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Timber Creek, near McGill, Nevada.

WATER RESOURCES – RECONNAISSANCE SERIES

REPORT 42

WATER-RESOURCES APPRAISAL OF STEPTOE VALLEY, WHITE PINE AND ELKO COUNTIES, NEVADA

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Estimated Runoff from the Mountains

A reconnaissance technique for estimating runoff from mountain areas recently has been developed for areas where few streamflow data are available. The general method has been described by Riggs and Moore (1965, p. D199-D202). By means of short-period or miscellaneous measurements, adjustments of regional values can be made to compensate for local variations in precipitation, geology and soils, topography, and vegetation.

The estimated average annual runoff from the mountains is 78,000 acre-feet (table 5). Nearly half the runoff comes from the drainage areas of Duck and Steptoe Creeks. About 20 percent of the runoff is derived from the Cherry Creek Range and most of this is developed in the areas drained by McDermitt and Goshute Creeks.

The above estimate is for runoff from the mountain areas generally above 7,000 feet. Runoff also occurs from precipitation on the alluvial apron and valley lowland, although generally this runoff is erratic and less susceptible to management for use. An impressive example of lowland runoff occurred in early March 1966. Accumulated snow on the valley lowland melted during a several-day period of mild temperatures. The rapid melting resulted in a large volume of water thinly spread over much of the lowland. Part of this melt-water collected into channels as lowland runoff. Runoff so generated contributed significantly to the flow of Steptoe and Duck Creeks in their lowland segments.

Table 5. -- Estimated average annual runoff

(Based on record at Cleve Creek near Ely extended to 1915-23, 1945-65)

Mountain segment	Location	Area		Estimated runoff	
		Acres	(percent of runoff area)	(Acre-feet per year)	(percent of total runoff)
Schell Creek Range (including Luck Creek Range)	West flank of mountain above 7,000 feet	286,000	53	a 52,000	67
Egan Range	East flank of mountains above 7,000 feet	162,000	30	11,000	14
Cherry Creek Range	East flank of mountains above 7,000 feet	95,000	17	15,000	19
Total		543,000	100	78,000	100

a. Of this total about 37,000 acre-feet is derived from the drainage area between and including Steptoe Creek and East Creek, a tributary of Duck Creek.

For the most part, however, usable streamflow is derived by runoff from the mountains. Limited data for Duck and Steptoe Creeks indicate that most of the runoff from these mountains is supplied from snowmelt during the spring months. This is better illustrated by the record of Cleve Creek, the nearest stream for which published records are available. Cleve Creek drains a part of the east flank of the Schell Creek Range. Its drainage divide in part is coincident with those of Duck and Steptoe Creeks.

The monthly distribution of streamflow of Cleve Creek is given in table 6. The graphs of monthly discharge in percent of mean annual discharge are shown in figure 5. The data show that about 45 percent of the mean annual runoff occurs in the three spring months, April through June. Of course, in a given year, runoff may be distributed quite differently than for the average conditions. Thus, mild winter temperatures may result in distributing much of the snowmelt through several months preceding April. On the other hand, if much of the annual precipitation occurs as summer thundershowers, a significant part of the annual runoff may occur during the summer months.

The disposal of the indicated runoff was not measured directly for the purposes of showing the general proportions of the hydrologic system in the budget discussed later in the report. However, some of the runoff, (a) is lost by evapotranspiration as it flows on the valley fill and as diversion to irrigate cultivated crops, wet meadow, or pasture, either directly or after a period of retention as soil moisture, (b) recharges the ground-water reservoir and, (c) reaches the valley lowland where it is lost by evapotranspiration either directly or after a period of retention as soil moisture or ground water or, to a minor amount, becomes outflow through the gap at the north end of the valley. A general evaluation of the flow system in Steptoe Valley suggests that the approximate average magnitude may be about 26,000, 24,000, and 28,000 acre-feet per year for item (a), (b), and (c), respectively. The proportionally large value of 28,000 acre-feet for runoff to the valley lowland results from a significant part of the flow of Duck Creek being routed to the valley lowland and a large part of the flow of Steptoe Creek being used for irrigation on the valley lowland.

Table 6. -- Summary of streamflow of Cleve Creek near Ely

(Discharge in cubic feet per second; periods of record, 1915-16 and 1960-65)

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Year
Average	5.93	6.15	5.64	5.41	6.09	7.14	11.6	16.9	16.3	8.04	6.45	5.90	8.46
Maximum month	8.76	8.97	7.25	8.09	8.05	14.8	24.4	24.2	27.2	10.1	8.79	8.23	a 10.7
Minimum month	4.56	4.53	4.27	4.05	4.42	4.65	6.34	8.58	6.25	4.96	3.99	3.75	b 5.15

a. Average for maximum recorded water year.

b. Average for minimum recorded water year.

