Volcanic ash soils, stream baseflow and water balance in subalpine basins of western Montana, USA

Mark K. Dixon

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VOLCANIC ASH SOILS, STREAM BASEFLOW AND WATER BALANCE IN
SUBALPINE BASINS OF WESTERN MONTANA, USA

by

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The occurrence, depth, and hydrologic properties of volcanic ash derived soils were investigated in a subalpine basin of western Montana. An identifiable ash layer was present at 35 of the 58 sampling sites in the study basin. Ash soils occurred most frequently on north and west facing slopes, and less frequently on east and south facing slopes. Ash occurred consistently on moderately steep slopes (less than 25%), and less often on steeper slopes. Ash thickness averaged less than 13 centimeters, and varied from 3 to 45 centimeters. Slope, aspect and elevation were not statistically significant in explaining ash thickness. Mean bulk density of ash soils were 0.72 g/cm$^2$ compared to 1.09 g/cm$^2$ for granitic derived soils. Volcanic ash soils were dominated by silt size particles, and granitic soils dominated by sand. Average plant available water (PAW) by weight was significantly different for ash soils (64%) and granitic soils (28%), but not significantly different by volume (44% and 30% respectively).

Recession rates of stream baseflow were compared among gaged tributaries to the Bitterroot River in western Montana to identify causal factors related to basin morphology and determine whether volcanic ash soils play a role in rates of baseflow recession. Bitterroot Range streams had a significantly higher recession rate than Sapphire streams due to granitic geology, thin sandy soils, and recent glaciation. Key quantitative geomorphic factors related to recession rate were basin shape and gaging station elevation. Gaging stations located along Lost Horse Creek show a consistent recession rate. The thin layer of volcanic ash soils most likely does not play a significant role in recession rates.

Hydrologic Simulation Program - Fortran (HSPF) was used to model the water balance of a subalpine basin. Total evapotranspiration during the two-year study was equal to 20-percent of total precipitation and runoff was 77-percent. Low evapotranspiration rates in the upper Lost Horse Creek basin lead to the generation of a considerable amount of runoff per land area per unit of precipitation. Results demonstrate the importance of subalpine basins for generating surface runoff to semi-arid valleys.
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Chapter 1: The Occurrence and Hydrologic Properties of Volcanic Ash Soils in a Subalpine Basin of Western Montana.

INTRODUCTION

Aeolian inputs are important to soil hydrologic properties where soils are relatively young and soil forming processes are slow (Birkeland, 1984). Fine silt and clay sized particles, important to soil structure and aggregation, are continual inputs to systems from desert dust, glacial loess, and volcanic eruptions. Volcanic eruptions, in particular, are important sources of airborne particles in the atmosphere (Harris, 1988). Local eruptions can deposit considerably more material depending on the distance from the source and prevailing wind direction (Selby, 1985). Knowledge of the occurrences and physical properties of ash-derived soils are important for assessing the hydrologic function of watersheds.

The connection between precipitation and stream runoff is extremely complex, but begins with an understanding of the physical properties of surface soil. The surface soil layers affect the infiltration of rain and snowmelt water and how this water will be passed to layers lower in the profile or whether the moisture will be transpired by vegetation. In conjunction with other basin characteristics, the physical properties of surface soils can affect the amount and timing of stream runoff (Brooks et al., 1991).
The Bitterroot Mountains of western Montana have a layer of volcanic ash derived from the Cascade Range volcanoes of Oregon and Washington (Fryxell, 1965; Mehringer et al., 1977; Fosberg et al., 1979). Although the granitic rocks of the Idaho batholith dominate the bedrock geology of the range, a thin surface ash layer is present in much of the higher elevations of the range (NRCS and USFS unpublished data). The physical properties of soils derived from volcanic ash contrast greatly with the native sandy soils of granitic origin. Ash soils have a much lower bulk density, a very high water holding capacity and a finer particle size distribution (Page-Dumroese, 1993; Geist and Cochran, 1991). Ash soils also affect water availability to plants (McDaniel et al., 1994), but whether the ash has a significant role in basin outflow processes is not known.

**Ash Soils**

The occurrence of volcanic ash in Idaho and western Montana is well documented. Hutchison (1959) described the occurrence of Tertiary volcanic ash in the northern part of the Bitterroot Valley. This ash is most likely from local sources, but is not found in Bitterroot Range headwaters basins due to recent glaciation (Weber, 1972).

Mehringer et al. (1977a; 1977b; 1984), Fryxel (1965), and Foit et al. (1993) studied lake and bog sediment cores in western Montana and dated ash from Glacier Peak at roughly 11,000 years and Mazama ash at 6,850 years. Glacier Peak ash is generally found in close contact with parent materials, before soils had formed on the landscape. The ash is believed to have fallen over the area shortly after melting of the last glaciers to occupy the Bitterroot Range. Mazama ash was four to five times thicker than Glacier Peak ash. Nimlos (1980, 1981) and Nimlos and Zuuring (1982) studied volcanic ash soils in
western Montana and described their general occurrence, physical and chemical properties. They found that ash occurred on all aspects and landforms in areas receiving greater than 100-centimeters precipitation, on north and gentle slopes in areas receiving 56 to 100-centimeters precipitation, and never in areas receiving less than 56-centimeters precipitation.

Ottersburg and Nielsen (1977) conducted a survey of soil scientists who characterized ash soil layers in the region by low bulk density, brown color (7.5 to 10 YR 3/4-5/6), and primarily silt size particles. Thickness of the ash layer was associated with vegetation type, physiographic position and geographic location. Nimlos (1980, 1981) described ash soils as having low bulk density, high porosity, high water transmission and retention values. Although a wealth of information is available, most research has been conducted on a regional scale. Little is known about the occurrence and physical properties of volcanic ash at the basin scale.

Under certain conditions, the deposition of volcanic ash in the silt and finer size fractions are of great importance. Allophane, an amorphous clay, is a weathering product of volcanic ash soils (Flach et al., 1980). This non-crystalline clay plays an important role in the physical characteristics of soils derived from volcanic ash (Nimlos, 1981). Additions of volcanic ash to soils derived of contrasting parent materials can potentially affect the physical properties of these soils.

In the mountains of western Montana, areas underlain by coarse subsoils, such as those derived from granitic parent materials, deserve special attention. Soils derived from granitic rocks tend to be sandy, which contrasts with the silty nature of volcanic ash soils.
In addition, the bulk density of ash soil is significantly lower than that of other mineral soils (Page-Dumroese, 1993). Physical properties imparted by the ash may be of great significance to plant growth and hydrologic processes in these locations.

OBJECTIVES

This study documents the occurrence and hydrologic properties of volcanic ash soils in a high elevation basin in the Bitterroot Range of western Montana. Of interest is the depth of the volcanic ash soil layer and its occurrence on varying landforms in the upper Lost Horse Creek Basin. By measuring the water holding capacity of the soils and comparing them to the soils of granitic origin we can begin to understand the hydrologic importance of volcanic inputs to the system. The results of this study will aid in the understanding of the distribution of ash soils and their role in the hydrologic function of this headwaters basin.

STUDY AREA

Site Description and Location

The Lost Horse Creek basin is located in the Bitterroot Mountain range of western Montana. Lost Horse Creek is one of the many eastward flowing tributaries to the Bitterroot River (Figure 1-1). The focus of this study was the upper basin defined by the watershed area above the bridge where the road crosses Lost Horse Creek (Figure 1-2). The upper basin is 1551 hectares in size and ranges in elevation from 1,750 meters at the upper bridge stream gages site to 2,560 meters at Kerr Peak, the highest point in the
basin. The study area is located entirely within the Bitterroot National Forest and is surrounded on three sides by the Selway-Bitterroot Wilderness area.

Figure 1-1. Lost Horse Creek study site showing the location of weather stations and stream gages and its location in the Bitterroot Basin of western Montana.
The climate of the Bitterroot drainage is dominated by weather systems from the Pacific Ocean for much of the year, especially during the winter. However, this area lays on the climatic boundary between warm moist air from the Pacific (maritime climate) and dry cold continental air masses (continental climate) to the east. During the summer and brief periods in the winter, the climate is similar to the drier/colder mountains farther to the
east (Finklin, 1983). According to the Twin Lakes SNOTEL station, located in the basin, average annual precipitation is 160 centimeters, where 60 to 80 percent (67 percent avg.) falls as snow from late October to mid-April. The ground surface is typically covered by snow from late October to mid June. Peak runoff occurs in Lost Horse creek during the snowmelt period of late May or early June. July and August are the driest months in the basin, accounting for only 4 and 3 percent of annual precipitation respectively.

The study basin consists of four sub-basins each with a tributary stream that forms Lost Horse Creek. From north to south, there is the Twin Lakes and Mud Lake sub-basin, then the steep "center basin", the Bailey Lake sub-basin and the Meadow sub-basin that emanates from Bear Creek Pass. The topography of the upper basin is quite varied and shows the influence of recent glaciations, including: sharp ridgelines, U-shaped valleys, steep headwalls, lakes and numerous small ponds.

The upper elevations of the basin have extensive areas of exposed granite and scree slopes. The granite is part of the Idaho batholith, and the Bitterroot Mountains are its farthest east extension. As a result, soils in the basin are quite sandy with sandy-loam and loamy-sand textures. Although the eruption of Glacier Peak approximately 12,000 years ago deposited ash throughout the region, the eruption of Mt. Mazama approximately 6,600 to 7,000 years ago was more significant (Fryxell, 1965) (Figure 1-3). For this study, the parameter of interest was in the surface layer of volcanic ash, known to be present throughout the basin, but with an unknown distribution and thickness.
Figure 1-3. Illustration of ash fallout from the last two significant volcanic eruptions, Glacier Peak (dashed line) erupted approximately 12,000 years before present and Mt. Mazama (dotted polygon) 7,000 years BP. Based on map by Fryxell (1965).
The upper basin is dominated by subalpine fir (Abies lasiocarpa) and lodgepole pine (Pinus contorta) forest. Engleman spruce (Picea englemanii) is also present as is subalpine larch (Larix occidentalis) in the highest elevations. In 1988 a fire burned approximately 36 percent of the upper basin. The fire was intense, leaving little of the subalpine fir/lodgepole pine forest within the burn perimeter (Figure 1-4a). Within much of the burn area, the fire completely removed the soil organic layer causing localized erosion, especially in the uplands. During the ensuing years, there has been a modest amount of natural revegetation within much of the burn perimeter (Figure 1-4b).

The basin is generally in an undisturbed state with the exception of a road, which comes from the Bitterroot Valley in Montana and terminates at two points. Upper and lower Twin Lakes are both naturally occurring, but are now regulated by low earth fill dams. Bailey Lake is located away from the road and is not regulated. The area receives a moderate amount of recreation use since the road is one of the few high elevation access points to the Selway-Bitterroot Wilderness. Access is, however, limited to those with high clearance vehicles due to the primitive nature of the road. Outfitters, fishermen and backpackers are the primary users of the area.
Figure 1-4. The 1988 burn area in the upper Lost Horse Creek study basin: a). Looking northeast with Bailey Lake in the foreground. Lower Twin Lake and Kerr Peak are visible in the background, and b). close-up view of recovering vegetation.
METHODS

Field Data Collection

Elevation, slope, and aspect maps were produced in a geographic information system (GIS) using digital elevation models (DEM) of the basin. Visible bedrock and scree slopes were digitized into the GIS from post 1988 fire aerial photos of the basin. Bedrock and scree slopes were excluded from consideration for locating soil-sampling points. Land cover attributes were digitized from pre and post fire air photos. The maps were used as a general guide for locating soil pits on various landforms throughout the basin. Parameters such as slope, aspect, and elevation for each soil description were measured on site.

There were two types of soil descriptions used in this study. The first type was used for documenting only the occurrence and depth of the volcanic ash layer. Only site related parameters (elevation, slope, and aspect) and depth of the ash layer were documented. The second type was used for describing soil physical parameters. In addition to the information collected in the first type of soil description, the second type included a brief soil profile description and sample collection for measuring physical parameters in the laboratory.

Profile descriptions for each horizon included: depth, wet and/or dry color, texture, structure, presence and thickness of volcanic ash. Slope, aspect and elevation were recorded for each profile along with a short description of the immediate area.
Field determination of bulk density was measured at several soil profile locations using the excavation method (Blake and Hartge, 1986). After digging a soil pit and identifying horizons, surface soils adjacent to the pit wall were removed to expose the surface of a horizon. A plexiglass template with a 5-cm. diameter hole was placed on the surface of the exposed horizon. Soil was carefully removed from the area inside the template to at least 5-cm. depth and placed in a labeled container. The excavated hole was then filled loosely with measured sand from a graduated cylinder. The sand had been pre-sieved to a medium coarseness (passing a no. 20 sieve and retained on a no. 60 sieve) to ensure consistent volume. Bulk density was calculated by dividing the oven dry weight of the excavated soil by the volume of the sand that filled the hole. This process is repeated when sampling subsequent horizons from the same soil pit.

**Soil Laboratory Analysis**

*Particle Size Analysis*

Percent sand, silt, and clay particle size was determined for each of the samples by hydrometer using a modified Day method (Gee and Bauder, 1986). The method employs Stokes law using particle-settling times to determine size distribution of the sample. Each soil sample was air dried, and passed through a 2-mm sieve to remove coarse fragments. The samples were allowed to soak for at least 2-hours in a solution of calgon (sodium hexametaphosphate) to disperse clay size particles. The samples were then transferred to mixing cups to be mixed vigorously for 30-minutes to further aid in dispersion. Each sample was transferred to a 1-liter cylinder. Hydrometer readings were taken at 40 seconds and at 2-hours.
**Plant Available Water**

Plant available water (PAW) was determined for each soil sample by calculating the amount of water held between 33.3-kilopascals (kP) (field capacity) and 1,500-kP (permanent wilting point) tension (Klute, 1986). Intermediate moisture/tension measurements of 100-kP and 500-kP were made to further define the moisture release curve for a few samples. Each sample was saturated with water for at least 1 week prior to being placed in the pressure plate apparatus. This ensured all soil pores were saturated before applying pressure to the sample. The 33.3-kP pressure was operated for 1-hour before samples were removed. For higher pressures, 100-kP, 500-kP and 1500-kP, the samples were allowed to equilibrate for 24 hours in the pressure plate before being removed.

After samples were removed from the pressure plate, they were weighed and placed in a drying oven. After 24 hours, the dried samples were allowed to cool in a desiccator then re-weighed. The dry weight of the sample was subtracted from the wet weight to determine the water content. This procedure was replicated at least twice on each sample and the water content averaged. Water content at 33.3-kP was subtracted from the value at 1500-kP to obtain PAW.

**RESULTS**

**Basin Characteristics**

Over 70 percent of the upper basin is comprised of east and west facing slopes (Figure 1-5a). The study basin is oriented in the north-south direction, which contrasts with most
other Bitterroot Range basins including the lower elevations of the Lost Horse basin. The study basin is steep with almost 60 percent of the land surface falling within the steep category (25-55 percent slope) (Figure 1-5b). Including water bodies, less than 2 percent of the study basin is flat to gently sloping (less than 6 percent slope). Elevation is distributed normally in the study basin with a mean elevation of 2,067 meters (Figure 1-5c).

According to the air photo analysis and field surveys, approximately 35 percent of the basin burned during the fire of 1988 (Figure 1-5d). Prior to the fire, approximately 48% of the upper basin was covered by dense forest of subalpine fir, lodgepole pine and engleman spruce and 35 percent of the basin had a moderate to sparse tree cover. About one-third of both the densely forested area and moderately forested area burned in 1988. The remaining burn area consisted of meadows and other grassy areas in the basin.

Exposed bedrock is common throughout the upper basin, even in areas that appear to be moderately to densely forested. From air photos, however, the upper basin appears to have only about 10 percent covered by scree slopes and open bedrock. In a few locations the basin is characterized by large unbroken slabs of granite and in others locations by thin soils covering the bedrock. Results from seismic profiles in the meadow area of the basin showed that bedrock is consistently less than 2-meters from the surface, this being in an area where one would expect to find the deepest unconsolidated materials (see Chapter 2). Depth to bedrock in the uplands is probably much less than 2-meters over most of the basin.
Figure 1-5. Lost Horse Creek basin land classification by: a). aspect, b). slope (darker = steeper), c). elevation, and d). burn area.
Volcanic Ash Occurrence

Figure 1-6 shows the locations of 58 soil-sampling sites distributed throughout the study basin. The sampling locations represent the diversity of landforms, vegetation and geography found in the upper Lost Horse Creek basin (Table 1-1). Of the 58 sampling sites, a total of 35 had an ash layer identified according to the criteria described in the methods section. At the remainder of the locations, there was no identifiable ash layer present. The ash layer was relatively easy to identify by its contrast with the underlying soil of granitic origin. A typical soil profile with ash presented an abrupt boundary between the ash and the sandy granitic subsoil (Table 1-2). Some of the remaining soils may have been influenced by volcanic ash, but mixing with soils derived from parent materials of local origin masked the characteristics (Appendix A).
Figure 1-6. Map of the upper Lost Horse basin soils sampling locations and their relationship to the 1988 burn area.
Table 1-1. Percent of samples in each class compared to percent of basin area in each class.

<table>
<thead>
<tr>
<th>ASPECT</th>
<th>North</th>
<th>East</th>
<th>South</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin Area</td>
<td>15</td>
<td>41</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>Samples</td>
<td>17</td>
<td>47</td>
<td>10</td>
<td>26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SLOPE</th>
<th>Gently Sloping 2-6%</th>
<th>Moderately Steep 13-25%</th>
<th>Very Steep &gt;55%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin Area</td>
<td>2</td>
<td>24</td>
<td>59</td>
</tr>
<tr>
<td>Samples</td>
<td>19</td>
<td>33</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEVATION</th>
<th>&lt; 1900</th>
<th>1900-2000</th>
<th>2000-2100</th>
<th>2100-2200</th>
<th>&gt;2200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin Area</td>
<td>15</td>
<td>19</td>
<td>27</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Samples</td>
<td>17</td>
<td>26</td>
<td>38</td>
<td>16</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1-2. Typical ash soil profile in the Lost Horse Basin.

