Water Balance and Pumping Capacity of the Lower Portneuf River Valley Aquifer, Bannock County, Idaho

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Staff Report 06-5
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SUMMARY

A detailed water balance of the southern portion of the lower Portneuf River valley (LPRV) aquifer, completed in 1993-94, has been updated to reflect new information on potential recharge sources, to evaluate recharge potential in the northern valley, and to provide a baseline for evaluating the aquifer's future response to drought conditions and increased demand.

The water balance results, derived from a period spanning 510 days in 1993 and 1994, reflect near-normal hydrologic conditions. More than 75 percent of the aquifer's capacity originates in the southern Bannock Range as precipitation and snowmelt in the Mink Creek, Gibson Jack, and City-Cusick Creek watersheds; about 15 percent originates in the upper Portneuf River basin (entering the LPRV as ground-water underflow through the Portneuf Gap); and less than 5 percent originates as snowmelt in the Pocatello Creek watershed. Leakage from the Portneuf River contributes less than 5 percent to system capacity, most of it during high-flow and flood conditions. Total annual pumping capacity for a normal water year, as determined from the 1993-94 water balance is 7.25 ± 0.4 billion gallons (Bgal) or about 22,000 ± 1000 acre-feet per year.

These results indicate that total demand was already at 100-115 percent of system capacity more than a decade ago. During 1993-94, municipal pumping (Pocatello and Chubbuck) accounted for 6.5 billion gallons of total demand, with the remaining 0.8 Bgal

per year tapped for non-municipal uses. Agricultural withdrawals accounted for 5-10 percent of total demand, with domestic and self-supplied industrial withdrawals each at about 5 percent; non-metered golf course irrigation accounted for 2 percent.

Aquifer recharge in a below-normal water year may be as much as half that of a normal water year. Storage (water level) in the southern aquifer has declined by more than 10 feet since about 1975, and represents direct evidence that long-term demand has exceeded long-term capacity for more than two decades.

Local watersheds have little or no potential to increase the aquifer's total capacity via additional surface water or ground water supplies. For example, diversion of half of all streamflow in the southern Bannock Range would increase total water capacity by less than 5 percent, and in the absence of other sources of ground-water recharge that originate outside the LPRV watershed, any exploitation of deeper aquifers in the LPRV would not increase long-term capacity.

INTRODUCTION

BACKGROUND AND SCOPE

The cities of Pocatello, Chubbuck and Inkom rely on ground water from the lower Portneuf River valley (LPRV) aquifer for all of their drinking, commercial and industrial water needs. In response to a request by Pocatello's Community Development and Research Department for a best available estimate of future water capacity, an initial draft of this report was prepared in 1999. The results of that analysis and of the original water balance estimate compiled in 1993-94 (Welhan et al., 1996) have since been supplemented by additional new information, including better estimates of non-municipal pumping demand.

The original 1993-94 water balance provided an estimate of ground-water recharge derived from the southern LPRV. The results of that analysis are used to estimate evapotranspiration and runoff losses in the southern LPRV, allowing the southern aquifer water balance results to be extended to include the northern aquifer, so that overall system recharge capacity can be quantified.

This report focuses on the shallowest portion of the LPRV aquifer system and the sources of recharge derived from precipitation intercepted by its watershed. The term "capacity" is herein defined as the volume of ground water that can be withdrawn annually without exceeding the system's natural rate of recharge. As such, it is equivalent to the term "safe yield", which is defined as the rate of extraction of ground water that does not exceed the rate of annual recharge (Todd, 1959). "Optimal yield," an extension of the safe yield concept, reflects broader economic and social objectives of a specific water management policy, including longer-term considerations such as conjunctive management of surface and ground water supplies, water banking, artificial recharge, and managed drawdown (Domenico, 1972). For example, successive annual ground-water overdrafts might be considered acceptable under a long-term drought management policy, given the expectation that future recharge would compensate for past depletions; more than a certain number of successive overdrafts could trigger short-term water rationing.

Because the LPRV is a geographically small watershed its principal aquifer, which supplies all municipal water needs, is prone to large annual pumping-induced storage fluctuations (i.e., large seasonal swings in ground-water level). Pocatello and Chubbuck do not have an explicit long-term water management policy, so a *de facto* strategy has historically focused on short-term safe yield rather than long-term optimal yield. To avoid confusion with a policy-driven definition of acceptable pumping rates, this report focuses only on the short-term response of the aquifer and its annual pumping capacity (safe yield) under normal hydrologic conditions.

The results of this analysis comprise a baseline against which long-term storage trends and aquifer response can be evaluated, and a forecasting model developed, to anticipate future pumping capacity under above-normal and below-normal hydrologic conditions.

HYDROGEOLOGIC SETTING AND PREVIOUS WORK

The LPRV watershed comprises the lowermost portion of the Portneuf River basin (Figure 1). The LPRV aquifer (Figure 2) merges with the Snake River Plain aquifer to which it is tributary and is part of a larger aquifer system that extends beyond the border of the LPRV watershed at Portneuf Gap into Marsh Creek Valley. Southeast of Red Hill, the shallow municipal aquifer is unconfined, less than 250 feet deep, and comprised of clean, highly permeable glacial flood gravels (Welhan et al., 1996). Northwest of Red Hill, it grades into a multi-layered confined system of deeper, silt- and gravel-hosted aquifers that have been tapped to depths of 300-900 feet by municipal and industrial wells. The developed portions of both the northern and southern aquifers overlay several thousand feet of deeper valley-fill sediments. Ground-water recharge originates in the southern Bannock Range, predominantly as snowmelt in the Mink Creek, Gibson Jack, City, and Cusick Creek watersheds, as well as from the upper Portneuf watershed as underflow through the Portneuf Gap (Welhan and others, 1996).

Figure 2 shows the areal distribution of 30-year mean annual precipitation (University of Idaho, 1993) over the principal recharge source areas of the southern Bannock Range. Figure 3 summarizes the valley's hypsography, showing how areas of greatest mean annual precipitation are coincident with the highest elevations.

Details of the water balance for the southern portion of the aquifer are reproduced in Appendix A, revised and updated from Welhan et al. (1996). Their accounting covers a 510-day period from April, 1993 to September, 1994 and reflects water balance

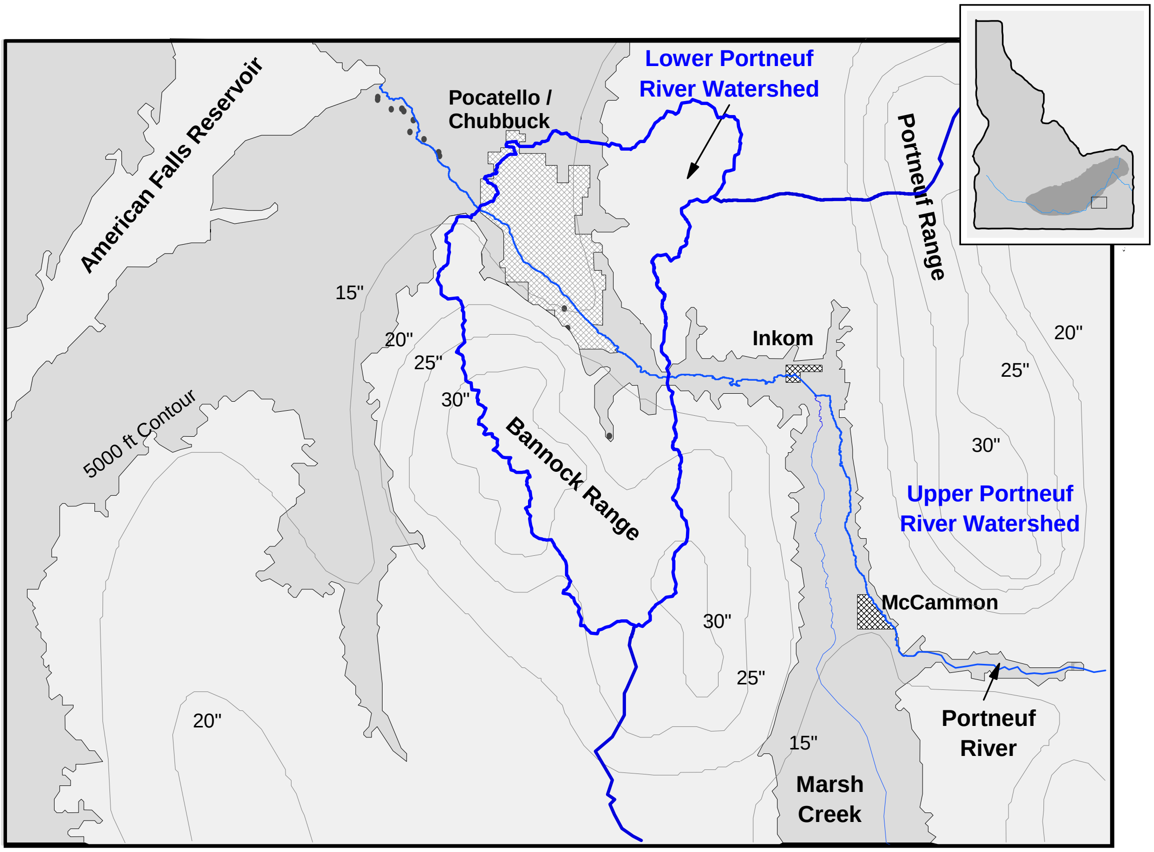

Figure 1. Location of the lower Portneuf River watershed in relation to local highlands having in excess of 30 inches of precipitation annually. Isohyetal lines are based on 30-year mean annual precipitation published by the University of Idaho (1993).

conditions during a period of back-to-back above-normal (1993) and below-normal (1994) water years such that the annualized recharge and discharge fluxes determined for the accounting period are an approximation of normal annual hydrologic conditions. The water balance accounting for the southern aquifer is unusually well-constrained by the bedrock geometry in the vicinity of Red Hill and Portneuf Gap (Reid, 1997), allowing for unusually accurate estimates of underflow to be calculated into and out of the southern aquifer.

Figure 4 summarizes total annual precipitation for the southern Bannock Range. Direct measurements have been available from the NRCS SnoTel station at Wildhorse Divide (see Figure 2) since 1983; prior to 1983, annual estimates are based on Pocatello airport weather station records and a correlation (r = 0.77) between annual precipitation at the two stations (see Figure A-2 in the Appendix).