Ground-Water

The principal ground-water reservoir is in the valley-fill deposits of Steptoe Valley. Water occupies the open spaces between the individual particles of the unconsolidated to partly consolidated silt, sand, and gravel. The top of the zone of saturation or water table is within a few feet of land surface throughout most of the valley lowland northward from McGill. It also is shallow in the lowland near Ely and Comins Lake, but is deeper along the valley axis southward from the Comins Lake area. The depth to water generally increases toward the mountains beneath the alluvial apron. The water-level contours (see pl. 1) show the general form of the water table. The water-level gradient slopes toward the valley axis from the mountains and northward along the axis of the valley and conforms in a subdued way to the general slope of the land surface.

Ground water also occurs in fractures or solution openings in the consolidated rocks, especially the Paleozoic carbonate rocks. Ground water has been encountered extensively in drilling and underground mining operations in the Ruth-Kimberly area. Many of the springs in the mountains attest to the fact that ground water occurs and is transmitted in the consolidated rocks. The large yields of Murry and McGill Springs indicate that the consolidated rocks locally transmit substantial quantities of water. However, water occurs in and is transmitted through only a small fraction of the total volume of consolidated rocks.

Ground water in the consolidated rocks and in the valley fill is supplied by recharge from precipitation. The higher average precipitation in the mountains and its accumulation as snow during the winter months is favorable for recharge to the ground-water reservoir in the valley fill. Water moves from the high areas in the mountains toward the valley lowland where most of the ground water is discharged by evapotranspiration. The natural recharge to a ground-water system tends to equal natural discharge during extended periods of climatic equilibrium. Within such periods, however, intervals occur when recharge is greater than or less than discharge, and these will be reflected in corresponding increases or decreases in ground-water storage.

The extensive spring area along the west side of the lowland in Campbell Embayment has given rise to speculation that some or most of the water of the springs is supplied from Butte Valley to the west. Data and estimates obtained in this investigation suggest there is sufficient recharge within the drainage area of Steptoe Valley to supply the estimated discharge; indeed, the recharge estimate is higher than the natural discharge estimate. The altitude of the water level in the valley-fill reservoir of Butte Valley is roughly 6,125 feet at the topographically low part of the valley floor in T. 21 N., R. 61 E. This altitude is only slightly higher than the approximate 6,100-foot altitude of the western line of springs in Campbell Embayment in Steptoe Valley. The distance between the two areas is at least 12 miles. The indicated potential gradient between these two areas toward

