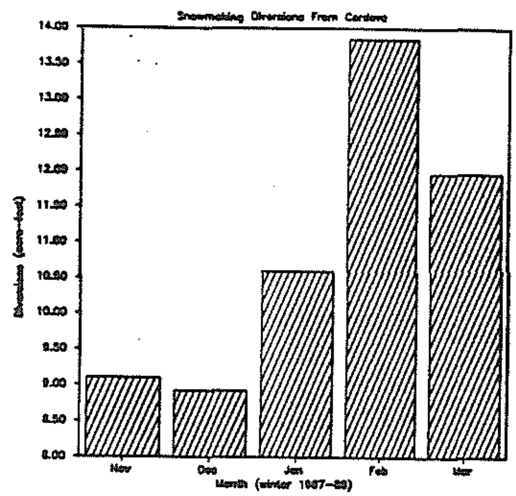
While the application was pending Miracle Mountain Inc. built a storage pond (capacity 2.3 acre feet) on Cordova Creek near the main lodge and ticket office to dam flows for snowmaking and filed an emergency application to divert flows for the winter of 1987-88. The permit was approved and the resort (Ski Rio) diverted 54.5 acre-feet of surface flow for snowmaking and 3.34 acre-feet of ground water for the ski resort operations from November through April 1987-88.

The closest non-applicant water rights are 1.47 acres of surface right from Onesimo Archuleta acequia, in Cordova Canyon, and two domestic wells owned by Alfonso Gonzales (RG-23532) and Arturo Gallegos (RG-36174) near the mouth of the canyon. The purpose of this report will be to determine whether winter diversions from Cordova Creek for snowmaking will impact the nearest existing water rights.

SNOWMAKING AT SKI RIO

Ski resorts generally produce most artificial snow in the early season and depend upon natural snow through the rest of the season (personal communication, Louis Abruzzo, Sandia Peak Corp., 1988). Ski Rio's records indicate continuous snowmaking throughout the 1987-88 ski season.

Figure 1.



From mid-November to late March approximately 54.5 acre-feet of Cordova Creek water was diverted for snowmaking at the resort. Ski Rio reported to Mike Pitel, with the New Mexico Economic Development & Tourism Department, that their base snowpack was 45 percent below normal for the winter of 1987-88 (Figure 9). Records from the New Mexico Water Supply Outlook (May 15, 1988) confirm that snowpack and precipitation for the Rio Grande Basin were below average for late winter 1987-88 (Figure 10).

Kevin Beardsly, Ski Rio mountain manager, (personal communication) suggests that last winters diversion was enough to cover their slopes but, the resort had plans to expand their water lines further up the mountain. The purpose of the expansion would be to help bridge the gap between the natural snowpack on the upper mountain and the artificial snowpack on the lower mountain during water low years.

Ski Rio has water lines that parallel the three main ski slopes. Snowmaking equipment can be hooked into the mains and used to make snow on the adjacent ski runs. In order to produce artificial snow the water is funneled through a misting device that sprays the water particles up into the air where crystalization takes place. The process at Ski Rio has used up to one acre foot per night to produce snow (November 19, 1987). Artificial snow was produced on 55 acres at Ski Rio in the winter of 1987-88 (Slingerland, 1988).

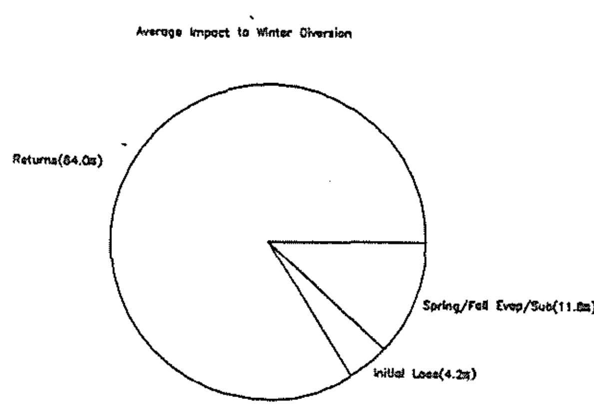
Consumptive Use of Water Used for Snowmaking

Smart and Fleming (1985) designed an experiment to estimate the CU of water during artificial snowmaking for the Santa Fe Ski Area in the Santa Fe National Forest, near Santa Fe, New Mexico. The study used a mass balance approach to determine the CU from the evaporation (2.5 percent) occuring during the snowmaking process and the CU from the evaporation and sublimation (7.5 percent) of the artificial snowpack for fall and spring conditions. Smart and Fleming's 1985 estimate of 10 percent CU for the Santa Fe Ski Area may be a reasonable estimate of the CU at Ski Rio. The ski areas are situated on like soils and topography with similiar slope orientation.

Wright Water Engineers and Leaf (1986, p. 9) investigated the CU of water used to make artificial snow for Colorado Ski Country USA. The study assembled data from six different ski resorts throughout Colorado and modeled the watershed loss associated with the snowmaking. The average CU from the six resorts for an average water year was 22 percent, 6 percent initial loss and 16 percent watershed loss.

Ski Rio is located halfway between Santa Fe Ski Area and the resorts studied in Colorado. The conditions and settings from both studies are similiar and so an average between the two CU estimates has been used in this study. The estimate for CU of Cordova Creek water at Ski Rio is 16 percent of the total diversion.

Figure 2.



GEOLOGY AND HYDROGEOLOGY

The following briefly summarizes the geology and hydrogeology of the area. For more detailed descriptions of the geology the reader is referred to the list of references in this report. A few of the suggested readings are ; McKinlay, 1956, Clark, 1966, and Wilson and Associates, 1978 & 1981.

The Rio Costilla Ski Area is located south of Amalia, New Mexico. The total area of the ski resort is encompassed within the Cordova Creek watershed, a tributary to the Rio Costilla.

The dominant geology of the watershed is Pre-Cambrian metamorphosed quartzite, schist, gneiss and plutonic granite overlain by Tertiary volcanic and associated rocks (McKinlay, 1956, Figure 6). Quaternary and Tertiary alluvium fills the valleys and hollows of the flanks of the mountains down to the Rio Costilla Valley.

The mountain valley alluvial deposits are of limited areal extent but are the primary aquifers for most all of the wells in the mountains (Wilson, 1978). Some wells have been finished in the underlying hard rock but drillers report no increase in yield associated with the plutonic, volcanic and metamorphic rocks (personnal communication, Joe Arguello, local driller).

Nine wells were located in alluvium throughout the ski area in search of ground water. Western Technologies (1987) logged four wells drilled in 1987 but the remaining five wells have no known logs. Western's report indicates that the nine wells range from 158 to 292 feet deep and yield from <5-40 gallons per minute (gpm) with an average of 23 gpm. Walter Gallegos, a Ski Rio employee, reports that yields (personal communication) in the winter are 25 percent of summer yields from the ski area wells.

Western Technologies Aquifer Test

Western performed a pumping test in June 1987 on Lemos Well No. 9 (Figure 5) and recorded recovery measurements afterwards. The well is situated in an alluvial channel of an intermittent tributary to Cordova Creek, is reported to be 120 feet deep, and is screened from 20 to 120 feet below land surface (BLS). Static water level in the well was approximately 17 feet BLS prior to the aquifer test.

The well was pumped for six hours at 29 gpm. The water level in the well at the time of pump shutdown was 43 feet BLS. Seventeen hours after pump shutdown water levels had only risen four feet. This response seems to indicate little or no recharge contributed to the recovery in the well (during the test) and that most of the water had come from storage. The estimates for transmissivity obtained from this aquifer test have been considered site specific due to the nature of the aquifer system (varied thickness and saturated thickness of alluvium) from one location to another in the channel.

SEO Field Investigation of Closest Non-Applicant Wells

The closest water right owners to Ski Rio are those in the Rio Costilla Valley near Amalia 2,000 feet lower in elevation (Figure 11). These rights are situated in an aquifer system probably influenced primarily by the flows of the Rio Costilla and to a certain extent by contributions from tributaries to the river valley. Cordova Creek is one of those tributaries.

Very little downhole data exists for wells in the Amalia area as drillers have failed to submit well logs for the numerous wells of the area. SEO staff gathered water level data for nine wells (Table 8) in the vicinity of the confluence of Cordova Creek and the Rio Costilla in April, 1988. The wells ranged in depth from 25 to 160 feet with water at 4 to 18 feet BLS. The wells are emplaced in alluvial sediments deposited by the river. Joe Arguello, of Arguello Drilling, suggested (personal communication) alluvial valley sediments are extensive and that none of the wells of the area had penetrated the entire thickness.

