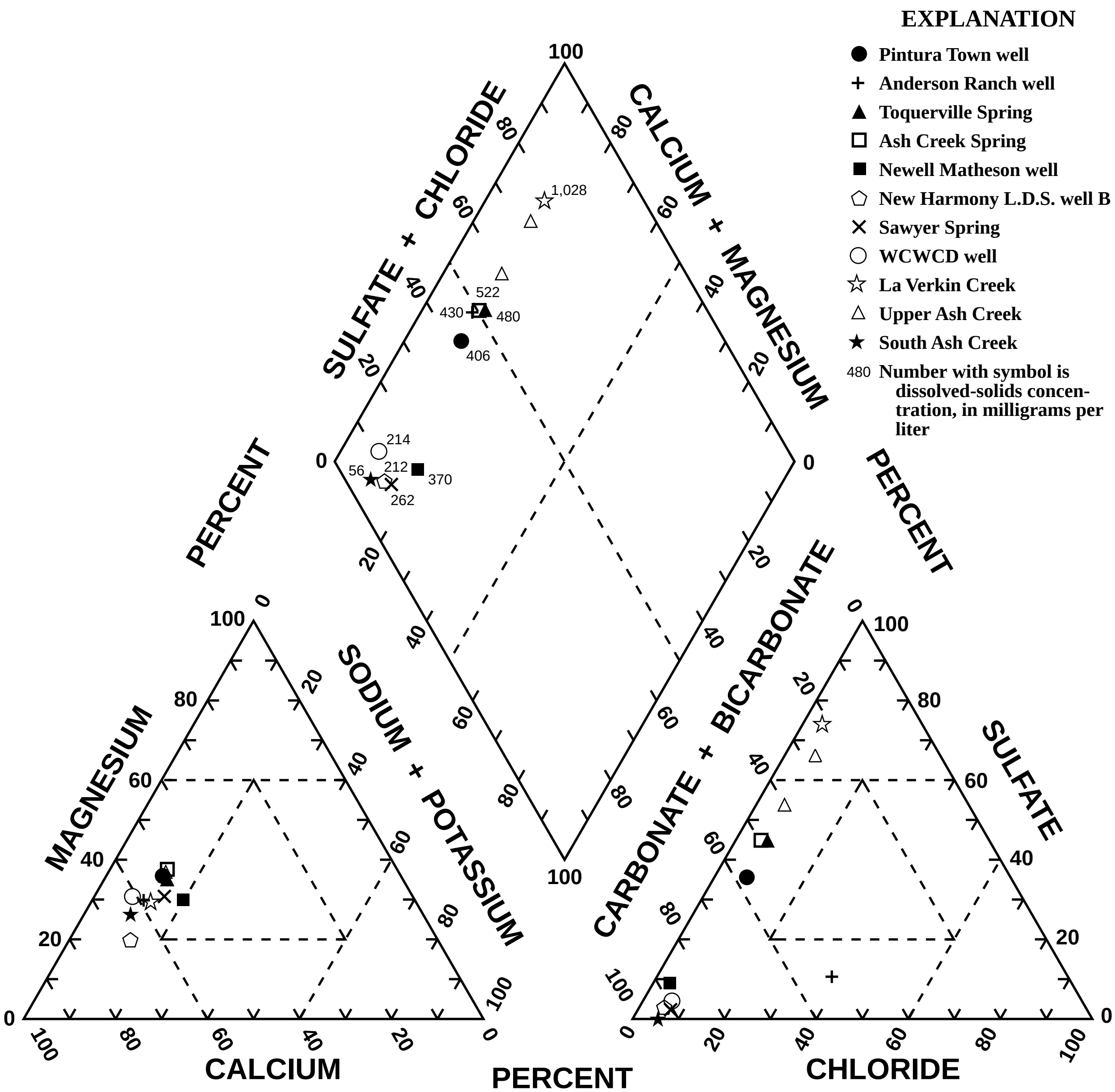

Figure 14. Chemical composition of ground water and surface water along the Ash Creek drainage, Utah.

water system. Additionally, the recharge could be better defined by measuring seepage losses (1) along creeks entering the lower Ash Creek drainage, (2) from Ash Creek Reservoir, and (3) along Ash Creek between Toquerville Springs and the confluence with the Virgin River. Such information would be helpful in more accurately identifying possible sources of water for Toquerville and Ash Creek Springs.

GROUND-WATER HYDROLOGY

Upper Ash Creek Drainage Basin Ground-Water Flow System

The 134-mi^2 drainage basin for Ash Creek Reservoir includes several geographic features that affect the ground-water system in distinctive ways. The basin floor is where most of the irrigation, evapotranspiration, ground-water discharge, and stream-aquifer interaction occur. The Hurricane Fault is a hydrologic boundary along the eastern edge of the basin floor and likely precludes subsurface flow into the system from the Markagunt Plateau. The high plateau east of the Hurricane Fault is where precipitation is greatest, but recharge to the principal alluvial aquifers is only through ephemeral streams that flow across the Hurricane Fault. Because of the large amount of precipitation along the north slope of the Pine Valley Mountains, recharge from infiltration of precipitation to the upper Ash Creek drainage basin ground-water system is assumed to be substantial. Along the low hills to the west and north, precipitation and recharge from infiltration of precipitation are assumed to be moderate. Lastly, the fractured basalt flows at the south end of the basin likely act as a drain for subsurface outflow from the ground-water system. A generalized conceptualization of how water recharges to and discharges from the upper Ash Creek drainage basin ground-water system is shown in figure 15.

Aquifer System Geometry and Hydrologic Boundaries

The upper Ash Creek drainage basin includes numerous igneous and sedimentary rocks, and unconsolidated deposits that contain ground water (pl. 1). The aquifer system of the upper Ash Creek drainage basin consists of three aquifers, all on the west side of the Hurricane Fault. The uppermost Quaternary basin-fill