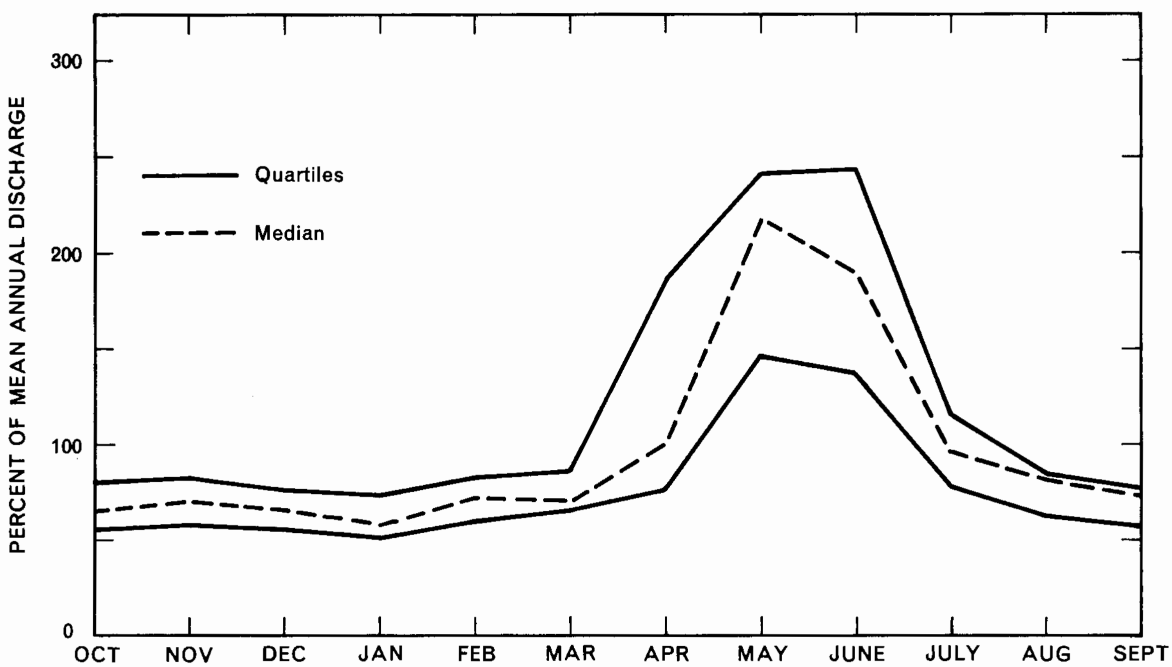

Figure 5.—Monthly discharge in percent of mean annual discharge of Cleve Creek

Steptoe Valley, is very low. Further, the Egan Range, which is between the two areas, receives moderate precipitation. The proportionally small runoff from the range suggests that ground-water recharge may be proportionally high. Thus, Egan Range is inferred to represent an hydraulic high, and be an effective barrier to ground-water flow between the valley-fill ground-water reservoirs in Butte and Steptoe Valleys.

Estimated Average Annual Recharge

An empirical method has been used (Eakin and others, 1951) to estimate ground-water recharge. Precipitation is assumed generally to increase with altitude, and the proportion of precipitation reaching the ground-water reservoir is assumed generally to increase with increased precipitation. The lowest zone in which effective precipitation occurs is considered to be the middle to upper segments of the alluvial apron. The precipitation map of Nevada (Hardman and Mason, 1949, p. 10) modified by Hardman in 1964 is used for delineation of the precipitation zones. Areas of the precipitation zones are determined approximately at altitude increments of 1,000 feet. The area of these zones times the average precipitation times the assumed percentage of recharge equals the estimated recharge from precipitation in that zone. The sum for the several zones then gives the average annual recharge for the valley. Table 7 gives the pertinent values. The estimated average annual recharge to Steptoe Valley of 85,000 feet is 7 percent of the total precipitation, this is somewhat higher than the percentages for most valleys in this part of the State, which commonly average about 5 percent. This in turn suggests that the estimate of recharge may be high.

Table 7. -- Estimated average annual precipitation and ground-water recharge

Precipitation range (inches)	Approximate equivalent altitude zone (feet)	Effective area represented by this zone (acres)	Average annual precipitation (feet)	Average annual precipitation (acre feet)	Estimated recharge: Percentage of precipitation	Estimated recharge (acre-feet per year)
> 20+	above 9,000	57,000	1.75	100,000	25	25,000
15 to 20	8,000 to 9,000	156,000	1.46	230,000	15	34,000
12 to 15	7,000 to 8,000	a 266,000	1.12	300,000	7	21,000
8 to 12	6,000 to 7,000	b 213,000	0.83	180,000	3	5,400
< 8	below 6,000	573,000	0.6	340,000	--	--
Total (rounded)	--	1,265,000 (1,975 sq. mi.)	--	1,200,000	--	85,000

a. About 29,000 acres of the zone was shifted to the 6,000-to 7,000-foot zone for computing recharge on the basis that the next lower zone was more typical of recharge conditions; additionally, about 184,000 acres of this zone were considered to have essentially no effective recharge and thus were shifted to the lowest zone for computing valley area.

b. About 340,000 acres of this zone are on the lower part of the alluvial apron and were considered out of the topographic position of assumed effective recharge; the area was shifted to the less-than-6,000-foot zone for purposes of computing valley area.

Estimated Average Annual Discharge

Ground water is discharged naturally from the valley-fill reservoir almost entirely by evapotranspiration in the lowland of Steptoe Valley. Only a small amount may be discharged by underflow or surface flow through the gap north of Currie. The estimated discharge, summarized in table 8, is about 70,000 acre-feet a year. Spring discharge in the valley lowland is estimated to be about 22,000 acre-feet, which in turn is lost by evapotranspiration largely from the wet-meadow and saltgrass area listed in table 8. Some ground water is discharged from springs in the mountains in addition to that discharged from the valley lowland. For the most part, spring discharge in the mountains becomes a part of the streamflow or is removed by evapotranspiration in the mountain canyons. Ground water discharged in the mountains is not included in the estimates in table 8.