CORDOVA CREEK WATERSHED HYDROLOGY

The Cordova Creek watershed encompasses 6 square miles on the north flank of Latir Peak. Of interest are 3.1 square miles of the watershed which will contribute to the creek's flows at the Ski Rio pond site. The elevation of this segment of the watershed ranges from 9480 to 11,437 feet above sea level.

Annual Runoff From Cordova Creek

The New Mexico Interstate Stream Commission (ISC, 1981) has developed an altitude-runoff relationship for watersheds of northern New Mexico. This method uses regression analysis for 28 years (1950-1978) of gaged data from eight different watersheds in the northern part of the state to determine a relationship between altitude and runoff. The data indicate a high correlation with a regression coefficient of "r = 0.97."

This study focuses on the upper half (52 per cent) of the Cordova Creek watershed. The average elevation is 10,458 feet and the average runoff per square mile from the ISC relationship is 193 acre-feet/year. In an average year an estimated 600 acre-feet will flow through the pond site.

Monthly Runoff of Cordova Creek

Although monthly flows of Cordova Creek have never been gaged, flows in adjacent and similiar stream systems have. The relationship between the flows of similiar stream systems, namely Latir Creek near Cerro, Rio Hondo near

Valdez, and Red River (RR) below Zwergle damsite were compared for years when gages were operated simultaneously on all three. The purpose of this comparison was to determine similarities in the runoff pattern between the watersheds on a seasonal basis.

The averages of the percentage of the total annual runoff per month (e.g. assume runoff = Q, [May Q Latir/annual Q Latir + May Q Hondo/annual Q Hondo + May Q RR/annual Q RR]/3 = average percentage of the total annual Q for month of May) are tabulated below. The pattern of percentages were very similiar for the time period measured (water years 1963-68). The averages below should be a reasonable approximation of the runoff patterns in the Cordova Creek watershed.

Table 1.

Percentage Annual Runoff vs. Estimated Monthly Runoff
(acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ttl
% annual Q	5.3	4.2	3.6	3.3	2.9	3.6	6.5	17.7	22.5	11.7	11.5	7.3	100
estimate Q	32	25	22	20	17	22	39	106	134	70	69	44	600

In an effort to estimate high and low runoff conditions for Cordova Creek watershed, historical records for Latir Creek were examined. Latir was chosen because of its proximity to Cordova (directly adjacent) and because of the large number of years its gage has been in operation

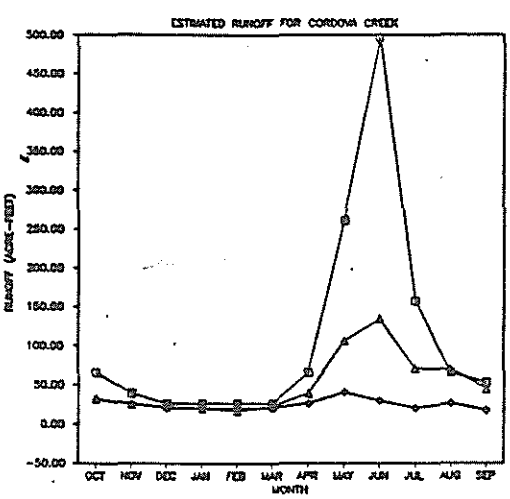
(1937-1969). The runoff for 1941-42 was 218 percent of the average and 1956-57 was 48 percent of the average. If these percentages are applied to the average runoff at the Ski Rio pond (600 acre-feet/year) the estimates for the high and low conditions would be 1308 and 288 acre-feet/year respectively. If the flow patterns also mimicked those high and low flow years then flows might occur as follows:

Table 2.

Estimated Monthly Runoff for High, Average, and Low Water Years (acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ttl
HIGH	65	39	26	26	26	26	68	261	497	157	65	52	1308
AVER	32	25	22	20	17	22	39	106	134	70	69	44	600
LOW	30	26	20	17	17	20	26	40	29	20	26	17	288

Figure 3.



Ground Water Surface Water Relationship

Cordova Creek is perennial. The relationship between ground water and surface water in the mountains is dependent upon runoff. During periods of excess runoff the stage of the creek is greater than the head in the aquifer such that it recharges the aquifer. During periods of minimal runoff the stage of the creek is very low relative to the head in the aquifer. During these periods aquifer contributions make up most of the baseflow in the creek (Wilson, 1978).

Winter recharge is a very small fraction of total annual recharge to the aquifer. This generally is attributed to greater head in the aquifer (relative to the stage in the creek) during winter months and lower temperatures which increase water viscosity and freeze some flows. When snow melts in the late spring and early summer, more water percolates to ground water and runoff increases flows in the surface water system.

Runoff Scenarios

If Miracle Mountain is allowed to divert winter flows from Cordova Creek for snowmaking then flow patterns will change. Winter flows will decrease (below the pond) and spring flows will increase. If it is assumed that 16 percent of the water used to make snow will be consumptively used then 84 percent will return to the system in the middle to late spring.

Actual diversions made during the winter of 1987-88 can serve as an estimate of how future diversions may be made. Two different scenarios have been examined; the case of an average water year and that of a low water year. The amount of water diverted during 1987-88 is a reasonable estimate of the average that may be diverted in an average water year (see next paragraph).

Table 3.

Average Water Year
Estimated Account of Flow At Ski Rio Pond
(acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ttl
A -	32	25	22	20	20	22	39	103	134	70	69	44	600
B -	0	9	9	10	14	12	0	0	0	0	0	0	54
C +	0	0	0	0	0	0	3	15	27	0	0	0	45
D -	1	1	1	1	1	1	1	1	1	1	1	1	12
E	31	15	12	9	5	9	41	117	160	69	68	43	579

A- estimated monthly flow condition for Cordova Creek
B- flow diverted for snowmaking, Winter 1987-88
C- artificial snowmelt runoff, total diverted - 16 percent
D- ground-water diversion (considered CU until proven otherwise)
E- approximate flow when snowmaking operation in operation

Ski Rio reported that snowfall for the area (1987-88) was 110 inches and suggested (Figure 9) that snowfall was 45 percent below average. Actually, 1987-88 snowfall may be close to average. Wilson (1978), suggests that 30 to 45 percent of the precipitation in Taos County falls from October to May. An isopluvial map (Figure 8) for Taos County indicates the average precipitation for the Ski Rio area is 25 inches per year. So, precipitation for October through May should range from 7.50 to 11.25 inches. A general rule of thumb for converting moisture to snow is 1 to 10. That is, 1 inch of rain equals 10 inches of snow. This applies to freshly fallen snow and is a function of a number of factors (humidity, temperature, etc.). Using this relationship one might reason that 110 inches of snow for the area should be about average.

Thus, in a water low year it would be reasonable to assume that more artificial snow will have to be made to make up for a lack of natural snowfall. For this study it was assumed that up to fifty percent more water (worst case scenario) may need to be diverted.

Table 4.

Low Water Year
Estimated Account of Flow At Ski Rio Pond Site
(acre-feet)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ttl
A-	30	26	20	17	17	20	26	40	29	20	26	17	288
B -	0	14	15	15	16	19	0	0	0	0	0	0	79
C +	0	0	0	0	0	0	4	23	39	0	0	0	66
D -	1	1	1	1	1	1	1	1	1	1	1	1	12
E	29	11	4	1	0	0	29	62	67	19	25	16	263

A- estimated monthly flow condition for Cordova Creek
B- flow diverted for snowmaking, Winter 1987-88 x 150 percent
C- artificial snowmelt runoff, total diverted - 16 percent
D- ground-water diversion (considered CU until proven otherwise)
E- approximate flow when snowmaking operation in operation

Closest Water Right Owners

The closest surface water right to Ski Rio is 1.47 acres of right in Cordova Canyon owned by Onesimo Archuleta.

The pre-snowmaking average monthly flow in Cordova Creek at the point of this diversion is compared with post snowmaking monthly flow below. The estimates for a water poor year were used to examine a worst case scenario.

Table 5.