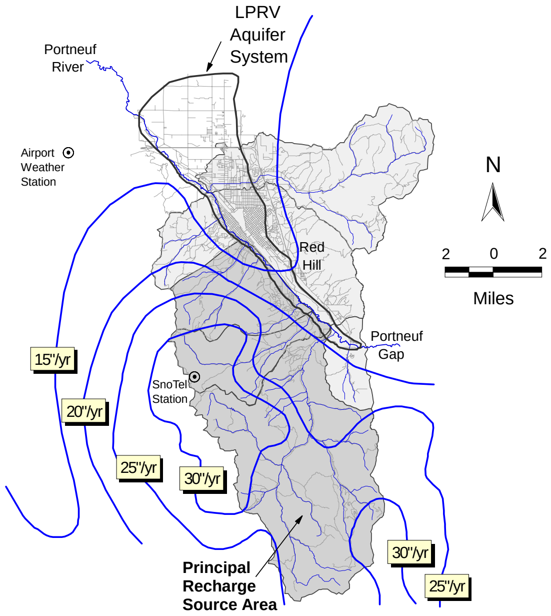

Figure 2 - Geographic relationship between the lower Portneuf River valley (LPRV) aquifer system and local watersheds (dark shading) that contribute the largest fraction of total recharge.

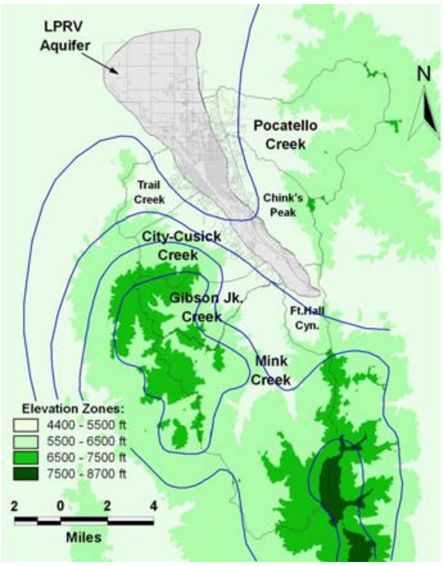

Figure 3 - Hypsography of the LPRV compared to mean annual precipitation (isohyetals taken from Figure 2). Areas of principal snowpack accumulation occur at the highest elevations (darkest shading), which coincide with areas of highest annual precipitation.

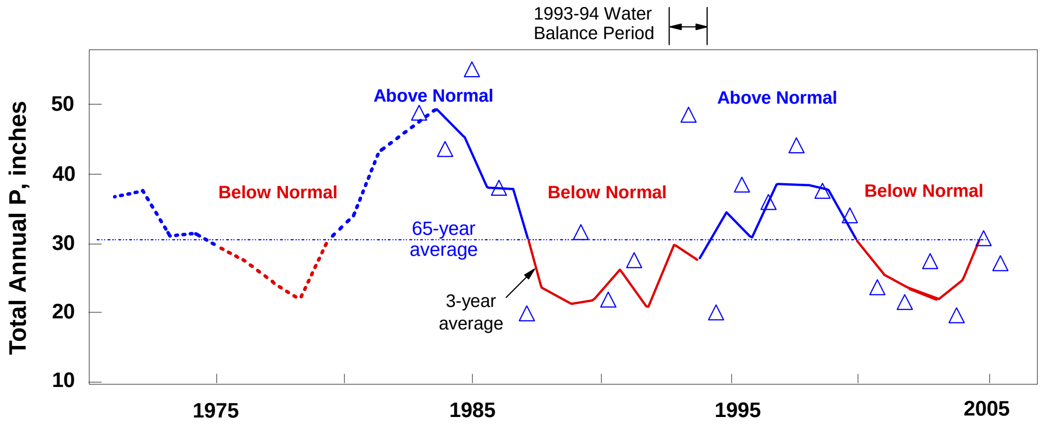

Figure 4 - Total annual precipitation at Wildhorse Divide in the Bannock Range. Solid and dotted lines represent three-year moving averages of, respectively, measured annual precipitation (triangles) and estimates reconstructed from Pocatello airport data using a linear correlation between the two stations (see Appendix, Figure A-2).

THE 1993-94 SOUTHERN AQUIFER WATER BALANCE

The 1993-94 water balance was originally computed using indirect evidence that Portneuf River leakage was a minor source of aquifer recharge (Welhan et al., 1996), an hypothesis that has been corroborated by recent chemical mass balance modeling and analysis of base-flow discharge data (Meehan, 2005).[1] Chemical mass balance arguments were also used to infer that the recharge contribution from the southeastern side of the valley was <10% of the recharge originating from the southern Bannock Range (Welhan et al., 1996).

Figure 5 summarizes the results of the 1993-94 water balance, details of which are provided in the appendix. Municipal wells withdrew water from the southern aquifer at a rate of 1.32 billion gallons per year (Bgal/yr). Recent estimates of non-municipal withdrawals include: 0.14 Bgal/yr by private wells (BBC Research, 2001)[2]; 0.11 ± 0.04 Bgal/yr for agricultural use (BBC Research, 2001, based on irrigated land area in 2000); and non-metered golf course withdrawals of 0.15 Bgal/yr (based on City of Pocatello records for their metered facilities, extrapolated to non-metered facilities). Ground-water flow through the Portneuf Gap contributed slightly more than 1 Bgal/yr. The calculated

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[1] High-flow conditions during spring runoff and flood stages may be the only times when the river loses substantial water to the aquifer; see appendix, Sections A.1.2 and A.2.2.

[2] Assumed to be in a fixed proportion relative to municipal demand

water balance residual, 5.7 ± 0.04 Bgal/yr, represents all other recharge sources (including the Bannock range and the eastern side of the valley, plus river losses). The river is estimated to contribute about 0.3 Bgal/yr (see appendix, Sections A.1.2 and A.2.2.). Therefore, assuming that recharge from the eastern side of the valley is negligible, the Mink Creek /Gibson Jack /City-Cusick Creek watersheds contribute about 5.4 ± 0.1 Bgal/year, or more than five times that from the upper basin, as underflow through the Portneuf Gap. Total recharge to the southern aquifer is 7.25 ± 0.4 Bgal/yr, with three-quarters of that (5.3 Bgal/yr) serving as recharge to the northern aquifer.

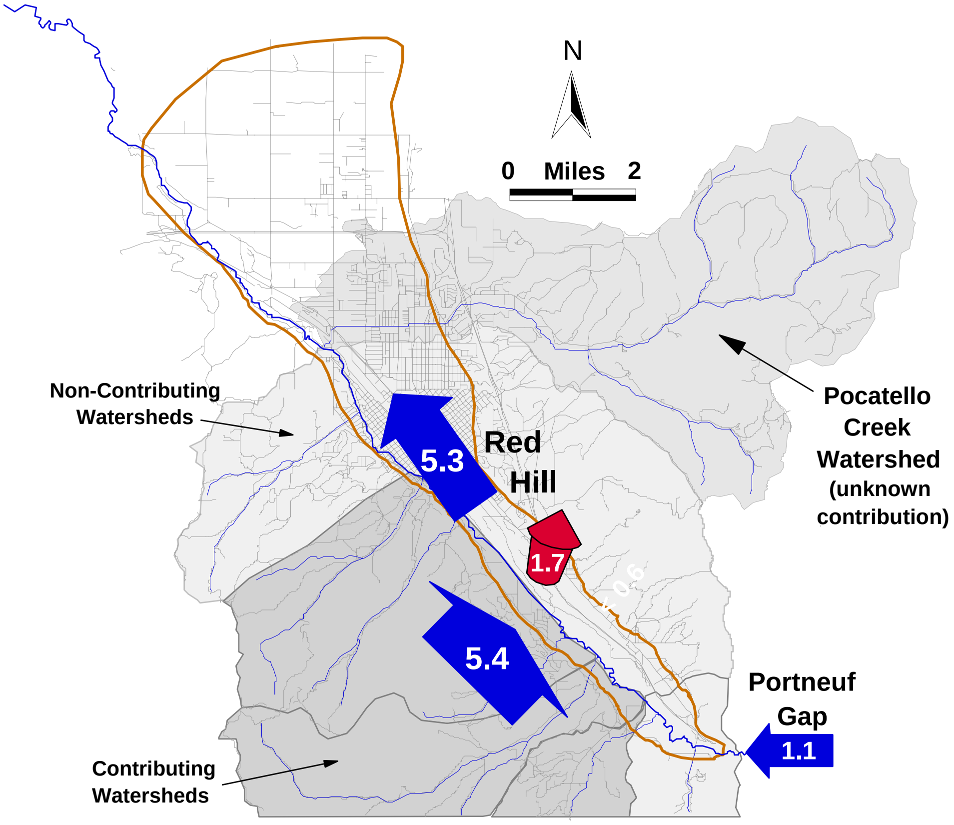

Figure 5 - Southern aquifer water balance, after Welhan and others (1996), revised with new information. All quantities are in billions of gallons (Bgal) per year. Total pumping withdrawals are shown in the conical arrow. Annual recharge from the Portneuf River is estimated at 0.3 Bgal/yr and the change in aquifer storage during the 1993-94 accounting period was -0.29 Bgal/yr.

GROUND-WATER RECHARGE TO THE NORTHERN AQUIFER

Based on hypsography (Figure 3), Pocatello Creek may be the only other watershed capable of supplying any significant amount of snowmelt-derived recharge to the LPRV aquifer. However, its importance as a tributary ground water source is unknown, and estimates of surface runoff and evapotranspiration losses are unavailable to estimate its recharge potential. In contrast, the recharge rate for the southern Bannock Range is an unusually accurate estimate because of constraints imposed by bedrock geometry on the underflow calculations (Appendix A). A similar approach cannot be taken for the northern aquifer because underflow cannot be independently estimated. Instead, outflow to the Snake River Plain must be estimated as a separate water balance residual, based on independent estimates of recharge from the northern valley's tributary watersheds. To do so, the southern Bannock Range recharge rate was used to estimate total evapotranspiration (ET) and runoff losses relative to mean annual precipitation in the Bannock Range, which were then applied to watersheds in the northern LPRV to estimate recharge potential.