<table>
<thead>
<tr>
<th>Site</th>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Matrix Color (moist)</th>
<th>Bulk Density (g cm$^{-3}$)</th>
<th>Available Water by mass (%)</th>
<th>Sand-Silt-Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL-2</td>
<td>A</td>
<td>0-7.6</td>
<td>10 YR 3/2</td>
<td>0.64</td>
<td>138.5</td>
<td>48-42-10</td>
</tr>
<tr>
<td></td>
<td>Bw</td>
<td>7.6-16.5</td>
<td>10 YR 5/6</td>
<td>0.60</td>
<td>138.1</td>
<td>38-50-12</td>
</tr>
<tr>
<td></td>
<td>2A</td>
<td>16.5-35</td>
<td>10 YR 4/3</td>
<td>0.98</td>
<td>60.8</td>
<td>46-40-14</td>
</tr>
<tr>
<td></td>
<td>2B</td>
<td>35 +</td>
<td>10 YR 5/6</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

The occurrence of volcanic ash was associated with aspect, slope, and elevation (Table 1-3). Ash soils occurred most frequently on north and west facing aspects. Ash occurred less frequently on east facing slopes and especially on drier south facing slopes. Ash occurred consistently at all sites that were on a slope no greater than 25% (moderately steep). Steep and very steep slopes greater than 25% had a significantly lower ash incidence. Elevation appeared to play little or no role in whether ash was present. Ash occurred at more than half the sites below 2100 meters elevation and only one-third of the sites between 2,100 and 2,200 meters. Both sites located above 2,200 meters had an ash layer. Between elevations of approximately 2,200 and 2,400 meters, the basin is steep.
to very steep with scree slopes and exposed granite. No sampling sites were located in this elevation band. Above this, a gentler surface exists at the highest elevations of the basin (above 2,400 meters) where ash is present among subalpine larch ribbon forest.

Table 1-3. Ash occurrence at soil sample sites with respect to aspect, slope and elevation.

<table>
<thead>
<tr>
<th>ASPECT</th>
<th>North</th>
<th>East</th>
<th>South</th>
<th>West</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. Sampling Sites</td>
<td>10</td>
<td>27</td>
<td>6</td>
<td>15</td>
<td>58</td>
</tr>
<tr>
<td>Ash Soil Present</td>
<td>9</td>
<td>13</td>
<td>2</td>
<td>11</td>
<td>35</td>
</tr>
<tr>
<td>Percentage of Sites with Ash</td>
<td>90%</td>
<td>48%</td>
<td>33%</td>
<td>73%</td>
<td>60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SLOPE</th>
<th>Gently Sloping 2-6%</th>
<th>Sloping 6-13%</th>
<th>Moderately Steep 13-25%</th>
<th>Steep 25-55%</th>
<th>Very Steep &gt;55%</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. Sampling Sites</td>
<td>11</td>
<td>16</td>
<td>19</td>
<td>11</td>
<td>1</td>
<td>58</td>
</tr>
<tr>
<td>Ash Soil Present</td>
<td>7</td>
<td>11</td>
<td>13</td>
<td>4</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Percentage of Sites with Ash</td>
<td>64%</td>
<td>69%</td>
<td>68%</td>
<td>36%</td>
<td>0%</td>
<td>60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ELEVATION (meters)</th>
<th>&lt; 1900</th>
<th>1900-2000</th>
<th>2000-2100</th>
<th>2100-2200</th>
<th>&gt;2200</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total No. Sampling Sites</td>
<td>10</td>
<td>15</td>
<td>22</td>
<td>9</td>
<td>2</td>
<td>58</td>
</tr>
<tr>
<td>Ash Soil Present</td>
<td>6</td>
<td>8</td>
<td>16</td>
<td>3</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Percentage of Sites with Ash</td>
<td>60%</td>
<td>53%</td>
<td>73%</td>
<td>33%</td>
<td>100%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Ash Layer Thickness

The thickness of the volcanic ash layer varied from a minimum of 3 centimeters at a variety of sites up to 45 centimeters at a single location (Table 1-4). At sites with an ash layer, the mean depth was 12.9 centimeters and the median depth was 10 centimeters. Some local deposits of ash were thicker than others. The site near Bailey Lake, site o-11, had an unusually thick ash layer that was 45 centimeters deep. This site was located near a seasonal stream on relatively gentle terrain. There were other locations that had ash layers between 28 and 30 centimeters thick (Figure 1-7). These unusually thick ash
deposits were associated with less steep terrain and were frequently near the base of steeper slopes.

Table 1-4  Ash depth summary at soil sampling sites with respect to aspect, slope and elevation.

<table>
<thead>
<tr>
<th>Ash Depth (cm)</th>
<th>ASPECT</th>
<th>East</th>
<th>South</th>
<th>West</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>13.4</td>
<td>12</td>
<td>--</td>
<td>14.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Median</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Maximum</td>
<td>45</td>
<td>30</td>
<td>--</td>
<td>30</td>
<td>45</td>
</tr>
</tbody>
</table>

| Ash Depth (cm) | SLOPE | Gently Sloping | Moderately Steep | Very Steep |
|               |       | 2-6%          | 6-13%            | 13-25%     | 25-55% | >55% | Total |
| Mean          | 13.1  | 14.2          | 12.3             | 10          | --     | 12.9 |
| Median        | 12    | 12            | 8                | 10          | --     | 10   |
| Maximum       | 30    | 30            | 8                | 10          | --     | 45   |

| Ash Depth (cm) | ELEVATION (ft) | < 1900 | 1900-2000 | 2000-2100 | 2100-2200 | >2200 | Total |
|               |               |       |           |           |           |       |       |
| Mean          | 9.8           | 10.9  | 15.1      | 9.3       | 18.5     | 12.9  |
| Median        | 10            | 10    | 10        | 10        | 18.5     | 10    |
| Maximum       | 15            | 17    | 45        | 12        | 23       | 45    |
None of the factors: slope, aspect or elevation were significant in explaining thickness of the ash layer (p-values < 0.05). Even though mean thickness was different depending on location, the variation within each of the categories was so great that they were statistically the same. The gently sloping (< 6%) and sloping categories (6-13%) showed a greater average ash layer thickness than steeper categories (Figure 1-8a). As the land surface becomes steeper beyond the "sloping" category (> 13%) mean and median ash
thickness declined, but not significantly. In the very steep category (> 55%), there were no sampling sites with an identifiable ash layer.

Although aspect was a strong indicator of ash occurrence, it was only weakly related to the thickness of the ash layer when present (Figure 1-8b). West-facing slopes had a slightly thicker ash layer on average than the other aspects. The median depth of the ash layer was 12 centimeters compared to 10 centimeters for north, east and south-facing slopes. Since there were only 2 sites on south facing slopes with an ash layer, the results are not compelling.

Elevation was also not significant in explaining the thickness of volcanic ash in the basin (Figure 1-8c). At sites having a discernable ash layer, median depth was about 10 centimeters throughout the range in elevations of the basin with the exception of the two highest elevation sites. There were only two sites at the highest elevation with an ash layer, a very small sample size. The 2000 to 2100 meter elevation interval had considerably more variability than the other elevation classes. This is due in part to there being many more samples in this elevation band, which encompasses approximately 30 percent of the basin area.
Figure 1-8. Ash thickness by: a). slope class, b). aspect, and c). elevation in the upper Lost Horse Creek basin.
Physical Properties

Bulk Density

Soil bulk density measurements represent 29 horizons from 14 separate soil pit locations. Of the 29 samples, 17 were identified as derived from volcanic ash parent material, 10 samples as being derived from granitic parent materials, and 2 samples from soil horizons with very high organic matter content. As expected, the bulk densities of the ash soil samples were lower than native granitic soils. The mean bulk density of ash soils was 0.72 g/cm\(^3\) compared to 1.09 g/cm\(^3\) for the granitics. The soil horizons with high organic content had the lowest bulk density at 0.25 and 0.50 g/cm\(^3\). Figure 1-9 illustrates the considerable variation in the bulk density of both ash and granitic soil types, but with little overlap in values between the two. An analysis of variance confirms that the mean bulk density of the ash-derived soils significantly differs from the granitic soils (p < 0.001).
Figure 1-9. Boxplot comparison of volcanic ash and granitic parent materials bulk density for soils in the upper Lost Horse basin.

Ash soil bulk density ranged from 0.51 g/cm³ to 1.15 g/cm³. Samples with the highest bulk density incorporated not only volcanic ash, but also visible sand and small gravel particles that added to their bulk density. For example, sample TL-6 had a bulk density of 1.15 g/cm³, the highest of the ash-derived soil samples. This value is outside the range of typical volcanic ash soil bulk density values reported in the literature. However, this layer contained many concretions that are typical of ash soils, and had a mix of coarser grained granitic particles.

The lowest bulk density of 0.51 g/cm³, sample RL-1a, came from the site at the highest elevation in the basin (Figure 1-6). At this location, there are few sources for colluvial contamination of the ash layer from upslope granite outcrops or boulders, and little in the
way of source area for wind transported loess. Parallel strips of granite cobbles and boulders run along the upwind side of each ribbon of the ribbon type forest. Figure 1-10 shows an example of the “forest strip–ash soil–rock band–forest strip” sequence near site RL-1 on Kerr Peak. Dense roots from the alpine grasses made bulk density excavation quite difficult in this location, which may be another factor contributing to the low bulk density of this sample.

Figure 1-10. Alpine larch ribbon-forest on Kerr Peak in upper Lost Horse basin near soil pit RL-1 where volcanic ash depth is up to 14 centimeters deep.

Bulk densities of granitic soils ranged from 0.92 to 1.29 g/cm$^3$. Sample ML-3b had the lowest bulk density of the granitic soil samples (0.92 g/cm$^3$). As with sample TL-6 described above, this sample had a concentration of light colored, coarse sand sized particles. The area surrounding this site had a number of decomposing granite cobbles
and boulders on the surface. Some of the overlap in bulk density values may reflect mixing of the ash soils with the granitic parent materials.

**Particle Size**

A total of 39 samples were obtained for particle size analysis. The samples represent 39 distinct soil horizons in 16 different soil profiles (Figure 1-11). The most notable characteristic of the diagram is a lack of clay particle size class in the soils of the upper basin. Most soil samples contained less than 10% clay with very few having more than 15% clay size particles. The volcanic ash soils had particle sizes that averaged 30 percent sand, 60 percent silt, and 10 percent clay size particles. In contrast, the non-ash soils averaged about 55 percent sand, 35 percent silt and 10 percent clay size particles.
Layers identified as volcanic ash showed a considerable difference in particle size distribution from soil layers deeper in the same profile that were of granitic origin. The ash soils contained a much higher fraction of silt, while the granitic soils were dominated by sand. In samples where ash derived soils had coarser particles, they were usually light colored quartzite sand with a granitic origin.
Water Holding Characteristics

The average moisture content at field capacity (33.3-kP) of volcanic soils was 96 percent compared to 44 percent by weight for granitic soils (Table 1-5). Moisture content at field capacity for volcanic ash ranged from 35 percent to 215 percent while granitics ranged from 23 to 102 percent. At permanent wilting point (1500-kP), moisture content averaged 34 percent by weight for volcanic ash soils and 16 percent for granitic soils. Moisture content at permanent wilting point ranged from 22 percent to 76 percent for volcanic ash soils and 8 to 33 percent for granitics.
Table 1-5. Water content, percent available water by mass and volume, and bulk density of soils in the Upper Lost Horse Creek study basin.

<table>
<thead>
<tr>
<th>Soil Sample</th>
<th>Water Content by mass</th>
<th>Available Water by mass (%)</th>
<th>Bulk Density (g/cm(^3))</th>
<th>Available Water by volume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33.3(kP) 500(kP) 1500(kP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BL-2a</td>
<td>215.0</td>
<td>76.4</td>
<td>138.5</td>
<td>0.64</td>
</tr>
<tr>
<td>BL-2b</td>
<td>209.0</td>
<td>70.9</td>
<td>138.1</td>
<td>0.60</td>
</tr>
<tr>
<td>BL-2c</td>
<td>88.7</td>
<td>27.9</td>
<td>60.8</td>
<td>0.98</td>
</tr>
<tr>
<td>LB-2a</td>
<td>91.5</td>
<td>37.8</td>
<td>29.4</td>
<td>62.1</td>
</tr>
<tr>
<td>MB-3a</td>
<td>70.5</td>
<td>26.5</td>
<td>21.9</td>
<td>48.5</td>
</tr>
<tr>
<td>ML-3a</td>
<td>181.0</td>
<td>59.7</td>
<td>121.2</td>
<td>0.55</td>
</tr>
<tr>
<td>ML-5a</td>
<td>44.8</td>
<td>13.1</td>
<td>31.7</td>
<td>0.79</td>
</tr>
<tr>
<td>ML-5b</td>
<td>41.1</td>
<td>16.7</td>
<td>13.1</td>
<td>28.0</td>
</tr>
<tr>
<td>ML-6a</td>
<td>58.2</td>
<td>17.2</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>ML-6b</td>
<td>34.4</td>
<td>15.0</td>
<td>14.3</td>
<td>20.1</td>
</tr>
<tr>
<td>RL-1a</td>
<td>104.4</td>
<td>29.4</td>
<td>74.9</td>
<td>0.51</td>
</tr>
<tr>
<td>RL-1b</td>
<td>85.2</td>
<td>36.2</td>
<td>49.0</td>
<td>0.61</td>
</tr>
<tr>
<td>RL-2a</td>
<td>113.0</td>
<td>29.0</td>
<td>84.0</td>
<td>0.68</td>
</tr>
<tr>
<td>RL-2c</td>
<td>68.4</td>
<td>18.5</td>
<td>49.9</td>
<td>0.69</td>
</tr>
<tr>
<td>RL-2d</td>
<td>83.8</td>
<td>46.5</td>
<td>40.1</td>
<td>43.7</td>
</tr>
<tr>
<td>TL-1b</td>
<td>109.7</td>
<td>56.8</td>
<td>52.8</td>
<td>0.58</td>
</tr>
<tr>
<td>TL-6</td>
<td>35.2</td>
<td>8.9</td>
<td>26.2</td>
<td>1.15</td>
</tr>
<tr>
<td>average</td>
<td>96.1</td>
<td>34.1</td>
<td>64.3</td>
<td>0.72</td>
</tr>
<tr>
<td>GRANITIC</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>BL-1a</td>
<td>35.3</td>
<td>10.4</td>
<td>24.9</td>
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<td>25.5</td>
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<td>24.4</td>
<td>1.15</td>
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<tr>
<td>LB-2b</td>
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<td>9.9</td>
<td>19.0</td>
<td>1.29</td>
</tr>
<tr>
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<td>21.3</td>
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</tr>
<tr>
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<td>32.9</td>
<td>69.0</td>
<td>0.95</td>
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<tr>
<td>RL-1c</td>
<td>52.1</td>
<td>21.5</td>
<td>30.6</td>
<td>0.97</td>
</tr>
<tr>
<td>RL-2e</td>
<td>38.6</td>
<td>14.1</td>
<td>24.5</td>
<td>1.00</td>
</tr>
<tr>
<td>TL-8a</td>
<td>23.1</td>
<td>7.7</td>
<td>15.3</td>
<td>1.24</td>
</tr>
<tr>
<td>TL-8b</td>
<td>27.3</td>
<td>9.1</td>
<td>18.2</td>
<td>1.22</td>
</tr>
<tr>
<td>average</td>
<td>43.8</td>
<td>15.5</td>
<td>28.3</td>
<td>1.10</td>
</tr>
<tr>
<td>HISTOSOL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TL-3a</td>
<td>341.1</td>
<td>88.9</td>
<td>252.1</td>
<td>0.25</td>
</tr>
<tr>
<td>TL-3b</td>
<td>124.7</td>
<td>40.8</td>
<td>83.9</td>
<td>0.50</td>
</tr>
<tr>
<td>average</td>
<td>232.9</td>
<td>64.8</td>
<td>168.0</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Average plant available water (PAW) by weight for volcanic ash soils was 64 percent and individual sample PAWs ranged from 20 percent up to 139 percent by mass. In contrast,
granitic soils averaged 28 percent water holding capacity by weight and individual samples ranged from 15 to 69 percent. Figure 1-12a illustrates the difference in plant available water between ash derived soils and granitic soils. Results from a one-way ANOVA show a statistically significant difference (p<0.05) between water holding capacities of the two soil types by weight (Table 1-6a).

When PAW of these same soils are calculated by volume, however, the difference is not as evident. Since ash soils have a low bulk density, less than 1.0 gram per cubic centimeter, the relative available water is much reduced. As a result, water-holding capacity by volume for ash soils averages 44 percent compared to 30 percent for granitic soils. Ash soils range from 16 to 89 percent and granitics from 19 to 65 percent since they have a bulk density greater than 1.0 g/cm$^3$. Figure 1-12b illustrates that there is an overlap in volumetric PAW by soil type compared to PAW by weight. Table 1-6b gives the results from an analysis of variance showing that the difference between the two is not statistically significant (p>0.05).
Figure 1-12. Plant available water for soils in the Lost Horse study basin: a). per unit mass, and b). per unit volume.
Table 1-6. Analysis of variance results showing a significant difference in percent water holding capacity by weight (p=0.009), and no statistically significant difference in percent water holding capacity by volume (p>0.089) for ash derived soils compared to granitic derived soils in the Lost Horse Creek study basin.

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>a). Available Water by Mass (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>7998.608</td>
<td>16</td>
<td>7998.608</td>
<td>8.059</td>
<td>.009</td>
</tr>
<tr>
<td>Within Groups</td>
<td>23821.367</td>
<td>24</td>
<td>992.557</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>31819.974</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b). Available Water by Volume (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1139.492</td>
<td>16</td>
<td>1139.492</td>
<td>3.147</td>
<td>.089</td>
</tr>
<tr>
<td>Within Groups</td>
<td>8690.094</td>
<td>24</td>
<td>362.087</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9829.586</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A statistically significant relationship (p < 0.001) exists between percent silt and soil bulk density (R² = 0.72) for all samples in the study basin (Figure 1-13a). As the silt content of soils in the upper basin increase, a decline in soil bulk density is expected since ash soils tend to have higher silt content and lower bulk density than granitic soils. Likewise a significant relationship exists between the silt fraction and plant available water by both mass and volume (p-values < 0.001 and 0.01 respectively) (Figure 1-13b).