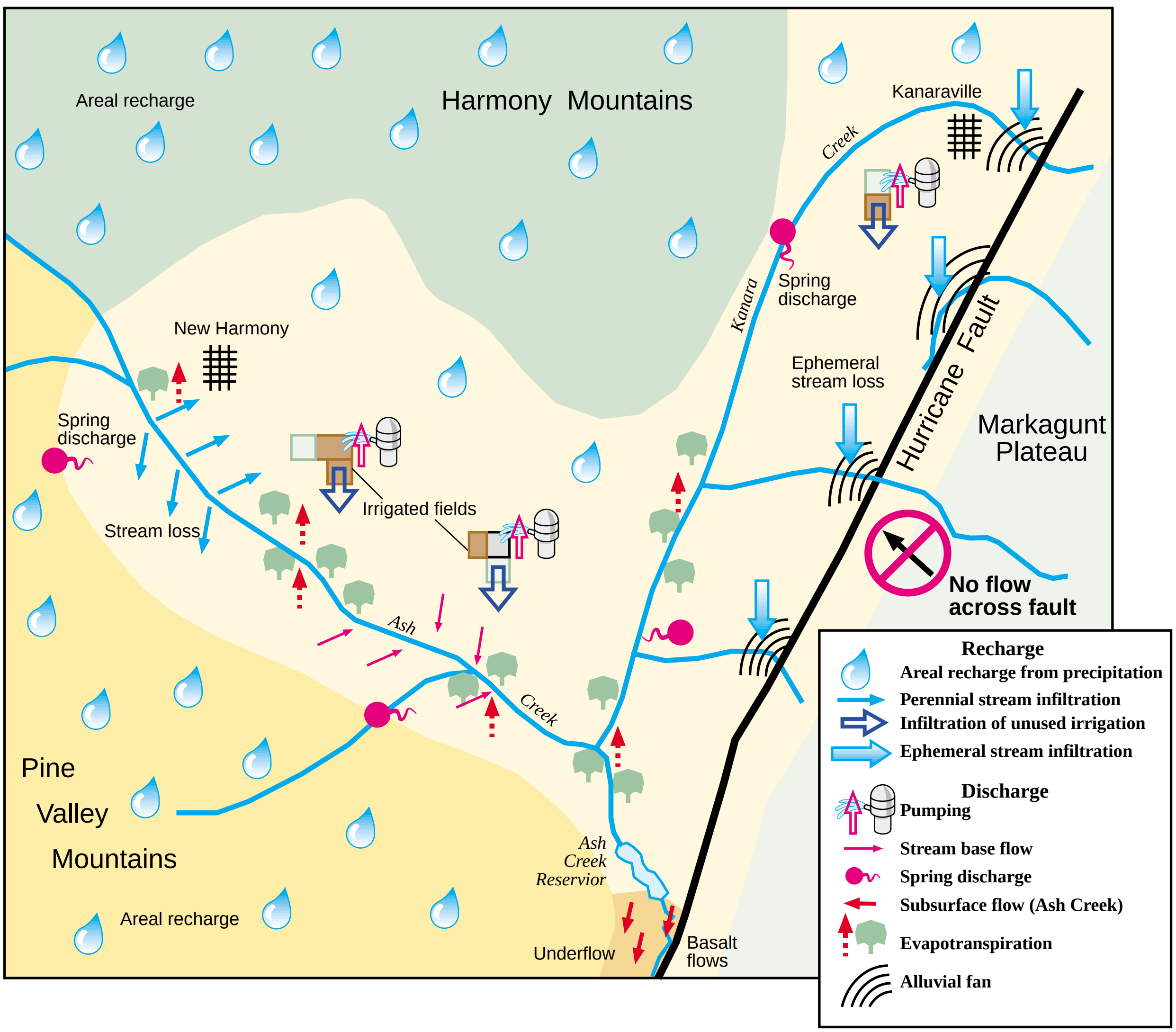

Figure 15. Generalized diagram showing sources of recharge to and discharge from the upper Ash Creek basin ground-water system, Utah.

aquifer has the smallest areal extent. It is confined between the Hurricane Fault and the beginning edge of the Harmony and Pine Valley Mountains (fig. 16). From west to east it is about 2 to 3 mi wide near Kanarraville where the edge of the Harmony Mountains are closest to the Hurricane Fault, and about 6 mi wide at the latitude of the town of New Harmony. The Tertiary alluvial-fan aquifer, which is thought to underlie the basin-fill aquifer in the vicinity of Kanarraville, extends about 5 mi west from the Hurricane Fault where it ends at the lower slopes of the Harmony Mountains. The alluvial-fan aquifer is about 6.5 mi wide at the latitude of the town of New Harmony. The Tertiary Pine Valley monzonite aquifer and other consolidated rock aquifers of the Harmony Mountains extend throughout the rest of the drainage basin and underlie the alluvial-fan aquifer at the southwest end of the Ash Creek valley. The existence of this aquifer at depth under the alluvial-fan deposits in the middle and northern parts of the valley has not been confirmed.

The basin-fill aquifer is thickest (1,500 ft) (Hurlow, 1998) near the Hurricane Fault, about 200 to 500 ft thick east of New Harmony, and less than 100 ft thick under most of the Ash Creek stream channel. The aquifer thins to less than 200 ft on the west as it merges with the alluvial-fan aquifer near the base of the Harmony Mountains. The alluvial-fan aquifer is thought to be about 1,200 to 1,400 ft thick throughout the upper Ash Creek drainage basin (Hurlow, 1998, pl. 2). The thickness of the Pine Valley monzonite aquifer is unknown, but it is thought to be in excess of 2,000 ft.

The hydrologic boundaries of the system are thought to correlate closely with structural and watershed boundaries. The eastern boundary is presumed to be the Hurricane Fault, which, because of the large offset and associated fine-grained fault gouge (Hurlow, 1998), would likely be a barrier to ground-water flow from the east. The northern boundary is a ground-water divide north of Kanarraville, as defined in Thomas and Taylor (1946). Water-level measurements from 1995 indicate that the location of this divide has apparently moved about 2 mi farther south than the reported location in 1946, probably because of increased well discharge in Cedar Valley to the north. The northern, western, and southern lateral boundaries of the basin-fill and alluvial-fan aquifers are defined by their areal extent. The boundaries for the Pine Valley monzonite aquifer are defined by the watershed boundary (surface-water divide) of Ash Creek basin. The southern discharge boundary of all three aquifers is presumed to be the fractured basalt flows near Ash Creek Reservoir in the narrow part of the Ash Creek Valley. Ground water can move through fractures in this basalt or through interbedded and underlying coarse-grained, unconsolidated deposits reported by Hurlow (1998). All three aquifers are assumed to be present in this area, although the existence of the alluvial-fan and Pine Valley monzonite aquifers is not a certainty because no wells have been drilled to that depth. The depth of the lower boundary for the system, the contact between the fractured igneous rocks and underlying formations, is not known. It is assumed that no ground water moves across this contact. The upper boundary of the system is the transition between the saturated and unsaturated material regardless of which aquifer is uppermost, and is the main avenue for recharge to and discharge from all aquifers.

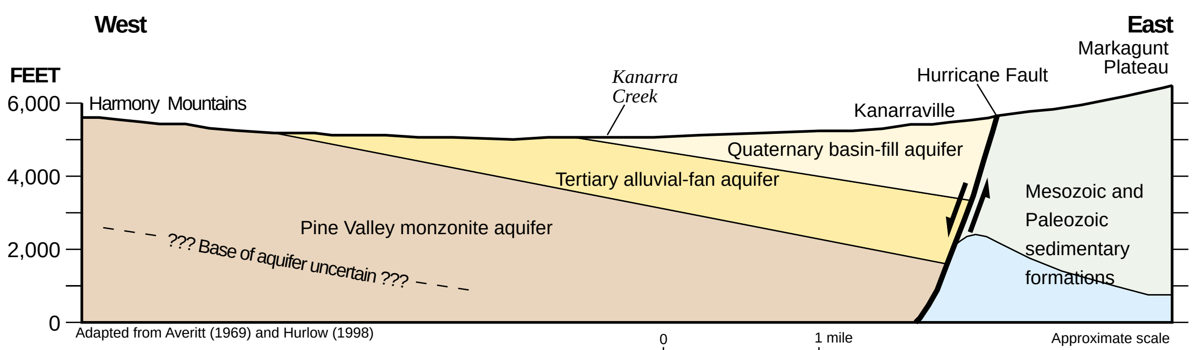

Figure 16. Schematic hydrogeologic section showing subsurface geometry from northwest to southeast near Kanarraville, Utah.

Table 5. Transmissivity of three aquifers in the upper Ash Creek drainage basin, Utah

Aquifer	Transmissivity range from aquifer testing (feet squared per /day)	Hydraulic conductivity from (Cordova, Sandberg, and McConkie, 1972) (feet per day)	Average specific capacity	Minimum specific capacity	Maximum specific capacity	Number of specific-capacity values available
			(gallons per minute per foot of drawdown)			
Basin fill	[1]2,540 -16,000	35 to 200	9.7	0.1	47	16
Alluvial fan	—	—	1.5	.05	2.5	9
Pine Valley monzonite	—	—	12.2	.5	73	11

[1]Range based on four aquifer tests.