An estimate of net ET loss in the Bannock Range can be made by comparing the recharge rate calculated from the southern aquifer water balance with annual precipitation and runoff estimates for the same area. Based on data in Figure 1, the Mink Creek, Gibson Jack, City, and Cusick Creek watersheds intercept an elevation-weighted total of 26.1 inches of precipitation (33.5 Bgal/yr) in an average water year. Of this, 16 percent (5.4 Bgal/yr, derived from the water balance residual) recharges the southern aquifer. Unpublished stream gauging data collected in 1995 (a near-normal year for precipitation) indicates that Mink Creek runoff represented 3 percent of the precipitation intercepted by that watershed; prorated by area, total runoff from the Gibson Jack and City-Cusick Creek watersheds, together with Mink Creek, amounts to 1.2 Bgal/yr. Net ET loss therefore comprises about 80% of the annual precipitation intercepted by the southern Bannock Range during a normal water year. In comparison, Balmer and Noble (1979) determined ET losses of 70-90 percent for nearby watersheds in southeast Idaho.

Evapotranspirative loss was assumed to be inversely proportional to altitude and the amount of precipitation intercepted (i.e., the rate of ET loss is lowest at highest elevations). To achieve an 80 percent overall ET loss rate, zonal loss rates for the southern Bannock Range were determined by trial and error: 100 percent in elevation zones having less than 25 inches of mean annual precipitation[3]; about 85 percent in zones with 25-30 inches of precipitation; and about 65 percent in zones having more than 30 inches. Applying these ET loss rates to other watersheds in the LPRV, Pocatello Creek is the only one in the northern LPRV capable of supplying any significant recharge.

Results of the calculation are summarized in Table 1, showing the amount of annual area-weighted precipitation and the amount available as recharge plus runoff from each watershed. Pocatello Creek's estimate represents an upper limit because the ET loss rate determined for the Bannock Range had to be adjusted downward to obtain a non-zero recharge estimate. Note that the results corroborate the assumption made in the

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[3] Potential evaporation, alone, is of the order of 61 inches (CH^2M-Hill, 1994a).

1993-94 water balance accounting, that recharge from the eastern side of the valley (Eastern slope) is indeed negligible.

TABLE 1 - Estimated ground-water recharge plus runoff per major watershed, based on evapotranspiration losses estimated from the 1993-94 water balance and prorated on the basis of area and precipitation.

Watershed	Area (sq.mi.)	Weighted mean annual precipitation (inches/yr)	Available as recharge plus runoff (inches/yr)	
Mink Creek	48.2	27.1	5.0	5.4 Bgal/yr recharge contribution
Gibson Jack Creek	11.3	27.1	6.3	
City / Cusick Creek	14.4	21.9	1.7	
Eastern slope	18.4	14.0	0.0	
Fort Hall Canyon	5.7	20.4	0.0	
Trail Creek	7.6	16.9	0.0	
Pocatello Creek	27.7	14.5	< 1.2	(0.5 Bgal/yr)

OVERALL AQUIFER WATER BALANCE

The water balance for the entire aquifer system was calculated using the 1993-94 water balance results for the southern aquifer and the recharge estimates derived for tributary watersheds in the northern aquifer. Table 2 summarizes annualized pumping totals for Pocatello and Chubbuck municipal wells during the accounting period of 1993-94 (conditions equivalent to a normal water year) and for 2000 (a drought year), as well as estimated non-municipal demand.

Table 3 and Figure 6 summarize the water balance of the entire aquifer system under normal hydrologic conditions. The LPRV's total capacity during the 1993-94 accounting period was 7.25 ± 0.4 Bgal/yr. Of this, municipal demand consumed 80-85 percent. Total non-municipal demand is less certain, but the range in Table 2 is believed to be a reasonable representation of actual demand. If so, then total demand may have exceeded aquifer capacity in 1993-94 by as much as 15 percent. In times of drought, this overdraft would be even more acute.

Several important caveats should be noted. First, this analysis considers only intra-basin (meteoric) sources of recharge and focuses on the shallowest portion of the aquifer system. Little is known of the deeper sediments in the system, particularly the role that deep fracture systems and faults may play in capturing meteoric recharge that originates outside the LPRV watershed, or the rate at which water in the deepest zones into or out of the shallow aquifer. Secondly, the flux of ground water past Red Hill may not represent all of the recharge contributed by the southern valley to the northern aquifer. It is possible that some recharge that originates in the southern Bannock Range bypasses Red Hill and contributes directly to the northern aquifer. This would not affect the southern aquifer water balance calculation but would augment overall aquifer capacity. Finally, since the Portneuf River is a gaining stream in the northernmost part of the LPRV and is lined through much of the central part of the valley, it is assumed to be a recharge source only in the southern valley.

TABLE 2 - Summary of municipal and estimated non-municipal pumping withdrawals in the LPRV during 1993-94 (corresponding to a normal water year) and 2000 (a drought year).

	1993/94[1]	2000[2]
South Aquifer		
Municipal	1.32	1.72
Domestic	0.14	0.18
Agricultural	0.11 ± 0.04	0.15 ± 0.05
Industrial	0	0
Golf courses	0.15	0.09
Totals	1.72 ± 0.04	2.13 ± 0.05
North Aquifer[3]		
Pocatello Municipal	4.53	3.82
Chubbuck Municipal	0.65	0.62
Domestic	0.31 ± 0.16	0.26 ± 0.14
Agricultural	0.39 ± 0.13	0.33 ± 0.11
Industrial	0.25 ± 0.07	0.27 ± 0.05
Golf courses	0	0
Totals	6.12 ± 0.36	5.33 ± 0.34
Entire Aquifer		
Municipal	6.49	6.16
Domestic	0.44 ± 0.17	0.43 ± 0.14
Agricultural	0.50 ± 0.17	0.47 ± 0.15
Industrial	0.25 ± 0.07	0.31 ± 0.09
Golf courses	0.15	0.09
Totals	7.83 ± 0.40	7.47 ± 0.39

[1] Annualized on the basis of the 510-day accounting period.

[2] Actual municipal and estimated non-municipal withdrawals.

[3] Includes "central aquifer" wells, as defined by Welhan et al. (1996).

Note that under pre-development conditions (no pumping diversions), the LPRV would have contributed in excess of 7 Bgal/yr to the Snake Plain aquifer as tributary underflow. Under current pumping conditions, this has been reduced to less than 0.5 Bgal/yr; in fact, at the high-end range of pumping estimates, the LPRV is actually drawing water from the eastern Snake River Plain aquifer. Aside from the obvious implications for water-rights conflicts, the effect of overpumping the northern aquifer could be to pull in contaminants from areas north of Chubbuck.

TABLE 3 - Water balance for the entire LPRV aquifer system under normal hydrologic conditions, based on the 1993-94 accounting period.

Recharge	
Portneuf Gap underflow	1.06
Portneuf River losses	0.26[1]
Maximum Pocatello Creek recharge	0.50
Southern Bannock Range recharge	5.4 ± 0.1
Total capacity	7.25 ± 0.4
Discharge	
Pocatello municipal pumping	5.85
Chubbuck municipal pumping	0.65
Self-supplied domestic pumping	0.44 ± 0.17
Self-supplied agricultural irrigation	0.50 ± 0.17
Self-supplied industrial pumping	0.25 ± 0.07
Non-metered golf course use	0.15
Total pumping withdrawals	7.83 ± 0.4
Change in Aquifer Storage	-0.46
Outflow to Snake River Plain aquifer	0.2 to -0.5 (inflow)

[1] Since the Portneuf River becomes a gaining stream in the northern part of the northern aquifer, river losses are assumed to occur only in the southern valley.

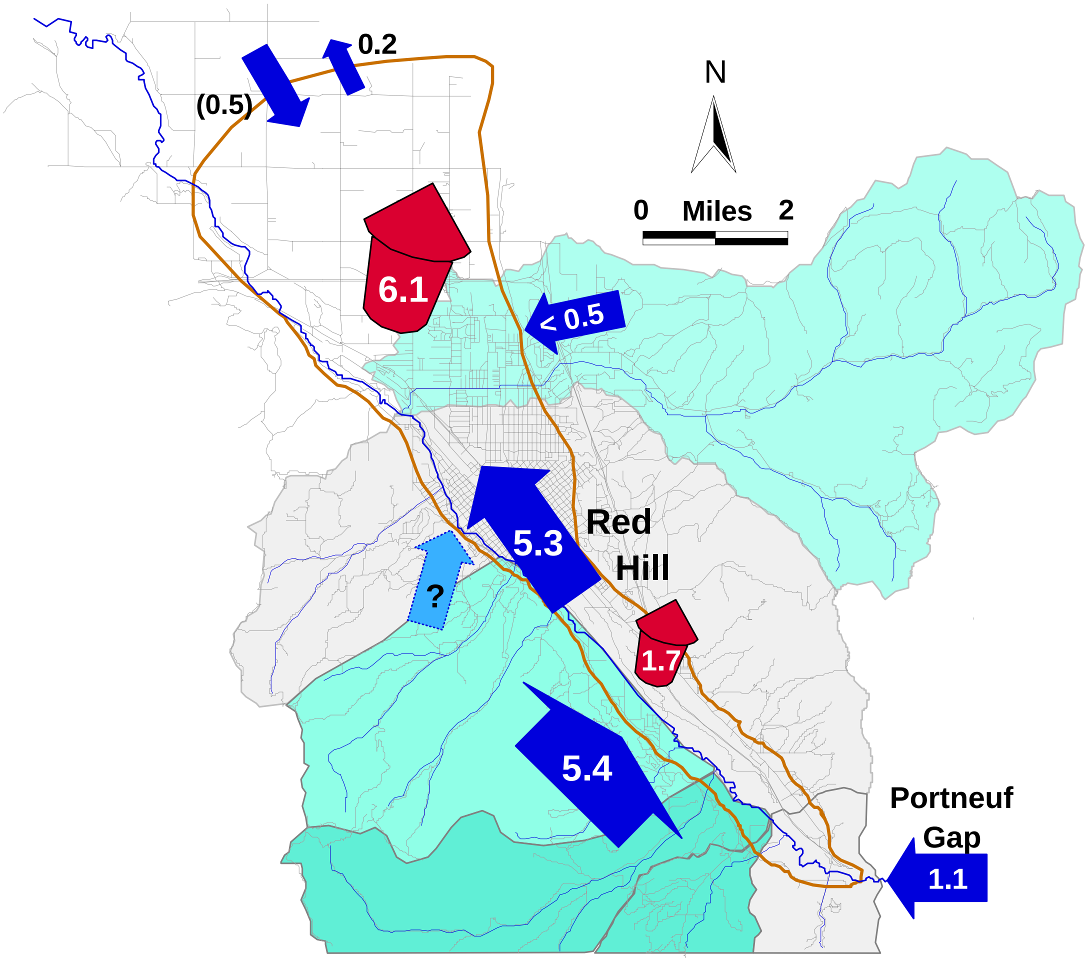

Figure 6 - Water balance for the entire LPRV aquifer system, reconstructed from the 1993-94 accounting for the southern aquifer. Pumping withdrawals (in conical arrows) reflect actual municipal demand plus estimated non-municipal demand. All values are in Bgal/yr. Estimated river recharge is 0.3 Bgal/yr (contributing only in the southern valley), and total storage change over the entire aquifer is -0.46 Bgal/yr.