Flow of Cordova Creek at Archuleta Property
(acre-feet/month)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ttl
A-	7	5	4	4	4	4	6	8	6	4	5	4	61
B-	31	11	4	1	0	0	29	62	67	19	25	16	265
C-	38	16	8	5	4	4	35	70	73	23	30	20	326
D-	36	30	23	20	20	23	31	47	35	23	30	20	338
E-	-2	-14	-15	-15	-16	-19	+4	+23	+38	+0	+0	+0	-12

A- Cordova flow, water low year(WLY) from watershed below pond site
B- WLY flow in Cordova from watershed above pond with snowmaking
C- total flow in WLY at Archuleta property with snowmaking
D- flow in WLY if snowmaking not under way
E- annual difference in flow pattern at Archuleta property with snowmaking under way

The closest well owners to the mouth of Cordova Creek are Arturo Gallegos (RG-36174) and Alfonso Gonzales (RG-23532). The two wells are 85 and 70 feet deep respectively. SEO measurements in April 1988 indicate 58 and 53 feet of saturated thickness in the two wells (Table 11).

To estimate a worst case scenario a hypothetical pumping well was located in Cordova Creek Canyon and used to divert 17 acre-feet/year. Textbook examples of hydraulic conductivity and specific yield from like sedimentary deposits in New Mexico (Trauger, 1972 p. 65) combined with known saturated thicknesses were used to derive an estimate of the hydrologic parameters (T= 58 ft^2/day and S= 0.07) of the area. The Theis solution (Figure 12) was used to estimate the impacts of pumping this well at 17 acre-feet/year over time. The results are given below.

Table 6.

RG-36174, Arthur E. Gallegos
(radius from pumping well = 600 ft)

Time	10 years	20 years	30 years	40 years
Saturated Thickness	55.0 ft	55.0 ft.	55.0 ft.	55.0 ft
Drawdown	8.3 ft	10.2 ft.	11.3 ft.	12.1 ft.
Remaining	46.7 ft.	44.8 ft.	43.7 ft.	42.9 ft.

Table 7.

RG-23532, Alfonso Gonzales
(radius from pumping well = 1200 ft)

Time	10 years	20 years	30 years	40 years
Saturated Thickness	53.0 ft.	53.0 st.	53.0 ft.	53.0 ft.
Drawdown	4.6 ft.	6.4 ft.	7.5 ft.	8.3 ft.
Remaining	48.4 ft.	46.6 ft.	45.5 ft.	44.7 ft.

These results are conservative as; 1) the estimate for transmissivity is very low, 2) the Rio Costilla and/or Cordova Creek are not considered as sources to the wells, 3) it has been assumed that the 17 acre-feet CU would have all come from ground water, and 4) the hypothetical well has been located only 600 and 1200 feet from the existing wells.

IMPACTS TO THE RIO GRANDE

The Rio Grande is used for irrigation along most of it's length. In fact, flows in the Rio Grande at the Colorado-New Mexico border are primarily returns from irrigation in the San Luis Valley of Colorado (Wilson, 1978). The river is also known to gain as it passes through Taos County. Wilson (1978, p. V-3) suggests that flows are doubled, by the addition of 250,000 to 300,000 acre-feet in a "typical year", by the time they leave the county.

The gains experienced by the Rio Grande in Taos County are from groundwater flux from the east. The accretion is derived from aquifers east of the river fed by mountain front recharge in the Sangre de Cristo Mountains. Cordova Creek contributes to recharge in the Costilla Valley which in turn contributes to groundwater flux to the Rio Grande.

While inflow from Cordova Creek and the associated alluvium do recharge sediments of the Rio Costilla Valley, 17 acre-feet/year of CU should not significantly impact the valley aquifer system. Wilson (1980) suggests that a typical value for recharge in Taos County is 1-2 inches per year. This translates into 320 to 640 acre-feet/year of recharge from Cordova Creek to the Rio Costilla Valley. Thus, 17 acre-feet/year CU from ski resort operations amounts to 2.6 to 5.3 percent of the total recharge estimate to the Costilla Valley and 0.0068 to 0.000057 percent of the average flux to the Rio Grande.

The amount of CU is so small compared to annual variations in climate and the overall flux to the Rio Grande that we will probably not see significant impacts on the Rio Grande. However, this study examines a worst case scenario. An analytical model, that assumes Theissian conditions, was used to estimate the impacts to the river from the subtraction of 17 acre-feet/year of recharge from the system. The Glover-Balmer equation estimates the impacts to a river system over time from nearby pumping wells. The 17 acre-feet/year of CU (potential recharge) was modeled as a pumping well and pumped for forty years to determine the impacts to the Rio Grande (Figure 13). Estimates for the hydrologic parameters input for the model were taken from Wilson (1978, p. VI-23). Results are tabulated below:

Table 8.

Glover-Balmer Estimates of Impacts to the Rio Grande

Time (years)	Rate of Depletion (ac-ft/yr)	Accumulated Depletion Volume (acre-feet)	Depletion Volume in Time Period (acre-feet)
10	10.8	59.9	59.9
20	14.8	191.1	131.2
30	16.2	347.3	156.2
40	16.7	512.4	165.1

According to the conditions of the water rights permit the ski resort is required to offset the CU of the diversions. Ski Rio owns 159 acre-feet/year of storage right in Costilla Reservoir. Thus, the resort should release storage waters to offset CU from the reservoir at the beginning of the irrigation season.

A part of the water released from the reservoir will recharge the Costilla Valley aquifer system. The rest may be consumed by irrigators or continue down river. This study has not attempted to quantify the recharge from the releases nor the returns to the system after the water has been used by irrigators.

CONCLUSIONS

1. The consumptive use of Cordova Creek water from snow-making operations is approximately 16 percent of the total water diverted to make snow.
2. In an average year approximately 600 acre-feet/year of surface water flows past the Ski Rio pond site. In a water low year approximately 290 acre-feet flow past the pond site.
3. The creek and aquifer system are interconnected. Diversions from either will diminish flow in the system.
4. The diversion of 54 acre-feet of surface water and 12 acre-feet/year of ground water from the Cordova Creek system during winter months in an average water year will reduce flow at the pond site by 10 to 15 acre-feet/month and increase spring and early summer flows by 2 to 26 acre-feet/month (Table 3). The section of Cordova Creek watershed below the pond site continues to contribute to flows throughout the year.
5. Flow in the creek at the pond site in a water low year will be reduced in December and January to 4 acre-feet/ month and in February and March to 0 acre-feet/month assuming Ski Rio diverts 82 acre-feet/season of surface flow and 12 acre-feet/year ground water (Table 4). The section of Cordova Creek watershed below the pond site will continue to contribute to flow throughout the year.

6. The runoff associated with snowmaking diversions will increase irrigation season flows. The available early irrigation season flow for Onesimo Archuleta will increase by 4 to 49 acre-feet/month in a water low year.
7. The closest wells in the valley, RG-36174 and RG-23532, near the mouth of Cordova Creek canyon will experience a maximum of 12.1 and 8.3 feet respectively of drawdown after 40 years of diversions.
8. Impacts on the Rio Grande from the diversions will be a maximum of 16.7 acre-feet/year after 40 years. This assumes no recharge or returns from Costilla Reservoir storage releases and Cordova Creek runoff. Spring runoff and reservoir release recharge have not been quantified but these returns combined with seasonal fluctuations should diminish the above estimate of annual impacts to the Rio Grande.