The silt fraction of soils in the study basin explains approximately 72 percent of the variation in soil bulk density measurements (Figure 1-13a). As the percentage of silt in a soil sample increases, bulk density is expected to decrease. Likewise, the percentage of silt size particles in a soil sample is an indicator of plant available water in the soils of the upper Lost Horse basin (Figure 1-13b). As the silt fraction increases, plant available water is expected to increase.
Figure 1-13. Scatter plots illustrating statistically significant relationships between: a) soil bulk density and silt size fraction, and b) plant available water (by both mass and volume) and silt size fraction in soils of the upper Lost Horse basin.
DISCUSSION

Volcanic Ash Occurrence and Distribution

Ottersburg (1977) concluded that ash thickness decreases as one goes south of the main Mazama fallout path, where the ash is found mainly on north and east aspects of higher mountain slopes. In this study, we found ash occurred most frequently on north and west facing slopes. East facing slopes in the upper Lost Horse Creek basin consisted of steep valley headwalls and ridge-tops. This accounts for the absence of ash soils on these sites. The steepest west-facing slopes held little or no ash, in contrast to gentler west-facing slopes.

Nimlos (1985) concluded that ash soils should be found on all aspects and landforms at elevations in the study basin. Ash soils were found at all elevations on and most landforms of upper Lost Horse Creek, but not consistently. The relatively small elevation changes in the upper Lost Horse Creek study basin do not seem to significantly influence the distribution of ash in this high location.

Local topographical differences seem to affect whether volcanic ash occurs at a site. For example, near the base of a slope where there is a large upslope “source area” for colluviation. Locations protected from prevailing winds with minimal slope also seem have a higher accumulation. Slopes with less than 10% gradient have thicker ash accumulation than steeper slopes. Often, however, one will find areas such as those described above with no discernable volcanic ash layer. McDaniel et al. (1994) hypothesizes that immediately after ash is deposited over the landscape, it is subject to
redistribution and weathering, and that the presence of ash may be quite variable over a very small geographic area. It is likely that considerable disturbance to the surface soil layers has occurred during the past 7,000 years.

Ottersburg and Nielsen (1977) found that soil scientists in western Montana and Idaho regarded fire as harmful to andic layers due to accelerated erosion. McDaniel et al. (1994) concluded that at some drier sites steep slopes, greater likelihood of fire and erosion may result in removal of ash influence. Many other surface disturbances have certainly occurred since the ash was deposited; these include: tree wind throw, freeze-thaw, and burrowing from animals (David, 1970).

Exfoliation from surface boulders and exposed bedrock are an important input of coarse materials to the finer grained ash soils in the basin. The ground surface within the burn area and in the vicinity of large boulders was scattered with the light colored exfoliated particles. From field observations, high temperatures from the intense fire resulted accelerated exfoliation. Even so, exfoliation of the granitic boulders and bedrock is a likely source of coarse particles without the accelerating effect of fire.

**Particle Size**

Particle size distributions of ash soils in this study were very similar to those found by other investigators in the region (Table 1-7). Ash soils in western Montana and northern Idaho are consistently dominated by the silt size fraction. In volcanic ash horizons analyzed in this study and other studies, about 60 percent of the soil consists of silt, roughly 30 percent sand and the remaining 10 percent in clay. In general, as one moves
away from the source of the volcanic eruption, the finer the ash deposits. Studies in Oregon, near the source of the volcano, show much higher sand content than ash soils farther east.

Table 1-7. Particle size distributions and distance from source for relatively pure Mazama ash soils.

<table>
<thead>
<tr>
<th>Author</th>
<th>Location</th>
<th>Distance</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chichester et al. (1969)</td>
<td>Central Oregon</td>
<td>&lt; 100km.</td>
<td>70-80</td>
<td>20-30</td>
<td>2.0-7.0</td>
</tr>
<tr>
<td>McDaniel et al. (1993)</td>
<td>Northern Idaho</td>
<td>750km.</td>
<td>36-40</td>
<td>55-57</td>
<td>5.0-7.0</td>
</tr>
<tr>
<td>Fosberg (1979)</td>
<td>Northern Idaho</td>
<td>750km.</td>
<td>silt or silt loam texture</td>
<td>7.6-8.9</td>
<td></td>
</tr>
<tr>
<td>Nimlos (1981)</td>
<td>Montana</td>
<td>800km.</td>
<td>30,30,36</td>
<td>65,63,55</td>
<td>5,7,9</td>
</tr>
<tr>
<td>This Study</td>
<td>W. Montana</td>
<td>800 km</td>
<td>30</td>
<td>60</td>
<td>10</td>
</tr>
</tbody>
</table>

Redistribution of ash by wind and water erosion and burrowing animals explains the presence of coarse local mineral grains (David, 1970). Uplift of larger particles by freeze/thaw cycles may also explain the existence of larger particles from local sources. Tree wind-throw and resulting uplifted roots may also play a role in the mixing process of volcanic ash with coarser locally derived sub-soils. With so many possibilities for disturbance, and after many thousands of years, it is difficult to imagine why the ash layer is yet discernable.

The 1988 fire that consumed much of the vegetation in the upper reaches of Lost Horse Creek was also a source of coarse rock particles. Theses were observed on the surface next to granite boulders and bedrock outcrops. The intense heat of the fires induced accelerated weathering. Arno (1983) estimated pre-1900 fire frequencies in lower subalpine forests (6,700-7,500 ft) of seral lodgepole pine and potential climax subalpine
fir ranged from 17 to 28 years. Given this frequency, one would expect a considerable amount of coarse grain incorporation in to the surface ash layers.

McDaniel (1993) found that particle size distribution of ash soil is coarser with decreased elevation because of increased mixing and reworking with coarser textured soils. The author suggested that frequent fire and steeper slopes in the lower elevations are capable of causing reworking and redistribution of ash. Since this study was confined to a relatively narrow elevation band, no noticeable differences were detected in particle size distribution by elevation. Ottersburg (1977) speculated that contamination of the ash layer by soils derived from native materials is more likely where ash deposits are thinner. Although this makes intuitive sense, it would be very difficult to test.

**Bulk Density**

The template method for bulk density worked reasonably well at most sites, but proved somewhat difficult where root density was high. Roots tended to disturb and compact the adjacent soil. Using scissors to cut the roots helped to minimize disturbance. The low bulk density of incorporated roots may have contributed to the low bulk density (0.3 g/cm$^3$) of some soil samples.

The most unique feature of soils derived from volcanic ash is the natural low bulk density. Most published literature shows undisturbed ash soils with average bulk density values near 0.70 g/cm$^3$. Table 1-8 provides examples of bulk density values for ash soils from a variety of locations. Most of the bulk density values for ash soils obtained in the study basin compared favorably to values reported by others.
Table 1-8. Published bulk density values for volcanic ash soils.

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>LOCATION</th>
<th>BULK DENSITY (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page-Dumroese (1993)</td>
<td>Idaho, USA</td>
<td>0.43-0.84</td>
</tr>
<tr>
<td>Geist et al. (1989)</td>
<td>Oregon and Washington, USA</td>
<td>0.61-0.74 [66.9 avg.]</td>
</tr>
<tr>
<td>Fosberg et al. (1979)</td>
<td>Idaho, USA</td>
<td>0.80-0.90</td>
</tr>
<tr>
<td>Ottersburg (1977)</td>
<td>Western Montana</td>
<td>0.70-0.97</td>
</tr>
<tr>
<td>Parfitt and Kimble (1989)</td>
<td>New Zealand</td>
<td>0.60-0.70</td>
</tr>
<tr>
<td>Arnalds et al. (1995)</td>
<td>Iceland</td>
<td>0.60-0.74</td>
</tr>
<tr>
<td>Martini (1976)</td>
<td>Costa Rica</td>
<td>0.52-0.89</td>
</tr>
<tr>
<td>This Study</td>
<td>Western Montana</td>
<td>0.51-0.85</td>
</tr>
</tbody>
</table>

The low bulk density of volcanic ash soils is most likely not due low particle density. Most researchers find particle densities of 2.7-2.9 g/cm³, which is within the range of particle densities for most parent materials. When care is taken to remove entrapped air from particles, particle density values are within the range of other minerals (Maeda et al., 1977). These authors further state:

"...If the unit particle of allophane is accepted to be a hollow spherule of 50 Å outside diameter and about 30 Å inside diameter, water movement into and out of this sphere would be difficult and account for the low mineral density sometimes measured."

According to Nanzyo et al. (1993) rhyolitic and dacitic ashes have bulk densities around 1.5 g/cm³ and the value decreases with the amount of weathering. He concludes that development of the porous soil structure from continued weathering of ash is responsible for low bulk densities. Intense weathering environments promote the formation of allophane, which is important to the low bulk density characteristic of ash soils.
**Water Content**

Nimlos (1981) concluded that available water is from 2 to 4 times greater in volcanic ash soils than in lower horizons without ash. In this study, volumetric plant available water of the volcanic ash layers were often double or triple that of the underlying granitic soils. In some cases, however, the values were very similar on a volumetric basis even though plant available water by weight was much higher in the volcanic ash soils. Ottersberg (1977) found a similar result, concluding that the low bulk density of volcanic ash soils often lessened or eliminated the difference in volumetric plant available water between the ash soils and underlying soils with parent materials of local origin.

Measurements of 1500-kP water content and plant available water made in this study are consistent with the few values reported in the literature. McDaniel et al. (1993) and McDaniel et al. (1994) reported on the physical properties of volcanic ash influenced soils in northern Idaho. Table 1-9 shows the particle size distributions and 1500-kP water content for soils along a south-facing gradient from highest to lowest elevation. By comparison, the soils had much lower silt content than soil samples in this study. As a result, 1500-kP water content is lower in all cases with the exception of their highest elevation site, site 112, which is within the lower range of values reported in this study for ash soils, but are closer to the average of values reported for granitic soils in this study. The south facing aspect of the McDaniel et al. (1993 and 1994) sites may explain the lower than expected silt fraction and 1500-kP water content in the soil samples.
Table 1-9. Particle size distribution and 1500-kP water content for volcanic ash influenced soils along a gradient in northern Idaho from McDaniel et al. (1994).

<table>
<thead>
<tr>
<th>Site and Horizon</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>1500 (kP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 112</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>38.3</td>
<td>56.2</td>
<td>5.5</td>
<td>14.6</td>
</tr>
<tr>
<td>bs1</td>
<td>39.3</td>
<td>54.5</td>
<td>6.2</td>
<td>18.5</td>
</tr>
<tr>
<td>bs2</td>
<td>39.1</td>
<td>55.6</td>
<td>5.4</td>
<td>13.2</td>
</tr>
<tr>
<td>bs3</td>
<td>45</td>
<td>51</td>
<td>4</td>
<td>8.7</td>
</tr>
<tr>
<td>Site 107</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>64.8</td>
<td>31</td>
<td>4.1</td>
<td>6.5</td>
</tr>
<tr>
<td>bw1</td>
<td>62</td>
<td>34.6</td>
<td>3.5</td>
<td>7.2</td>
</tr>
<tr>
<td>bw2</td>
<td>65.6</td>
<td>31.2</td>
<td>3.2</td>
<td>4.4</td>
</tr>
<tr>
<td>bw3</td>
<td>69.9</td>
<td>27.8</td>
<td>2.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Site 104</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>80.5</td>
<td>16.3</td>
<td>3.2</td>
<td>4.4</td>
</tr>
<tr>
<td>bw1</td>
<td>82</td>
<td>15.5</td>
<td>2.6</td>
<td>3.7</td>
</tr>
<tr>
<td>bw2</td>
<td>84.9</td>
<td>13.6</td>
<td>1.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Fosberg (1979) reports on water content and plant available water for a soil in northern Idaho. Table 1-10 shows that 33.3-kP and 1500-kP water content, 56 and 16 percent respectively, were within the range of values reported for volcanic ash soils in this study. Plant available water that averaged about 40 percent by volume is close to the mean value found in this study.

Table 1-10. Bulk density, water content and plant available water for an uncultivated volcanic ash soil in northern Idaho from Fosberg et al. (1979).

<table>
<thead>
<tr>
<th>Uncultivated Soil</th>
<th>BD</th>
<th>33.3 (kP)</th>
<th>1500 (kP)</th>
<th>PAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>B21ir</td>
<td>0.9</td>
<td>53.5</td>
<td>15</td>
<td>38.5</td>
</tr>
<tr>
<td>B22ir</td>
<td>0.81</td>
<td>55</td>
<td>16.5</td>
<td>38.5</td>
</tr>
<tr>
<td>B23ir</td>
<td>0.8</td>
<td>58.8</td>
<td>16.9</td>
<td>41.9</td>
</tr>
<tr>
<td>average</td>
<td>0.84</td>
<td>55.77</td>
<td>16.13</td>
<td>39.63</td>
</tr>
</tbody>
</table>

Ottersberg (1977) found 1500-kP water content ranging between 10 and 40 percent and 33.3-kP water content ranging between 42 and 65 percent for a variety of sites in western
Montana (Table 1-11). The silt content of the soils was between 61 and 77 percent, consistent with expected values of relatively uncontaminated volcanic ash soils in the region (Nimlos, 1981). Plant available water ranged from 30 to 45 percent, also consistent with values reported in this study.

Table 1-11. Particle size distribution, bulk density, water content and plant available water for volcanic ash soils in western Montana from Ottersburg (1977).

<table>
<thead>
<tr>
<th>Series</th>
<th>Layer</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>BD (g/cm³)</th>
<th>33.3 (kP)</th>
<th>1500 (kP)</th>
<th>PAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>B21</td>
<td></td>
<td>24</td>
<td>62</td>
<td>14</td>
<td>48.9</td>
<td>10.8</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>B22</td>
<td></td>
<td>21</td>
<td>75</td>
<td>4</td>
<td>62.6</td>
<td>22.8</td>
<td>39.8</td>
<td></td>
</tr>
<tr>
<td>Unnamed 4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B21</td>
<td></td>
<td>18</td>
<td>69</td>
<td>13</td>
<td>55.7</td>
<td>10.7</td>
<td>45.0</td>
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</tr>
<tr>
<td>B22</td>
<td></td>
<td>17</td>
<td>77</td>
<td>6</td>
<td>53.4</td>
<td>13.4</td>
<td>40.0</td>
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<tr>
<td>Truefissure</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B21ir</td>
<td></td>
<td>24</td>
<td>70</td>
<td>6</td>
<td>0.68</td>
<td>47.2</td>
<td>11.8</td>
<td>35.4</td>
</tr>
<tr>
<td>B22ir</td>
<td></td>
<td>28</td>
<td>67</td>
<td>5</td>
<td>0.75</td>
<td>42</td>
<td>10.8</td>
<td>31.2</td>
</tr>
<tr>
<td>Wishard</td>
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<td></td>
<td></td>
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<td></td>
</tr>
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<td>A11</td>
<td></td>
<td>17</td>
<td>66</td>
<td>18</td>
<td>0.6</td>
<td>64.3</td>
<td>40.7</td>
<td>23.6</td>
</tr>
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<td>64</td>
<td>17</td>
<td>0.86</td>
<td>49.7</td>
<td>14.6</td>
<td>35.1</td>
</tr>
<tr>
<td>A13</td>
<td></td>
<td>21</td>
<td>67</td>
<td>12</td>
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<td>51.5</td>
<td>9.9</td>
<td>41.6</td>
</tr>
<tr>
<td>Unnamed 5</td>
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<td>A1</td>
<td></td>
<td>26</td>
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<td>13</td>
<td>64.5</td>
<td>23.9</td>
<td>40.6</td>
<td></td>
</tr>
<tr>
<td>B21</td>
<td></td>
<td>24</td>
<td>68</td>
<td>11</td>
<td>43.6</td>
<td>13.1</td>
<td>30.5</td>
<td></td>
</tr>
<tr>
<td>B31</td>
<td></td>
<td>20</td>
<td>69</td>
<td>11</td>
<td>44.7</td>
<td>12.6</td>
<td>32.1</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td></td>
<td>21.67</td>
<td>67.92</td>
<td>10.83</td>
<td>0.74</td>
<td>52.34</td>
<td>16.26</td>
<td>36.08</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

Volcanic ash soils play an important role in the hydrologic function of headwaters basins, especially where water storage available for plants is limited. In this study we can conclude that ash soils are widespread throughout the Lost Horse Creek study basin, and exist to varying degrees on all aspects and landforms. However, the ash does not exist as a continuous blanket across the landscape. Instead, the volcanic ash horizons have been
transported out of the basin, redistributed locally, and mixed with granitic parent materials continuously over the past 7,000 years. Wind and water erosion after wildfire, tree wind throw, freeze-thaw, and burrowing animals have contributed to the genesis of these soils.

In the Lost Horse Creek study basin, recent glaciation, poor water holding capacity of coarse granitic soils of local origin, and slow rate of soil formation combine to increase the importance of ash fall inputs to the soil system and the hydrologic cycle. Because of these properties, we can conclude that this high elevation basin would look and function somewhat differently without volcanic ash.
INTRODUCTION

The stream baseflow period of late summer is critical for those dependent on surface water resources in the western United States. After snowmelt and during periods with little or no precipitation, streamflow is sustained by the discharge of groundwater to the channel (Moore, 1997; Tallaksen, 1995; Zecharias and Brutsaert, 1988; Hall, 1968; Barnes, 1939). As dry conditions persist, groundwater storage is depleted primarily by gravity drainage, and secondarily by evapotranspiration resulting in a decline in the rate of stream discharge. This decline in streamflow during periods with no precipitation, snowmelt and flow augmentation from dam releases is called the baseflow recession. Since the baseflow recession period coincides with high demand for surface water, an understanding of its behavior is essential for users of surface water resources in arid and semi-arid climates.