Aquifer Properties

The three aquifers defined for the upper Ash Creek drainage basin have variable transmissivity and storage capacity. On the basis of specific-capacity values from wells, aquifer testing, and previously reported transmissivity values, the Pine Valley monzonite aquifer is the most transmissive and the alluvial-fan aquifer is the least transmissive (table 5). The basin-fill aquifer is moderately permeable around Kanarraville, but poorly permeable near the Hurricane Fault directly east of New Harmony. Cordova, Sandberg, and McKonkie (1972) reported that the hydraulic conductivity of the basin fill near Kanarraville was about six times higher than it was 5 mi farther south. The reasons for this difference are unknown but are probably related to depositional history. Specific capacity of the alluvial-fan aquifer indicates that it may be a poor aquifer. Specific-capacity values are about 10 times smaller than values for the other two aquifers. The Pine Valley monzonite aquifer is transmissive where wells penetrate fractures in the rock. Analysis of water-level data after 6 days of constant-rate pumping from an irrigation well and an observation well south of Ash Creek indicates that horizontal anisotropy is substantial and that the aquifer properties cannot be analyzed by using flow equations for porous media. The observation well and pumped well were about 500 ft apart and apparently open to the same fracture, which was highly conductive. Drawdown in the pumped well pumping at 1,100 gal/min was only 15 ft after 6 days of pumping. The specific capacity of the well was 73 gal/min/ft of drawdown, the highest measured value for the basin. However, without additional observation wells located off of the fracture zone connecting the two wells, the long-term production capability of the aquifer cannot be determined with confidence (Victor Heilweil, U.S. Geological Survey, 1998, written commun., Aquifer test at well C-38-13-35aba,).

The presence of a proposed fault (Hurlow, 1998) that runs approximately north-to-south beneath New Harmony and then southwest into the Pine Valley Mountains (pl. 1) may have some effect on the hydraulic conductivity of the Pine Valley monzonite aquifer. Differences in water levels between wells drilled on the west and east sides of this fault zone indicate a relatively steep hydraulic gradient (about 0.035), whereas hydraulic gradients to the east are less steep (0.014 to 0.019). This indicates that the fault zone may have a lower transmissivity (and hydraulic conductivity) perpendicular to the fault direction than there is in areas that are not faulted. Hugh Hurlow (Utah Geological Survey, oral commun., 1998) has also observed northeast-southwest fractures at outcrops of the Pine Valley monzonite. This could cause anisotropic conditions in this part of the Pine Valley monzonite aquifer.

The storage capacity of aquifers is often assumed to be the percentage of interconnected pore space in the aquifer, or effective porosity. This is true in theory but not in practice. All water in pore spaces cannot be removed because of the molecular attraction of water to the aquifer materials. The actual storage capacity is better measured through hydraulic testing which allows for the estimation of the aquifer’s storage properties; storage coefficient for confined aquifers and specific yield for unconfined aquifers. Both confined and unconfined conditions likely occur in various places throughout the study area in the aquifers described. Confined conditions result when fine-grained layers overlie and confine coarse-grained layers that are more transmissive. This confinement allows hydraulic heads to increase to greater than atmospheric pressure, and water removed comes from a release in that pressure and subsequent compaction of the aquifer skeleton and expansion of water. Water released from an unconfined aquifer is from dewatering the pore space in the aquifer (Freeze and Cherry, 1979). On the basis of aquifer tests and observation of sediments penetrated in drill holes, Cordova, Sandberg, and McConkie (1972) estimated the storage coefficient of the basin-fill aquifer to range from 0.0001 to 0.0004, and specific yield to be about 0.30. Storage properties of the alluvial-fan and Pine Valley monzonite aquifers are not available from aquifer testing. Although the transmissivity and hydraulic conductivity in the alluvial-fan aquifer are probably an order-of-magnitude lower than those of the basin-fill aquifer, it cannot be assumed that the storage coefficient in that aquifer is similarly low. However, specific yield would likely be somewhat less than that of the basin-fill aquifer because of the greater degree of cementation, tighter packing of grains, and poorer sorting of grain sizes, which would tend to decrease effective porosity, increase specific retention of ground water, and decrease specific yield. The storage capacity of a fractured crystalline rock such as the Pine Valley monzonite will be substantially smaller than either of the aquifers composed of unconsolidated deposits. Primary porosity, the principal factor that determines the amount of ground water stored, is typically only a fraction of 1 percent in crystalline rocks and rarely exceeds 2 percent (Freeze and Cherry, 1979). Secondary porosity from fracture openings, although responsible for large ground-water velocities, is not large enough to create substantial storage capacity. Bulk fracture porosity generally accounts for only a few percent of effective porosity in consolidated rocks, and even then is usually only present in the first 300 ft below land surface.

Recharge

The Upper Ash Creek drainage basin ground-water system is recharged by rain and melting snow that infiltrates until reaching the uppermost saturated zone. This process includes seepage losses from perennial streams, by periodic seepage losses from ephemeral streams, and possibly by infiltration of unconsumed irrigation water. The amount of recharge by these mechanisms is estimated to range from 6,100 to 18,800 acre-ft/yr.

Precipitation

Precipitation is the principal means by which the ground-water system of the upper Ash Creek drainage basin is recharged; however, it is believed that only precipitation falling west of the Hurricane Fault recharges the system through direct infiltration. Several things typically happen to precipitation as it falls or after it falls. It can evaporate as it is falling, after it reaches land surface, or after it enters the subsurface. It can be intercepted by plants above ground or used by plant roots below land surface. It can run off into drainage channels and eventually flow into stream channels. It can infiltrate into the unsaturated zone below the plant root zone and remain there until subsequent infiltration pushes it deeper into the uppermost saturated zone. Estimated total annual precipitation for the Ash Creek drainage basin is about 153,000 acre-ft (table 6). About 109,000 acre-ft falls on the west side of the Hurricane Fault and the remainder falls on the Markagunt Plateau east of the fault. Only a small amount of the total precipitation typically recharges a ground-water system through direct infiltration.

Average annual recharge from precipitation was estimated using precipitation-recharge relations developed in previous studies. On the basis of budget calculations and change in storage, Bjorklund, Sumsion, and Sandberg (1978) estimated that about 8.5 percent of total precipitation recharges the ground-water systems in Cedar and Parowan Valleys, north of the upper Ash Creek drainage basin. If this percentage is assumed, total average annual recharge to the Ash Creek aquifer system is estimated to be 9,200 acre-ft (table 6). Harrill and Prudic (1998) and Anderson (1995) developed precipitation-recharge relations for alluvial basins of Nevada and Arizona. These relations were developed by correlating known or estimated recharge with the amount of precipitation in excess of 8 in. falling on a basin. The recharge estimates were obtained from several sources including ground-water flow modeling, water-budget analyses, chloride-balance (Dettinger, 1989), and the Maxey-Eakin method (Maxey and Eakin, 1949). Precipitation in excess of 8 in. for the upper Ash Creek drainage basin west of the Hurricane Fault is about 66,000 acre-ft/yr. Recharge from infiltration of precipitation west of the Hurricane Fault using Harrill and Prudic’s relation was 3,600 acre-ft/yr. Recharge using Anderson’s relation was 2,600 acre-ft/yr. The percentage of recharge derived from precipitation is areally variable and depends on a host of climatic factors such as the amount and duration of

Table 6. Precipitation and recharge in subbasins of the upper Ash Creek drainage basin, Utah

Name of subbasin	Range of normal annual precipitation 1961-90 (feet)	Area of basin (acres)	Annual volume of precipitation (acre-feet)	Volume of precipitation greater than 8 inches (acre-feet per year)	Recharge using Anderson (1995) (acre-feet per year)	Recharge using Harrill and Prudic (1998) (acre-feet per year)	Recharge using 8.5 percent of total precipitation Bjorklund, Sumsion, and Sandberg (1978) (acre-feet per year)	Area (square miles)
Subbasins west of the Hurricane Fault								
Upper Ash Creek Valley floor	1.46-1.96	22,000	33,240	18,580	600	900	2,800	34.3
Harmony Mountains	1.46-1.88	16,710	27,850	16,720	500	800	2,400	26.1
Pine Valley Mountains	1.46-2.46	25,140	47,440	30,680	1,000	1,600	4,000	39.3
Subtotal	1.46-2.46	63,850	108,530	65,980	2,100	3,300	9,200	99.7
Subbasins east of the Hurricane Fault								
Kanarra Creek	1.71-2.54	6,410	14,040	9,760	No recharge to upper Ash Creek drainage basin by direct infiltration east of fault			10
Spring Creek	1.71-2.46	3,620	7,640	5,230				5.7
Camp Creek	1.71-2.38	2,900	6,030	4,100				4.5
Taylor Creek	1.63-2.29	4,400	8,600	5,670				6.9
Other	1.54-2.04	4,620	7,840	4,760				7.2
Subtotal	1.54-2.54	21,950	44,150	29,520				34.3
Total	1.46-2.54	85,800	152,680	95,500				134

precipitation, topographic setting, altitude, temperature, aspect, vegetation, latitude, and others. For example, a smaller percentage of the total precipitation near Ash Creek Reservoir (about 17 in. annually) probably recharges the basin-fill aquifer than in the Pine Valley Mountains, where total precipitation is about 29 in. annually. The variability between methods is attributable mostly to climatic factors, particularly temperature. Lower altitudes typically have higher temperatures, which results in more of the precipitation being evaporated and transpired than would occur at a higher altitude.