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APPENDICES

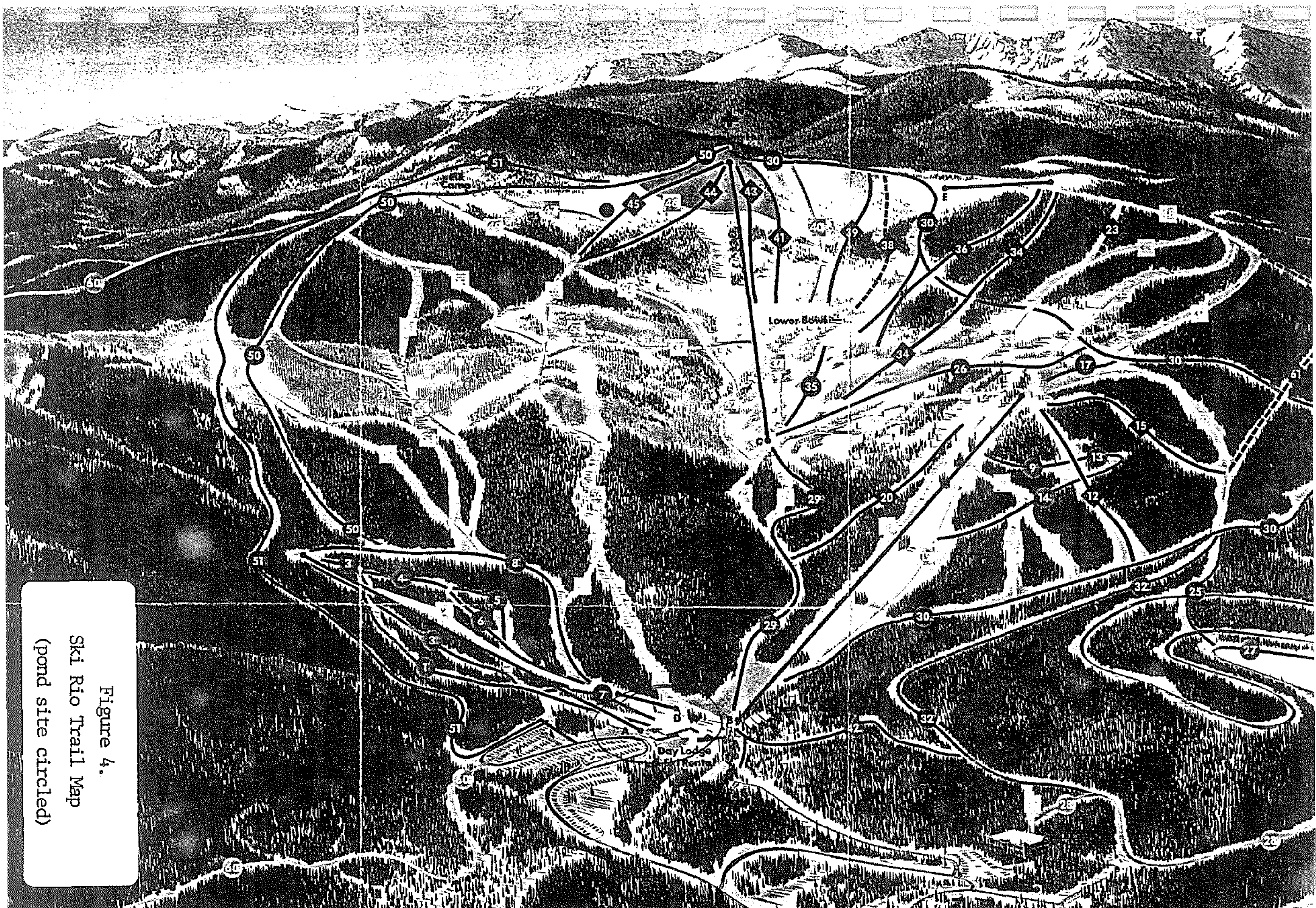


Figure 4.
Ski Rio Trail Map
(pond site circled)

a Triple Chair
Triple Chair
ie Double Chair
Pony Tow

6. Itty Bitty
7. Peak-a-Boo
8. Sneak Attack
9. Tiger Trail
13. Sam's Curve

More Difficult

2. Gotta Bluff
10. Silver Bullet
11. Ryan's Run
16. Smart Money
40. Body Heat
46. Suzie-Q
47. Naked Lady
48. Looped
49. Hard To Hold

Most Difficult

12. Foxy Lady
15. Tequila Plunge
20. Racer's Edge

Cross Country

27. Turn Around
60. Joyce's Temptation
28. Paradise Found

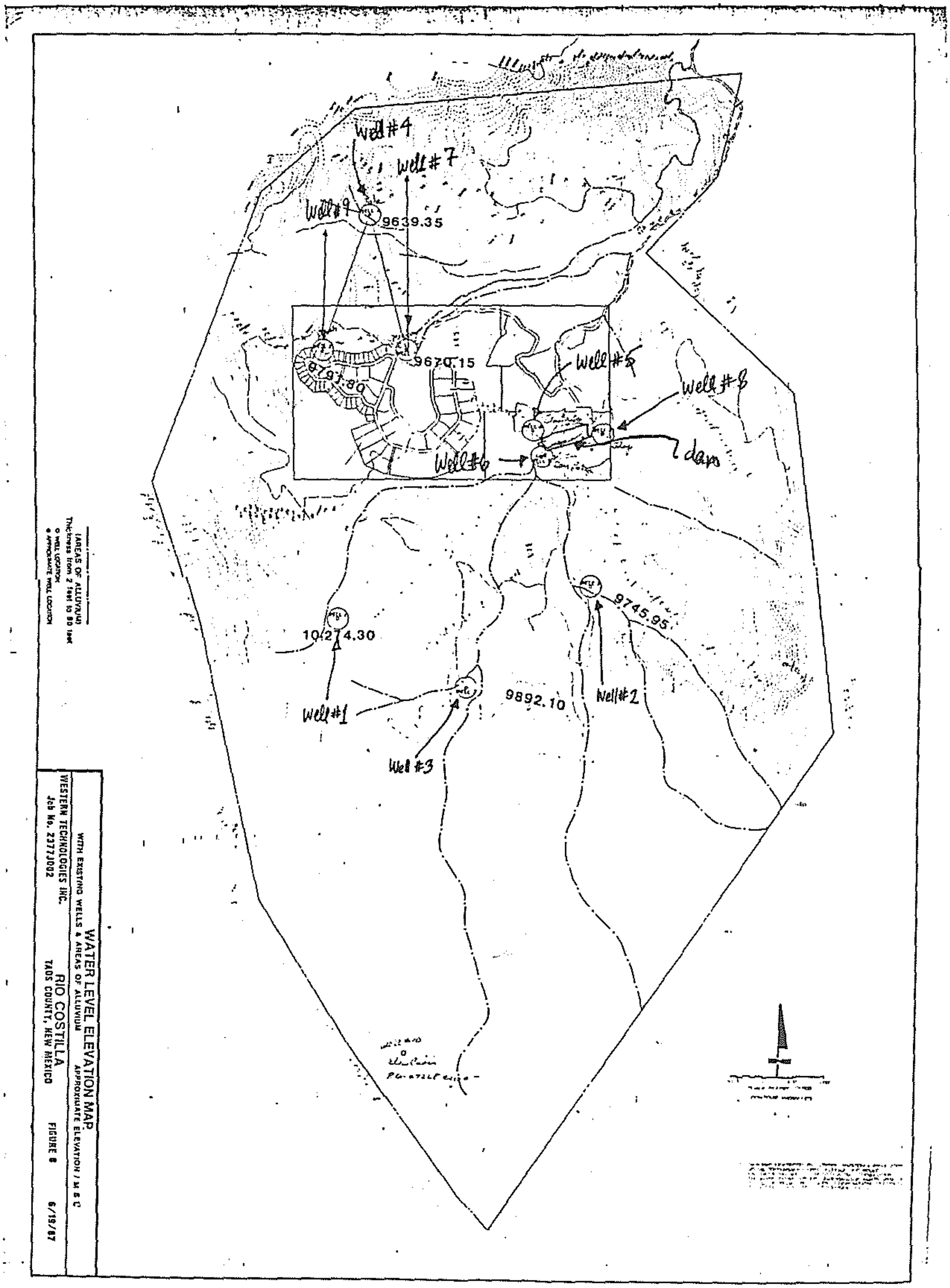


Figure 5.
Ski Area Well Location Map
(Western Tech, 1987)