In addition to ground water discharged by evaporation and transpiration from the valley lowland, surface water supplied by overland runoff from the mountains, by snowmelt on the valley lowlands, and by occasional high-intensity showers also is evaporated or transpired from the valley lowland.

Storage

The volume of ground water stored in the valley fill of Steptoe Valley is many times the volume annually recharged to and discharged from the ground-water reservoir. Although the total volume of ground water in storage is not known, the following calculation illustrates that the quantity is very large. On the assumption that the average drainable pore space (specific yield) of the upper part of the saturated valley fill is 15 percent, the volume of ground water in storage in the saturated upper 100 feet beneath a one-township area (about 23,000 acres) is about 35,000 acre-feet. Beneath the 143,000-acre evapotranspiration area, indicated in table 8 and shown on plate 1, the volume of ground water stored in the upper 100 feet of saturated valley fill would be about 2.1 million acre-feet. As the depth to water below land surface generally is less than 20 feet, the indicated 2.1 million acre-feet of stored water is within 120 feet of land surface in most of the evapotranspiration area.

Perennial Yield

The perennial yield of a ground-water system may be taken as the amount of water that can be withdrawn from the system for an indefinite period without causing continuing depletion of storage or a deterioration of the water quality beyond the limits of economic recovery. Economic feasibility involves factors other than those of the hydrologic system. However, based on the hydrologic system, the perennial yield may be taken to be a quantity of water equivalent to the average annual natural recharge to or

Table 8. -- Estimated average annual ground-water discharge by evapotranspiration in the valley lowland

Phreatophyte	Area (acres)	Assumed average rate of evapotranspiration (feet)	Estimated evapotranspiration (acre-feet)
Wet-meadow and saltgrass areas, including lowland spring areas. Water table generally at or near land surface	18, 000	1. 5	27, 000
Saltgrass, rabbitbrush, some greasewood, and playa areas, including Goshute Lake playa. Water table generally less than 10 feet below land surface	50, 000	. 5	25, 000
Greasewood-rabbitbrush areas with some saltgrass; commonly marginal to the first two areas above. Water table generally less than 20 feet below land surface	53, 000	. 3	16, 000
Scattered saltgrass, rabbitbrush, and greasewood area. Water table generally less than 12 feet below land surface	22, 000	. 1	2, 200
Total (rounded)	143, 000		70, 000

discharge from that system, based on a one-time use of the stored water. In effect this can be accomplished most efficiently by developing ground water in or adjacent to areas of natural discharge.

In Steptoe Valley, the average annual recharge and natural discharge were estimated to be 85,000 and 70,000 acre-feet per year, respectively (tables 7 and 8). Because as previously mentioned, the estimated recharge may be somewhat high and because the estimated natural discharge is considered to be better controlled, the perennial yield provisionally may be taken to be about 70,000 acre-feet.

Effects of Pumping in the Valley-Fill Reservoir

Withdrawals from wells in areas of natural discharge permit direct salvage of that discharge and impose a minimum effect on the ground-water system. The greater the distance the wells are from natural discharge areas the greater the percentage of pumped water that comes from storage and the less the salvage of natural discharge. To date, sufficient data are not available to demonstrate fully the effects of pumping from wells in Steptoe Valley. However, aquifer response to pumping varies with the quantity pumped, the duration of pumping, the distribution of wells, and the storage and transmissive characteristics of the aquifer. The effects of varying some of these factors can be illustrated by assuming certain conditions that might reasonably be expected to occur in this area.

Assume that pumping rates are 1,000 gallons a minute; the upper part of the saturated valley fill generally has coefficients of storage between 0.1 and 0.2 and transmissibility values between 10,000 and 100,000 gallons per day per foot. By further assuming that the valley-fill ground-water reservoir grossly functions as an approximate equivalent of a thick, unbounded, and relatively uniform aquifer, the Theis non-equilibrium formula (Theis, 1935, and Theis _in_ Bentall and others, 1965) can be used for illustrative computation. Table 9 illustrates the effects on drawdown and radius of influence resulting from successively varying several of the factors.