Baseflow not only provides a sustained water source for municipal drinking water, waste treatment, mining, irrigation, and ranch operations, but it is also critical to wildlife and fisheries during the dry season when rainfall is minimal or nonexistent. Since surface water rights are tied to interpretation of historic flow records, consumptive uses of water have senior rights. When instream flow rights exist, they are unlikely to provide requirements for aquatic and terrestrial biotic communities during most years (Benjamin and Van Kirk, 1999). Since most surface water resources in the western United States are over-appropriated, there is a need for improving our understanding of hydrologic pathways in natural systems during periods of low-flow.
Baseflow recession analysis is important for forecasting low-flows and for low-flow frequency analysis (Tallaksen, 1995; Gottschalk et al., 1997), describing groundwater aquifer characteristics, comparing outflow characteristics of drainage basins (Knisel, 1963; Farvolden, 1963) and estimating groundwater recharge in a drainage basin (Meyboom, 1961; Ruttledge, 1993). Recession parameters are typically required as input to rainfall-runoff models (Vogel and Kroll, 1996). Regional studies of baseflow recession parameters can help to delineate areas of homogeneous baseflow regimes, and to estimate recession characteristics at un-gaged locations (Singh and Stall, 1971). With the recent focus on surface water quantity and quality from headwaters basins, understanding factors that affect stream baseflow is essential.

**Previous Research**

Much of the research on baseflow recession has focused on stream hydrograph analysis that began around the turn of the century with Maillet (1902). He understood that during periods with no inputs to groundwater storage streamflow is generated only by the depletion of stored water. Likewise, according to Darcy’s Law, as the hydraulic gradient towards the channel decreases, so does stream discharge. Barnes (1939) separated flow into three components depending on its source; surface flow, storm seepage and baseflow. The first two, surface flow and storm seepage, rely on shorter and quicker hydrologic pathways to the stream channel. Baseflow, on the other hand, relies on relatively long pathways. Hence, variation in soil and aquifer materials will affect the rate of discharge of groundwater to the stream channel.
There is a considerable body of work in the published literature focusing on recession analysis methodology (eg. Tallaksen, 1995). The parameter of interest in recession analysis is the average rate of decline in flow at a point along a stream channel that is usually an existing gaging station. Recession analysis from gaging station records involves choosing segments of stream flow that are unaffected by snowmelt, rainfall, flow diversion and flow augmentation. These segments are then arranged or averaged to derive a “characteristic recession”. Various mathematical expressions have been used to model this decline (Barnes, 1939; Toebes and Strang, 1964; Singh and Stall, 1971; Vogel and Kroll, 1996).

Hall (1968) published a lengthy review of baseflow recession including the history of recession theory, analysis, analytical expressions and applications. Tallaksen (1995) published an updated comprehensive review of baseflow recession analysis. Unfortunately, there are few examples of applied field studies. The few applied studies in the published literature have explored the relationship of stream baseflow characteristics to basin geomorphic parameters (Farvolden, 1963; Zecharia and Brutsaert, 1988). Others have compared drainage basins and geologic formations using baseflow recession (Knisel, 1963; Browne, 1981; Vogel and Kroll, 1992; Sugiyama, 1996). Others have investigated the relationship of baseflow to soil moisture in regions where extensive groundwater aquifers do not exist (Hewlett, 1961; Hewlett and Hibbert, 1963; Anderson and Burt, 1980).

Gottschalk et al. (1997) and others have used recession curves to derive low-flow distributions. Meyboom (1961) used baseflow recession to estimate groundwater
recharge. Dixon and Potts (1996) showed that disturbance such as fire can affect stream baseflow by altering the hydrologic balance. Given the amount of scientific literature devoted to developing methods for baseflow recession analysis, there are very few examples of applied studies using recession analysis. Nevertheless, recession analysis can be useful in describing similarities and differences in outflow processes between drainage basins. To date, there are no known studies relating the factors affecting baseflow recession in Rocky Mountain headwaters basins where a unique combination of geology, geomorphology and climate create chronic water shortages on an annual basis.

Objectives

The purpose of this study is to characterize baseflow recession in headwaters streams of the Bitterroot River basin of western Montana. One objective was to derive baseflow recession constants for each gaged stream and identifying basin characteristics that lead to variability of recession rates in these basins. Further detailed study in the Lost Horse Creek basin, one of the Bitterroot tributary streams, was conducted during two field seasons to document variation in the recession rate along the course of the stream. In addition, groundwater levels and soil moisture were monitored in the upper basin to document their relationship with stream discharge during the dry season. Water level data were collected to illustrate the relationship between water table decline and stream recession and to document the variation in groundwater flow paths during the study period. Results from this study will aid in the understanding of the low-flow hydrology of subalpine basins and assist in land and water use management decisions in the region.
STUDY SITE DESCRIPTION

Location of Study Area

The Bitterroot Valley is located in western Montana, south of Missoula (Figure 2-1). The valley is bound on the east by the Sapphire Mountain Range and on the west by the main stem of the Bitterroot Mountains. The head of the Bitterroot Valley is at Lost Trail Pass on the Montana / Idaho border at 2,135 meters. The Bitterroot River drains an area of approximately 7,250 square kilometers where it joins the Clark Fork River near Missoula, Montana at 975 meters above sea level.

This study focused on gaged tributary basins to the Bitterroot River emanating from both the Bitterroot Range and the Sapphire Mountains. Tributary streams in the Sapphires include: Burnt Fork Creek, Skalkaho Creek and Sleeping Child Creek. In the Bitterroot Range, gaged streams include Kootenai Creek, Bear Creek, Blodgett Creek, Fred Burr Creek, Lolo Creek and Lost Horse Creek. The US Geological Survey operated gaging stations on all of these streams with the exception of Lost Horse Creek, which was gaged by the U.S. Forest Service from 1979 to 1981. Stream gaging resumed during this study at the same location on Lost Horse Creek in 1995 and 1996. Table 2-1 summarizes site characteristics of the gaged basins selected for this study.
Figure 2-1. Map of Bitterroot Valley and the location of study basins.
Table 2-1. USGS Gaging stations used for recession analysis.

<table>
<thead>
<tr>
<th>Bitterroot Tributaries</th>
<th>Lat (ddmmss)</th>
<th>Long. (ddmmss)</th>
<th>Basin Area (km)^2</th>
<th>Elevation (meters)</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sapphire Range</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skalkaho Creek</td>
<td>460940</td>
<td>1135652</td>
<td>227.4</td>
<td>1339</td>
<td>1949-80</td>
</tr>
<tr>
<td>Sleeping Child Creek</td>
<td>460758</td>
<td>1140326</td>
<td>168.9</td>
<td>1247</td>
<td>1973-77</td>
</tr>
<tr>
<td>Burnt Fork Creek</td>
<td>462750</td>
<td>1135640</td>
<td>189.6</td>
<td>1301</td>
<td>1938-62</td>
</tr>
<tr>
<td><strong>Bitterroot Range</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kootenai Creek</td>
<td>463214</td>
<td>1140931</td>
<td>74.9</td>
<td>1152</td>
<td>1949-63</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>462300</td>
<td>1141300</td>
<td>69.4</td>
<td>1149</td>
<td>1938-59</td>
</tr>
<tr>
<td>Blodgett Creek</td>
<td>461610</td>
<td>1141410</td>
<td>67.1</td>
<td>1234</td>
<td>1947-69</td>
</tr>
<tr>
<td>Lost Horse Creek</td>
<td>460605</td>
<td>1141542</td>
<td>170.9</td>
<td>1292</td>
<td>1979-81 and 1995-1996</td>
</tr>
<tr>
<td>Fred Burr Creek</td>
<td>462120</td>
<td>1144510</td>
<td>45.8</td>
<td>1265</td>
<td>1946-51</td>
</tr>
<tr>
<td>Lolo Creek</td>
<td>464500</td>
<td>1140900</td>
<td>647.5</td>
<td>1003</td>
<td>1950-60</td>
</tr>
</tbody>
</table>

The Lost Horse Creek basin was chosen for further detailed study of baseflow and groundwater. The soils and water balance of the upper part of the Lost Horse Creek basin are discussed in other chapters. The basin is located approximately 8 kilometers southwest of Darby, Montana. Unlike other Bitterroot Range tributary basins, Lost Horse Creek has a road that leads from the valley to the upper basin facilitating easy access (Figure 2-2). In addition to the recording gage at the mouth of the canyon, four additional gaging stations were located along Lost Horse Creek. The primary concern was to place the stream gages at locations with bedrock control to minimize flow losses around the gage. The first site, Dome gage, was located approximately 9 kilometers upstream from the recording gage on Lost Horse Creek. The second site, Falls gage, was located approximately 1.6 kilometers upstream from the confluence of Lost Horse Creek and Tenmile Creek. The third gage, Upper Bridge, was located just upstream of the bridge over Lost Horse Creek, where the upper basin tributaries come together. The last,
Meadow gage, was located in the meadow area near the road heading toward Bear Creek Pass. Table 2-2 summarizes the characteristics of the Lost Horse basin gaging stations.

<table>
<thead>
<tr>
<th>Lost Horse Basin</th>
<th>Lat (dd:mm:ss)</th>
<th>Long. (ddd:mm:ss)</th>
<th>Basin Area (km)</th>
<th>Elevation (meters)</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow</td>
<td>460734</td>
<td>1142931</td>
<td>2.7</td>
<td>1831</td>
<td>1995-96</td>
</tr>
<tr>
<td>Upper Bridge</td>
<td>460830</td>
<td>1142905</td>
<td>15.6</td>
<td>1748</td>
<td>1995-96</td>
</tr>
<tr>
<td>Falls</td>
<td>460821</td>
<td>1142541</td>
<td>36.2</td>
<td>1639</td>
<td>1995-96</td>
</tr>
<tr>
<td>The Dome</td>
<td>460743</td>
<td>1142151</td>
<td>68.2</td>
<td>1490</td>
<td>1995-96</td>
</tr>
<tr>
<td>Lower Bridge</td>
<td>460605</td>
<td>1141542</td>
<td>170.9</td>
<td>1292</td>
<td>1979-81 and 1995-1996</td>
</tr>
</tbody>
</table>

Figure 2-2. Map of the Lost Horse Creek study area with stream gaging locations and weather stations.
Climate

The climate of the Bitterroot basin is dominated by weather systems from the Pacific for much of the year, especially during the winter. However, this area lies roughly on the climatic boundary between warm, moist air coming in from the Pacific and dry, cold air of continental origin. During the summer, and occasionally during brief periods in the winter, the climate may be more similar to the drier, colder mountains and valleys farther to the east (Finklin, 1983).

The climate in the Bitterroot basin varies by elevation and location. Figure 2-3 illustrates that climate stations in the valley at Stevensville and Hamilton receive the least precipitation; about 32-cm. per year, while higher elevation stations in the Sapphire and Bitterroot mountains receive up to 16.5-centimeters per year. Stations on the west side of the valley in the Bitterroot Mountains have higher average annual precipitation for a given elevation than do those located on the east side in the Sapphire Mountains.

The Bitterroot basin receives the majority of its precipitation during the winter. As a result, snow is the dominant form. Farnes and Schafer (1972) estimate that as much as 70% of the annual precipitation falls as snow in this region. At the Twin Lakes SNOTEL station, the warmer months of May through October have the least precipitation. These months account for only 30 percent of the annual precipitation (Figure 2-4). In contrast, almost 70 percent of the annual precipitation falls during the winter months of November through April. Presumably, most of this 70 percent is in the form of snow.
Figure 2-3. Plot of the average annual precipitation with elevation at stations located in the Bitterroot Basin.

Figure 2-4. Percent of annual precipitation by month at the Twin Lakes SNOTEL station in the Lost Horse Creek Basin. (based on 18-years record)
Streamflow

Hydrographs of Bitterroot tributary streams are dominated by snowmelt during the late spring and early summer. Peak runoff is associated with peak spring snowmelt in late May or early June. Figure 2-5 shows the Skalkaho Creek hydrograph for years 1949 through 1979. The hydrograph is similar in character to those of other Bitterroot River tributaries. As the snowmelt season progresses, the hydrograph falls off sharply until most or all of the snow is gone in the headwaters basins by mid-July. Hydrographs from Bitterroot tributary streams continue to decline through the months of August and September with occasional spikes from large storm events.

Figure 2-5. Annual streamflow hydrograph of Skalkaho Creek for water-years 1949 through 1979. Peak streamflow occurs around June 1 and declining streamflow by mid-July.
Geology and Soils

Granitic rocks of the Idaho batholith dominate the geology of the Bitterroot Range. Metamorphosed Precambrian sedimentary rock (metasediment) is found to the north of Stevensville, Montana (Figure 2-6). The Idaho batholith occupies most of central Idaho and the Bitterroot front in western Montana (Alt and Hyndman, 1986). The Idaho batholith consists of large masses of fairly uniform rock, largely quartz monzonite, surrounded by a border zone of diverse rocks with a gneissic texture (Ross 1950). The Sapphire mountains on the east side of the Bitterroot Valley are formed mostly of Precambrian sedimentary rocks otherwise known as Belt series metasediments and partly of Cretaceous intrusive rocks similar to that of the Idaho batholith (Alt and Hyndman, 1986).
Figure 2-6. Geologic map of the Bitterroot basin with the dating of study basins. Source data from Raines and Johnson, 1995.
Table 2-3 summarizes the geology of each study basin interpreted from the 1:500,000 geologic map of Montana (Raines and Johnson, 1995). The geology of the individual study basins is somewhat varied, but in general the Bitterroot basins are all underlain by intrusive granitics of the Idaho batholith (quartz monzonite) (Raines and Johnson, 1995). There are occasional glacial deposits and valley alluvium along the stream courses. Bands of granite bedrock spanning the valleys interrupt the alluvium frequently along the valley length creating cascades or waterfalls in the stream channel. Near the mouths of the canyons and along the face of the Bitterroot Range are border zone intrusives (granite gneiss). The Lolo Creek basin lies on the dividing line between the Idaho batholith intrusives to the south and the Belt series metasediments to the north. Lolo Creek also has significant amounts of alluvium filling a wide valley bottom, unlike the other Bitterroot Range tributaries.

The Sapphire basins are all quite different from each other and different from the Bitterroot basins. Burnt Fork basin is underlain primarily by belt series metasediments with small patches of Idaho batholith granitics in the higher elevations. The geologic map shows a considerable amount of glacial deposits in the valley bottom of this basin making up an estimated 15 to 20% of the basin area. The Skalkaho Creek basin is mixed geologically. About half of the basin is underlain by the Idaho batholith border zone intrusives (granite gneiss), similar to those along the Bitterroot front and approximately 30% of the basin is Belt series metasediments. The remaining 20% of the Skalkaho Creek basin and the entire Sleeping Child Creek basin is underlain by Idaho batholith intrusive (quartz monzonite).

<table>
<thead>
<tr>
<th>Geologic Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sapphires</strong></td>
<td></td>
</tr>
<tr>
<td>Skalkaho Creek</td>
<td>Skalkaho Creek basin is underlain by approximately 50% Idaho batholith border zone intrusives (granite gneiss), 30% Belt series metasediment, and 20% Idaho batholith intrusive (quartz monzonite).</td>
</tr>
<tr>
<td>Sleeping Child Creek</td>
<td>Sleeping Child basin is underlain almost entirely by Idaho batholith border zone intrusive.</td>
</tr>
<tr>
<td>Burnt Fork Creek</td>
<td>Burnt Fork is primarily underlain by Belt Series metasediments with small patches of Idaho batholith intrusives. The map shows a considerable amount of glacial deposits in the valley bottoms making up from 15 to 20% of the basin area.</td>
</tr>
<tr>
<td><strong>Bitterroots</strong></td>
<td></td>
</tr>
<tr>
<td>Kootenai Creek</td>
<td>Mostly underlain by Idaho batholith with some glacial deposits and valley alluvium. Small area of border zone intrusives near the mouth of the canyon</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>Mostly underlain by Idaho batholith with some glacial deposits and valley alluvium. Small area of border zone intrusives near the mouth of the canyon</td>
</tr>
<tr>
<td>Blodgett Creek</td>
<td>Blodgett Creek is mostly underlain by Idaho batholith with some glacial deposits and valley alluvium. Small area of border zone intrusives near the mouth of the canyon</td>
</tr>
<tr>
<td>Lost Horse Creek</td>
<td>Mostly underlain by Idaho batholith with some glacial deposits and valley alluvium. Small area of border zone intrusives near the mouth of the canyon. Lost Horse shows a greater area of valley alluvium than other basins along the Bitterroot Range front.</td>
</tr>
<tr>
<td>Fred Burr Creek</td>
<td>Fred Burr Creek is mostly underlain by Idaho batholith. Small area of border zone intrusives near the mouth of the canyon. Fred Burr basin shows no valley alluvium on the geologic map.</td>
</tr>
<tr>
<td>Lolo Creek</td>
<td>Lolo Creek is the largest basin and encompasses a variety of geologic types. The headwaters area on the south side of the basin, which were formerly glaciated, are underlain by Idaho batholith and associated intrusives make up about 50 percent of the basin. The north side of the basin is primarily Belt Series metasediments. The Lolo Creek valley is much wider than others and holds a significant amount of alluvium. There are also some glacial deposits on the south side of the valley.</td>
</tr>
</tbody>
</table>

**Physiography**

The Bitterroot Mountains rise abruptly from the valley floor reaching heights up to and over 3,000 meters in the southern part of the range. The mountain front forms a smooth slope inclined at angles of 15-26 degrees (Lindgren, 1904). Glacial features such as U-shaped valleys, cirques, and high elevation glacial lakes characterize the Bitterroot...
Range. The deep valleys emanating from the Bitterroot Range trend east-west and are relatively uniform. Figure 2-7 shows the typical shape of Bitterroot Range tributaries.

The Sapphire Mountains are generally lower in elevation reaching maximum heights of below 2,750 meters. In contrast to the Bitterroot Range, most of the Sapphires were never glaciated (Alt and Hyndman, 1986). Rounded mountains and an irregular front characterize the range. Stream valleys emanating from the Sapphires are dendritic in pattern indicating less control over their course from the underlying geology than the Bitterroot Streams.