The estimated precipitation on the upper Ash Creek valley floor is about 33,000 acre-ft/yr. Infiltration of precipitation likely is smallest here because lower altitudes and higher temperatures increase soil-zone evaporation and transpiration. In addition, infiltration of precipitation likely has been decreased in specific valley locations because of human development such as roads, houses, and croplands. The minimum amount of estimated infiltration, determined from precipitation-recharge relation developed by Harrill and Prudic (1998) and Anderson (1995), is about 600 acre-ft/yr. The maximum amount of estimated infiltration, determined by the Cedar-Parowan basin study (Bjorklund, Sumsion, and Sandberg, 1978) is about 2,800 acre-ft/yr.

The Pine Valley and Harmony Mountains receive about 75,000 acre-ft of precipitation annually, much of it as snow during the colder months when temperatures and evaporation rates are low. The mountains typically have a thinner soil cover than the valley floor, which allows more rapid infiltration. However, steeper slopes promote more rapid runoff than the flat areas in the valley; thus, slowly melting snow provide the optimum recharge source. The minimum amount of estimated infiltration, determined from precipitation-recharge relation developed by Anderson (1995), is about 1,500 acre-ft/yr. The maximum amount of estimated infiltration, determined from the Cedar-Parowan basin study, is about 6,400 acre-ft/yr.

Streams

Discharge measurements along perennial and ephemeral streams indicate that the upper Ash Creek drainage basin ground-water system is partially recharged by stream seepage. Discharge in Ash Creek was measured at eight sites from just south of the town of New Harmony to the abandoned Highway 91 bridge near Ash Creek Reservoir (fig. 17) as part of a seepage study done in October 1995 (Wilkowske and others, 1998, table 6). The study indicates that seepage to the aquifers may occur in the central and lower reaches of the stream. Streams draining the Markagunt Plateau are ephemeral before they cross the Hurricane Fault but lose all of their flow after crossing the fault. During spring runoff they may flow throughout their entire length. One-time measurements on four of these streams in 1995 indicated a combined discharge of about 4 ft^3/s (2,900 acre-ft/yr). Analysis of base flow for these streams indicates that recharge could be occurring during the winter when vegetation is dormant and during spring runoff. Other ephemeral streams flow for brief periods when snow is melting or intense rainfall occurs. The amount of recharge resulting from these flows is not known.

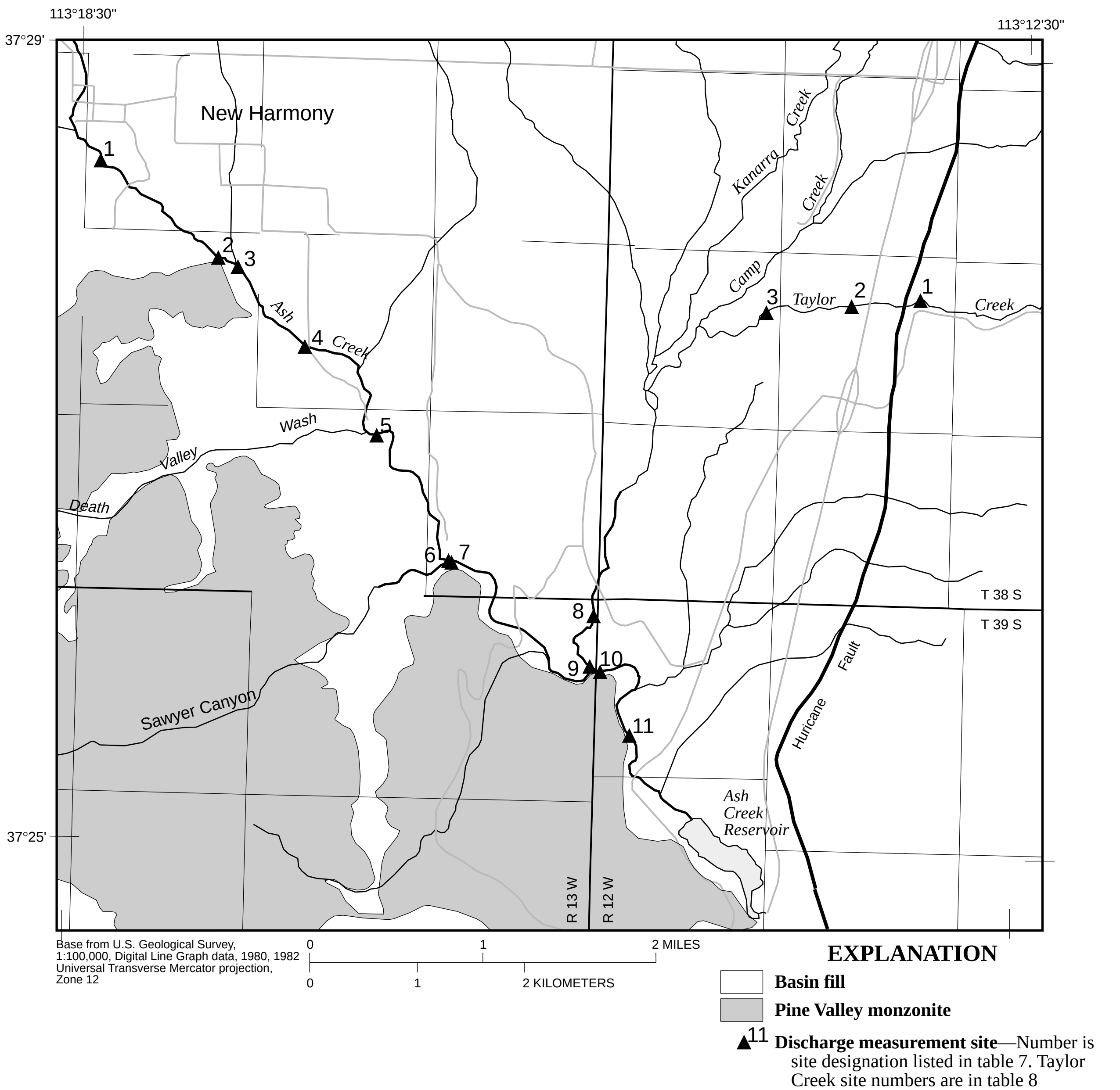

Figure 17. Location of streamflow-gaging sites for seepage investigations on Ash, Sawyer, Kanarra, and Taylor Creeks, upper Ash Creek drainage basin, Utah.