Table 9. -- Effects of pumping from an unbounded aquifer

a. Effect of varying coefficient of storage (S). 1/
(Assume T = 50,000; Q = 1,000; t = 10,000 (27.4 years))

Coefficient of storage	Drawdown(s), in feet, at distance (r) from well			Approximate distance from well where drawdown = 0 ft.	
	r = 1 ft	r = 10 ft	r = 100 ft	feet	miles
0.1	48.3	37.9	27.4	70,000	13.25
0.15	47.4	37.0	26.5	58,000	11
0.2	46.7	36.3	25.8	53,000	10

b. Effect of varying coefficient of transmissibility (T).
(Assume S = 0.15; Q = 1,000; t = 10,000)

Coefficient of transmissibility	Drawdown(s), in feet, at 100 feet from well	Approximate distance from well where drawdown = 0 ft.	
		feet	miles
10,000	113.5	29,000	5.5
50,000	26.5	58,000	11
100,000	14.0	80,000	15

c. Effect of varying rate of pumping (Q).
(Assume T = 50,000; S = 0.15; t = 2,000 (5.48 years))

Rate of pumping Q, in gpm	Drawdown(s), in feet, at distance (r) from well			Approximate distance from well where drawdown = 0 ft.	
	r = 1 ft	r = 10 ft	r = 100 ft	feet	miles
1,000	43.6	33.2	22.6	29,000	5.5
2,000	87.2	66.4	45.2	29,000	5.5
4,000	174	133	90.4	29,000	5.5
8,000	348	266	181	29,000	5.5
16,000	696	532	362	29,000	5.5

(table continued)

Table 9. -- Continued

d. Effect of varying duration of continuous pumping (t).
(Assume T = 50,000; S = 0.15; Q = 1,000)

Duration of pumping		Drawdown(s), in feet, at distance (r) from well			Approximate distance from well where drawdown = 0 ft.	
days	years	r = 1 ft	r = 10 ft	r = 100 ft	feet	miles
100	.27	37.0	26.5	15.8	5,500	1
500	1.37	40.2	29.6	19.5	13,000	2.5
1,000	2.74	42.2	31.6	21.2	21,000	4
2,000	5.48	43.6	33.2	22.6	29,000	5.5
5,000	13.7	45.8	35.4	24.7	39,000	7.4
10,000	27.4	47.4	37.0	26.5	58,000	11
18,000	49.3	48.0	37.8	26.4	70,000	13.2

e. Effect of cyclic pumping, 100 days per year.
(Assume T = 50,000; S = 0.15; Q = 1,000)

Pumping for 100 days a year, beginning with the day pumping began		Drawdown(s), in feet, where radius = 100 feet
At end of	100 days	a 15.8
Do.	360 days (1 year)	.7
Do.	720 days (2 years)	.9
Do.	1,080 days (3 years)	1.0
Do.	1,440 days (4 years)	b 1.1
Do.	1,800 days (5 years)	1.1

a. Refer also to item 1 in table 9d above.
b. After 4 years, maximum effect of cyclic pumping in antecedent years is reached at this radius.

1. Notations for table 9.

T = The coefficient of transmissibility, in gallons per day per foot (gpd per ft) of the aquifer;
S = The coefficient of storage of the aquifer, a dimensionless ratio;
Q = The rate of discharge in gallons per minute (gpm), of the pumped well;
s = The water-level drawdown, in feet, in the pumped well, in an observation well, or at any point in the vicinity of the pumped well;
r = The distance, in feet, from the pumped well to an observation well or to a point for which the drawdown is to be determined;
t = The time, in days, since pumping began.

Table 9a indicates that, other things being equal, the lower the value of the coefficient of storage, the greater the drawdown and the greater the radius of influence that is required to yield the same amount of water from storage. Initial responses to pumping from valley-fill deposits, such as occur in Steptoe Valley, commonly indicate that the ground water is under artesian conditions. That is, apparent values of the coefficient of storage are significantly smaller than those used in the examples. For the same pumping rates, the early periods of pumping probably would develop larger drawdowns than are indicated by the examples herein. However, over long pumping periods the apparent coefficient of storage gradually would increase to values characteristic of unconfined conditions, such as those used as examples in this report.

Table 9b shows that low values of transmissibility result in large drawdowns with a small radius of influence, whereas for large values of transmissibility drawdowns are small but the radius of influence is very large. Increasing the pumping rate results in larger drawdowns within the same areas of influence as those shown in table 9c. Increasing the duration of pumping increases both the drawdown and the radius of influence, as shown in table 9d, where water is derived entirely from storage and other factors remain constant.