DISCUSSION AND CONCLUSIONS

THE IMPACT OF DROUGHT

The water balance results indicate that the aquifer's safe yield was being exceeded under normal hydrologic conditions a decade ago. For comparison, Table 4 presents an approximate water balance accounting of the southern aquifer for a drought year (2000). Underflows at Portneuf Gap and Red Hill were assumed to reflect differences in saturated cross-sectional flow area, only. River losses were assumed to be the same as estimated for 1993-94. Table 4 shows that the water balance residual for 2000 (essentially, Bannock Range recharge) is fully half that in 1993-94. Because 95 percent of total recharge originates in the southern LPRV, drought will clearly have a substantial impact on overall system capacity.

TABLE 4 - Comparison of southern aquifer water balance under normal hydrologic conditions (for the combined 1993-94 accounting period) and drought conditions (year 2000). All values are in billions of gallons per year.

	1993/94	2000
***Losses** (withdrawals + outflow)*		
Pocatello municipal wells	1.32	1.72
Domestic wells	0.14	0.18[2]
Agricultural wells	0.11 ± 0.04	0.15 ± 0.05[2]
Non-metered golf courses	0.15[1]	0.09[2]
Total pumping demand	1.72 ± 0.04	2.13 ± 0.05
Red Hill underflow	5.33	5.14[3]
***Gains** (recharge + inflow)*		
Portneuf Gap underflow	1.06	1.01[3]
Portneuf River losses	0.3	0.3
Change in aquifer storage	-0.29	-3.35
Calculated recharge residual (all unknown recharge sources)	5.7 ± 0.1[4]	2.9
Bannock Range recharge	5.4 ± 0.1[4]	2.7

[1] Country Club golf course demand assumed equivalent to Highland's (0.1 Bgal/yr); Riverside non-metered withdrawal is about 50% of Highland's (J. Ulrich, oral comm., 2006).

[2] Proportions relative to municipal demand were assumed constant between 1993-94 and 2000; non-metered golf course use was estimated from actual demand at Highland.

[3] Hydraulic gradients were assumed not to differ substantially from 1993-94; underflow estimates were adjusted only for a decrease in cross-sectional saturated flow area due to a 5.5 foot average water table decline during 2000.

[4] The range primarily reflects uncertainty in estimated non-municipal demand.

LONG-TERM STORAGE TRENDS

As noted in Section A.3 of the appendix, deep wells in the northernmost portion of the LPRV aquifer can draw on water from the eastern Snake River Plain (ESRP) aquifer when LPRV demand exceeds capacity. If so, then future drilling and production in the northern aquifer would be expected to have little impact on LPRV aquifer capacity but could exacerbate water rights conflicts with ESRP irrigators.

In the southern LPRV, concerns over aquifer storage are paramount. Changes in storage (water level) primarily reflect the difference between capacity (recharge) and pumping demand (see equation A.1 in the appendix). Figure 7 shows water levels in Pocatello municipal well 28 together with records of monthly production in the southern aquifer and local precipitation (a measure of available recharge). Seasonal pumping demand in the southern aquifer (Figure 7.b) has the largest impact on aquifer storage, with fluctuations of 5-10 feet (e.g., Figure 7.c, between 1990 and 1995). This is 30 percent greater than seasonal, pumping-induced variations in water level in the confined northern aquifer. The effect of such large fluctuations is felt by all wells in the southern aquifer. From 1990 to 2005, Pocatello's average monthly production in the southern aquifer increased by 50 percent (heavy line in Figure 7.b); between 2001 and 2004, during the recent drought, annual production increased by 25 percent. Municipal well 44, the southernmost in the well field, came on line in August, 1999, and its peak production was realized the following year (0.7 Bgal/yr, ca. 40 percent of the southern well field's production). However, declining water levels at the pump bowls have since forced a steady 5 percent annual decline in its production.

Superimposed on these short-term storage fluctuations is a long-term downward trend (Figure 7.c). Over a time scale of 25-30 years, the southern aquifer's water table has declined approximately 20 feet. Water level records for the LPRV prior to 1970 are unavailable, so it is not possible to conclude whether the trend is a recent phenomenon or part of an even longer cyclic response to climatic variations. U.S. Geological Survey monitoring well records dating back to 1952, both up- and down-gradient of the LPRV and as far away as Blackfoot, indicate that storage in eastern Idaho aquifers began to decline about 1970 to 1975. Some of this might be attributed to the fact that the region has experienced three droughts but only two above-normal periods in that time frame. Drought severity, however, either in terms of 3-year average annual precipitation (Figure 7.a), snowpack water content (not shown), or duration, has not increased during that time, and the number of years of above-normal precipitation is exactly the same as the number of below-normal years.

Regardless of its cause, the trend clearly indicates that the LPRV's long-term optimal yield (as well as its short-term annual safe yield) have been--and are being--exceeded. Such a trend reflects the interplay of several factors:

(i) magnitude of the recharge deficit relative to demand in dry years (Table 4);
(ii) cumulative impact of successive dry years (compare Figure 7.a and 7.c); and
(iii) growing demand due to more wells and extended pumping schedules during hotter, drier summers.

In the five years of drought since well 44 came on line, water levels in the southern aquifer dropped lower than at any time on record. However, no single well's pumping impact can be held responsible, and curtailing an individual well's production would have little effect on the long-term storage trend, just as individual above-normal or below-normal water years have little long-term impact. For example, although 2006's above-normal snowpack and flooding-enhanced recharge (not shown in Figure 7.c) dramatically reversed the 25-year storage decline, its impact will be short-lived unless it is followed by several normal and/or above-normal water years. Regardless of 2006's individual impact, a continuing long-term decline in aquifer storage can be expected unless long-term demand is brought in line with long-term capacity.

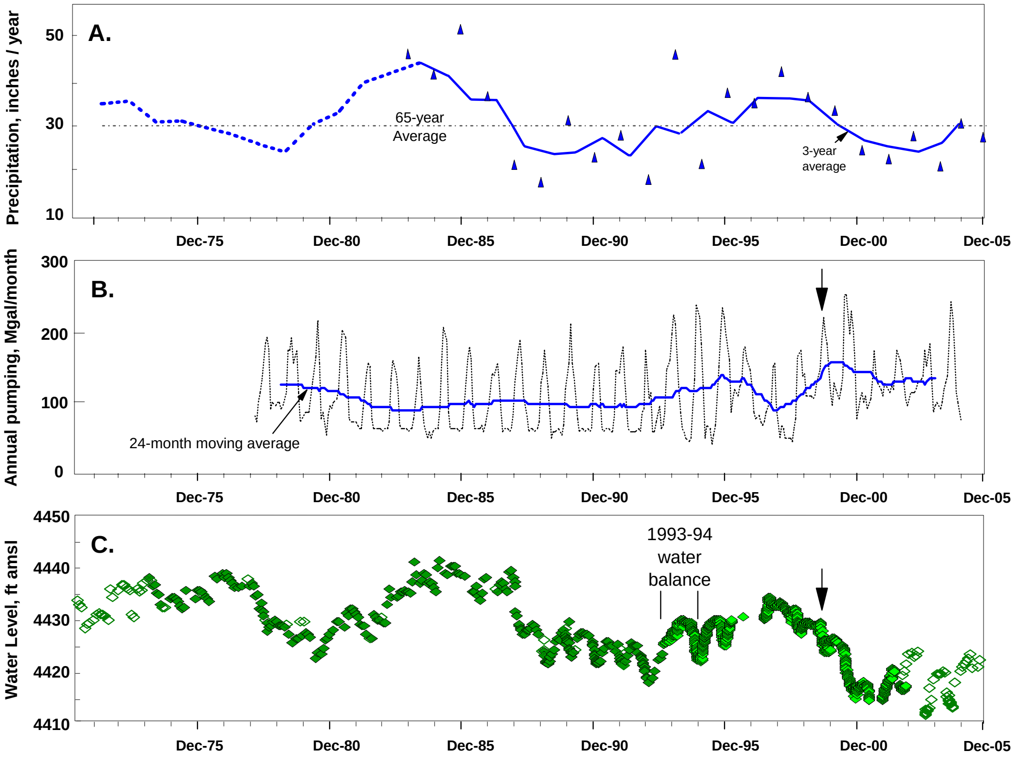

Figure 7 - Comparison of (a) total precipitation at Wildhorse Divide (from Figure 4), (b) total municipal production from wells in the southern aquifer (as monthly totals and two-year moving average), and (c) fluctuations in southern aquifer storage as measured at Pocatello municipal well 28. Solid symbols represent measured values (data logger readings span the period from early 1993 to late 2003); open symbols were estimated from nearby wells. Arrow indicates when well 44 came on line.

To illustrate this point, consider the period of above-normal and below-normal water years between 1995 and 2005. Extrapolating from the results of Table 4 and assuming that, on average, annual capacity is reduced by 50 percent in every below-normal water year but only increases by 25 percent in above-normal water years[4], the impact on average annual capacity would be a net reduction of 12 percent over this ten-year period. That is, in order to manage the aquifer using an optimal yield strategy (and only considering annual capacity as the optimization criterion) would dictate more than a 10% reduction in total demand to remain in balance with fluctuating recharge on a decadal time scale.

CAPACITY AUGMENTATION

Measurements of discharge and stage on lower Mink Creek for 1995 (unpublished data) indicate that runoff from the Bannock Range comprises a minor fraction of the LPRV's overall water budget. Baseflow in Mink Creek in 1995 was about 2 ft^3/sec with spring runoff averaging about 12 ft^3/sec for two months of the year. Annually, this represents about 3 percent of the total precipitation intercepted by the watershed. If half of this were diverted to recharge the aquifer, it would add 0.3 to 0.4 Bgal (about 5 percent) annually to the system's ground water capacity. Other sources of surface water, such as from the Portneuf River, would have to be developed to justify a managed recharge strategy in the future.