Perennial Streams

Ash Creek is fed from tributaries flowing out of the Pine Valley and Harmony Mountains. It is perennial in certain reaches and ephemeral in others. Average discharge for nine years of streamflow record from a streamflow-gaging station near the present site of Ash Creek Reservoir (1939-47) is 10.6 ft^3/s (7,700 acre-ft/yr). Monthly mean discharge averaged for the period of record ranges from 1.1 ft^3/s (800 acre-ft/yr) in July to 28.8 ft^3/s (20,900 acre-ft/yr) in April. Base flow, the flow attributed only to ground-water inflow, was estimated from monthly mean flows for December and January and probably ranges from 1 to 4 ft^3/s (725 to 2,900 acre-ft/yr). Cordova, Sandberg, and McConkie (1972) estimated about 3 ft^3/s (2,200 acre-ft/yr) of seepage to Ash Creek in 1970. On the basis of a seepage investigation in October 1995 (fig. 17), some reaches of the stream lose water to the aquifers (table 7). A half-mile long stream reach starting about 2 mi downstream from New Harmony lost about 0.6 ft^3/s (440 acre-ft/yr) to the unconsolidated aquifers. The reach from the Sawyer Creek confluence to about 1 mi upstream of the Ash Creek Reservoir spillway lost about 0.7 ft^3/s (500 acre-ft/yr) to the same aquifers. A seepage study in October 1995 (Wilkowske and others, 1998) along the perennial section of Kanarra Creek near the inflow to Ash Creek indicates that the last $^1/_3$ mi of Kanarra Creek upstream from its confluence with Ash Creek lost about 0.08 ft^3/s (60 acre-ft/yr) to the aquifers. Because only one series of seepage investigations has been conducted, it is not known if losses measured in October 1995 were sustained throughout the year, or even if these losses are sustained from year to year. On the basis of the yearly variability in flow in all perennial streams, total recharge from perennial streams is estimated to range from 0.7 to 1.5 ft^3/s (500 to 1,100 acre-ft/yr).

Table 7. Measurements of discharge, temperature, and specific conductance and analysis of seepage losses and gains at selected sites on Ash, Kanarra, and Sawyer Creeks, upper Ash Creek drainage basin, Utah

[ft^3/s, cubic feet per second, acre-ft/yr, acre-feet per year]; µS/cm, microsiemens per centimeter at 25 decrees Celsius

<table>
<tr><th>Measurement site</th><th>Date</th><th>Discharge ft^3/s</th><th>Losses (Recharge to the aquifer) ft^3/s (acre-ft/yr)</th><th>Gains (Discharge from the aquifer) ft^3/s (acre-ft/yr)</th><th>Temperature, degrees Celsius</th><th>Specific conductance, µS/cm at 25°C</th></tr>
<tr><td colspan="7">Ash Creek</td></tr>
<tr><td>Ash Creek #1</td><td>10-10-95</td><td>0.553</td><td></td><td rowspan="2">.97 (700)</td><td>13.0</td><td>340</td></tr>
<tr><td>Ash Creek #2</td><td>10-10-95</td><td>1.52 outflow</td><td></td><td>12.0</td><td>435</td></tr>
<tr><td>Ash Creek #3</td><td>10-10-95</td><td>.090</td><td></td><td rowspan="2">.96 (695)</td><td></td><td></td></tr>
<tr><td>Ash Creek #4</td><td>10-10-95</td><td>1.05</td><td rowspan="2">.61 (440)</td><td>15.0</td><td>520</td></tr>
<tr><td>Ash Creek #5</td><td>10-10-95</td><td>.444</td><td rowspan="3">0</td><td></td><td>470</td></tr>
<tr><td>Mountain Spring diversion</td><td></td><td>.2 estimated outflow</td><td></td><td></td><td></td></tr>
<tr><td>Ash Creek #6</td><td>10-11-95</td><td>.238</td><td rowspan="4">.51 (370)</td><td>10.0</td><td>510</td></tr>
<tr><td>Sawyer Creek #7</td><td>10-11-95</td><td>1.56 inflow</td><td></td><td>12.0</td><td>480</td></tr>
<tr><td>Kanarra Creek #9</td><td>10-11-95</td><td>.280 inflow</td><td></td><td>16.0</td><td></td></tr>
<tr><td>Ash Creek #10</td><td>10-11-95</td><td>1.57</td><td></td><td>11.5</td><td>840</td></tr>
<tr><td>Ash Creek # 11</td><td>10-11-95</td><td>1.39</td><td>.18 (130)</td><td></td><td>16.0</td><td>830</td></tr>
<tr><td>Total</td><td></td><td></td><td>1.30 (940)</td><td>1.93 (1,400)</td><td></td><td></td></tr>
<tr><td colspan="7">Kanarra Creek</td></tr>
<tr><td>Kanarra Creek start</td><td>10-11-95</td><td>0</td><td></td><td rowspan="2">.357 (260)</td><td></td><td></td></tr>
<tr><td>Kanarra Creek #8</td><td>10-11-95</td><td>.357</td><td rowspan="2">.080 (60)</td><td>16.0</td><td>2,500</td></tr>
<tr><td>Kanarra Creek #9</td><td>10-11-95</td><td>.280</td><td></td><td>16.0</td><td></td></tr>
</table>

Ephemeral Streams

Recharge from ephemeral streams whose source is the Markagunt Plateau depends substantially on the hydrologic character of the Hurricane Fault. Observations indicate that ground-water movement in the sedimentary formations east of the Hurricane Fault is different than ground-water movement west of the fault and that the two ground-water systems may be isolated from one another. Water-level data from wells completed in the basin-fill aquifer near the fault zone indicate that potentiometric contours would be nearly perpendicular to the fault. This is typical of no-flow boundaries. Results from three surface-water discharge measurements in October 1995 along Taylor Creek and single discharge measurements on Camp and Spring Creeks as they traverse the fault indicated that virtually all flow ceased a short distance (less than 0.75 mi) after traversing the fault zone (table 8). October through March is usually when these stream flow because vegetation along the channels is dormant. Thus, if recharge occurs at a similar rate for 6 months, the likely minimum recharge to the basin-fill aquifer from these streams when they flow is assumed to be equal to one-half of base-flow discharge of the streams. Additional recharge could take place during the higher flows of spring runoff, but the amount of this recharge is unknown.

Long-term discharge records exist only for Kanarra Creek; thus, an estimate of average base flow for Spring, Camp, and Taylor Creeks was roughly determined by (1) deriving a mean annual discharge by using the regression equation from Christensen and others (1985), (2) adjusting the calculated mean annual discharge on the basis of the difference between calculated and measured mean-annual discharge for Kanarra Creek, and (3) estimating base flow for Spring, Camp, and Taylor Creeks by using the ratio (base flow/mean annual discharge) from Kanarra Creek. The result was a minimum annual recharge rate of almost 7 ft^3/s during the 6 months while the streams were flowing, or an annual total of 2,500 acre-ft.

Several ephemeral stream washes also begin in the Harmony and Pine Valley Mountains and drain into Kanarra and Ash Creeks. During sporadic runoff, these washes may recharge about 1,000 acre-ft/yr to the Pine Valley monzonite, alluvial-fan, and basin-fill aquifers where they traverse the formations, but the amount is highly speculative.

Irrigation

Recharge to the ground-water system of the upper Ash Creek drainage basin by infiltration of unconsumed irrigation water has not been confirmed by measurements. This recharge mechanism has been observed and documented for other basins of western Utah (Susong, 1995; Thiros and Brothers, 1993; Mower and Sandberg, 1982; and Bjorklund, Sumsion, and Sandberg, 1978) and is primarily a result of flood irrigation or liberal sprinkler-irrigation practices. Estimates of recharge that occur in other areas by this means range from 0 to 50 percent of the water applied.

Table 8. Miscellaneous discharge measurements at selected sites along Kanarra Creek and its tributaries, upper Ash Creek drainage basin, Utah

[ft^3/s, cubic feet per second, acre-ft/yr, acre-feet per year; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Site (see fig. 19 for map location)	Date	Discharge, in ft^3/s	Losses (recharge to the aquifer), in acre-ft/yr, ft^3/s		Temperature, in degrees Celsius	Specific conductance in μS/cm at 25°C
Taylor Creek #1	10-12-95	.280			10.5	1,360
Taylor Creek #2	10-12-95	.170	80	(.11)	16.5	—
Taylor Creek #3	10-12-95	.013	115	(.157)	19.0	1,380
Taylor Creek 300 feet west of #3	10-12-95	0	10	(.013)	—	—
Camp Creek at mouth	10-13-95	.057	40	(.057)	6.0	2,150
Spring Creek at mouth	10-13-95	.063	45	(.063)	10.5	780
Kanarra Creek at mouth just above diversions	10-12-95	3.39	2,455	(3.39)	11.5	—

The records of the Utah Division of Water Rights indicate that are about 50 wells, 4 springs, and about 20 streams are used primarily for irrigation. The total amount of water allowed for irrigation in 1998 was about 40,000 acre-ft and consisted of about 25,000 acre-ft from streams, 15,000 acre-ft from wells, and 1,500 acre-ft from springs. If one-fourth of the permitted water right were used, about 10,000 acre-ft annual recharge from irrigation could range from 0 acre-ft (sprinkler irrigation) to about 5,000 acre-ft (flood irrigation). Because most of the irrigation observed was being applied with sprinklers, recharge from this mechanism is thought to be at the lower end of this range.