The effect of noncontinuous pumping is illustrated in table 9e where a cyclic pumping pattern of 100 days a year is used. Thus, after 100 days of pumping the drawdown at 100 feet from the well is shown as 15.8 feet; at the end of one year, or 260 days after pumping ceased the residual drawdown is shown as 0.7 foot. The residual drawdown due to pumping in antecedent years increases to a maximum of about 1.1 feet at a radius of 100 feet at the end of four years. For example, at the end of the sixth pumping cycle (1900 days) the drawdown at 100-foot radius would be 15.8 feet (as at the end of the first pumping cycle) plus the residual drawdown from antecedent pumping (1.1 feet) or a total drawdown of about 17 feet. This may be compared with the 22.6-foot drawdown at a radius of 100 feet for the 2,000-day continuous pumping period shown in table 9. Thus, a cyclic or intermittent pumping schedule results in less drawdown at the 100-foot radius than would occur had the pumping been continuous.

From the information in table 9, it is evident that the area of influence of individual wells would overlap somewhat between wells in irrigated areas, where well-spacing of ¼- to ½-mile is common. This can result in a pattern of drawdown and area of influence that is difficult to identify accurately in detail. However, a general pattern can be described that illustrates the magnitude of effect of pumping several wells at the same time. Assume that there are 16 wells spaced on ½-mile centers forming a square of four rows of four wells each, as would occur with wells in the center of one-quarter sections in a 4-square-mile area. Assume further, that each well is pumped at the rate of 1,000 gallons a minute continuously for 10,000 days (27.4 years). The combined pumping rate for the 16 wells is equivalent to a withdrawal of about 25,000 acre-feet per year. The assumed aquifer characteristics are T = 50,000 and S = 0.15, the same as generally assumed for computations in table 9. Under these conditions at the end of 10,000 days of pumping, the distance to zero drawdown would be about 12 miles from the center of pumping. Closer to the well field, drawdown would be about 5, 10, 40, 50, 75, and 100 feet at distances from the center of pumping of about 9, 7.75, 3.85, 3.3, 2.3, and 1.5 miles, respectively. Drawdowns of about 160 feet would occur adjacent to the wells at the corners of the well field, and drawdowns on the order of 190 feet would occur adjacent to the four inside wells of the well field.

These effects, as noted above, are for continuous pumping. If the same annual quantity (about 25,000 acre-feet)were pumped under a 100-day per year cyclic pattern, about 58 wells pumping at the rate of 1,000 gpm would be required. Using the same spacing as in the previous example ½-mile centers, the well field would occupy a 14-square mile area. Analysis of this cyclic pattern is more difficult than in the previous example. Generally, though, a larger proportion of water would be withdrawn from the larger area of the well field, and the radius of influence would be somewhat less than half the 12 miles computed for the continuous pumping patterns, both patterns being for 10,000-day, elapsed-time periods.

Further, if the well field and area of significant pumping influence are in an area of natural discharge by evapotranspiration, the drawdowns would be reduced in proportion to the amount of salvage of the natural discharge. After the amount of salvage is equal to the net amount of water pumped, the drawdowns and area of influence will be only of the magnitude necessary to divert the amount of water salvaged through the wells. Thus, in this use the water withdrawn by the wells is supplied by recharge to the area of pumping influence rather than from storage within the area of influence as in the circumstances previously assumed.

It should be recognized that the chemical quality of water obtained in areas of natural discharge may not be as good as in other parts of the ground-water system; it may in fact be unsuitable for the intended use. However, development in or closely adjacent to the areas of natural discharge would result in a minimum effect on the ground-water system.

Drawing upon the illustrative computations of the effects of pumping discussed above, we may consider briefly the effects of particular pumping patterns in Steptoe Valley. For this purpose, four areas are used to represent various segments of Steptoe Valley: (a) Adjacent to and east of Goshute Lake at the north end of the valley; (b) the area in and adjacent to the lowlands southeast of Cherry Creek; (c) the Duck Creek fan and adjacent lowlands to the west and northwest; and (d) the lowland between Ely and McGill. The general assumptions used in computations for table 9 also serve as the reference for the discussion of pumping effects for these areas; that is, T = 50,000, S = 0.15, Q = 1,000 gpm per well, t = 10,000 days. Further, a well field comprises either 16 wells on ½-mile centers in a 4-square-mile area for continuous pumping, or about 58 wells on ½-mile centers in a 14-square-mile area for cyclic pumping of 100 days a year. A withdrawal of 25,000 acre-feet a year by either continuous or cyclic pumping also is assumed.