Figure 2-7. Photograph of the Lost Horse Creek basin looking westward towards the Montana/Idaho divide. The glacial character is typical of all Bitterroot Range tributary basins.
METHODS

Hydrologic Data Collection

Historical Data

Stream discharge data for eight gaging stations operated by the U.S. Geological Survey in the Bitterroot basin were obtained from the USGS web server. The period of record for these stations varied from 5-years to 42-years (Table 2-1). Other USGS gaging station records were inappropriate for recession analysis due to very short periods of record, infrequent observations, and significant irrigation diversion during the baseflow period. An additional stream gage operated by the Bitterroot National Forest from 1979 to 1981 was located at Lost Horse Creek. Stream gaging was re-established at this site during the course of this study, adding to the 3 years of existing record. A total of nine discharge records from the Bitterroot basin were used for baseflow recession analysis.

Field Data Collection

Continuous water stage was monitored at the bridge near the mouth of the Lost Horse Creek Canyon (lower Lost Horse bridge). This is the same location used by the U.S. Forest Service to gage Lost Horse Creek from 1979 through 1981. A Stevens Type F recorder was installed in the existing stilling well to record water levels. In 1979, 1980 and 1981 the Forest Service developed a stage rating curve for this location. A total of 10 additional discharge measurements were made at the location during the course of this study using a Price AA current meter and standard methods (Buchanan and Sommers, 1968).
For the detailed study of baseflow recession, four additional sites were chosen along Lost Horse Creek for monitoring stream discharge. The new stations were equipped with staff gages that were read on a regular basis during the field season. Price AA and mini current meters were used to measure discharge at all gaging stations throughout the range of flows observed. Current meters were inspected before each use according to USGS specifications (Smoot and Novak, 1968). Discharge measurements were taken to minimize measurement error using standard USGS methodology (Buchanan and Sommers, 1968).

Three of the staff gages were placed along the main stem of Lost Horse Creek and one other placed in a small tributary (Table 2-2). Moving in the upstream direction on the main stem the stations were named: Dome, Falls and Upper Bridge according to nearby features. The gaging stations along the main stem were located at cross-sections with bedrock channel control. Bedrock control assures a stable rating curve since the control conditions will not change from year to year. The bedrock substrate also minimizes the amount of subsurface water bypassing the gaging station. The other gaging station, the Meadow gage, was located in a small tributary near the headwaters of the basin below Bear Creek Pass. Due to local conditions, this gage was not located at a cross-section exhibiting bedrock channel control (Figure 2-2).

Discharge measurements were taken throughout the two field seasons to develop rating curves at each of the gaging stations. For monitoring recessions, staff gages were read during the receding limb of the hydrograph. The continuous stage record at the lower
Precipitation Data

Two NRCS SNOTEL stations, located within the study basin, monitor precipitation, temperature, and snow water equivalent (Figure 2-2). The Twelvemile Creek site is located in the valley bottom at 1,710 meters elevation. This site has been in continuous operation since 1979. The Twin Lakes site at 1,950 meters elevation is located near the headwaters of the basin and has been in operation since 1980. Both of these sites are telemetered and allowed near real-time monitoring of storm events during the field season.

Recession Analysis

Recession analysis involves three steps. First, periods of characteristic recession are identified and extracted from the gaging station record. Second, a model is chosen to describe the recessions. Last, the model is fit to the extracted recessions to derive the parameter or parameters of interest to be used in the comparison.

Recession Segment Selection

Baseflow recession segments were derived for each of the gaging station records using a supervised-automated procedure. An algorithm for selecting recession segments was developed as part of this study and coded in FORTRAN to read formatted USGS gaging station records available through their web server. The automated procedure allows
relatively rapid processing of lengthy streamflow records and is less subjective than methods that involve picking segments by eye from a hydrograph.

The program was written to allow the user to define the month or months to be considered in the recession analysis. For this study, the months of July, August and September were chosen to avoid the effect of snowmelt on the stream hydrograph. The user then specifies the minimum length of a recession segment. For this study, the minimum length chosen was 5 days due to the relatively short recession periods in these streams.

A recession segment is defined as a period where stream discharge strictly declines each day in succession (Figure 2-8). The computer program plots the first recession segment encountered in the record on the screen. The recession segment can be accepted and written to the output file, discarded, or edited by changing the length of the recession by removing values at the beginning or end of the period. The first few days after a hydrograph peak are typically removed to minimize their effect on the recession slope (Bako and Hunt, 1988). After editing, the recession segment can be accepted or rejected. If accepted, data from the segment is written to the output file. If rejected, the program proceeds to the next segment in the record that meets the criteria.
Figure 2-8. An example hydrograph with a typical recession segment showing the peak event prior to the recession, the period of surface/subsurface flow immediately following the runoff event, and the recession period.

This process is repeated until the entire record for a gaging station is processed and all accepted recession segments have been written to the output text file. Table 2-4 is an example output file showing the segment number, date, mean daily discharge, day since beginning of recession and log-transformed discharge. The output file is formatted for analysis in a statistical package such as SPSS. Appendix B includes a listing of the source code for the program written in standard Fortran 77 and an example input file.
Table 2-4. Example output from recession selection program illustrating 3 individual recessions.

<table>
<thead>
<tr>
<th>Recession Segment Number</th>
<th>Date</th>
<th>Discharge (cfs)</th>
<th>Recession Day</th>
<th>Log-Discharge (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7/17/47</td>
<td>46</td>
<td>1</td>
<td>1.663</td>
</tr>
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<td>1</td>
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<td>40</td>
<td>3</td>
<td>1.602</td>
</tr>
<tr>
<td>1</td>
<td>7/20/47</td>
<td>38</td>
<td>4</td>
<td>1.58</td>
</tr>
<tr>
<td>1</td>
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<td>5</td>
<td>0.748</td>
</tr>
<tr>
<td>2</td>
<td>9/5/47</td>
<td>5.5</td>
<td>6</td>
<td>0.74</td>
</tr>
<tr>
<td>3</td>
<td>8/7/48</td>
<td>17</td>
<td>1</td>
<td>1.23</td>
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<tr>
<td>3</td>
<td>8/8/48</td>
<td>16</td>
<td>2</td>
<td>1.204</td>
</tr>
<tr>
<td>3</td>
<td>8/9/48</td>
<td>15</td>
<td>3</td>
<td>1.176</td>
</tr>
<tr>
<td>3</td>
<td>8/10/48</td>
<td>14</td>
<td>4</td>
<td>1.146</td>
</tr>
<tr>
<td>3</td>
<td>8/11/48</td>
<td>13</td>
<td>5</td>
<td>1.114</td>
</tr>
<tr>
<td>3</td>
<td>8/12/48</td>
<td>12</td>
<td>6</td>
<td>1.079</td>
</tr>
<tr>
<td>3</td>
<td>8/13/48</td>
<td>11</td>
<td>7</td>
<td>1.041</td>
</tr>
</tbody>
</table>

Recession Constant Derivation

The standard model used for deriving the recession rate is based on theoretical groundwater flow. The model has the following form (Barnes, 1939):

\[ Q_t = Q_o K^{(t)} \]  

(1)

Where:

\( Q_t \) = Outflow at any time

\( Q_o \) = Outflow at time \( t_0 \)
$K = $ Recession Constant

From equation (1) the value of outflow at any time $t$ ($Q_t$) can be determined from an initial flow value ($Q_0$) and the recession constant ($K$) for a gage site. To determine the recession constant $K$, equation (1) can be rewritten as:

$$\log Q_t = \log Q_0 + t \log K \quad (2)$$

The recession constant for a string of flow values is the slope of $\log Q_t$ against $t$.

A method of deriving the average slope of recession segments by Bako and Hunt (1988) was applied to each of the gaging station output files. This method uses analysis of covariance to derive an average recession parameter (slope) and provides a confidence interval of the slope of individual segments (Brownlee, 1965). The output file from the recession segment selection program for each station was imported into SPSS software for analysis in this manner. The data are read into the general linear models routine in SPSS with log-flow as the dependent variable, recession number as the factor, and time the covariate. The resulting parameter estimations give the average slope and a 95% confidence interval for the estimate.

**Basin Characteristics**

Morphological characteristics for each of the headwaters basins were obtained from PAMAP and Arcview GIS (Geographical Information System). Gaging station locations were digitized into the GIS along with an outline of the basin area. The outline of each basin was used to create a data subset from 30-meter digital elevation models (DEM)
acquired from the US Geological Survey. Basin parameters were derived in the GIS to describe characteristics of the study basins including: basin area, total drainage length, mean basin slope, mean basin elevation, gaging station elevation and basin length. Drainage density, average basin width, basin shape, and relief ratio were derived from the basin parameters (Table 2-5). Using the DEM, the GIS creates a slope value for each pixel based on the elevation of surrounding pixels. The mean slope is the average of all the slope values within the basin of interest. Total basin stream length was calculated by summing all the digitized stream segments identified by crenulations on USGS 1:24,000 quad sheets.

Table 2-5. Derived Basin characteristics (Gordon et al., 1992 and Selby, 1985)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Density</td>
<td>Channel length / basin area</td>
</tr>
<tr>
<td>Mean Basin Width</td>
<td>Basin length / basin area</td>
</tr>
<tr>
<td>Basin Shape</td>
<td>Basin length / basin width</td>
</tr>
<tr>
<td>Relief Ratio</td>
<td>Max. – min. elevation / basin length</td>
</tr>
</tbody>
</table>

**Groundwater**

Thirty shallow piezometers were installed in the upper meadow of the Lost Horse Creek basin. This location was chosen because of its accessibility and that groundwater was near the surface, easing the problem of deep well installation in the rocky soils. The wells were located in a grid upstream from the meadow stream gage, consisting of 5 transects perpendicular to the valley with 5 or 6 wells in each transect (Figure 2-9). Wells were surveyed to a common datum at a marked point on the well casing. For mapping, coordinate locations of each well were obtained using a hand-held GPS.
Figure 2-9. Location map of piezometers, stream gauges and soil moisture tensiometers in the upper meadow of the Lost Horse Creek basin.

Well casing was constructed of standard 3/4 inch diameter PVC pipe sealed with a cap at the bottom. Using a hacksaw, each well was slotted from near the base to a point above
the expected high groundwater level. A cap was made for the top of each well constructed of 1-inch PVC. Each well was installed to the maximum depth possible using hand tools. In most cases the maximum depth was no more than 1-meter due to large rocks encountered at that depth. Each hole was finished using a 3-inch bucket auger and backfilled with coarse sand to a height above the slots on the well casing. Larger rocks were packed around the well casing to secure it in place. The remainder of the hole was filled with native soil banked around the well casing to prevent water flow along the well casing during rain.

Water level measurements were made throughout the two field seasons during periods of continuous dry weather. Water levels were measured by applying water sensitive clay to a steel tape and measuring down from the marked point on the well casing. The measured depth to water surface was converted to water table elevation using survey data.

During the second field season, wells were placed in the stream bed in the upper meadow to further characterize the groundwater flow paths and vertical gradients in the stream. These wells, constructed of ¾-inch galvanized steel, were driven into the bed of the stream to a depth of 1-meter. Water levels were measured both inside and outside the well throughout the second field season.

**Soil Moisture**

Soil moisture was monitored during the first field season using ceramic tipped tensiometers with vacuum gages. Tensiometers were installed in pairs at 30 and 60-centimeter depth. The instruments were located adjacent to the upper meadow along a
hillslope transect in four groups with two tensiometers in each group. These tensiometer nests were located near well transect number two (Figure 2-9). Calibration of tensiometers was achieved by correcting all measurements to a common vacuum gage.

Prior to installation, all tensiometers were placed in a bucket of saturated sand and allowed to equilibrate for 48-hours. Field installation involved driving a hollow iron pipe to the desired depth. The size of the pipe was slightly smaller than the diameter of the tensiometers to insure good contact between the ceramic tip and the soil. The instruments were placed in the hole and pushed until firm contact with the soil was achieved. Loose soil was packed around the base of each tensiometer to prevent water from running down the sides and affecting the readings.

The tensiometers were filled with a dye colored water solution and all air bubbles were evacuated from the chamber using a handheld vacuum pump. Calibration of tensiometers was achieved by correcting all measurements to a common vacuum gage located on the pump. Measurements were taken in concert with groundwater well level measurements. After measurement, the instruments were filled with the water solution if necessary and the pump was applied to remove air bubbles.

**Seismic Profile**

A portable Bison seismic refraction unit was used to get depth to bedrock in the upper meadow area of the basin. The unit consisted of two geophone detectors connected to a timer. Seismic waves were generated by a sledge hammer blow on a metal plate. This
method is appropriate when bedrock is less than 35-feet below the ground surface, as it was in this location (Mooney, 1973).

A simple model is used to calculate the distance from the ground surface to bedrock from first arrival times of the refracted waves (Burroughs et al., 1965). The following equation was applied to the resulting data:

\[ D_1 = \frac{X_1}{2} \sqrt{\frac{(V_2-V_1)}{(V_2+V_1)}} \]  \( (3) \)

\[ V_1 = \frac{X_1}{T_1} \]  \( (4) \)

\[ V_2 = \frac{(X_2 - X_1)}{T_2} \]  \( (5) \)

\( D_1 \) is the depth to the \( V_2 \) (bedrock) layer. The breakpoint in the time vs. distance curve has the coordinates of \( T_1 \) and \( X_1 \) respectively. The quotient of these represents the seismic wave velocity in the \( V_1 \) (unconsolidated surface material) layer. \( V_2 \) is the slope of the second half of the broken line representing the seismic wave velocity in the bedrock layer. A total of six point measurements were taken in the meadow area of the upper basin to provide a cross-section of depth to bedrock across the valley. The seismic points were taken at the location of tensiometers and piezometers along transect number 2 (Figure 2-9).
RESULTS

Bitterroot Tributaries

Stream Gaging

A rating curve was established for the Lost Horse Creek lower bridge site for measurements performed during the course of this study. A total of 10 measurements were made at the lower bridge gaging station during the 1995 and 1996 field seasons. The discharge measurements were concentrated on the lower end of the stage/rating curve during the baseflow period. Stage/discharge data were also available from the US Forest Service for 1979 to 1981 at this same location. After a plot of flow measurements from both periods revealed no visible difference in the stage/discharge relationship, the data were combined into a single rating curve for the station. Figure 2-10 shows the rating curve for the Lower Lost Horse site.
Stream gaging at the Lost Horse Creek lower bridge commenced on April 23, 1995, before any significant snowmelt had occurred in the basin. Flow started to rise in mid-May of this year as the winter snowpack began to melt and high flows continued through early July. Figure 2-11a shows the hydrograph for water-year 1995. The streamflow peaks were a result of both snowmelt and precipitation in the basin. For example, during the May 12 peak flow event, considerable rain combined with noticeable snowmelt to bring a rapid rise in the hydrograph. Flow quickly declined following a cessation of rain on May 13 and a cooling trend. The next peak event, starting just a few days later, was due to snowmelt alone. During this event temperatures in the upper elevations of the basin exceeded 21 degrees Celsius.
On June 1 of 1995 the water level of Lost Horse Creek rose to the level of the stage
recorder box. To prevent damage to the stage recorder, it was removed until the water
level dropped below the level of the housing. The water level receded by June 13 and the
recorder was replaced. During the gap in record, stream discharge exceeded an estimated
36.8 meters^3/second at the lower bridge.

By mid June of 1995 most of the snow had melted from the basin. However, a
considerable amount of snow lay on the protected north facing slopes in the upper basin.
In early July another peak event submerged the recorder box for a few hours after close to
7.5-centimeters of rain fell over some parts of the upper basin in 24-hours (Figure 2-11a).
High antecedent moisture conditions from recent snowmelt contributed to the magnitude
of the event.

The recession limb of the 1995 hydrograph for Lost Horse Creek began by mid-July,
after all snow was gone from the upper basin. The smooth recession line was broken by
hydrograph responses from a number of precipitation events. A notable event occurred on
August 16 where 4-centimeters of rain was recorded at the Twin Lakes precipitation gage
in the upper basin. After September 1st there was only one short dry period in mid-
September, during which the recorder malfunctioned. The remainder of the 1995 was
characterized by frequent days of precipitation and associated hydrograph responses.

The 1996 field season followed an exceptionally high snow year in the Lost Horse Basin.
The snow persisted for almost 3 weeks longer than normal according to the Twin Lakes
snow pillow. A number of visits to the lower bridge gaging station were made in late
May and early June, but stream levels were too high to install the water level recorder.
After most of the snow had melted from the basin, the water level recorder was installed on July 8 for the 1996 field season. Figure 2-11b illustrates that stream discharge decreased steadily though July and August and into mid-September. In terms of precipitation, 1996 was uneventful compared to the previous year. Only 1-centimeter of precipitation fell during July and 3.6-centimeters inches during August. This compares to the previous year where 16-centimeters of precipitation fell in July and 9.4-centimeters in August.

Flow levels dropped so dramatically in 1996 that headgates on the Twin Lakes were opened to augment streamflow. The unusual looking rises in stream discharge on August 18 and August 28 are a result of drawdown from the reservoirs (Figure 2-11b). Records from this period were excluded from the subsequent recession analysis. In contrast, there were no known storage releases from the lakes during the 1995 field season.
Figure 2-11. Stream discharge, Precipitation and Snow Water Equivalent in the Lost Horse Creek basin during: a) the 1995 field season, and b) the 1996 field season.
Recession Analysis

Results from the automated recession segment selection program were very close to those obtained by manually extracting recession segments for Blodgett Creek. There were minor variations in the length of a few recession segments, but final results were nearly identical. The program facilitated accurate extraction of periods of decreasing streamflow, presented them as a scatter plot, and properly wrote the data to an output file.

Using the automated procedure to extract recession segments from a long continuous discharge record saved considerable time compared to doing the same task manually in a computer spreadsheet. The time to analyze the 22-year record for Blodgett Creek was around 15 minutes with the automated procedure compared to over 3 hours doing the same in a spreadsheet. The time savings resulted from automatic weeding out of unwanted data points, automatic plotting of data points that fit the criteria, and writing the output to a formatted text file ready for statistical analysis.

A total of 26 recession segments were extracted from the 22-year Blodgett Creek discharge record. Figure 2-12 illustrates that the recession period lasted from a minimum of 5 days up to a maximum of 22 days. Baseflow period discharge values for this station varied over an order of magnitude from 0.11 m-3/s to approximately 2.83m-3/s, and the apparent slope of individual recessions varied only slightly among the segments. Appendix C contains plots of individual recession segments for the remaining gaging stations.
Figure 2-12. A plot illustrating 26 recession segments extracted from the 22-year Blodgett Creek discharge record. Average recession duration was 9-days at this site.