Ground-Water Movement

Ground water in the aquifer system of the upper Ash Creek drainage basin generally moves from the surrounding mountains toward the valley floor and thence from the valley-floor margins toward Ash and Kanarra Creeks. Water-level measurements in the basin-fill aquifer indicate that ground-water movement within the basin generally is south from Kanarraville and east from New Harmony toward Ash Creek Reservoir (fig. 18a). Water levels measured in a few wells that tap the alluvial-fan aquifer near its margin indicate that ground water moves in a similar direction as in the basin-fill aquifer (fig. 18b). Water levels in wells that tap the Pine Valley monzonite aquifer south and southeast of New Harmony indicate a similar movement of ground water, from the Pine Valley Mountains toward the valley floor and thence toward Ash Creek Reservoir (fig. 18c).

Vertical movement between aquifers and within aquifers is indicated by observed differences in water levels in nearby wells that are finished at different depths. A downward gradient is indicated within the basin-fill aquifer near the Hurricane Fault and less than 1 mi east of New Harmony. The downward gradient near the fault supports the concept of recharge from ephemeral streams, but not from east of the fault. Upward gradients are evident within the alluvial-fan aquifer 3 mi east of New Harmony and within the Pine Valley monzonite aquifer along Ash Creek between New Harmony and Ash Creek reservoir.

Discharge

Principal sources of discharge from the upper Ash Creek drainage basin ground-water system are well withdrawal, evaporation, transpiration by riparian vegetation, spring discharge, surface-water seepage gains in Ash Creek, and subsurface outflow via the fractured basalt in the vicinity of Ash Creek Reservoir (fig. 15).

Wells

Annual municipal well discharge for New Harmony and Kanarraville has been sporadically recorded since 1979, and the amount of irrigation, stock, and domestic well discharge in the basin can only be estimated. Kanarraville and New Harmony each have one municipal well. Recorded discharge from the Kanarraville municipal well has varied from 12 acre-ft in 1979 to 65 acre-ft in 1994, averaging about 30 acre-ft/yr. New Harmony municipal well discharge has varied from 24 acre-ft in 1980 to 47 acre-ft in 1986, averaging about 33 acre-ft/yr. Both municipalities supplement well discharge with water from springs.

Total irrigation, stock watering, and domestic well discharge has been estimated to range from 1,200 to 1,500 acre-ft/yr from about 120 wells in the upper Ash Creek drainage basin. Most of these wells list irrigation as the principal use, with stock watering and household as secondary uses. Irrigation well discharge has not changed substantially for the last 30 years. Cordova, Sandberg, and McConkie (1972) estimated irrigation well discharge to be about 1,000 acre-ft in 1968, 1,340 acre-ft in 1969, and 1,250 acre-ft in 1970. On the basis of the increase in population, irrigated acreage, and several discharge ratings done in 1995, total well discharge in 1995 was estimated to range from 1,200 to 1,500 acre-ft.

Evapotranspiration

Evapotranspiration in upper Ash Creek drainage basin likely occurs along perennial and ephemeral stream channels and in low areas adjacent to these channels. About 300 acres of cottonwood trees were mapped from areal photographs (fig. 19). The most dense growths exist along Ash Creek and Kanarra Creek, but there also are groves along Camp, Taylor, and Sawyer Creeks. There are about 4,300 acres of pasture grasses along the upper reaches of Kanarra Creek and around New Harmony. Although unknown, ground water was assumed to supply the entire demand for the growth of this vegetation.

There have been several different estimates of water use by vegetation. Using the Blaney-Criddle method (Criddle, Harris, and Willardson, 1962), Cordova, Sandberg, and McConkie (1972) estimated use

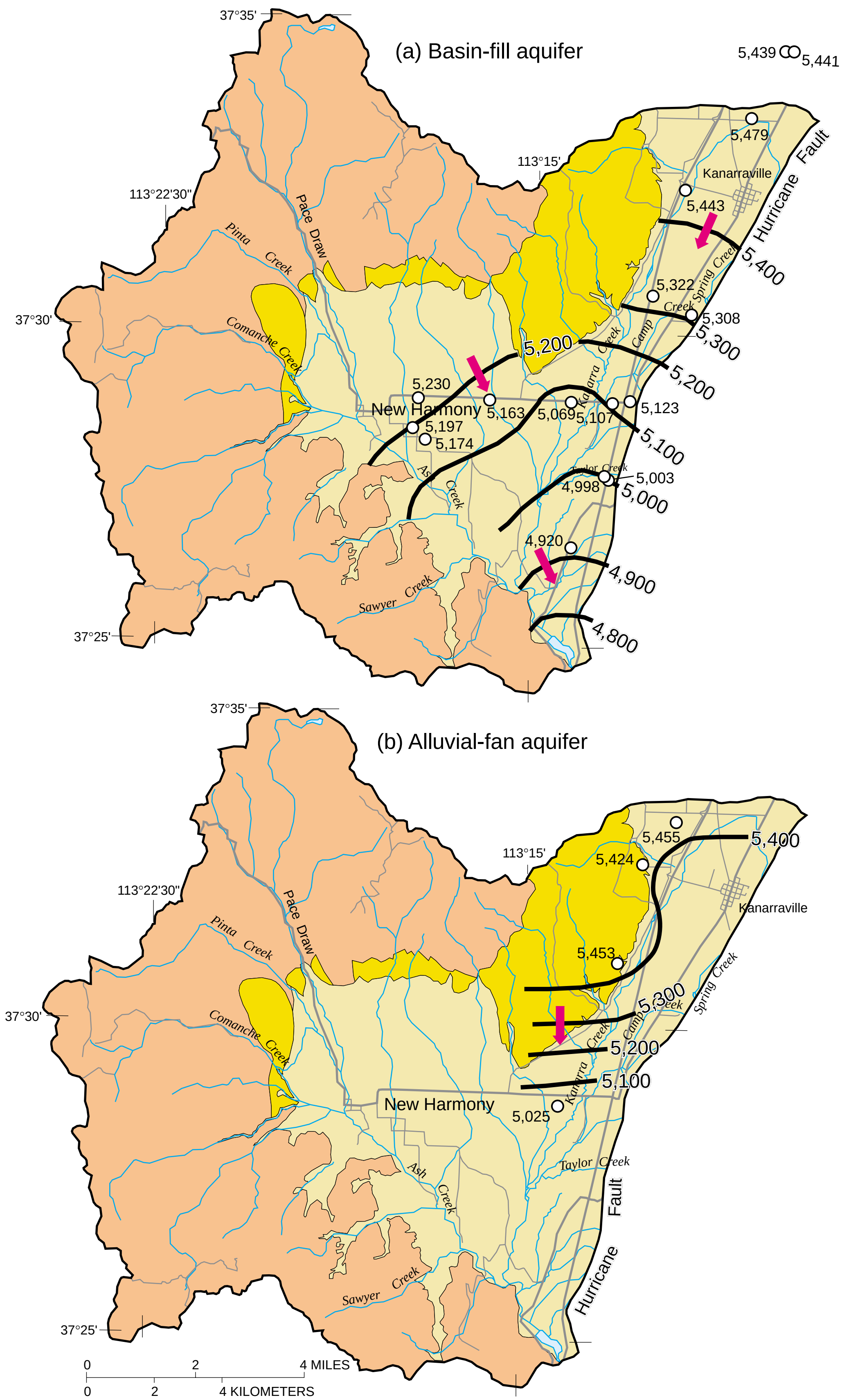

Figure 18. Approximate potentiometric contours in the three aquifers of the upper Ash Creek drainage basin, Utah