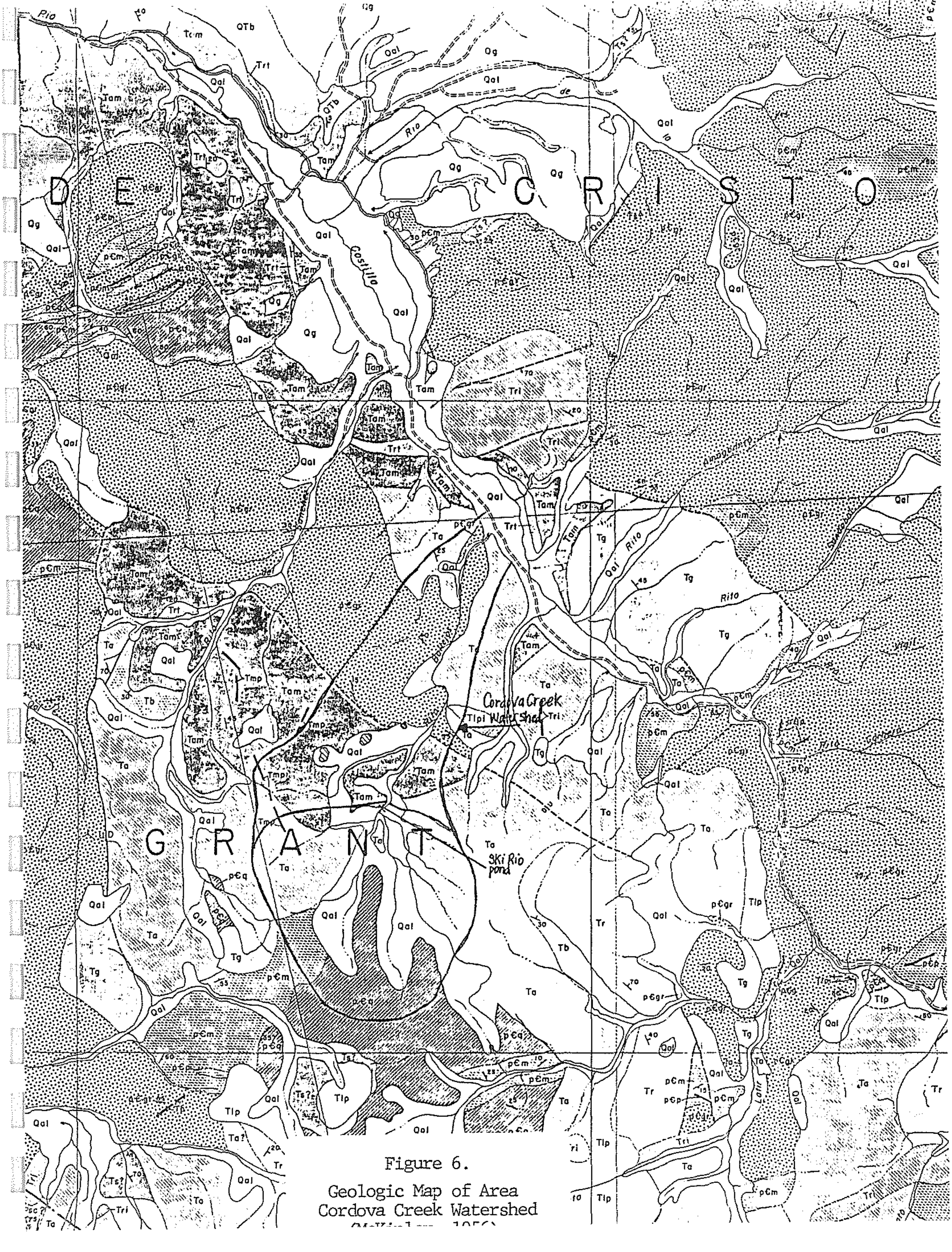


Figure 6.
Geologic Map of Area
Cordova Creek Watershed
(McKinlay, 1956)

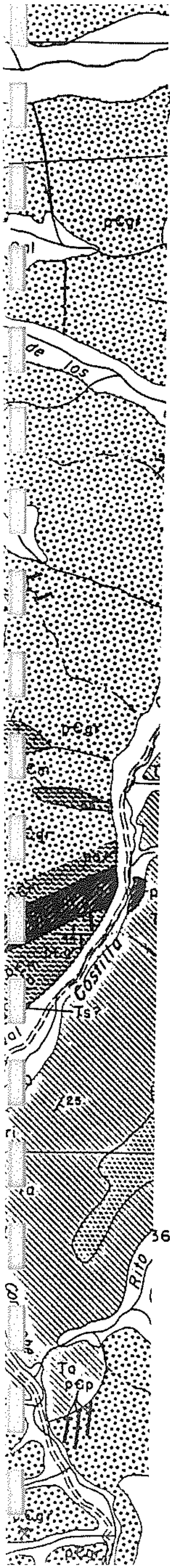


Figure 7.
Legend for Geologic Map
(McKinlay, 1956)

QUATERNARY

Qal

Valley alluvium
Stream gravel, talus and glacial debris.

Qg

Coarse fan gravels
Gravels and sands along the mountain front and 200 to 300 feet above the present stream channels.

Qa

Quaternary andesite
Dikes of gray porphyritic andesite.

QTb

Quaternary basalt
Gray to dark gray basalt flows.

ANGULAR UNCONFORMITY

TERTIARY

Tg

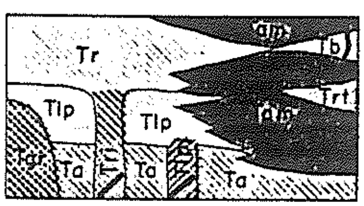
Tertiary gravels
Semiconsolidated conglomerate and coarse sandstone.

UNCONFORMITY

Altered rock
Areas of hydrothermal alteration where the rock units were undifferentiated.

Tmp

Monzonite porphyry
Dikes of gray to dark green monzonite porphyry.



Tertiary volcanic complex
and associated rocks
Tam, Amalia formation, *sandstone and conglomerate, basalt flows, and rhyolite tuffs.* Trt, *welded tuff layer.*
Tr, *gray to light-pink rhyolite tuffs and flows.*
Tri, *rhyolite dikes and flows.*
Tb, *olivine basalt flows.*
Tgr, *cream to light-pink porphyritic granite.*
Tlp and Tlpi, Latir Peak formation,
Tlp, *light-gray to reddish andesite*

TERTI

Tertiary volcanic complex
and associated rocks
Tam, Amalia formation, *sandstone and conglomerate, basalt flows, and rhyolite tuffs.* Trt, *welded tuff layer.*
Tr, *gray to light-pink rhyolite tuffs and flows.*
Tri, *rhyolite dikes and flows.*
Tb, *olivine basalt flows.*
Tgr, *cream to light-pink porphyritic granite.*
Tlp and Tlpi, Latir Peak formation,
Tlp, *light-gray to reddish andesite*
and latite porphyry flows or sills(?).
Tlpi, *gray andesite and latite porphyry dikes.*
Ta, *red, purple to green andesite flows, sills(?), breccias and tuffs.*

UNCONFORMITY

Ts?

Early Tertiary(?) sediments
Gray to red sandstones, shale, conglomerates, and thin limestones.

UNCONFORMITY

CARBONIFEROUS-PERMIAN(?)

CPsc

Sangre de Cristo formation
Red arkosic shale, sandstone, and conglomerate

ANGULAR UNCONFORMITY

PRECAMBRIAN

p€g

Metagabbro
Altered gabbro and diabase dikes and stocks.

p€p

Pegmatites
White to pink in color, usually composed of quartz, microcline, orthoclase, and some muscovite with small amounts of garnet and magnetite.

p€gr

Granite
Pink to cream microcline-rich granite and granite gneiss, includes pegmatite material and some migmatite

p€q
p€m

Metamorphic rocks
p€q, Cabresto(?) quartzite, *gray to cream massive quartzite, in places layers of mica gneiss and graphite mica gneiss*
p€m, *Undifferentiated amphibolite schist and gneiss, mica schist and gneiss, quartzite and migmatites.*