The only known sources of natural recharge in the LPRV are meteoric waters falling on the watershed itself (intra-basin recharge). Although some instances of thermal waters are known in the northern valley (Corbett et al., 1980), there is no evidence for deep, extra-basin recharge. In the absence of such a source, system capacity cannot be increased by exploiting deeper aquifers in the LPRV. Although producing horizons are known to exist at greater depths than currently tapped by municipal wells (e.g., artesian zones below 300 feet in the southern aquifer and productive zones below 800 feet in the northern aquifer), they would not increase the aquifer's long-term capacity unless they were recharged from sources outside the LPRV watershed. The only exception would be water flowing in very deep zones not in hydraulic communication with the shallow aquifer, but it is highly unlikely that such water would not be recharged outside the LPRV watershed, anyway. The most likely benefit to be derived from wells that tap deeper zones would be in making up short-term deficits in the shallow aquifer.

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[4] Because evapotranspirative losses are the largest determinant of annual effective recharge, the effect on recharge availability is larger in drought years than in wet years.

ACKNOWLEDGMENTS

Many people have cooperated directly and indirectly over the years toward this ongoing research effort. I wish to thank the City of Pocatello's Water Department including Public Works Director Greg Lanning for his support; past and present Water Superintendents Fred Ostler and Jay Ulrich and their staff, including Janene Orr and Tom Dekker, for access to the city's water records; and the city engineering staff for providing map and geographic data. I also wish to thank Steve Smart, Public Works Director of the city of Chubbuck for his enthusiastic support and interest, as well as for access to city water data and reports, and John Sigler, Environmental Engineer with the City of Pocatello, for reviewing the report prior to its release.

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APPENDIX A

1993-94 Water Balance for the Southern Portion of the Lower Portneuf River Valley Aquifer

Revised from: "The Lower Portneuf River Valley Aquifer: A Geologic / Hydrologic Model and Its Implications For Wellhead Protection Strategies"; J. Welhan, C. Meehan, and T.Reid, 1996; Final Report, EPA Wellhead Protection Demonstration Project and the City of Pocatello Aquifer Geologic Characterization Project; Chapter 6.

A.1. PRINCIPAL RECHARGE SOURCES

A.1.1. Precipitation

Table A-1 summarizes mean annual temperature, humidity and precipitation as recorded at the Pocatello Airport weather station. Precipitation in the lower basin varies from less than 15 inches (38 cm) in the Portneuf River valley to more than 30 inches (76 cm) in the Bannock Range (Figure A-1). A SnoTel station at Wild Horse Divide at an elevation of 6526 ft (1990 m) in the southern Bannock Range averaged 29.7 inches (75.4 cm) over 11 years of record (1983-1994). As shown in Figure A-1, Bannock Range precipitation is the nearest source of local recharge to the LPRV aquifer system, other than underflow from the upper Portneuf basin through the Portneuf Gap, and likely plays a significant role in the aquifer's water balance

TABLE A-1. Summary of meteorological data, Pocatello airport weather station (from National Weather Service, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?id7211, based on 68 years of record).

													-------Annual--------		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean	1993	1994
Average Temperature, ºF:															
	23.8	29.0	36.8	46.6	54.3	62.2	70.8	69.2	59.3	48.1	36.0	26.3	46.7	43.2	48.3
Average Snowfall, inches:															
	6.57	5.35	3.51	0.41	0.01	0	0	0.04	1.77	4.65	8.61	9.35	41.6	29.6	30.3
Average Total Precipitation, inches:															
	1.10	0.92	1.12	1.13	1.35	1.02	0.53	0.61	0.79	0.87	1.05	1.07	11.5	17.9	9.09
Average Daytime Relative Humidity, %:															
	73	66	56	43	39	37	30	29	33	42	63	73	49	53	47

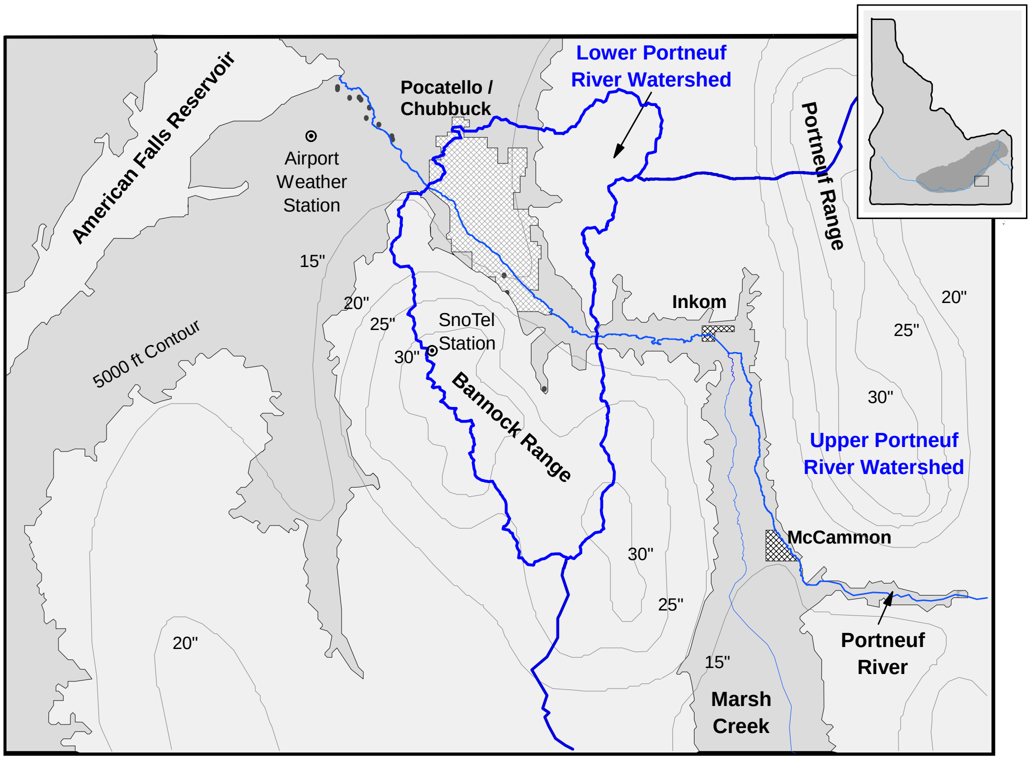

Figure A-1. Thirty-year total mean annual precipitation over the Lower Portneuf River basin and surrounding highlands. Precipitation isohyetals taken from University of Idaho (1993).

Historic trends in precipitation at the Pocatello Airport weather station and at Wild Horse Divide are summarized in Figure A-2 showing that total precipitation on the Bannock Range is a little more than twice that at the Pocatello Airport. Three-year moving averages of total precipitation on the Bannock Range tend to mimic the aquifer's storage variations (for example, the above-normal precipitation at Wildhorse Divide during the 1980s coincides with high ground water levels seen in wells). The synchronicity between aquifer storage and total precipitation suggests that an important part of the aquifer's recharge may be locally derived in the Bannock Range.

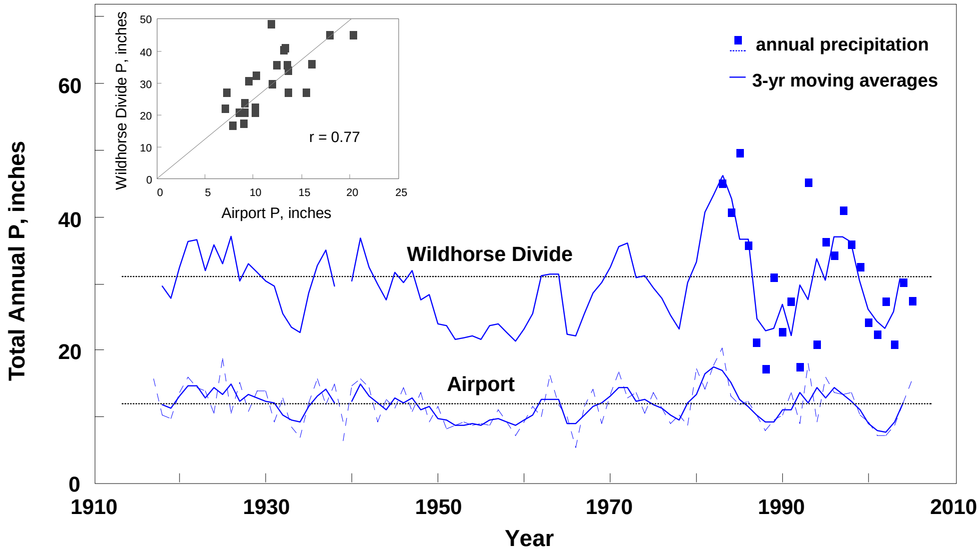

Figure A-2. Historic annual precipitation record at Pocatello Airport and at the SnoTel station on Wildhorse Divide, Bannock Range. Solid lines are three-year moving averages. The correlation between precipitation readings obtained at the two stations that was used to estimate precipitation at Wild Horse Divide prior to 1983 is shown in the inset. Airport data are based on official National Weather Service records since 1939 (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?id7211); prior to that, older NWS records were used.

A.1.2. Potential Surface and Ground Water Sources

Southern Bannock Range Recharge (Qb)

The major potential recharge sources are summarized in Figure A-3. Because of the chemical similarity of ground waters in the southern Bannock Range, recharge from Mink Creek, Gibson Jack Creek and the City-Cusick Creeks watersheds was lumped together as a single recharge component, Qb. Its magnitude is unknown but is expected to be large, given that local sources of recharge are implicated.