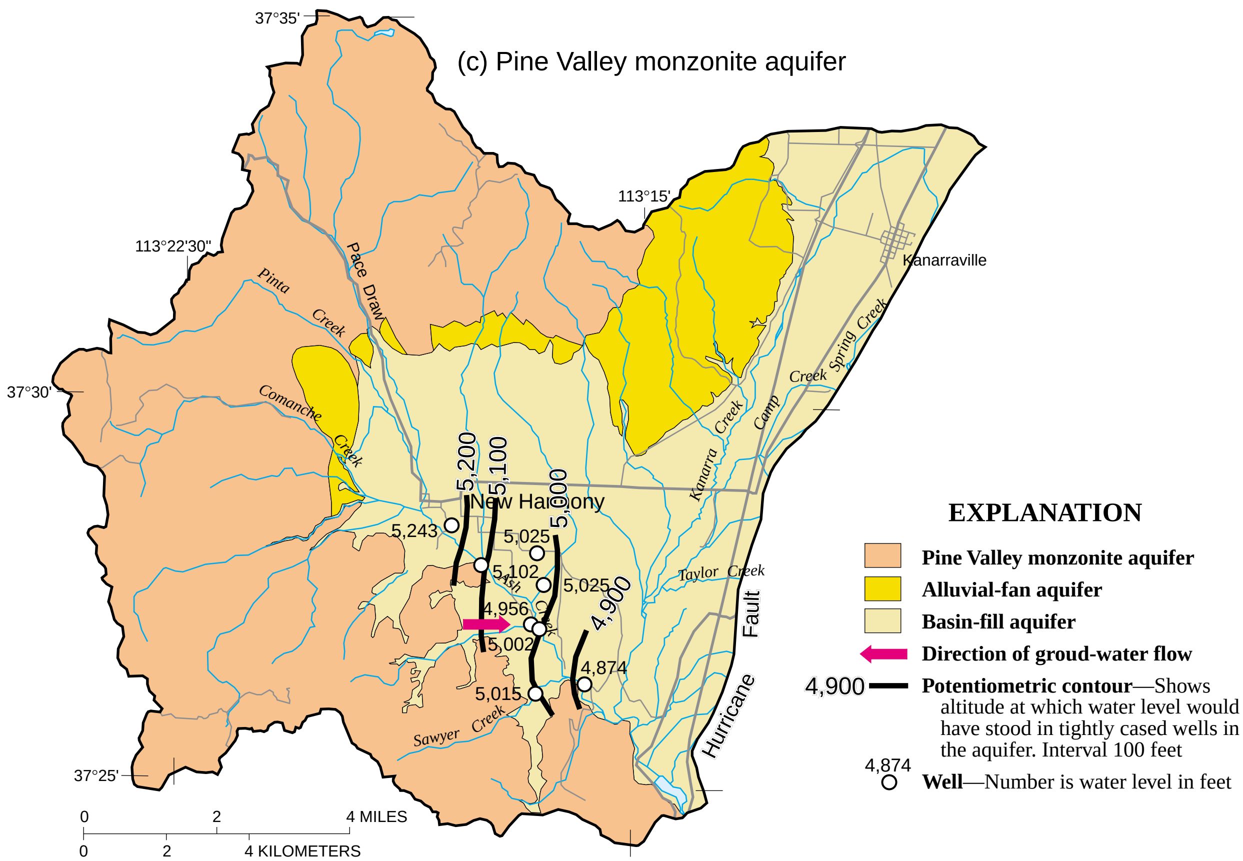

Figure 18. Approximate potentiometric contours in the three aquifers of the upper Ash Creek drainage basin, Utah—Continued

by cottonwood trees to be 3.6 ft/yr at 100 percent density, and by pasture grasses to be 2.9 ft/yr. Measurements of consumptive use by cottonwood trees in California (Muckel and Blaney, 1945) and in Arizona (Gatewood and others, 1950) indicate that annual use could be as much as 7 to 8 ft/yr. Because temperature varies, the amount of ground water consumed by riparian growth would vary seasonally; and because the depth to water varies, there could be areas where pasture grasses may not use any water from the saturated zone for transpiration. On the basis of this range of evapotranspiration rate and the extent and density of riparian growth, evapotranspiration loss in the upper Ash Creek drainage basin is estimated to range from 1,100 to 15,000 acre-ft/yr.

Springs

There are at least 25 springs in the upper Ash Creek drainage basin. Most are in the surrounding mountains and are near-surface, local-recharge-area systems that are not part of the basin-wide aquifer system. All springs that discharge at the level of the valley floor and a few that discharge near the base of the surrounding mountains are likely part of the basin-wide aquifer system (fig. 20). A long-term record of the seasonal and year-to-year variability in discharge from these springs is not available. Users, have a water right of about 1,000 acre-ft/yr, thus, discharge was assumed to be 1,000 acre-ft/yr (excluding Sawyer Spring). Comanche and Lawson Springs are the largest of all the springs. Other smaller seeps and springs discharge from the basin fill where the water table intersects land surface. On the basis of water-right information, spring discharge was estimated to range from 200 to 1,000 acre-ft/yr. Sawyer Spring is discussed in the following section.

Ash, Sawyer, and Kanarra Creeks

Cordova, Sandberg, and McConkie (1972, p. 19) estimated that 2,200 acre-ft of ground water seeped to Ash Creek above Ash Creek Reservoir in 1970. The seepage study performed on Ash Creek in October