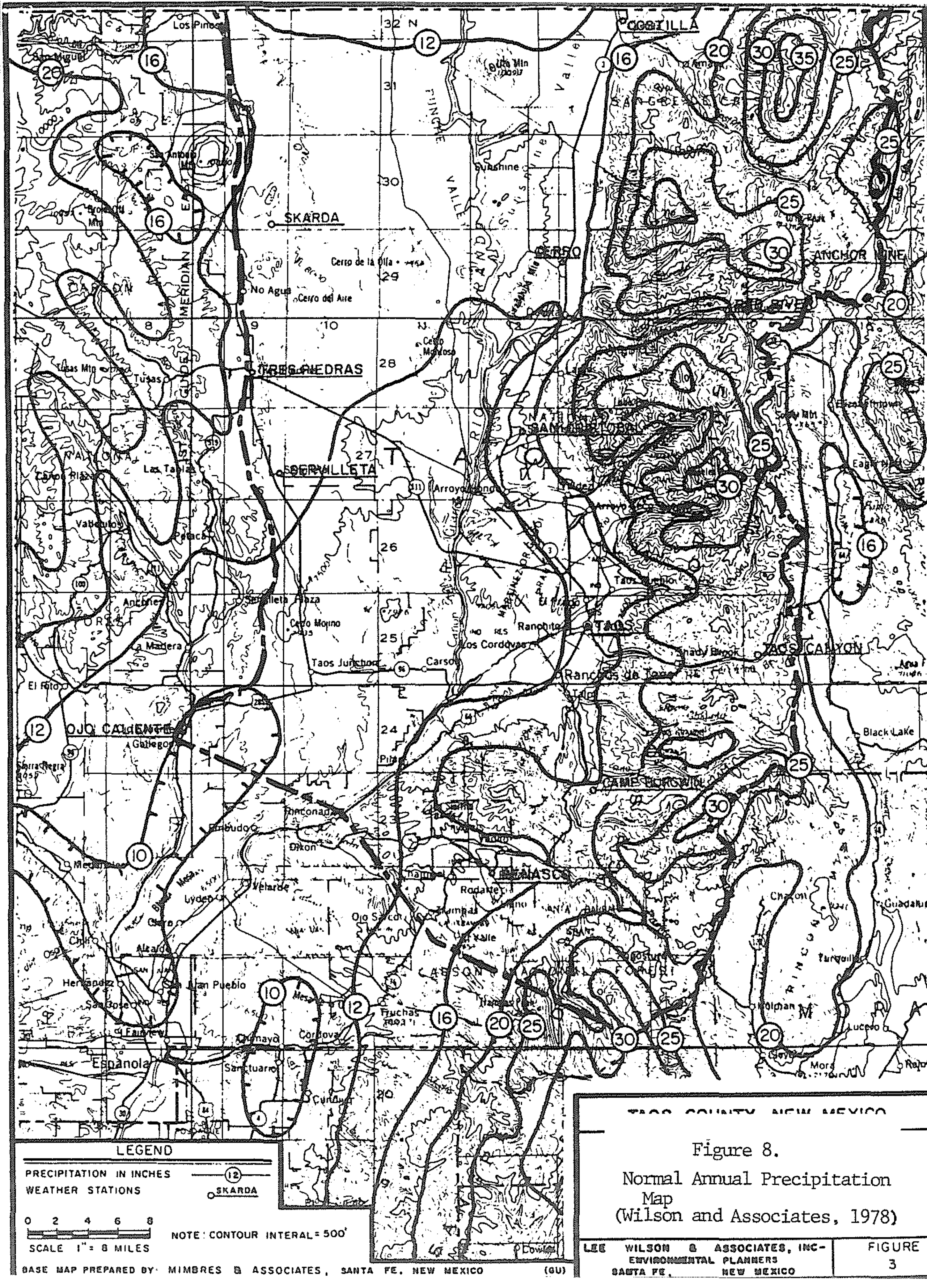


Figure 8.
Normal Annual Precipitation Map
(Wilson and Associates, 1978)

Snowmaking Keeps Ski Areas Off Rocks

By Paul Logan

JOURNAL STAFF WRITER

Although New Mexico's ski areas suffered a 15 percent drop in average snowfall last winter, the state still enjoyed its fourth best skier-day volume in the nine years of keeping such statistics.

"If our snowmaking systems had been up for an Academy Award this year, they'd have walked off with an Oscar for best performance," said Mike Pitel of the Economic Development & Tourism Department.

New Mexico had 1,017,025 skier days, about a 10 percent drop from last year's record total of 1,129,867, according to Pitel, a marketing analyst who compiled statistics from the state's 11 ski areas. A skier day represents a full-day lift ticket.

Pitel cited Cloudcroft, which only had 41 inches of snow for the season. Using its snowmaking equipment, Cloudcroft had 12,450 skier days, a 33 percent increase over last year's 9,370.

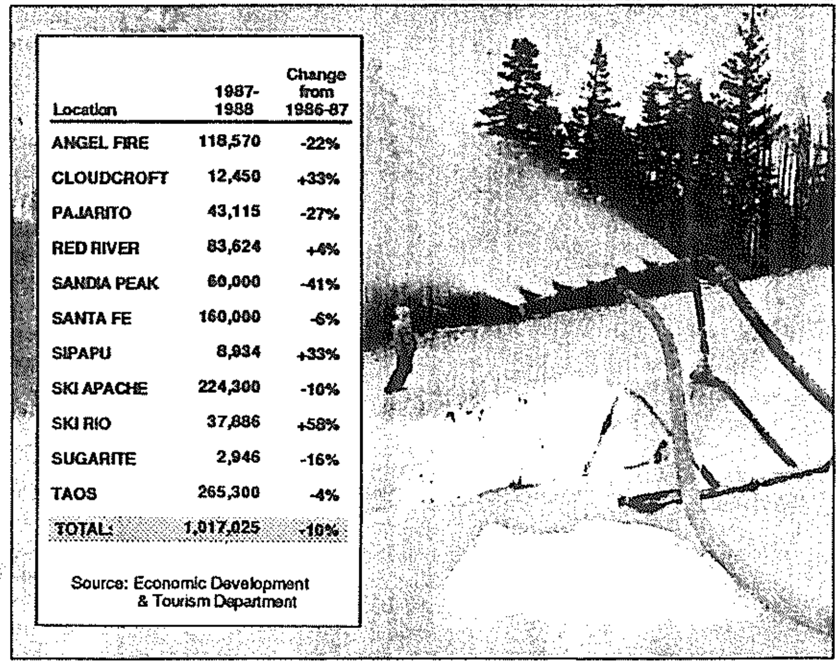
During the 1985-86 season, the snowpack was 30 percent below its average, according to Pitel. The state only had 708,466 skier days.

During the summer and fall of 1986, ski areas spent nearly $5 million to expand existing snowmaking systems, Pitel said.

"What happened this year just underscores the value of investing in snowmaking equipment," he said.

Many years ago, New Mexico was the first Rocky Mountain state to make this investment, Pitel said.

TOTAL NEW MEXICO SKIER DAYS



Location	1987-1988	Change from 1986-87
ANGEL FIRE	118,570	-22%
CLOUDCROFT	12,450	+33%
PAJARITO	43,115	-27%
RED RIVER	83,624	+4%
SANDIA PEAK	60,000	-41%
SANTA FE	160,000	-6%
SIPAPU	8,934	+33%
SKI APACHE	224,300	-10%
SKI RIO	37,886	+58%
SUGARITE	2,946	-16%
TAOS	265,300	-4%
TOTAL:	1,017,025	-10%

Source: Economic Development & Tourism Department

Every ski area but Los Alamos' Pajarito has snowmaking equipment.

Ski Rio set a record with 37,886 skier days, a 58 percent increase over last season — the biggest jump among the ski areas. Ski Rio only had 110 inches, 90 inches below its average. But the ski area helped its own cause by using various promotional discounts and introducing lodge facilities at the slope, according to Pitel.

Sipapu tied Cloudcroft for second place in percentage of increase over last year with 33 percent, going from 5,724 to 8,934 skier days.

Red River was the only other area on the plus side when compared to the 1986-87 season. Red River had a 4 percent increase, going from 80,107 to 83,624.

Red River had 52-inch drop in its snowpack average, but the area reported an increase in Kansas skiers, Pitel said.

Taos Ski Valley led the state in skier days with 265,300, a 4 percent drop from the 1986-87 state record season.

Although its number of California skiers dropped from the previous year, Taos reported that Texas skiers remained the same with the number of New Yorkers increasing 13 percent and Illinoisans 5 percent. There was also a noticeable increase in the overseas market.

Ski Apache was second in skier days with 224,300, Santa Fe third with 160,000 and Angel Fire fourth with 118,570. The latter only had half its annual snowfall with 85 inches.

Sandia Peak went from 101,000 skier days in 1986-87 to 60,000 for a 41 percent drop — the state's biggest, according to Pitel.

Since Sandia Peak closed early in March, Santa Fe and Taos probably benefited, he said.

Enchanted Forest, near Red River, reported 2,736 cross country skier days. Last year the state's only Nordic ski area had 2,001 skier days.

Pitel said New Mexico is attracting more skiers who are disenchanted with Colorado's higher lift ticket prices. According to the Colorado ski industry, the average ticket is $26. New Mexico's is about $22, he said.