Portneuf Gap Underflow (Qg) and River Losses (Qr)

Based on the upper basin's size (1160 mile^2) and the amount of precipitation it receives (19.6 inches; Norvitch and Larson, 1970), underflow through the Portneuf Gap (Qg) might be expected to be a significant component of aquifer recharge. However, during normal water years, the river's average discharge of 250 ft^3/sec relative to a basin-wide

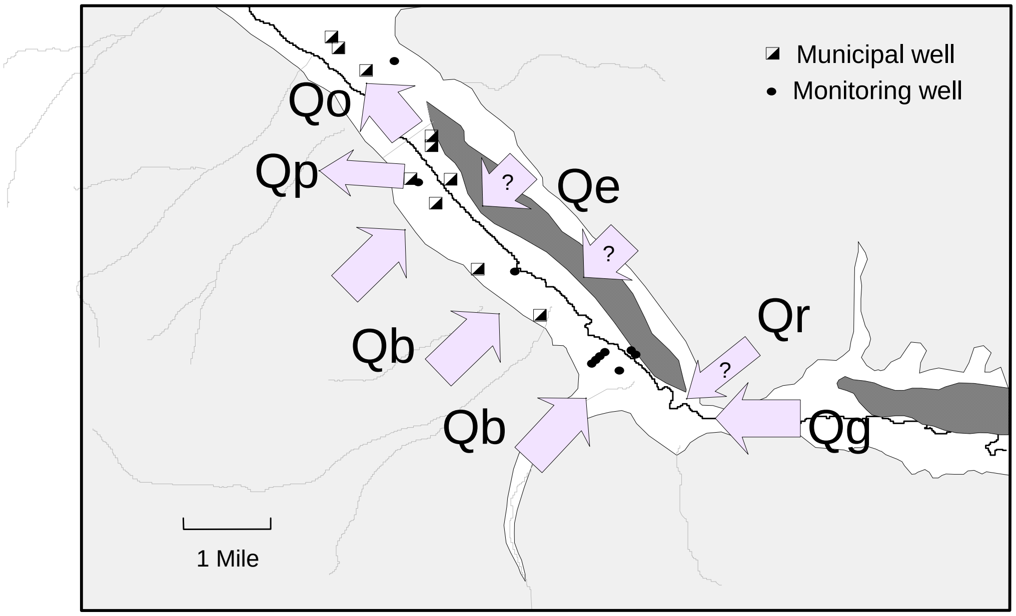

Figure A-3. Principal components of the water balance defined for the southern LPRV aquifer. Provisional water balances were constructed for the periods 4/93 - 10/93, 11/93 - 3/94, and 4/94 - 8/94, reflecting periods of major differences in aquifer storage response. Recharge from the eastern side of the valley may not be a significant source of recharge, based on chemical mass balance arguments. Qo is underflow past Red Hill; Qp is total pumping withdrawals; other terms are defined in the text.

annual average input rate of 1670 ft^3/sec of precipitation indicates that ground-water outflow plus evapotranspirative loss in the upper basin are of the order of 85 to 90% of precipitation input. Since annual potential evaporation is of the order of 61 inches or more than three times mean annual precipitation (CH^{2}M-Hill, 1994a), it is to be expected that evaporative loss, alone, would be the largest component of the basin water balance and that ground water outflow would be minor. For the purposes of computing the southern aquifer water balance, Qg was estimated from the saturated cross-sectional area of flow through the Gap, using Darcy's Law.

Norvitch and Larson (1970) proposed that the Portneuf River may lose a minimum of 8 ft^3/sec to ground water underflow somewhere between the lower reaches of the upper basin and the LPRV, with maximum possible estimates as high as 87 ft^3/sec. However, their hypothesis hinges on an estimate of specific discharge per unit basin area that was derived for the uppermost reaches of the upper Portneuf basin and applied to the lower reaches without justification. In contrast, their own river discharge measurements offer no evidence for significant river loss at base flow conditions. For example, the Portneuf River below the confluences of Rapid Creek and Marsh Creek in December, 1968 was 245.5 ft^3/sec. Approximately 5.5 miles downstream, immediately west of the Portneuf Gap, river discharge was 247 cfs. Discharge measured seven miles farther downstream, at the Pocatello gauging station (252 ft^3/sec), is higher because of tributary drainage contributions from the southern Bannock Range.

Although Norvitch and Larson did not measure tributary stream discharges along the lower Portneuf, our measurements on Mink Creek (the largest tributary stream in the LPRV) indicate a baseflow discharge of 1.65 ft^3/sec during July, 1994. When extrapolated to other tributary watersheds of the southern Bannock Range, and considering that 1994 was a below-normal water year, our data are consistent with a 5 ft^3/sec gain below the Portneuf Gap, as documented by Norvitch and Larson, and support the hypothesis that river loss to the aquifer (Qr) is small.[5]

Although the Portneuf River's mean annual discharge was near normal in 1993 (252 ft^3/sec) and below normal in 1994, and both years' mean discharges fall within a range that is comparable to Norvitch and Larson's 1968 base-flow stream measurements, we conclude that the Portneuf River does not lose significant amounts of water to the aquifer during base-flow conditions. However, the possibility remains that such losses may be significant on a transient basis, such as during bank-full and flood stage. In that case, Norvitch and Larson's (1970) river loss rate can be used to estimate Qr when river discharge is above normal (see Section A.2.1).

Leakage From the Eastern Valley Margin (Qe)

A potential source of recharge to the southern aquifer is ground-water inflow from the tributary aquifers on the eastern side of the valley. As documented in Welhan et al. (1996) and Meehan (2005), the shallow alluvial aquifer east of the Portneuf Basalt is highly contaminated with chloride, sulfate and nitrate. On chemical mass balance grounds, the influx of dilute Bannock Range waters, which are low in these constituents, has to be balanced by leakage from the eastern aquifer or another high-salt recharge source. In the absence of evidence to the contrary, it is assumed that Qe is a minor component of aquifer recharge. For calculation purposes, it is lumped together with other unknown recharge sources in the water balance residual (i.e., Qb + Qe + Qr).

Other Possible Sources

Although additional recharge sources may contribute to the LPRV aquifer, the current hydrogeologic model of the basin is incapable of identifying them or their relative

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[5] Recent corroboration of this hypothesis has come from a statistical analysis of recent base-flow discharge measurements taken below the Portneuf Gap as well as from chemical mass balance modeling of the southern LPRV aquifer (Meehan, 2005).

magnitudes. For example, low-temperature thermal water north of Pocatello Creek and in the Tyhee area north of Chubbuck is likely an expression of fault-controlled deep circulation contributing small amounts of water to the ground water regime in that area (Corbett et al., 1980). The Tyhee thermal waters are known to be elevated in sulfate and chloride relative to shallow ground water and would represent a potential source of salinity to the shallow ground water system. If similar thermal waters recharge the southern valley, they may be responsible for part or all of the salt added to the southern aquifer system, although their true contribution would be masked by leakage of shallow, contaminated water from the eastern aquifer (Meehan, 2005).

A.2. WATER BALANCE CALCULATIONS

A.2.1. Physical Constraints

The physical water balance for the southern aquifer can be written as:

$$\Delta S = Qg + Qb + Qe + Qr - Qo - Qp \qquad \text{(Eq'n A.1)}$$

where the terms are as defined in Section A.1.2 and Figure A-3. Direct precipitation input on the surface of the LPRV is neglected in this formulation because potential evapotranspiration on the valley floor is so much higher than precipitation. The magnitudes of several of these terms can be estimated on the basis of physical considerations, whereas others cannot even be crudely estimated (e.g., Qb, Qe).

Municipal well water level records in the southern aquifer permit a reasonably accurate estimate of storage change (ΔS) and pumping withdrawals (Qp). Of the remaining terms, estimates of Portneuf Gap underflow (Qg) and southern aquifer outflow (Qo) can be made on the basis of cross-sectional aquifer geometry, hydraulic conductivity, and gradient, using Darcy's Law. During river low-flow conditions, river losses are probably small, leaving only Bannock Range inflow (Qb) and possibly eastern aquifer leakage (Qe) as significant unknown terms.

Based on the timing of recharge events, variations in pumping withdrawals and aquifer storage, three accounting periods spanning about 17 months were used for the water balance calculations. All of these periods are referred to in terms of number of days since January 1, 1993. The first period, from Day 90-300 (April, 1993 - October, 1993) includes the only significant recharge event encountered during the study as well as 1993's period of peak summer well production. The second water balance period, from Day 300-450 (November, 1993 - March, 1994), spans a period of below-normal spring runoff and low seasonal well production rates when aquifer water levels remained fairly constant. The third accounting period, from Day 450-600 (April, 1994 - August, 1994), applies to 1994's period of peak pumping and a drastic decline in aquifer storage (in response to poor spring recharge and high pumping demand). All water balance terms were computed separately for each accounting period then summed over the entire 510-day time span and reported on an annualized basis (normalized to 365 days).

A.2.2. Individual Terms

Pumping Withdrawals (Qp)

Non-municipal pumping withdrawals were not considered in the original water balance estimate (Welhan et al., 1996). Estimates for self-supplied domestic use, agricultural and golf course irrigation, and industrial withdrawals have since become available and are documented in Table 2 in the accompanying report. Municipal pumping withdrawals were obtained from city records. Estimates of domestic and agricultural pumping were taken from BBC Research's (2001) evaluation of water use in the LPRV as of 2000; their domestic pumping estimate was cross-checked against the number of private well owners taken from a map of septic system users in the LPRV (Idaho Dept. of Environmental Quality, 2004), assuming that every septic system owner also operated a private well for domestic use. Self-supplied industrial pumpers were identified through City of Pocatello wastewater treatment records by comparing billed municipal water use with amount of wastewater treated; the difference represents a minimum estimate of self-supplied pumping withdrawals. The ratios of self-supplied to municipal withdrawals were assumed to be constant over time.

Well production in the southern aquifer during the provisional water balance period was summed over the individual accounting periods of the water balance. For example, during the period Day 300-450, Qp was 0.353 billion gallons (Bgal) or 47.2 x 10^6 ft^3; for Day 450-600, Qp was 0.79 Bgal (105.6 x 10^6 ft^3).

Southern Aquifer Outflow (Qo)

Figure A-4 shows a hydrogeologic cross section through the aquifer at Red Hill, based on drilling logs and a microgravity survey conducted to define the base of the aquifer (Reid, 1997). This cross-section location is considered the best-constrained for purposes of aquifer underflow calculations for several reasons: the availability of hydraulic conductivity estimates for wells 2 and 36; gravity-defined cross-sectional bedrock geometry at this location; and good correspondence between gravity and well control on the bedrock profile at this location.