The continuous pattern of pumping in area (a) would result in modifying the illustrative example somewhat as follows. As the radius of influence expanded into fine-grained deposits and volcanic bedrock, actual values of transmissibility would be lower than those used in the computation. This influence would be reflected in larger drawdowns, as suggested by table 9b, if the annual quantity of water withdrawn were maintained. Drawdowns after 10,000 days of pumping could be several tens of feet greater than the 160 to 190 feet indicated in the illustrative examples for the idealized well field providing all water were withdrawn from storage. However, a large area of natural discharge lies adjacent to and west of the hypothetical well field. As the area of pumping influence expanded into the area of natural discharge an increasing amount of water would be salvaged. In time, as much as 40 percent of the amount of water pumped annually might be supplied by salvaged water. This is equivalent to reducing by 40 percent the draft on stored water, as suggested by table 9c, and consequently drawdowns would be less than those in the illustrative example. The two effects, that is, the lower value of transmissibility and the salvage of natural discharge, would tend to be mutually compensating, and it is probable that the drawdowns in the well field would be generally comparable to those given in the illustrative example.

The radius of influence of a continuous pumping pattern in area (a) could finally extend several miles southward in the lowland. However, it is not likely that pumping in area (a) could cause significant drawdown in area (b), about 20 miles away, before the economic limits of pumping were reached in area (a).

Area (b) is centrally located in an extensive lowland area of natural ground-water discharge. Accordingly, the effects of salvage of natural discharge would begin early in the pumping period, although initial withdrawals from storage would be required before the natural discharge could be diverted through the wells. Under the continuous pumping pattern as discussed for area (a), the proportion of pumped water derived from salvage could be 50 percent or more. Under the cyclic pumping pattern, the much larger well field and the area of significant drawdown would be distributed largely within the area of natural discharge. If the pumping season coincided with or immediately preceded the seasonal period of principal natural discharge, the proportion of salvaged ground water would be greater than under the continuous pumping pattern.

The ground water directly salvaged from natural evapotranspiration may be of inferior chemical quality for use. The suitability of the water for the intended use becomes increasingly important as the proportion of salvaged water to total withdrawal increases. Further, if the water is used for irrigation within the area of the well field, a part of the water spread on the fields will return to the ground-water reservoir by deep infiltration. This recycled water will have a higher concentration than the initially pumped water. In time, water recycled in the well field may supply a significant percentage of the amount of water pumped. As this percentage increases the pumped supply would deteriorate further. This should not negate the possibility of development for irrigation, but it does indicate that possible changes of chemical quality with time should be considered.

Area (c) occupies the lower part of the Duck Creek fan northwest of McGill. The adjacent lowland area is relatively wet, being supplied with water from the large spring area south from Steptoe, and from Steptoe Creek, Duck Creek, and McGill Spring through Bassett Lake. Long-time pumping in area (c) would expand the area of influence to the lowland area of natural discharge by evapotranspiration. After the initial period of withdrawal from storage, lowering of water levels in the natural discharge area would begin to salvage some natural losses. Further lowering of water levels in the lowland area would induce recharge from overland runoff in the lowlands supplied by springs south of Steptoe, outflow from Bassett Lake, and perhaps from local runoff. If significant drawdowns were achieved in the natural discharge area, water obtained by salvage, induced recharge, and recycling could provide a large fraction of the annual withdrawal. If the cyclic pattern of pumping were used, the water stored beneath the larger area of the well field would supply most of the water pumped for many years before the salvaged water became a significant proportion of the total pumpage. The radius of measurable pumping influence would be restricted on the northwest, west, and south by the wet lowland which finally would act as a recharge boundary to the area of pumping. On the east the bedrock which crops out in the mountains would function as a partial barrier boundary due to lower transmissibility of the bedrock.

In area (d), between Ely and McGill, natural discharge of ground water by evapotranspiration is small compared to that in area (c). Most of the water withdrawn under a continuous pumping pattern would be from storage. Consolidated rocks of relatively low transmissibility are at the surface within about three miles of the center of pumping. As the area of influence reached rocks of lower transmissibility, withdrawals could be maintained only by increased drawdown. The cyclic pattern of pumping with its much larger well-field area, would obtain a larger percentage of its supply from storage beneath the well-field area. The intervals of nonpumping would permit partial recovery of water levels within the well field, by recharge from underflow and runoff from the southern or upgradient part of Steptoe Valley. Finally, if the annual withdrawal were 15,000 acre-feet a year instead of the 25,000 acre-feet used in the computation, the rate of drawdown would be reduced and pumping could be sustained over a longer period of time.