The total number of recession segments for the remaining gage sites varied from 6 at Sleeping Child Creek to 37 at Skalkaho Creek (Table 2-6). Skalkaho Creek happened to also have the longest period of record for any gage, 31 years. In general, the stations with the longest record had the greatest number of recession segments. The average duration of recession segments was quite short. Kootenai Creek had an average recession length of only 5.2 days compared to 9 days or more for most other gages. The short dry season, lasting only a couple months, is frequently interrupted by convective storms and frontal systems that result in few periods of prolonged stream recession.
Table 2-6. Results of recession segment extraction from Bitterroot gaging stations.

<table>
<thead>
<tr>
<th>Bitterroot Tributaries</th>
<th>Record Length (years)</th>
<th>Number of Segments</th>
<th>Average Length (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sapphire Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skalkaho Creek</td>
<td>31</td>
<td>37</td>
<td>8.0</td>
</tr>
<tr>
<td>Sleeping Child Creek</td>
<td>5</td>
<td>6</td>
<td>9.0</td>
</tr>
<tr>
<td>Burnt Fork Creek</td>
<td>23</td>
<td>10</td>
<td>7.8</td>
</tr>
<tr>
<td><strong>Bitterroot Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kootenai Creek</td>
<td>14</td>
<td>11</td>
<td>5.2</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>21</td>
<td>34</td>
<td>8.7</td>
</tr>
<tr>
<td>Blodgett Creek</td>
<td>22</td>
<td>26</td>
<td>9.3</td>
</tr>
<tr>
<td>Lost Horse Creek</td>
<td>5</td>
<td>15</td>
<td>8.9</td>
</tr>
<tr>
<td>Fred Burr Creek</td>
<td>6</td>
<td>10</td>
<td>9.1</td>
</tr>
<tr>
<td>Lolo Creek</td>
<td>11</td>
<td>7</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Results from recession analysis for the study streams show that Bitterroot Range streams have, on average, lower recession constant (higher recession rate) than streams emanating from the Sapphire range (Figure 2-13). The one exception is Lost Horse Creek, with a higher recession constant (0.952) than the remaining Bitterroot Range streams. The value for Lost Horse Creek is closer to those obtained from the Sapphire Streams. The most surprising result is the near identical recession constants for the remaining Bitterroot Range streams. Bear, Blodgett, Fred Burr and Lolo Creeks all have a recession constant near 0.930 with little variation. Kootenai Creek had a higher recession constant, but also higher variation most likely due to the short average length of individual recession segments.
Overall, Skalkaho Creek had the highest recession constant of all tributary streams in the study (0.970). The value is considerably higher than its Bitterroot Range counterparts and higher than the two other Sapphire streams, Sleeping Child and Burnt Fork Creeks (0.948, 0.949). Table 2-7 summarizes the recession model parameter results for all streams with 95 percent confidence intervals.
Table 2-7. Recession model parameters and confidence intervals for Bitterroot tributary streams. Qt = Outflow at any time t, Qo = Outflow at time to, K = Recession Constant

<table>
<thead>
<tr>
<th>Bitterroot Tributaries</th>
<th>Recession Model</th>
<th>Recession Constant</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q_t = Q_o (K)^{1}</td>
<td></td>
<td>Upper</td>
</tr>
<tr>
<td><strong>Sapphire Range</strong></td>
<td></td>
<td></td>
<td>0.9695</td>
</tr>
<tr>
<td>Skalkaho Creek</td>
<td>Q_t = Q_o (0.970)^{1}</td>
<td></td>
<td>0.9436</td>
</tr>
<tr>
<td>Sleeping Child Creek</td>
<td>Q_t = Q_o (0.948)^{1}</td>
<td></td>
<td>0.9465</td>
</tr>
<tr>
<td>Burnt Fork Creek</td>
<td>Q_t = Q_o (0.949)^{1}</td>
<td></td>
<td>0.9354</td>
</tr>
<tr>
<td><strong>Bitterroot Range</strong></td>
<td></td>
<td></td>
<td>0.9275</td>
</tr>
<tr>
<td>Kootenai Creek</td>
<td>Q_t = Q_o (0.939)^{1}</td>
<td></td>
<td>0.9286</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>Q_t = Q_o (0.929)^{1}</td>
<td></td>
<td>0.9509</td>
</tr>
<tr>
<td>Blodgett Creek</td>
<td>Q_t = Q_o (0.930)^{1}</td>
<td></td>
<td>0.9273</td>
</tr>
<tr>
<td>Lost Horse Creek</td>
<td>Q_t = Q_o (0.952)^{1}</td>
<td></td>
<td>0.9287</td>
</tr>
<tr>
<td>Fred Burr Creek</td>
<td>Q_t = Q_o (0.930)^{1}</td>
<td></td>
<td>0.9287</td>
</tr>
<tr>
<td>Lolo Creek</td>
<td>Q_t = Q_o (0.930)^{1}</td>
<td></td>
<td>0.9287</td>
</tr>
</tbody>
</table>

Figure 2-14 illustrates the expected rate of stream discharge decline from selected gages. Setting an arbitrary beginning discharge equal to 5 cubic meters per second (m^3 s^{-1}) during a typical summer dry period, the plot illustrates what one would expect if that dry period persisted for up to 20 days. After 10 days, discharge at Skalkaho Creek would decline to approximately 3.65 m^3 s^{-1}, while at the same time Lost Horse Creek discharge would decline to 2.98 m^3 s^{-1}. The remaining streams would be expected to decline to less than 2.6 m^3 s^{-1} in the same period, or approximately half their discharge at the beginning of the 10-day period. For a 20-day recession, Skalkaho Creek would be expected to decline from 5 m^3 s^{-1} to 2.4 m^3 s^{-1}, Lost Horse Creek to 1.5 m^3 s^{-1} and the remaining streams to less than 1.0 m^3 s^{-1}.
Figure 2-14. Hypothetical plot of a 20-day recession for Bitterroot River tributaries with a beginning discharge of 5 m$^3$ s$^{-1}$ where: $Q_t =$ Outflow at any time $t$, $Q_0 =$ Outflow at time $t_0$, and $K =$ recession constant.

Further investigation was conducted into the nature of individual recession segments for each of the Bitterroot gages. Of interest was the variation of individual recession segments given their length and the mean discharge. To accomplish this, a second computer program was written that reads the output from the previous program and produces an individual regression analysis for each recession segment (Appendix D). Table 2-8 is an example of the output from the regression program giving the length, mean discharge and slope of each recession segment for Lolo Creek.
Table 2-8. Output table of regression analyses of recession segments for Lolo Creek.

<table>
<thead>
<tr>
<th>Recession Segment No.</th>
<th>Y-Intercept</th>
<th>$R^2$</th>
<th>Segment Length (days)</th>
<th>Mean Flow (cfs)</th>
<th>Segment Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.25</td>
<td>0.990</td>
<td>6</td>
<td>122.5</td>
<td>0.899</td>
</tr>
<tr>
<td>2</td>
<td>2.47</td>
<td>0.993</td>
<td>13</td>
<td>160.0</td>
<td>0.917</td>
</tr>
<tr>
<td>3</td>
<td>2.68</td>
<td>0.997</td>
<td>37</td>
<td>122.2</td>
<td>0.931</td>
</tr>
<tr>
<td>4</td>
<td>2.32</td>
<td>0.987</td>
<td>9</td>
<td>151.0</td>
<td>0.939</td>
</tr>
<tr>
<td>5</td>
<td>1.76</td>
<td>0.983</td>
<td>8</td>
<td>41.4</td>
<td>0.931</td>
</tr>
<tr>
<td>6</td>
<td>2.21</td>
<td>0.985</td>
<td>10</td>
<td>96.6</td>
<td>0.911</td>
</tr>
<tr>
<td>7</td>
<td>1.86</td>
<td>0.988</td>
<td>12</td>
<td>43.1</td>
<td>0.924</td>
</tr>
</tbody>
</table>

Plots of recession segment length against segment slope for Bear Creek and Skalkaho Creek show a decrease in variation with an increase in segment length (Figures 2-15a and 2-15c). Individual recession slopes had the greatest variation when their length was less than about 8 days for these sites. When the recession segment length was greater than 10 days duration, there was less variation and each recession segment slope tended to be closer to the average value. Plots for the remaining gage sites show similar results (Appendix E).

Plots of mean discharge against slope shed light on the variation of the recession segments through various levels of flow. The plot for Bear Creek shows a scatter of points about the mean line with no apparent pattern (Figure 2-15b). In contrast, Skalkaho Creek shows that the slope of individual recession segments increased with mean discharge (Figure 2-15d). This result indicates that a log-linear model may not be appropriate for the Skalkaho site. Adding another term to the model would be necessary to more accurately describe the rate of recession at this location. The remaining gage sites do not exhibit noticeable variation in recession slope with increasing discharge (Appendix E).
A one way Analysis of Variance was conducted to determine whether the differences in recession rates between the streams emanating from the Sapphires and Bitterroot mountains were statistically significant. Table 2-9 shows that a significant difference does exist ($P = 0.024$). Differences in the mean recession constant between the two groups are greater than would be expected by chance. To test the null hypothesis that the groups come from populations with the same variance, the Levene test for homogeneity of variances was employed. Since the observed significance level is large ($P = .497$), the null hypothesis that the variances are the same cannot be rejected.
Table 2-9. ANOVA test of differences between recession rates from the Sapphire and Bitterroot Range tributaries.

<table>
<thead>
<tr>
<th>Source</th>
<th>D.F.</th>
<th>Sum of Squares</th>
<th>Mean Squares</th>
<th>F Ratio</th>
<th>F Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1</td>
<td>.0009</td>
<td>.0009</td>
<td>8.2054</td>
<td>.0242</td>
</tr>
<tr>
<td>Within Groups</td>
<td>7</td>
<td>.0007</td>
<td>.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>.0016</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Count</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard Error</th>
<th>95 Pct Conf Int for Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitterroot</td>
<td>6</td>
<td>.9352</td>
<td>.0092</td>
<td>.0038</td>
<td>.9255 TO .9448</td>
</tr>
<tr>
<td>Sapphire</td>
<td>3</td>
<td>.9559</td>
<td>.0124</td>
<td>.0071</td>
<td>.9251 TO .9866</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>.9421</td>
<td>.0141</td>
<td>.0047</td>
<td>.9312 TO .9529</td>
</tr>
</tbody>
</table>

Levene Test for Homogeneity of Variances

<table>
<thead>
<tr>
<th>Statistic</th>
<th>df1</th>
<th>df2</th>
<th>2-tail Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5126</td>
<td>1</td>
<td>7</td>
<td>.497</td>
</tr>
</tbody>
</table>

**Catchment Characteristics**

A total of five basin parameters were derived from the GIS to describe the characteristics of the study basins: Drainage density, mean basin slope, mean basin elevation, basin length and mean basin width. Basin length was divided by width to convert the measure to a dimensionless factor called basin shape. Table 2-10 shows that drainage density ranged from 1.68 km/km² at Bear Creek to 3.15 km/km² at Sleeping Child Creek. Overall the Sapphire range basins stream density averaged higher at 2.45 km/km² compared to an average of 2.12 km/km² in the Bitterroot basins.
Table 2-10. Bitterroot Tributary basin morphological parameters.

<table>
<thead>
<tr>
<th>Bitterroot Tributaries</th>
<th>Mean Basin Elevation (m)</th>
<th>Basin Length (km)</th>
<th>Mean Slope (percent)</th>
<th>Drainage Length (km)</th>
<th>Mean Basin Width (A/Lb)</th>
<th>Basin Shape (L/W)</th>
<th>Relief Ratio (∆ Elev/L)</th>
<th>Drainage Density (km/km²2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapphire Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skalkaho Creek</td>
<td>2029</td>
<td>20.4</td>
<td>41.3</td>
<td>542</td>
<td>11.1</td>
<td>1.84</td>
<td>68.5</td>
<td>2.38</td>
</tr>
<tr>
<td>Sleeping Child Creek</td>
<td>1932</td>
<td>24.0</td>
<td>31.1</td>
<td>532</td>
<td>7.0</td>
<td>3.42</td>
<td>59.7</td>
<td>3.15</td>
</tr>
<tr>
<td>Burnt Fork Creek</td>
<td>1961</td>
<td>24.5</td>
<td>40.3</td>
<td>343</td>
<td>7.8</td>
<td>3.15</td>
<td>54.0</td>
<td>1.81</td>
</tr>
<tr>
<td>Bitterroot Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kootenai Creek</td>
<td>2019</td>
<td>14.5</td>
<td>60.4</td>
<td>165</td>
<td>5.2</td>
<td>2.82</td>
<td>113.6</td>
<td>2.20</td>
</tr>
<tr>
<td>Bear Creek</td>
<td>1996</td>
<td>16.3</td>
<td>54.6</td>
<td>117</td>
<td>4.3</td>
<td>3.81</td>
<td>96.4</td>
<td>1.68</td>
</tr>
<tr>
<td>Blodgett Creek</td>
<td>2068</td>
<td>18.7</td>
<td>60.2</td>
<td>116</td>
<td>3.6</td>
<td>5.22</td>
<td>82.1</td>
<td>1.73</td>
</tr>
<tr>
<td>Lost Horse Creek</td>
<td>2014</td>
<td>21.3</td>
<td>49.9</td>
<td>439</td>
<td>8.0</td>
<td>2.66</td>
<td>69.4</td>
<td>2.57</td>
</tr>
<tr>
<td>Fred Burr Creek</td>
<td>2055</td>
<td>15.2</td>
<td>59.2</td>
<td>105</td>
<td>3.0</td>
<td>5.07</td>
<td>93.0</td>
<td>2.28</td>
</tr>
<tr>
<td>Lolo Creek</td>
<td>1618</td>
<td>43.6</td>
<td>33.1</td>
<td>1471</td>
<td>14.9</td>
<td>2.93</td>
<td>39.9</td>
<td>2.27</td>
</tr>
</tbody>
</table>

Sapphire tributary basins were less steep than their Bitterroot counterparts. Mean basin slope ranged from just over 60 percent at Kootenai Creek to 31 percent at Sleeping Child Creek. The Sapphire basins had an average slope of 38 percent compared to 53 percent for Bitterroot basins. Lolo Creek was much less steep (33 percent) than the remaining basins in the Bitterroot Range. The Lolo Creek basin is considerably larger and the gage is at a much lower elevation than the remaining streams emanating from the Bitterroot Range.

Mean elevation for most of the study basins is close to 2,000 meters above sea level. The Lolo Creek basin stood out from the other basins in the study with a much lower mean basin elevation of 1,618 meters. The Sleeping Child basin, however, had a lower mean elevation than the others in the Sapphire Mountains.

Drainage density plotted against the recession constant for each basin shows considerable scatter (Figure 2-16a). The weak positive trend in the relationship between these indicates
that as stream density increases in these basins, the recession rate would be expected to
decrease (the recession constant increases). However, the relationship is not statistically
significant at the 0.05 level (p = 0.257). The significance level may be due in some part to
the small sample size. The plot of mean basin slope against recession constant shows
little or no relationship (Figure 2-16b). The regression is not statistically significant (p =
0.264). Relief ratio against recession constant (Figure 2-16c) also showed considerable
scatter, and was not a statistically significant factor (p = 0.461).

Basin shape plotted against the recession constant showed a moderately strong negative
relationship ($R^2 = 0.56$) (Figure 2-16d). The relationship was statistically significant (p =
0.021). The relationship shows that a long basin in relation to its width would likely have
a higher rate of recession than one that is short in relation to its width. Likewise, gaging
station elevation was a statistically significant factor in explaining recession rate in the
study basins (p = 0.049). The scatter plot in Figure 2-16e shows a positive relationship
with an $R^2 = 0.45$. In this case, the lower in elevation that the gaging station is, the higher
the rate of recession (lower recession constant).
Figure 2-16. Recession constant parameters of study basins plotted against: a) drainage density, b) mean basin slope, c) relief ratio, d) basin shape, and e) gaging station elevation.
Figure 2-17 shows the remaining variables plotted against the recession constant. None of the variables; basin length, stream length, basin area and mean basin width, were statistically significant in explaining the variation of recession values. It is interesting to note that Lolo Creek sits apart from the rest in each of these plots. Eliminating that single data point would show that a relationship exists between the recession constant and basin area as well as stream length and mean basin width.

Table 2-11 illustrates the results of a multiple regression with recession rate as the dependent variable with basin shape and gage elevation as the independent variables. The model was statistically significant and able to explain 94 percent of the variation in the recession constants ($p = < 0.001$). The following equation is derived from the regression model:

$$K = 0.868 + (\text{Shape}) \times (-9.07 \times 10^{-3}) + (\text{Gage Elevation}) \times (8.635 \times 10^{-5})$$  \hspace{1cm} (6)

Where:

$K = \text{Recession Constant}$

$\text{Shape} = \text{Basin shape factor (Basin Length / Mean Width)}$

$\text{Gage Elevation} = \text{Gaging Station Elevation}$
Figure 2-17. Recession constant parameters of study basins plotted against: a) basin area, b) stream length, c) mean basin elevation, d) basin length, and e) mean basin width.
Since basin shape is the ratio of basin length divided by mean basin width, the model implies that at a given elevation, a basin that is long and narrow will have a higher rate of recession. Also, when there are two basins with the same shape factor, but at different gage elevations, the one at a higher elevation would have a lower recession rate.