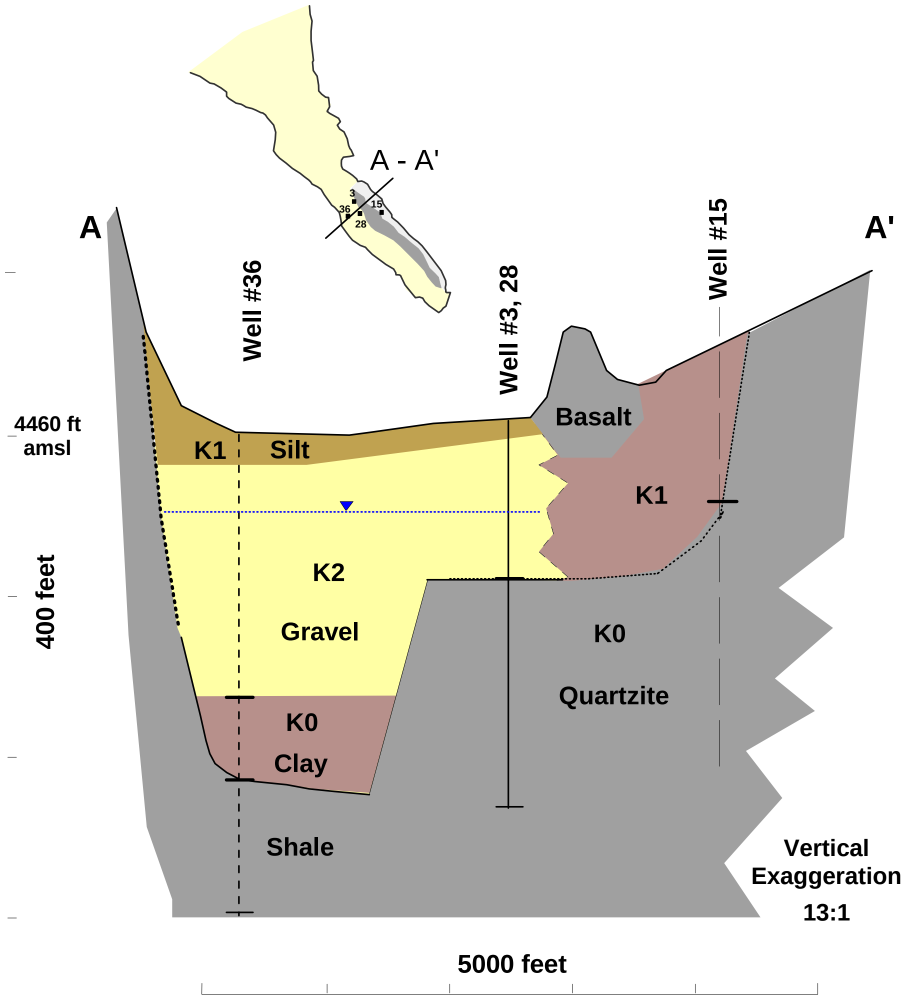

Figure A-4. Cross-section of the southern aquifer's bedrock-bounded outlet, looking to the northwest, immediately upgradient of Red Hill. Bedrock geometry is constrained by a detailed microgravity profile (Reid, 1997) and lithologic logs. Relative permeabilities: K0 < K1 << K2.

The maximum saturated cross-sectional area of the aquifer at well 36 is 2.5 x 10^5 ft^2, with less than a 4 percent variation among the water balance accounting periods. From pumping tests on Pocatello municipal well 36, the hydraulic conductivity of the aquifer (K2) is 8000 ft/day; silt- and clay-rich sediments and bedrock (K0, K1) in the section are at least three orders of magnitude less permeable. For an observed hydraulic gradient of 0.0013, underflow is estimated at 2.0 x 10^6 ft^3/day (5.3 Bgal/year).

Portneuf Gap Underflow (Qg)

Figure A-5 shows a cross-section of the Portneuf Gap, looking west. Micro-gravity data obtained from a traverse across the Portneuf Gap (Reid, 1997) were used to constrain the bedrock topography shown in the subsurface. Assuming that bedrock is relatively impermeable, the saturated area available for underflow through the Portneuf Gap is 3×10^4 ft^2. Based on four domestic wells whose water levels were monitored during 1994, the hydraulic gradient across the Gap was 0.0013. The hydraulic conductivity of gravels in this narrow notch was assumed to be comparable to or higher than the values seen at well 36 (also in a bedrock notch) and a value of 10,000 ft/day was assumed for these calculations. The estimated flux through the Gap is therefore 3.9×10^5 ft^3/day (1.06 Bgal/year). Since changes in saturated cross-sectional area were far less than the uncertainty in hydraulic properties, this flow rate was assumed to remain constant during the three water balance accounting periods.

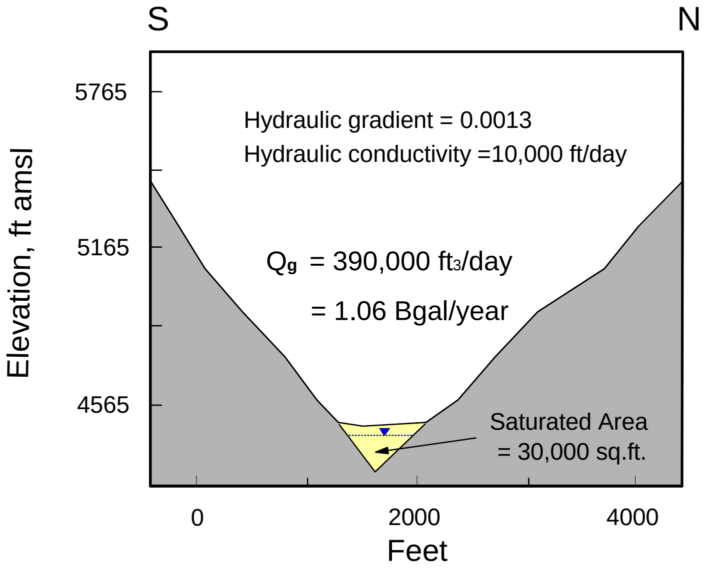

Figure A-5. Cross-section of the Portneuf Gap, looking west toward the southern aquifer, reconstructed from topography and gravity data.

Portneuf River Losses (Qr)

Norvitch and Larson (1970) postulated that the Portneuf River may lose water to the aquifer somewhere in the vicinity of the Portneuf Gap. Mean annual flow on the Portneuf River at Pocatello's gauging station is of the order of 8 ft^3/sec lower than the combined irrigation-adjusted flows of the Portneuf at the Topaz gage and Marsh Creek at the McCammon gauge. However, an analysis of discharge measurements made during base-flow conditions and chemical mass-balance modeling of the southern aquifer

(Meehan, 2005) indicate that the Portneuf River does not lose significant amounts of water to the aquifer.

Based on the southern aquifer's rapid response to past flooding conditions in the Portneuf Gap area,[6] it seems more likely that if the river does contribute substantial recharge below Portneuf Gap, it does so only during high-flow conditions. During the latter two water balance accounting periods, mean river discharge was within the base-flow regime in which Norvitch and Larson's (1970) data indicate negligible river losses. Therefore, significant river losses were assumed to have occurred only during the first water balance period, when river discharge exceeded 400 ft^3/sec for about 60 days. The difference in the water balance residual calculated with and without an additional 8 ft^3/sec river loss during this accounting period placed a lower limit on the magnitude of the annualized river recharge (Qr).

On this basis, the river's contribution to the aquifer during 1993 was 0.3 Bgal, on the assumption that a loss rate of 8 ft^3/sec applies only during spring runoff when flow exceeds 400 cfs and that negligible losses occur during normal and low-flow conditions. Prorated for a 365-day accounting period, river losses are estimated to contribute about 0.3 Bgal of aquifer recharge annually.

Aquifer Storage (ΔS)

Figure A-6 shows monthly water levels measured in southern aquifer production wells during 1993 and 1994, as derived from Pocatello Water Department records, together with continuous water level records from municipal well 28 and monitoring well PMW-2 and monthly water levels from a typical domestic well in the southernmost part of the aquifer near the Portneuf Gap. Water levels are shown as feet above the 4400 ft datum; wells with lower hydraulic heads are located farther downgradient. Changes in water level between the beginning and end of each water balance period are shown on the figure.

During Day 90-300, storage increased over the length of the aquifer but was greatest in the southernmost area, suggesting that a large part of the system's recharge originated from southern sources, such as the Portneuf Gap and the Mink Creek / Gibson Jack sub-basins. During Day 300-450, aquifer storage in the vicinity of wells 12 and 36 showed a slight decline, whereas storage appeared to decline about 2-3 times as much south of well 14. This suggests that most of the recharge during this period entered the aquifer north of well 14 (i.e., at the north end of the Gibson Jack watershed). During the third accounting period (Day 450-600), storage declines were approximately uniform in all parts of the southern aquifer, possibly indicating that the rates of recharge from the Bannock Range had, for the most part, approached baseflow along the length of the aquifer.

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[6] Based on prior anecdotal evidence and recently confirmed when the Portneuf reached flood stage in March-May, 2006, when the water table rose 18 feet in six weeks.

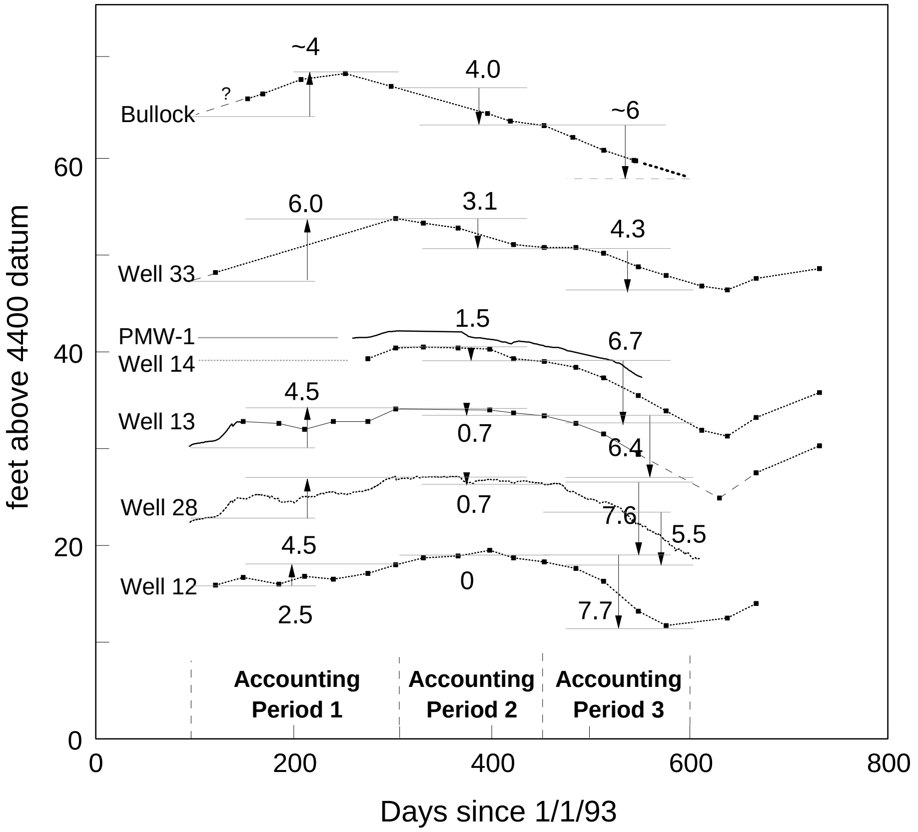

Figure A-6. Water level records in southern aquifer wells that were used to estimate changes in aquifer storage during the water balance period. Changes in head during each accounting period are shown beside the arrows indicating storage increase or decrease (in feet). During day 300-450 and day 450-600, heads declined an average of 1.0 ft and 6.4 ft, respectively. During day 90-300, heads increased an average of 5.0 feet, with the largest increase at Well 33 indicating that the Mink Creek / Gibson Jack watersheds contributed the most recharge. On the other hand, the southernmost wells showed the largest decline during day 300-450, suggesting that recharge from Mink Creek had waned by this time.