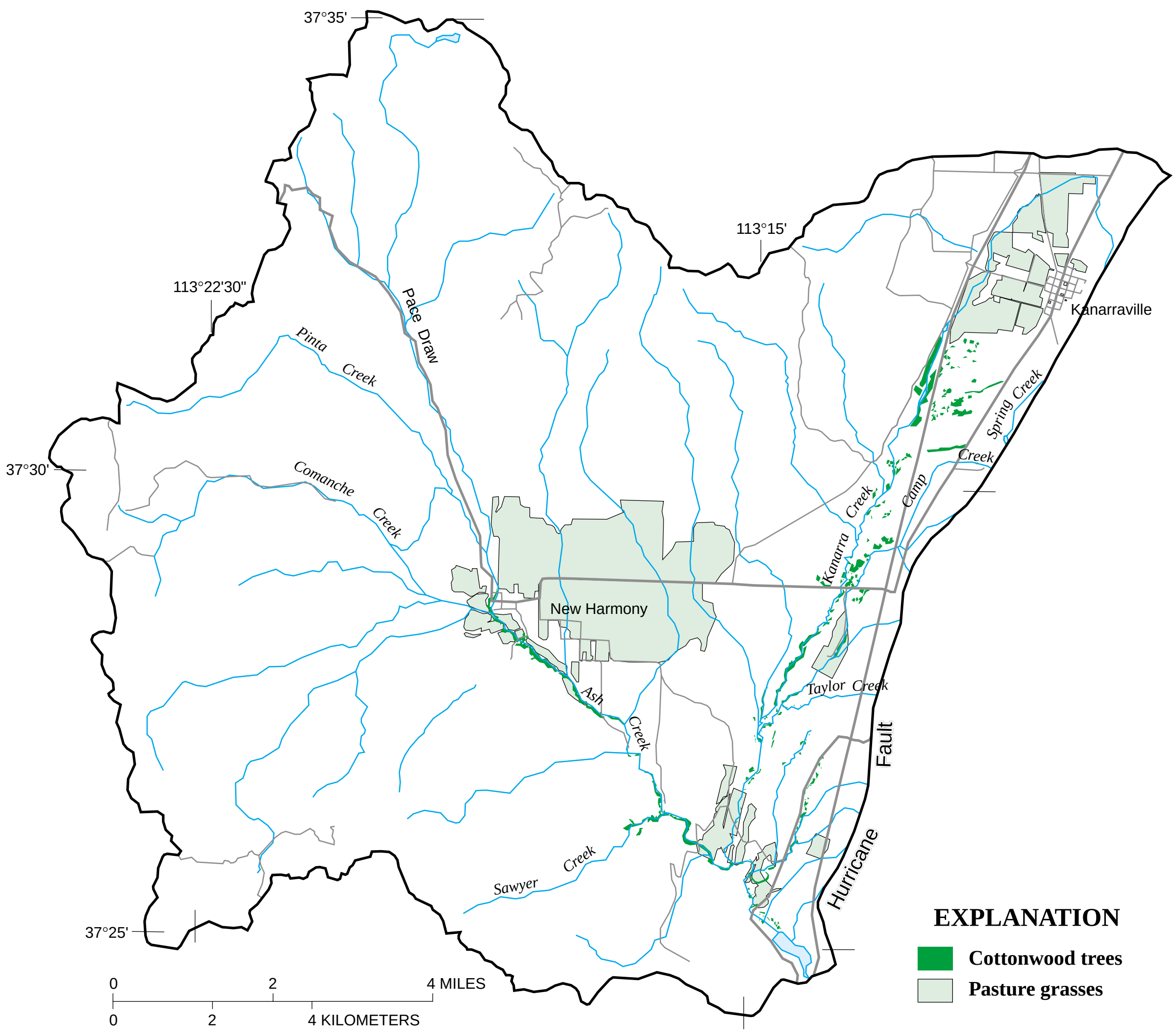

Figure 19. Areas of phreatophyte growth in the upper Ash Creek drainage basin, Utah.

1995, during a period of minimal evapotranspiration loss and inflow from runoff, showed that the stream gained about 1,400 acre-ft/yr, mostly in a 1.5- to 2-mi reach downstream from New Harmony (table 7, fig. 17). Sawyer Creek begins to flow at Sawyer Spring about 1/3 mi from its confluence with Ash Creek. This short reach, including Sawyer Spring, discharged about 1,100 acre-ft/yr from the Pine Valley monzonite aquifer in October 1995. Kanarra Creek begins to flow again about 1 mi upstream from its confluence with Ash Creek. In the first part of this perennial segment, the stream gained about 260 acre-ft/yr before losing flow in the last segment before the confluence. The seasonal and year-to-year variation in this discharge from the basin-wide aquifer system is unknown. The range of discharge by stream seepage is estimated to be 500 to 3,000 acre-ft/yr.

Subsurface Flow to Lower Ash Creek Drainage

The amount of ground water that potentially could discharge from the area as subsurface outflow through the deep alluvial deposits in the vicinity of Ash Creek Reservoir was estimated using Darcy's Law and approximations of aquifer geometry and water transmitting properties. Subsurface flow is calculated on the basis of the difference in water-level altitude in the aquifers at the reservoir and the aquifers to the south near Pintura, Utah. Well (C-39-13)25dcd-1, located about 3.5 mi south of Ash Creek Reservoir and finished in basalt, has a water level about 600 ft lower than the water level in the aquifer at the reservoir. This difference yields a head gradient of about 0.03 ft/ft. The aquifer through which ground water moves southward out of the upper Ash Creek drainage basin is of unknown thickness and width. However, on the basis of a descrip-

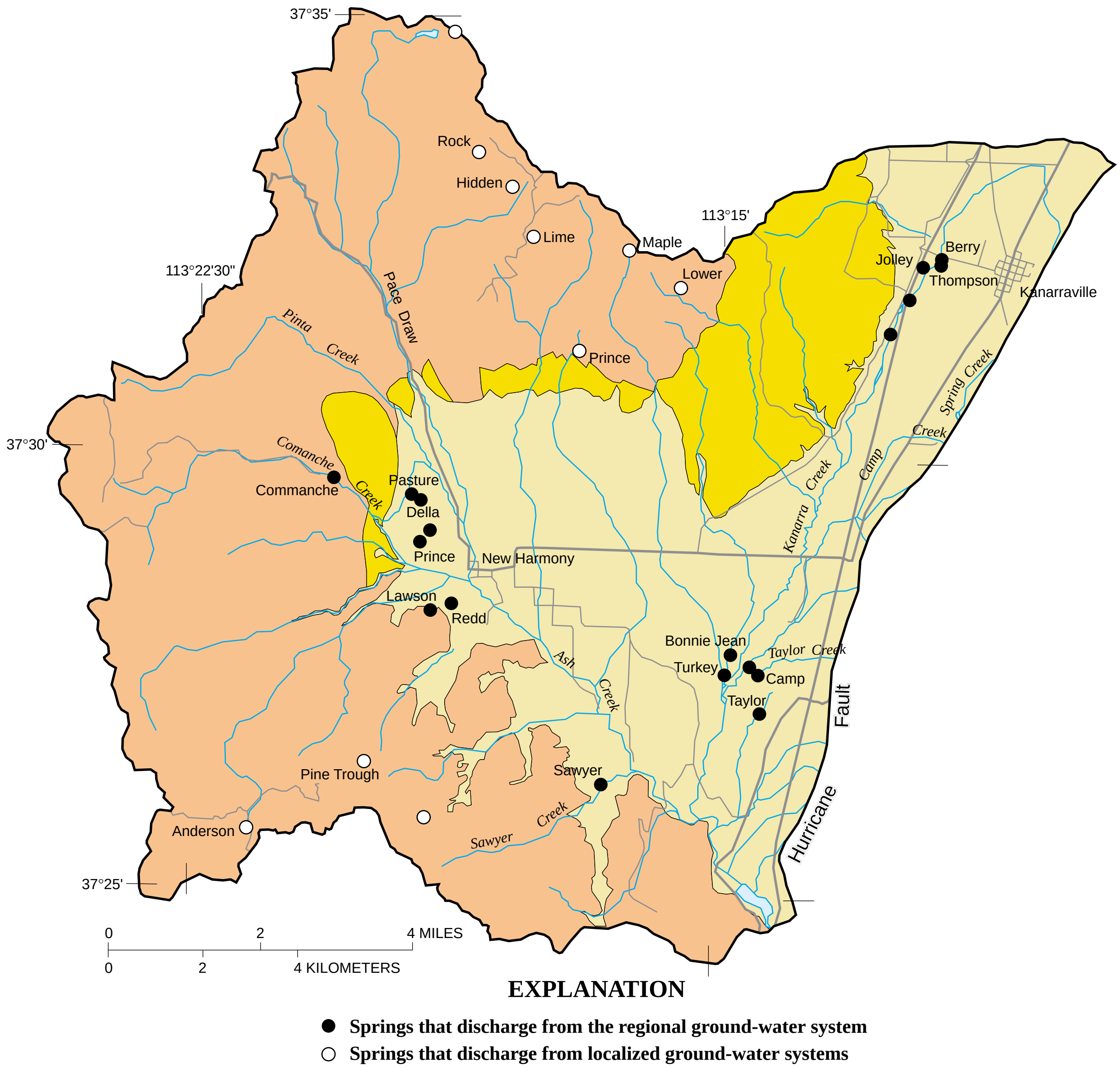

Figure 20. Location of local and regional springs in the upper Ash Creek drainage basin, Utah.

tion of the geologic framework by Hurlow (1998), thickness and width are estimated to be about 300 ft and 5,000 ft, respectively. Hydraulic conductivity of the interbedded alluvial deposits can be estimated to be similar to the lower values of the basin-fill aquifer because of compaction and cementation. A value of about 20 ft/d was estimated. Use of these numbers in Darcy's Law yields a maximum potential outflow of about 7,500 acre-ft/yr. Because of a general lack of information about geometry and hydraulics in this outflow area, this estimate is uncertain.

Ground-Water Budget

A compilation of potential inflow to and outflow from the upper Ash Creek drainage basin ground-water system is shown in table 9. Except for well discharge, all ground-water budget components have a large estimated range.

Navajo and Kayenta Aquifer System

The saturated parts of the Navajo Sandstone and Kayenta Formation, referred to in this section as the