Table 2-11. Results from multiple regression with recession rate as the dependent variable and independent variables basin Shape and gage Elevation.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.979</td>
<td>.958</td>
<td>.944</td>
<td>.003334</td>
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</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Regression</td>
<td>2</td>
<td>.001</td>
<td>68.424</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Residual</td>
<td>6</td>
<td>.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>8</td>
<td>.002</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>.868</td>
<td>.015</td>
<td>59.406</td>
<td>.000</td>
</tr>
<tr>
<td>Gage Elevation</td>
<td>8.635E-05</td>
<td>.000</td>
<td>.634</td>
<td>7.569</td>
</tr>
<tr>
<td>Basin Shape</td>
<td>-9.070E-03</td>
<td>.001</td>
<td>-.715</td>
<td>-8.533</td>
</tr>
</tbody>
</table>

Lost Horse Basin

Stage/Discharge Rating curves

Rating Curves were constructed for each of the gaging stations along Lost Horse Creek (Figure 2-2). Results for the lower bridge station are described in the previous section (Figure 2-10). For the remaining gaging stations, a total of nine measurements were made at each to define the stage/discharge relationship (Appendix F). Although the range of baseflow discharge is relatively narrow at these sites, measurements were made at a
variety of flows that encompassed all stages observed during the course of the study. Since each of these gages had bedrock control conditions, the resulting curves were stable and smooth. At the meadow station, a total of eight measurements were made during the two field seasons.

*Stream and Well Hydrographs*

During the 1995 field season, the number of stream gage observations varied from 17 at the Dome gage to 21 at the Meadow and Upper Bridge gage (Figure 2-18). Through mid-July, there were many days of precipitation making it very difficult to access the sites to make stage observations. Wells were measured a total of 11 times in the period between July 15, 1995 and September 15, 1995 (Figure 2-19). All wells were measured within two hours of each other (the minimum time required to read all wells in the grid). Although some of the wells in the uplands went dry during each field season, most of them remained readable throughout the study.
Figure 2-18. Hydrographs for all Lost Horse gaging stations and precipitation from SNOTEL stations, June through September, 1995.

Figure 2-19. Well hydrographs 1-C and 1-D, meadow gage hydrographs and precipitation during the 1995 field season.
The first reasonably dry period in 1995 began on about the 20th of July and lasted for approximately 3 weeks. Even during this period there were a few events that yielded between 0.25 and 0.75 centimeters of precipitation. On August 17 a storm brought almost two inches of precipitation to the basin. A sharp peak on the hydrograph is evident at the lower bridge recording gage (Figure 2-18). The recharge that occurred following the precipitation is noticeable as a rise in groundwater levels and stream discharge in the upper meadow (Figure 2-19). When baseflow resumed about August 21, flows were at the same level as on August 3.

A significant dry period followed that lasted into early September. The hydrographs at all stream-gaging stations fell continuously during this period. Recession rates appear very similar at all gages except for the meadow gage where the recession rate appears much greater (Figure 2-18). Another wet period began on September 2 that caused a significant rise in stream discharge and in groundwater levels. A short dry period followed just before the end of the 1995 field season in mid-September.

Figure 2-20 shows the potentiometric map for July 15, 1995 in the upper meadow illustrating that groundwater levels closely follow the ground surface topography. Equipotential lines are parallel to the stream on the upper slopes and perpendicular to the stream in the bottomlands. This illustrates that the direction of groundwater flow is towards the stream from the uplands on either side of the valley and with the direction of stream flow in the valley bottom. Potentiometric data from other dates show no noticeable difference in flow patterns in the meadow area (Appendix G).
Figure 2-20. Water surface contour map of the upper meadow area on July 15, 1995. Contour interval 1-foot.

During the 1996 field season a total of only seven stream flow observations and well measurements were taken at each site in the Lost Horse basin (Figure 2-21). Conditions
during the 1996 field season were quite different from the previous year. Total precipitation for the 1996 water year was 89 inches, the highest on record since the station came on line in 1979. Snow water equivalent was also very high: 47 inches at the Twin Lakes station on May 1. As a result, snowmelt came very late to the upper basin. The SNOTEL station at Twin Lakes recorded no snow just before July 1 this year, three weeks later than normal. There was considerable snow on north facing slopes in the upper basin as late as July 9, 1996.

Figure 2-21. Hydrographs for all Lost Horse Creek gaging stations and precipitation from SNOTEL stations. July through September, 1996.

Due to the late snowmelt, monitoring operations in the upper basin commenced on July 22. There were only two periods of recession, one started on July 22 lasting until July 27,
when precipitation caused a rise in the hydrograph at the lower bridge. The second recession period began about August 11 and lasted only until August 17. The hydrograph peak on August 18 was due to storage releases from Twin Lakes. This event, followed by precipitation, limited the usefulness of the record for the remainder of the 1996 field season. The hydrographs for wells 1-C and 1-D show a continuous decline in groundwater levels through the 1996 field season (Figure 2-22).

Figure 2-22. Well hydrographs 1-C and 1-D, meadow gage hydrograph and SNOTEL station precipitation during the 1996 field season.

Figure 2-23 provides hydrographs for wells installed in the streambed in the meadow during the 1996 field season. Streambed wells were placed in line with well transects 1, 2, 3 and 5 (Figure 2-9). Well number 1 shows that the water level in the stream was higher than that in the well during the entire period from late July to late August. A
downward gradient existed between the stream and groundwater at this well as it did at wells 3 and 5. At well 5 there was an especially strong downward gradient. This indicates that the stream lost water to the ground at these points. As the summer progressed, the gradient tended to increase between the stream and the local groundwater level at these wells. At well 2 there was little or no difference between the stream level and the water level in the well.
Figure 2-23. In-stream well measurements during the 1996 field season illustrating losing reaches at all locations except near well transect 2.
Recession Analysis

Recession constants for the Lost Horse gages demonstrated a high level of uniformity at most sites (Figure 2-24). The lower bridge gage had a recession constant (0.950) slightly higher than the other gages. This value is slightly lower than that reported in the previous section (0.952) because the analysis for this section was done only with the recession segments from period common with the other Lost Horse gages, data from 1979 to 1981 were excluded. The other three gages, Dome, Falls and Upper Bridge, had similar recession rates, 0.943, 0.944 and 0.944 respectively. The average recession constant for the Meadow gage was lower than the others (0.938), but also had a much higher variability than the others. This was evident in the 1995 hydrograph as well (Figure 18). Discharge at this gage declined more rapidly than at any of the other locations, and increasingly so as the season progressed. The recession results for the Lost Horse gages are summarized in Table 2-12.
Figure 2-24. Plot of the recession constants and 95 percent confidence intervals for gaging stations along the main stem of Lost Horse Creek.

Table 2-12. Lost Horse basin gage recession analysis results.

<table>
<thead>
<tr>
<th>Lost Horse Basin Gage</th>
<th>Recession Constant</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Number of Segments</th>
<th>Average Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow</td>
<td>0.938</td>
<td>0.904</td>
<td>0.974</td>
<td>6</td>
<td>6.7</td>
</tr>
<tr>
<td>Upper Bridge</td>
<td>0.944</td>
<td>0.937</td>
<td>0.951</td>
<td>5</td>
<td>7.2</td>
</tr>
<tr>
<td>Falls</td>
<td>0.944</td>
<td>0.933</td>
<td>0.956</td>
<td>5</td>
<td>7.2</td>
</tr>
<tr>
<td>Dome</td>
<td>0.943</td>
<td>0.933</td>
<td>0.953</td>
<td>5</td>
<td>7.2</td>
</tr>
<tr>
<td>Lower Bridge</td>
<td>0.950</td>
<td>0.944</td>
<td>0.957</td>
<td>5</td>
<td>7.2</td>
</tr>
</tbody>
</table>

*Geomorphic Characterization*

Basin geomorphic parameters were derived from the GIS for the basin area above each of the gages in the Lost Horse Creek basin. As one would expect, these measurements are not independent of each other as each successive gage site in the downstream direction
encompasses the characteristics of the gage above it. Instead of treating the characteristics independently, these data instead serve to show how the parameters change as one moves upstream towards the headwaters of the basin (Table 2-13).

Table 2-13. Lost Horse basin morphological parameters.

<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage Density (km/km^2)</th>
<th>Mean Slope (percent)</th>
<th>Mean Basin Elevation (m)</th>
<th>Maximum Elevation (m)</th>
<th>Basin Length (km)</th>
<th>Mean Basin Width (km) (A/Lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow</td>
<td>0.86</td>
<td>41.53</td>
<td>2047</td>
<td>2473</td>
<td>1.24</td>
<td>2.15</td>
</tr>
<tr>
<td>Upper Bridge</td>
<td>1.87</td>
<td>33.04</td>
<td>2063</td>
<td>2561</td>
<td>3.29</td>
<td>4.73</td>
</tr>
<tr>
<td>Falls</td>
<td>2.12</td>
<td>37.71</td>
<td>2048</td>
<td>2561</td>
<td>7.61</td>
<td>4.76</td>
</tr>
<tr>
<td>The Dome</td>
<td>2.21</td>
<td>42.77</td>
<td>2035</td>
<td>2579</td>
<td>12.61</td>
<td>5.41</td>
</tr>
<tr>
<td>Lower Bridge</td>
<td>2.57</td>
<td>49.86</td>
<td>2014</td>
<td>2773</td>
<td>21.33</td>
<td>8.01</td>
</tr>
</tbody>
</table>

Drainage density is defined in this section as the length of all channels, visible by crenulations on the 1:24,000 quad maps, divided by basin area. Drainage density ranged from a value of 2.57 km/km^2 in the basin area above the Lower Bridge to 0.86 km/km^2 in the basin area above the meadow gage. Channel density tended to decrease moving up basin from the lower bridge to the upper bridge. However, on the ground many channels do not show up as crenulations on the USGS quad map. For example, crenulations on the USGS map show the meadow area with a single straight reach of channel running through the center of the valley. In contrast, the field mapped stream channel in Figure 2-20 shows the sinuous main channel and tributaries about 4-times the channel length. As a result, channel density for the area above the meadow gage is much higher than indicated in the results, although this may also be true for other parts of the basin as well.

Average slope tended to decrease as did average and maximum elevation moving in the up-basin direction. The basin area above the lower bridge encompassed the south fork of
Lost Horse Creek, where the highest elevations of the Lost Horse drainage are found. In general the lower parts of the basin are quite rugged and steep compared to the upper extremities of the basin that have a gentler topography.

*Depth to Bedrock*

The upper meadow was chosen for investigating the thickness of the unconsolidated layer, or depth to bedrock. Of particular interest was the thickness of sediments available for water storage. One transect was surveyed with a portable seismic instrument across the valley bottom in line with well transect 2 (Figure 2-9). The transect consisted of six separate seismic lines, one point is derived from one surveyed line. Results from the survey show that the maximum depth to bedrock was only 2.1 meters. The unconsolidated materials were thickest near the ends of the transect and less than 1.2 meters deep at the middle of the valley near the stream channel.

Figure 2-25 provides a plot of first arrival time against distance for location 2-A. The plot shows both forward and reverse lines at this location along with the best-fit lines for the direct wave (the steeper line) and the refracted wave (the flatter line). Results for this location indicate that bedrock depth is just 1.4 meters from the ground surface. The scatter along the refracted line is “boulder scatter” indicating very large particles at depth along the survey line. Plots of the remaining seismic survey lines and calculations are located in Appendix H.
Figure 2-25. Plot with seismic investigation results at location 2-A illustrating best fit lines for direct and refracted waves.

Figure 2-26 shows the valley profile and depths to bedrock along well transect number 2 in the upper meadow. The plot is looking north, down-valley. The cross-section begins at N-3 and continues across the valley to well 2-A (Figure 2-9). Depth to bedrock decreased moving toward the valley bottom from N-3 to 2-E, and increased moving from 2-E to 2-A. Outcrops of granite bedrock were visible in the uphill direction from both ends of the seismic survey line indicating an interruption in the unconsolidated materials beyond the end of the transect.
Figure 2-26. Plot of the elevation profile and depth to bedrock along well transect 2, upper meadow Lost Horse basin.

Soil Moisture

Soil moisture tension was very low throughout the summer of 1995 at all the measurement sites indicating persistently high soil water content (Figure 2-27). Values ranged from about -5 kPa to a maximum tension value of only -21 kPa. For reference, field capacity is -9.8 kPa and wilting point is -1,470 kPa. Saturated soils are at -0.098 kPa, so for most of the year soils near the meadow were just above field capacity. Even so, the tensiometers were sensitive to precipitation inputs that occurred a few times during the summer. For example, at site N-3 (Figure 2-27a) there was an increase in tension as the soil drained after a significant rain event that occurred on August 17. The range in values, however, is extremely narrow throughout the year.
Soil moisture tension at the 12-inch and 24-inch depths mirrored each other very closely at sites N-4 and N-3 (Figure 2-27a and 2-27b). The tension values at the 12-inch depth were consistently 2 to 4 kPa higher (more suction) than at the 24-inch depth. Given that the difference in elevation at the tensiometer pair is equal to 30 centimeters (12 inches), and 3 kilopascals equals about -30 centimeters of suction, there was virtually no difference in potential between the pair at N-4 (Figure 2-28). Site N-3 showed slight upward moisture gradient and N-2 slightly higher, most likely due to evapotranspiration demand from the shallow root zone and the ground surface. Remaining well and soil moisture hydrographs are found in Appendix I.
Figure 2-27. Tensiometer pairs and precipitation at Twin Lakes SNOTEL station during the 1995 field season: a). pair N-3, and b). pair N-4.
Figure 2-28. A plot illustrating the vertical gradient between each tensiometer pair at the upper meadow. Pair N-4 shows no vertical gradient while further downslope at N-3 and N-2 gradients increase towards the surface. (a negative value indicates a gradient towards the surface)

DISCUSSION

Baseflow recession analysis provides a means for comparing runoff characteristics of drainage basins and predicting future low-flows. Not only is the baseflow recession constant required input for most rainfall-runoff models, but understanding groundwater outflow is essential in studies of water budget and catchment response (Zecharias and Brutsaert, 1988). Understanding groundwater depletion in a drainage basin is necessary for effective planning in areas with prolonged dry periods (Bako and Owoade, 1988). Recent research indicates that the baseflow recession constant can act as a surrogate for
basin scale hydraulic conductivity and is useful in regional low-flow investigations (Vogel and Kroll, 1992).

**Automated Recession Segment Selection**

A consistent procedure is required when comparing recession characteristics between drainage basins or interpolating values (Bako and Owoade, 1988). The automated recession segment selection procedures described in this study quickly and accurately obtain periods of recession from lengthy streamflow records. Not only does this procedure allow for repeatability, but also permits an efficient means of confirming recession analysis results. An automated procedure lends itself to comparing results from the same analysis for different users. Most importantly, an automated procedure provides the ability to change any of the selection criteria, allowing comparisons based on season, flow levels, and recession segment length. The interactive nature of the procedure presented in this study allows the user to discard unusual looking segments and to eliminate parts of a recession segment.

The methodology described in this study uses the declining hydrograph alone as a condition for selecting the recession segment. In some studies, precipitation records are used in conjunction with flow records to define periods of recession (Tallaksen, 1995). However, precipitation records that coincide with streamflow records are rarely if ever available for high elevation catchments. In this study only one catchment, Lost Horse Creek had a partial precipitation record that could be used in this manner. More often though, climate records exist for low elevation valley stations near populated areas where precipitation is considerably lower and less frequent, thereby minimizing their usefulness.
Recession Analysis

Initial values of discharge were restricted primarily by choosing hydrograph segments from the summer months of July through September. The seasonal approach is preferable in mountainous areas such as the western US where seasonal moisture conditions are the most consistent way of choosing periods of recession (Tallaksen, 1995). Although evapotranspiration from deep-rooted trees and riparian vegetation may have affected the hydrograph during the summer season, all analyses were conducted during this same period making the results comparable at the very least. Zecharias and Brutsaert (1988) argue, however, that evaporation from groundwater is only a minor portion of the total basin evaporation.

For picking recession segments from a streamflow record, Vogel and Kroll (1991; 1996) start the beginning of the recession period when a 3-day moving average declines. In other words, roughly 2 days following a decline in stream discharge one would expect all surface and sub-surface storm flow to cease. In mountain headwaters basins with thin, coarse-grained soils and high hydraulic conductivity, one would expect storm related runoff to move rapidly through the system. Recession segment plots generated for this study illustrated a linear decline after eliminating the first few days following a rise in stream discharge.

The procedure for defining streamflow recession in this study does not allow for non-linearity in the relation between log-discharge and time. Variation in saturated thickness, aquifer heterogeneities, significant groundwater flow past a gaging station, or high rates of evapotranspiration can all cause a non-linear recession curve (Rutledge, 1993).
Although variations in aquifer properties are difficult to quantify, significant groundwater flow past the gaging stations in this study is not likely. U.S. Geological Survey gaging stations are generally located in stable stream reaches that minimize this. The USGS gages in this study were located in narrow canyons, which have narrow or even non-existent floodplains. In addition, the climate and vegetation in the subalpine basins described in this study have relatively low evapotranspiration rates when compared to those in warmer and drier regions. Plots of individual recession segments showed that a log-linear model was appropriate for all gaging station records analyzed in this study.

Recession Constants

Recession constants from gaged tributaries of the Bitterroot River appear to be quite consistent when looking at groups of drainage basins based on geographic location. The Bitterroot Range tributaries have a significantly higher rate of recession than the tributaries across the valley in the Sapphire Range. The difference in geographic location coincides roughly with major geologic and geomorphic differences, although some exceptions do occur. It is no surprise that the highly glaciated Bitterroots, with the sandy granitic soils and limited groundwater storage capacity, have a significantly higher recession rate than the mostly un-glaciated Sapphire Mountains with mixed geologic history.

The seismic transect showed that unconsolidated materials are quite shallow in the Lost Horse Creek basin. Other headwaters basins in the Bitterroots should be very similar given their similar geology, glacial history, and surface appearance. Although the depth of soils must vary greatly in these headwaters basins, a flat meadow location, such as the
one chosen for this subsurface profile would be expected to have some of the deepest soils. It is clear from this result that water storage capacity is low in these basins, and that with the frequency of exposed granite on hillsides, the unconsolidated materials are not connected in the basin. Depth to bedrock in the unglaciated Sapphire Mountains is less clear. The dendritic drainage patterns of the Sapphire Mountains suggests less geologic control on their form. As a result, one would expect that the soils are generally deeper than those found in the Bitterroots, providing more storage capacity for sustaining stream baseflow.