If the Bannock Range is the most important source of recharge to the southern aquifer, the differential responses observed during the first two water balance periods suggest that ground water flow rates and recharge may differ along this part of the Bannock Range. This hypothesis is consistent with the varied geology of the Bannock Range, and the fact that areas of limestone, many of them containing evidence of karstification, exist in both the Mink Creek and Gibson Jack watersheds. Substantial areas of karst limestone have been identified in mapping work conducted in the Mink Creek basin (S. Van Hoff, unpubl. data), and limestone outcrops over much of the middle and lower reaches of the Gibson Jack watershed (Rodgers and Othberg, 1999).

Based on the average of water level changes shown in Figure A-6, an aquifer area of 89.5 x 10^6 ft^2, and a mean porosity of 0.25, storage increased by 112 x 10^6 ft^3 (0.84 Bgal) during Day 90-300 and decreased by 143 x 10^6 ft^3 (1.07 Bgal) during Day 450-600.

A.3. DISCUSSION OF WATER BALANCE RESULTS

Figure A-7 and Table A-2 summarize the results of the overall water balance accounting. Figure A-8 summarizes the results by each accounting subperiod. The water balance "residual" represents the total of all unknown recharge inputs including those from the Bannock Range, the eastern valley margin, and the Portneuf River. As discussed in Section A.1.2, Qe and Qr are both believed to be relatively small, so that the computed residual less Qr represents the sum of all Bannock Range recharge to the southern aquifer (Qb).

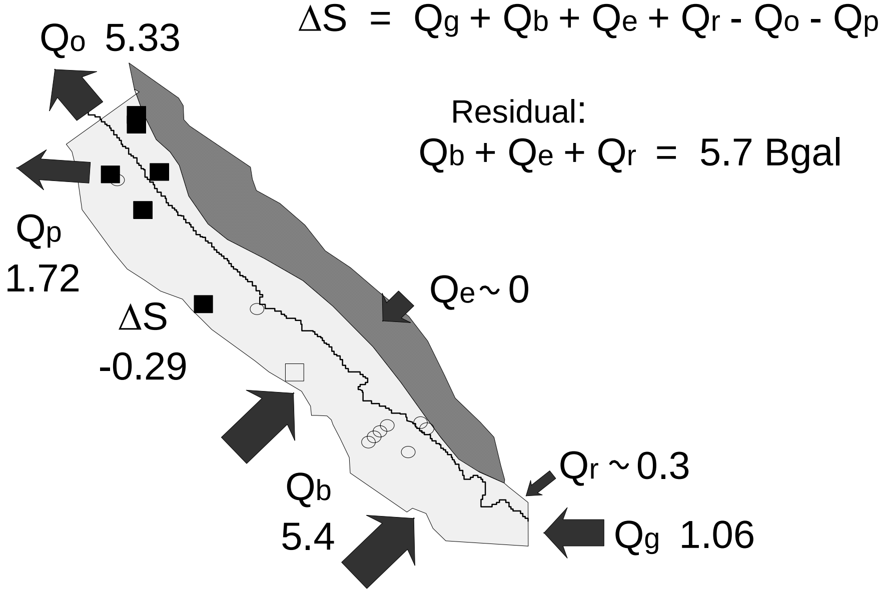

Figure A-7. Results of the southern aquifer water balance, as annual averages reflecting the 1993-94 accounting period. Best available estimates for inflow through the Portneuf Gap (Qg), underflow past Red Hill (Qo), total pumping demand (Qp), and storage change (ΔS) are expressed in billions of gallons per year. Bannock Range recharge (Qb) is believed to dominate the water balance residual (Qb + Qe +Qr) because recharge from the river and the eastern valley margin are thought to be small.

Referring to Figure A-8 and Table A-2, computed recharge was greatest during the first water balance accounting period, as would be expected for the period in which the system received its largest spring runoff pulse from above-normal snowpack. Recharge subsequently declined through the winter of 1993 and was far lower in 1994. The results clearly demonstrate that the southern aquifer is dependent on Bannock Range recharge to replenish storage lost during peak summer pumping, and that pumping has the largest impact on the aquifer during years of low precipitation (such as in 1994).

Note that annual withdrawals in the northern LPRV are three and a half times those from the southern aquifer (Table A-2). Since underflow across the bedrock lip at Red Hill (Qo) likely recharges the shallowest part of the northern aquifer and since most of the northern wells tend to be perforated in the uppermost confined aquifer, the southern aquifer probably supplies most of the pumping demand in Pocatello's northern well field. Chubbuck's municipal wells, farther to the north, are completed in volcanic units of the eastern Snake River Plain (ESRP) province and are >300 feet deep, so they may draw on a combination of ground water from LPRV and ESRP recharge.

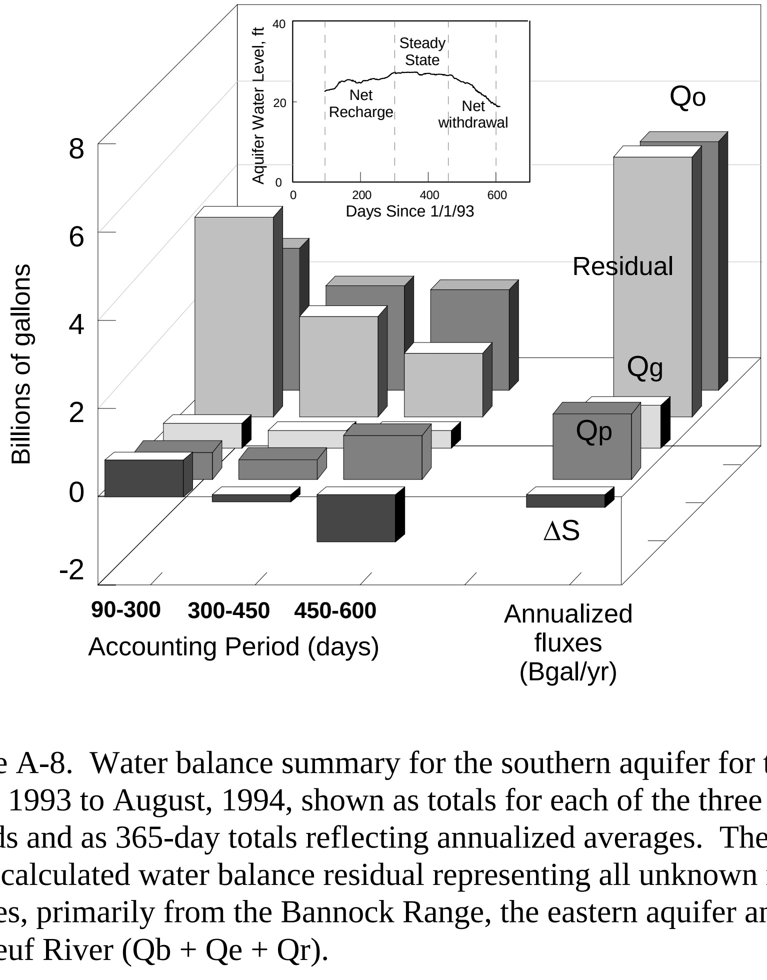

Figure A-8. Water balance summary for the southern aquifer for the period April, 1993 to August, 1994, shown as totals for each of the three accounting periods and as 365-day totals reflecting annualized averages. The "Residual" is the calculated water balance residual representing all unknown recharge sources, primarily from the Bannock Range, the eastern aquifer and the Portneuf River (Qb + Qe + Qr).

Table A-2. Summary of southern aquifer water balance. All values are in billions of gallons. Pumping totals include documented municipal and estimated non-municipal demand during the accounting periods. Portneuf River losses were assumed to have occurred only during high-flow conditions of 1993's spring runoff. The water balance residual includes recharge from all possible sources, including the river. Pumping totals for the northern aquifer are provided for reference.

Accounting period (days since 1/1/1993)	---------Pumping Totals---------- N. Aquifer	S. Aquifer (Qp)	Red Hill Outflow Qo
90-300 (wet spring)	3.72	0.88	3.05
300-450	1.23	0.46	2.24
450-600 (dry summer)	3.59	1.06	2.16
510-day Totals	8.54	2.40	7.45
365-day Totals	6.11	1.72	5.33

Accounting period (days since 1/1/1993)	S. Aquifer Storage ΔS	Portneuf Gap Inflow Qg	Portneuf River Qr	Water Balance Residual (Qb+Qe+Qr)
90-300 (wet spring)	0.84	0.61	0.31	4.16
300-450	-0.17	0.44	0.00	2.10
450-600 (dry summer)	-1.07	0.44	0.00	1.71
510-day Totals	-0.40	1.49	0.31	7.96
365-day Totals	-0.29	1.06	0.31	5.70

If the northern aquifer relies on outflow from the southern aquifer for most of its recharge, then the LPRV's ground-water capacity will be constrained by development activities in the southern aquifer. The 1993-94 water balance suggests that total pumping demand in the northern and southern well fields (6.8 Bgal/yr) was equal to the system's total recharge capacity (Qg + Qb + Qe + Qr = 6.8 Bgal/yr). Lacking a major source of recharge in the northern LPRV, any future system deficits (demand > capacity) will induce ground-water inflow from the ESRP into the northern LPRV; in other words, the LPRV may cease to be a tributary ground-water source to the ESRP aquifer. If so, then the most logical place to site new wells would be in the northern valley, since the LPRV's upstream capacity is close to or is being exceeded under normal hydrologic conditions and current demand.