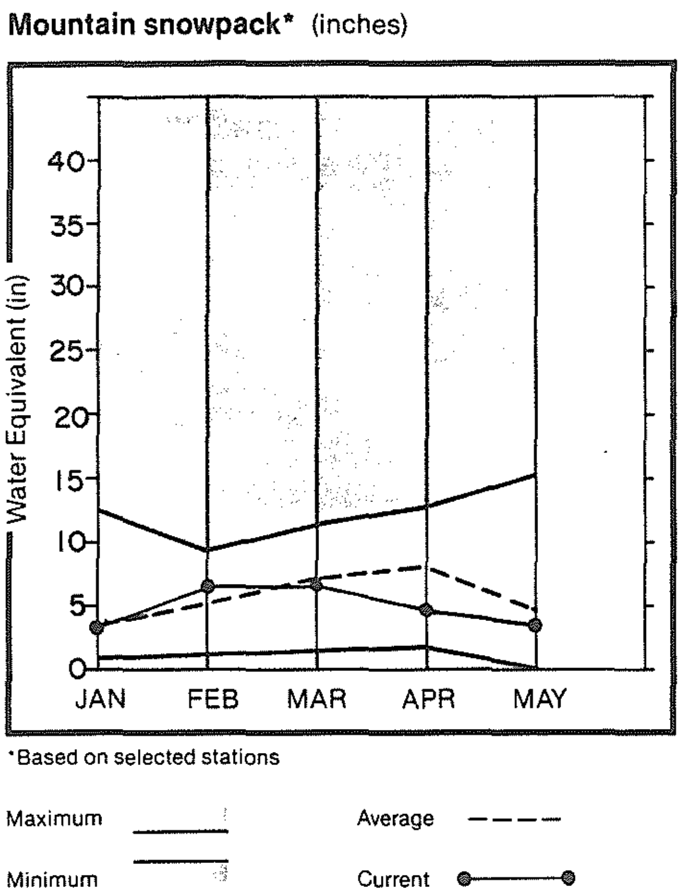
Albuquerque room rates are about 20 percent less expensive than Denver's, according to Pitel.

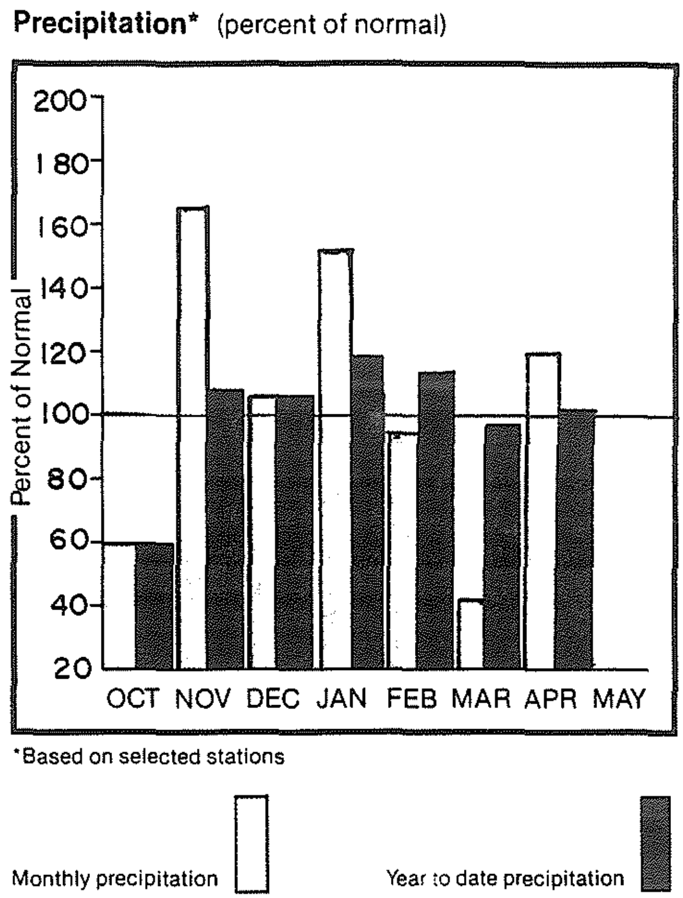
"New Mexico is being perceived by a growing number of skiers as a more affordable ski vacation," he said.

Figure 9.

Albuquerque Journal Snowmaking Article (May 15, 1988)

Rio Grande Basin





WATER SUPPLY OUTLOOK

Water supply forecasts in the basin continue to drop. All forecast points in the basin indicate that less than 76% of average volumes may be expected.

Figure 10.

N.M. Water Supply Snowpack and Precipitation Graphs for Winter 1987-88

For more information contact your local Soil Conservation Service office.

RG-37787 Field Investigation of Wells in the Vicinity of the Confluence of Cordova Creek and Costilla Creek, April 26, 1988

RSD RSD

Key Map Well Number	Owner's Name	State Engineer File #	Date Drilled	Name of Driller	Log In File Y/N	Total Depth Log/Rep't. (feet)	Log/Rep't Depth to Water (feet)	Measured Depth to Water (feet)	Size of Casing	Elevation at Well (feet)
1	David Arguello (Jose Arguello's son)	RG-33925	3-3-80	Arguello	Y	160	120	unable to measure	4" PVC	+/- ~~8440~~ 8515
2	Eddy & Joe Arguello	RG-37773	4-21-82	Arguello	Y	140	90	unable to measure	4" PVC	+/- ~~8390~~ 8340
3	Charlie Arguello	RG-39889	5-23-83	Arguello	N	60	unk.	unable to measure	6 5/8" PVC	+/- 8300
4	Jose Arguello, Sr.	RG-33924	3-4-80	Arguello	Y	25	7	16.65	4" PVC	+/- ~~8350~~ 8315
5	Joe E. Martinez	RG-48989	4-25-88	High Country (Arguello)	N	unk.	unk.	unable to measure	6 5/8" PVC	+/- 8350
6	Richard Bowman	unk.	unk.	unk.	N	unk.	unk.	6.14	6" PVC	+/- 8300
7	Joe E. Martinez	unk.	unk.	Tony & Sons	N	40	unk.	6.74	6" steel	+/- ~~8380~~ 8320
8	Arturo Gallegos	RG-38174	6-15-87	C.J.Tafoya	Y	85	85	26.98	6 5/8" steel	+/- ~~8330~~ 8370
9	Alfonso Gonzales	pre-basin	50's/60's	unk.	N	unk.	unk.	unable to measure	6 5/8" steel	+/- 8380
10	Alfonso Gonzales	RG-23532	6-4-74	Tony & Sons	Y	70	32	16.54	6 5/8" steet	+/- ~~8360~~ 83 8320
11	Alfonzo Gonzales,Sr.	pre-basin	unk.	Hand-Dug	N	unk.	unk.	unk.	unk.	+/- 8300
12	Mrs. Luise Lucero	unk.	1970's	Arguello(?)	N	unk.	unk.	unable to measure	6" PVC	+/- 8300
13	James Lucero	RG-48598	4-22-88	Arguello	N	+/-120	unk.	5.64	6 5/8" PVC	+/- 8310
14	Florinda Maestas	RG-48335	9 or 10/87	Arguello	N	50(est.)	unk.	unable to measure	5" PVC	+/- 8300
15	Clarence Lucero	RG-24977	6-25-74	Tony & Sons	Y	50	28	4.00	6 5/8" steel	+/- ~~8340~~ 8360
16	Lee Lucero (mobile home)	unk.	unk.	Arguello	N	unk.	unk.	8.84	6" PVC	+/- ~~8290~~ 8320
17	Lee Lucero (house)	unk.	unk.	Arguello	N	unk.	unk.	4.0	4" PVC	+/- ~~8290~~ 8275

RSD 5-9-88 corrections in elevation

Closest

Figure 11. Closes Water Right Owners (USGS Quad, Amalia, NM)

Figure 12.

Theissian Conditions

Theis Solution:

An analytical solution developed by Theis has the underlying assumptions:

1) The aquifer has a semmingly infinite areal extent

2) The aquifer is homogeneous, isotropic and of uniform thickness over the area.

3) The piezometric surface are (nearly) horizontal over the area

4) The aquifer is pumped at a constant discharge rate

5) The pumped well penetrates the entire aquifer on thus receives water from the entire thickness of the aquifer by horizontal flow.

6) The aquifer is confined

7) The flow to the well is in unsteady state

8) The water removed from storage is discharged instantaneously with the decline in head

9) The diameter of the pumped well is very small

10) The well is perfectly efficient

where $h_0 - h = \frac{Q}{4\pi T} W(u)$ and $u = \frac{r^2 S}{4Tt}$

$T = \frac{Q W(u)}{4\pi (h_0 - h)}$ and $S = \frac{4uTt}{r^2}$

Q = dischage

$W(u)$ = well function

T = transmissivity

t = time

r = radius

$h_0 - h = s$ = drawdown

Figure 13.

Glover-Balmer Paper

Volume 35, Number 3 June 1954

RIVER DEPLETION RESULTING FROM PUMPING A WELL NEAR A RIVER

Robert E. Glover and Glenn G. Balmer

Abstract--A well adjacent to a river will take a portion of its supply from the river. A theoretical formula is developed which permits the draft on the river to be computed in terms of the distance of the well from the river, the properties of the aquifer, and time. The formula applies where the river can be considered to flow in a straight course which extends for a considerable distance both upstream and downstream from the well location.