The assumed conditions, computations, and their application to selected parts of Steptoe Valley discussed above generally indicate the response to pumping that might be expected. These responses may be summarized as follows:

(1) The early years of pumping would tend to have greater drawdowns than indicated in the examples, because initial apparent coefficients of storage would be less than those determined after long-time periods of pumping;

(2) The water pumped would be withdrawn largely from storage during the early years of pumping. As water levels were drawn down in areas of natural discharge, an increasing proportion of water pumped would be supplied by salvage of natural discharge. Perhaps salvaged water would approach half of the total withdrawals after 10 to 20 years of pumping;

(3) The degree to which natural discharge of ground water can be salvaged by pumping is dependent upon the effectiveness with which pumping can lower water levels in the areas of natural discharge. Direct salvage of ground water by pumping in the area of natural evapotranspiration discharge may not be entirely desirable if the water in the area of evapotranspiration is of poor chemical quality;

(4) Pumping centers adjacent to natural discharge areas with the initial withdrawals largely from storage would minimize the potential problem of chemical suitability of salvaged water and permit a gradual increase in the proportion of salvaged water should that prove satisfactory; otherwise there would be some latitude to shift the pumping somewhat farther away to maintain the quality;

(5) The pumping distribution used for illustration in Steptoe Valley is partly dictated by practical problems of development. The use of several centers of pumping would distribute total withdrawal through the valley. Consequently, drawdowns in the well fields would be less than if pumping were cencentrated in a single field. Using similar reasoning, wide spacing of wells within centers of pumping would reduce the interference among wells and help to keep drawdowns nominal; and,

(6) The combined withdrawal of the illustrative examples is 90,000 acre-feet a year. A reduction of 5,000 acre-feet a year in the pumping from each center of pumping would result in a withdrawal of about 70,000 acre-feet of water a year, equivalent to the preliminary estimate of perennial yield. The effect of a lesser quantity of water withdrawn would be a proportional reduction of the drawdown from those of the examples. However, the

calculations suggest that pumping at an annual rate of about 70,000 acre-feet could be maintained for several tens of years at least if pumping were distributed in several centers in the valley.

Provisional Budget for the Valley-Fill Hydrologic System

The budget for the valley-fill hydrologic system given in table 10 is provisional in that it represents a general evaluation of gross conditions. Time was not available in this investigation to make direct determinations or field controlled estimates of details of certain items of the budget. Thus, the amount of precipitation, streamflow, and ground water consumptively used for irrigated crops was not determined. Rather, these losses were included in the broader categories of evapotranspiration from different sources (budget items 4, 5, and 6, table 10). Excess water in the mountains and alluvial apron moves downgradient toward the lowland, either as runoff or infiltration into the ground-water system. Thus, most of the water loss represented by each of the outflow budget items occurs in the valley lowland, whether or not the water is beneficially used.

The relatively large value for estimated subsurface inflow to the ground-water reservoir (item 3, table 10) is supported indirectly by the fact that many large springs in the valley issue from or adjacent to consolidated rocks. These springs occur both in the mountains and in the valley lowland. They indicate that the consolidated rocks, particularly the carbonate rocks are capable of transmitting significant quantities of water. In this case it is inferred that usually most of the ground-water recharge to the valley-fill system is supplied by water moving through the consolidated rocks and into the valley fill below land surface.

The relative balance between the inflow and outflow items in table 10 is due largely to the fact that several items are obtained by difference, in the absence of appropriate data. However, though the items may be in error to a degree, it is believed that the estimates provide a reasonable quantitative distribution of the major elements of the hydrologic system. Thus, the estimates provide an initial hydrologic framework from which the potential for development may be evaluated.

Table 10. -- Provisional budget for valley-fill hydrologic system

		Estimated average annual amount of acre-feet per year
INFLOW:		
(1) Precipitation on valley fill . . . . (table 7 - equivalent of lower two zones)	520,000	
(2) Runoff from mountains . . . . (table 5)	78,000	
(3) Ground-water inflow across subsurface contact of consolidated rock and valley fill [item 6 below minus 24,000 acre-feet of estimated recharge from runoff to the valley-fill (see section on runoff) and minus 5,400 of recharge from precipitation on the valley fill (table 7, recharge from lower two zones)] . . .	41,000	639,000
OUTFLOW:		
(4) Evapotranspiration from precipitation on the valley fill [precipitation on valley fill (item 1 above) minus estimated (5,400 acre-feet) recharge from precipitation on valley fill (table 7, recharge from lower two zones)] . .	515,000	
(5) Evapotranspiration from runoff . . . . . (see section on runoff)	54,000	
(6) Evapotranspiration from ground water. . (table 8)	70,000	
(7) Discharge through gap north of Currie. .	1,000	640,000
IMBALANCE: Outflow greater than inflow		1,000