When pumping of a well near a river begins, water is drawn, at first, from the water table in the immediate neighborhood of the well. As the zone of influence widens, however, it begins to draw a part of its flow from the river and, ultimately, the river supplies the entire flow. It is the purpose of this analysis to develop a formula for estimating the amount of flow drawn from the river at any time after pumping begins.

Notation:

- D saturated thickness of the water-bearing stratum or aquifer, feet
- K permeability, ft/sec
- Q flow of the well ft^3/sec
- q_1 flow crossing a straight line at a distance x_1 feet from the well if no river is present, ft^3/sec
- q the flow taken from a river at a distance x_1 feet from the well, ft^3/sec
- r a radius measured from the center of the well, feet
- s draw-down at the radius r at the time t, feet
- t time, from beginning of pumping, seconds
- V volume of water yielded by a horizontal square foot of the aquifer if the pressure is dropped one foot, dimensionless
- x and y rectangular coordinates measured from the center of the well, feet
- x_1 the distance of a well from a river, measured along a normal to the direction of flow. The river is assumed to extend indefinitely upstream and downstream from the well, feet
- $\alpha = KD/V$
- λ a time variable running between zero and t, seconds

The differential draw-down ds at the time t due to removal of the quantity of water $Qd\lambda$ at the time λ is [CARSLAW, 1921]

$$ds = [Q/4\pi KD(t-\lambda)]\, e^{-r^2/4\alpha(t-\lambda)}\, d\lambda \quad \ldots\ldots (1)$$

This expression satisfies the continuity condition

$$\partial s/\partial t = \alpha[(\partial^2 s/\partial r^2) + (1/r)(\partial s/\partial r)] \quad \ldots\ldots (2)$$

and the condition that the draw-down is zero everywhere when $(t-\lambda) = 0$. Let

$$u = r/\sqrt{4\alpha(t-\lambda)} \quad \ldots\ldots (3)$$

Then, by substitution and integration

$$s = (Q/2\pi KD)\int_{r/\sqrt{4\alpha t}}^{\infty} (e^{-u^2}/u)\, du \quad \ldots\ldots (4)$$

The relation between the formula for well draw-down presented here with the one used by THEIS [1941] can be established by a simple change of variable. If, in the expression will supply an additional flow to the well. These factors can be accounted for if a recharge well is placed at the point where the pumped well is imaged by the riverbank. A similar form to (11) would apply to the recharge well also, with the result that the flow across the line $x = x_1$ is doubled. Then the total flow across the line if the river maintains the level is

$$q/Q = 1 - P(x_1/\sqrt{4\alpha t}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

These results may be summarized as follows: The draw-down in an aquifer of infinite extent due to a well discharging at the rate Q is given by (4). This formula is valid, as a first approximation, if the draw-down s is small compared to the depth D. A similar well located at the distance x_1 from a river will draw the flow q from the river. The part of the total flow of the well which comes from the river is q/Q. The value of this ratio is given by (12).

Suppose we have three wells at distances of 1000, 5000, and 10,000 ft from a river, respectively, which have been pumped for a period of five years. It is desired to estimate the part of their flow which comes from the river. If the aquifer data are: $D = 100$ ft, $K = 0.001$ ft/sec, $V = 0.2$, $\alpha = KD/V = 0.5$, $t = 157{,}770{,}000$ sec, and $\sqrt{4\alpha t} = 17{,}763$; then the values for the three wells are as shown in Table 1.

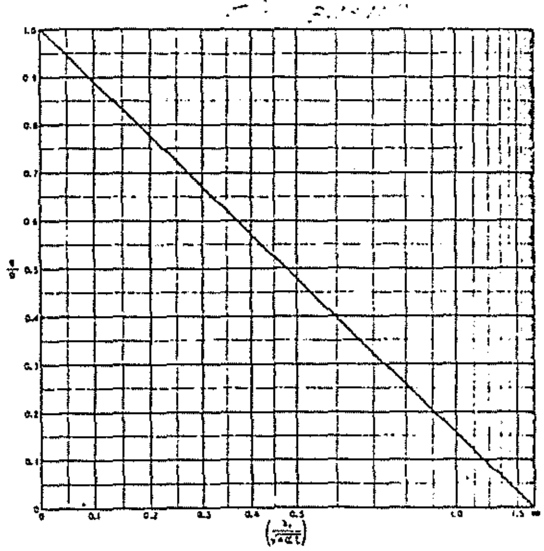


Fig. 1--The part of the well flow taken from the river as function of the parameter $x_1/\sqrt{4\alpha t}$

Table 1--Values for the three wells

Well	x_1	$x_1/\sqrt{4\alpha t}$	$P(x_1/\sqrt{4\alpha t})$[a]	q/Q[b]
1	1,000	0.0563	0.0635	0.9365
2	5,000	0.2815	0.3094	0.6906
3	10,000	0.5630	0.5741	0.4259

[a]From tables of the probability integral.
[b]From Eq. (12) or from Figure 1 directly.

Then at the end of five years the three wells are drawing, respectively, 93, 69, and 42 pct of their flow from the river.

While English units have been used here, the formulas given are valid when used in any consistent unit system. Such a system permits the use of only one unit of a kind. Since, in our case, only units of length and time are involved, change to another system of units can be accomplished by replacement of the foot and second units, used herein, with the new units.

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Denver Federal Center,
Denver 2, Colorado

(Communicated manuscript received May 15, 1953; open for formal discussion until November 1, 1954.)

$$s = (Q/4\pi KD) \int_{r^2/4\alpha t}^{\infty} (\epsilon^{-v}/v)\, dv$$

We make the substitution of variable

$$v = u^2$$

We obtain at once

$$s = (Q/2\pi KD) \int_{r/\sqrt{4\alpha t}}^{\infty} (\epsilon^{-u^2}/u)\, du$$

Eq. (4) is a form of the exponential integral [INGERSOLL and Others, 1948] which can be evaluated from tables [FEDERAL WORKS AGENCY, 1940; JAHNKE and EMDE, 1945] by use of the relation

$$\int_{r/\sqrt{4\alpha t}}^{\infty} (e^{-u^2}/u)\, du = -0.5\,\mathrm{Ei}\,(-r^2/4\alpha t) \qquad (5)$$

The draw-down produced in an aquifer of infinite extent due to a well pumped at the rate Q is given by (4). This expression is valid if s/D is small compared to unity.

We return now to (1) and set $r^2 = x^2 + y^2$. Then the flow of water across the line $x = x_1$ due to the withdrawal $Qd\lambda$ is obtained from the relation

$$\partial q_1/\partial\lambda = -KD \int_{-\infty}^{+\infty} (\partial^2 s/\partial x\,\partial\lambda)\, dy$$

$$= [2Qxe^{-x^2/4\alpha(t-\lambda)}/16\pi\alpha(t-\lambda)^2] \int_{-\infty}^{+\infty} e^{-y^2/4\alpha(t-\lambda)}\, dy \qquad (6)$$

The integral in this last expression is a form of the probability integral [FEDERAL WORKS AGENCY, 1941; JAHNKE and EMDE, 1945; PEIRCE, 1929]. This permits an evaluation of this expression in the form

$$\partial q_1/\partial\lambda = 2Q\alpha x e^{-x^2/4\alpha(t-\lambda)}/\sqrt{\pi}\,[4\alpha(t-\lambda)]^{3/2} \qquad (7)$$

To integrate this expression with respect to λ from $\lambda = 0$ to $\lambda = t$ set

$$v = x/\sqrt{4\alpha(t-\lambda)} \qquad (8)$$

Then, by substitution

$$q_1 = (Q/\sqrt{\pi}) \int_{x/\sqrt{4\alpha t}}^{\infty} e^{-v^2}\, dv \qquad (9)$$

This can be expressed in terms of the probability integral

$$P(Z) = (2/\sqrt{\pi}) \int_0^{Z} e^{-v^2}\, dv \qquad (10)$$

which has been extensively tabulated in terms of the upper limit Z. Then (9) can be put in the form

$$q_1/Q = 0.5\,[1 - P(x_1/\sqrt{4\alpha t})] \qquad (11)$$

This formula implies that there will be a drop in the ground water level along the line $x = x_1$. If a river exists at this distance from the well there will be no drop in level but, instead, the river