Lost Horse Creek had the highest recession rate of the Bitterroot Range tributaries. A possible explanation for this result is late-season snowmelt. As one moves south in the Bitterroot Range, elevation tends to increase. The south fork of Lost Horse Creek has the highest elevations of any tributary stream evaluated in this study, and seems to store snow all summer following high snow years, as occurred in water-year 1996. On August 11 and 12, 1996, a trip into high elevations of the South Fork of Lost Horse Creek revealed that some small streams draining the north slopes of the basin were at or near bankfull discharge. The high flow came from snow stored on north facing slopes in the basin. Temperatures during this period reached the low 80’s at the Twin Lakes SNOTEL station. If the assumed baseflow period includes snowmelt, then an important assumption that there is no surface storage during the baseflow recession period is violated. Unfortunately there are many streams that may not meet this assumption due to lack of knowledge about snow cover conditions, especially in years with a greater than normal snowpack.
The basin geomorphic parameters analyzed in this study include those that have been linked to groundwater outflow processes by other investigators (Horton, 1932; Farvolden, 1963; Riggs, 1972). Zecharias and Brutsaert (1988) argue that watershed slope affects depletion rates because the ground surface slope is roughly parallel to the slope of the impermeable layer. The steeper the slope, the steeper the rate of recession observed in the stream. The Bitterroot Basins were 1.5 to 2 times steeper on average than those in the Sapphires. Although not a statistically significant factor, this study confirms results from earlier studies that show steeper average watershed slope generally results in higher rates of recession.

Zecharias and Brutsaert (1988) conclude that groundwater discharge in a catchment is controlled by the physical and hydrologic properties of aquifer materials, which are usually reflected in the morphology of a basin. They found that mean land slope, drainage density, k/f ratio of hydraulic conductivity, and drainable porosity are all related to a "reaction factor", a surrogate for baseflow recession. Differences in recession rates of the Bitterroot basins appear to be divided by location. Since the glaciated streams in the Bitterroot Range have a significantly higher recession rate than those in the unglaciated Sapphires, groundwater storage capacity seems to be the key to understanding why the basins behave differently.

An investigation by Farvolden (1963) concluded that two measures of relief ratio, drainage density, basin width, and the average depth of the main channel determine the timing and amount of groundwater discharge. Riggs (1972) found that low-flow is related to drainage area and mean basin elevation for some basins in the eastern United States. In
this study none of the factors listed above were significantly related to the recession constant. However, the significant relationship between basin shape and gaging station elevation ($R^2 = 0.94$) in this study may be somewhat misleading. The Bitterroot basins in general are long and narrow in contrast to the Sapphire basins, which are less so. A narrow basin means that subsurface flow paths to the main channel are short compared to those in a wider basin. Shorter flow paths result in quicker declines in groundwater flows to the stream. The relationship between recession rate and gaging station elevation is not apparent, and may be influenced heavily by the low elevation and low recession rate of a single data point, Lolo Creek.

The average recession rate at Lolo Creek stands out because of the physical location of the gaging station. The Lolo Creek gage is located in a wide valley with a well developed flood plain and terrace features. This is in contrast to all other gages that are farther into the headwaters of their basins, located at stream reaches constricted by steep valley walls. Also, Lolo Creek is affected by irrigation diversion. It is not clear how much of an effect there is on the streamflow record. Irrigation diversions generally do not significantly affect the other streams.

In the Lost Horse Creek basin, recession rates were very similar for all gage sites except for the meadow gage. The remaining gages had surprisingly close recession rates. The similar recession rates can be attributed to a similarity of basin outflow processes throughout the drainage basin. From the results we can assume that from the headwaters, groundwater outflow processes change very little or not at all in the downstream...
direction. The lower recession rate is at the mouth of Lost Horse Creek may be explained by runoff contributed by snowmelt in the South Fork basin as explained above.

The results at the meadow gage were difficult to interpret because of problems with channel control near the location of the staff gage. It appeared that the stage/discharge relationship changed during the field seasons, due in part to the unstable channel bed and shifting woody debris in the channel downstream. An ideal gaging site could not be found in the area. Gaining and losing stream reaches in the meadow area add to the inconsistency of the record, and increase the likelihood that a significant amount of water may bypass the gaging station, especially later in the summer when groundwater levels are at a seasonal minimum.

Groundwater and soil moisture levels in the meadow area mirrored stream hydrographs during periods of recession. There were occasional precipitation events of sufficient magnitude during both field seasons that resulted in minor recharge to the limited groundwater reservoirs. These events were enough to allow soil moisture to stay quite high in the meadow area, even while groundwater levels continued to drop throughout the season. Large precipitation events had the effect of setting back the "recession clock" only a few days at the most.

CONCLUSIONS

There were four primary objectives in this study. The first two, which were the most important, were to develop models that adequately describe baseflow recession in the headwaters streams of the region and to identify basin geomorphic factors that lead to the
variability of recession rates in these streams. Bitterroot Range streams had higher rates of recession compared to those in the Sapphire Range. The massive granitic geology, coupled with thin, sandy soils in a recently glaciated landscape allows minimal water storage and high hydraulic conductivity that lead to steep recession curves. In contrast, the Sapphire Range with its deep non-glacial soils derived from a complex geology provide greater groundwater storage and lower hydraulic conductivity. Key quantitative geomorphic factors related to recession rates in the study basins were basin shape and gaging station elevation. Work in Lost Horse Creek, one of the Bitterroot Range tributaries, showed that recession rates were very consistent at gaging stations located along the stream.

The third objective was to develop a methodology for a quick and objective determination of recession parameters for stream gaging records. The methodology, based on an automated interactive procedure and Analysis of Covariance (ANCOVA), resulted in considerable time savings and repeatability compared to traditional manual methods. The fourth objective was to monitor groundwater levels in the upper Lost Horse basin during periods of recession. Groundwater levels, soils moisture, and stream discharge were closely related.

This study is a first step towards developing models for streamflow recession in the region. The results from this study will aid in understanding of the hydrology of these remote basins and assist in future water management decisions in western Montana. Application of the methodology described in this study will enable a better understand outflow processes in headwaters basins.
Chapter 3: Simulating the Hydrologic Balance of the Upper Lost Horse Creek Basin

INTRODUCTION

Streams emanating from snow-dominated headwaters basins are the source of most surface water in Montana. As the water flows to lower elevations, it supports agricultural operations, wildlife, and increasing recreational use. The surrounding forested lands also supply a resource for wildlife, timber, forage for cattle and a wide variety of recreational opportunities. The increasing demand for water, forest resources and recreation creates the need for a better understanding of the basic hydrology of headwaters basins.

Very little information is available about hydrologic processes in high elevation basins. Hydrologic pathways are poorly understood in part because of their remoteness and difficult working conditions, but also because of the low relative value we have placed in the past on understanding these systems. With recent focus on the effects of fire and resource extraction on stream habitat and riparian health, a better understanding of the fluxes in these higher elevation basins is warranted.

Although comprehensive water balance studies have been conducted in a variety of locations throughout the world (Glen, 1982; Lang and Musy, 1990), few studies focus on unglaciated high elevation areas where snow is the dominant form of precipitation (Stednick, 1981; Kattelman and Elder, 1991). Most studies conducted in the subalpine zone describe the response of streamflow and snow distribution from management activities (e.g. Leaf, 1975; Troendle and King, 1986; Bosch and Hewlitt, 1982), but there
are no known studies that quantify the components of the water balance in a high
elevation subalpine basin.

Many decisions concerning watershed management, environmental impacts, and resource
eextraction are based on incomplete or non-existent hydrologic data. Although a variety of
tools are available to estimate or quantify hydrologic processes in remote basins, these
tools have often been developed for use in more temperate climates and for agricultural
purposes. As a result, physically based hydrologic models such as HSPF (Hydrologic
Simulation Program - FORTRAN) have been developed that have wide application for
simulating hydrologic processes of remote basins (Bicknell et al., 1993).

The HSPF model is a comprehensive model for the simulation of hydrologic processes,
and associated water quality processes on pervious and impervious land surfaces and in
streams and well-mixed impoundments. The model uses continuous rainfall and other
meteorologic records to compute stream flow hydrographs and pollutographs. The HSPF
model simulates interception, soil moisture, surface runoff, interflow, base flow, snow
pack depth and water content, snowmelt, evapotranspiration, ground-water recharge and
a wide range of water quality and chemical processes.

The HSPF model has been used in a number of studies throughout the United States since
its original development as the Stanford Watershed Model (SWM) (Crawford, 1966). The
SWM was the first model attempting to simulate all components of the hydrologic cycle.
HSPF has undergone considerable changes since its original development, and is far
more comprehensive than the original SWM (Singh and Woolhiser, 2002). The
Environmental Protection Agency (EPA) and the US Geological Survey (USGS) currently support and update the model periodically.

The HSPF model was chosen for this study because of its robustness and its physically-based approach to modeling. Also, the HSPF model was chosen based on documented performance under a wide variety of conditions (e.g. Donigian et al., 1984; Ng and Marsalek, 1989; Dinicola, 1990). The model has been applied to large river basins (e.g. Stigall et al., 1993; Flippo, 1994; Laroche et al., 1996), and headwaters basins (e.g. Mastin, 1995; Chen et al., 1998; Srinivason et al., 1998; Dinicola, R.S., 2001). The model parameters have real world counterparts making it suitable for a water balance study. To our knowledge, the HSPF model has not been applied to any headwater basins in the Intermountain West where drainage basins exhibit a unique combination of climatic, geologic, and geomorphic characteristics.

The purpose of this study was to develop a model of the water balance for the upper Lost Horse Creek basin for water years 1995 and 1996. The focus was to collect hydrologic data for input to the model and calibrate the model to an observed stream discharge record. Output from the model was analyzed to quantify hydrologic pathways. The results will aid in understanding of the hydrology of remote subalpine basins and assist in future land management decisions in the region.
STUDY AREA DESCRIPTION

Site Description and Location

The Lost Horse Creek basin is located in the Bitterroot Mountain range of western Montana. Lost Horse Creek is one of the many eastward flowing tributaries to the Bitterroot River (Figure 3-1). The focus of this study was the upper basin defined by the watershed area above a gage located near the upper bridge on Lost Horse Creek road. The basin is located entirely within the Bitterroot National Forest and is surrounded on three sides by the Selway-Bitterroot Wilderness area.

The upper basin is generally in an undisturbed state with the exception of a road that comes from the Bitterroot Valley in Montana and terminates at two points (Figure 3-2). Upper and lower Twin Lakes, both natural, are now regulated by low earth filled dams. Bailey Lake is located away from the road and has a natural outlet. The area receives considerable recreation use since the road is one of the few high elevation access points to the Selway-Bitterroot Wilderness. Outfitters, fishermen and backpackers are the primary users of the area.
Figure 3-1. The Lost Horse Creek study site and instrumentation sites.
Figure 3-2. Map of Upper Lost Horse basin study area with the 1988 burn.

Geology and Soils

The upper basin is 1551 hectares in size and ranges in elevation from 1,750 meters at the lower bridge gage site to 2,560 meters on Kerr Peak. The upper basin consists of 4 well defined sub-basins each with tributary streams. The topography of the upper basin is
quite varied and shows the influence of recent glaciation. Sharp ridgelines, U-shaped valleys, steep headwalls, and numerous small ponds and lakes describe the physical characteristics of the basin.

The upper elevations have extensive areas of exposed intrusive granite. The Bitterroots of western Montana are the easternmost extension of the Idaho Batholith. As a result of bedrock properties, the soils in the basin are quite sandy, characterized by sandy-loam and loamy-sand textures. A thin discontinuous layer of volcanic ash is present in varying depths. The ash layer is absent from a substantial portion of the basin but is up to 36 centimeters thick in isolated locations. For a more complete description of the soils and geology of the upper basin see Chapter 2.

**Vegetation**

The tree cover in the upper basin is dominated by subalpine fir (*Abies lasiocarpa*) and lodgepole pine (*Pinus contorta*) forest. Occasional Engelmann spruce (*Picea engelmannii*) are found in the lowest elevation riparian areas. Alpine larch (*Larix lyallii*) and whitebark pine (*Pinus albicaulis*) are present, but only at the highest elevations. Figures 3-3 and 3-4 show where a fire burned across approximately 36 percent of the area of the upper basin in 1988. The fire was intense, leaving little of the forest within the burn perimeter. The fire removed the soil organic layer within much of the burn area causing localized erosion in the uplands. During the ensuing years, there has been minimal revegetation within much of the burn (Figures 3-5a and 3-5b).
Figure 3-3. Upper Lost Horse Creek basin and the 1988 burn area looking southeast from Kerr Peak towards Bailey Lake, meadow area and stream gaging station.

Figure 3-4. Upper Lost Horse Creek basin looking northeast with the 1988 burn area near Bailey Lake in the foreground. Lower Twin Lake and Kerr Peak are visible in the background.
Figure 3-5. Close-up photograph of burn area conditions in the Bailey Lake area with: a) bare soil, cobbles, beargrass, and pioneering plant species, and b) dead trees with Kerr Peak in the background.
Climate

The climate of the Bitterroot drainage is dominated by weather systems from the Pacific for much of the year, especially during the winter. However, this area lies on the climatic boundary between warm, moist air coming from the Pacific and dry, cold continental air masses. During the summer and brief periods in the winter, the climate may seem more like the drier, colder mountains and valleys further to the east (Finklin, 1983).

There are two climate stations operating within the Lost Horse Creek basin. The Twin Lakes and Twelvemile Creek snow telemetry (SNOTEL) stations. These are operated by the Natural Resources Conservation Service (NRCS). Both stations automatically gather precipitation, temperature, and snow water equivalent data. Both stations have been in continuous operation since the late 1970’s. The Twin Lakes station is at 1,950 meters elevation and the Twelvemile Creek Station at 1,710 meters. The Twin Lakes station is located within the upper basin study area (Figure 3-1).

At the Twin Lakes station, average annual precipitation is close to 163 centimeters while at Twelvemile Creek the average is approximately 117 centimeters. Figure 3-6 illustrates the difference elevation makes on annual precipitation amounts in the study basin. The lowest precipitation amounts were observed during water years 1987 and 1988, 1988 being the year of the fire in the upper basin. During the study period of 1995 and 1996 higher than average annual precipitation was observed, 178 and 224 centimeters respectively at the Twin Lakes station.
Figure 3-6. Annual and average annual precipitation at Lost Horse basin climate stations.

Most precipitation falls during the winter in the upper basin, snow is the dominant form in the higher elevation basins. Farnes and Schafer (1972) estimated that 70 percent of the annual precipitation falls as snow in the Bitterroot Mountains. Figure 3-7 shows the water year 1995 and 1996 monthly total precipitation and average monthly precipitation for the Twin Lakes SNOTEL station. The late summer months of July, August, and September have the least precipitation accounting for only 12 percent of the annual precipitation. Most of the precipitation falls as snow in the winter months of November, December, and January accounting for 35 percent of the annual precipitation.
Figure 3-7. Monthly precipitation at the Twin Lakes SNOTEL station.

Streamflow

Like other high elevation basins in this region, the hydrograph for the Lost Horse Creek basin is dominated by snowmelt. The snow that accumulates during the winter and spring in the upper basin typically begins to melt by the beginning of May. Peak runoff coincides with peak snowmelt and can occur from early May to late June.

After peak snowmelt, streamflow declines rapidly in Lost Horse Creek. By early July generally only patches of snow are left in protected north facing slopes contributing relatively little to runoff. Groundwater reservoirs that had been fully recharged during snowmelt begin to drain. Brief rain events during the remainder of the summer period are insufficient to affect much recharge to groundwater reservoirs.
METHODS

Model Overview

The HSPF model is designed to simulate all the water quantity and water quality processes that occur in a watershed (Bicknell et al., 1993). The HSPF model is semi-distributed; meaning it can reproduce spatial variability by dividing the basin into hydrologically homogeneous land segments and simulating runoff for each land segment independently using different meteorologic input data and watershed parameters. The HSPF model is the only one available that can simulate the continuous, dynamic event or the steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed. The model consists of a set of modules, which permit the continuous simulation of a comprehensive range of hydrologic and water quality processes. The three modules are PERLND - the module that simulates the water quality and quantity processes which occur on a pervious land segment, IMPLND - impervious land segment module for simulating urban areas where little or no infiltration occurs and RCHRES - the reach / reservoir routing routine for modeling the transport and fate of physical and biochemical constituents.

Since this study focused on the water balance for upper Lost Horse Creek basin, only the PERLND module was used for model runs. Within the PERLND module, there are separate sections that simulate components of the water budget. The SNOW section simulates snow accumulation and melt, section PWATER simulates the inputs, outputs and storages in the water budget, and section ATEMP performs the ancillary function of correcting air temperature for use in snowmelt algorithms. Finally, the model has various
utility modules such as COPY, DISPLY and PLTGEN for sending model output to text files for analysis.

Operating the HSPF model requires two primary files. The WDM (watershed data management) file and the UCI (user control input) file. The WDM file is a direct access binary file that contains time series data sets for driving model functions and data sets for model calibration. An auxiliary program, ANNIE, is required to produce the WDM file from text files (Lumb et al., 1990). The UCI file is a text file that controls the operation of the HSPF model. The UCI file tells the model the start and ending dates of simulation, location of external files (including the WDM file), identifies the modules used in the simulation and sends other commands to HSPF regarding model output. The most important function of the UCI file is to define the study basin land segments and their parameters.

The HSPF model and ANNIE program user interfaces harkens back to the dark ages of computing. The process of inputting time series data sets in to the WDM file requires another separate software program, IOWDM, followed by a lengthy process to make certain that data are in the WDM file in the expected form. Although algorithms in HSPF representing hydrologic processes have been updated over the years, the user interface has not. Recent integration of HSPF to the “Better Assessment Science Integrating point and Nonpoint Sources” or BASINS suite of hydrologic models has minimally improved the user interface of the HSPF model (USEPA, 2001).
Input Data

Data requirements for operating and calibrating the HSPF model can be broken into 3 categories:

1. Meteorological Input Data.

2. Land Segment Definition.

3. Calibration Data.

The model required a minimum dataset to drive the hydrologic processes including precipitation, temperature, solar radiation, dewpoint temperature, wind movement, and pan or potential evaporation. The HSPF manuals suggest 15-minute data or finer resolution when simulating chemical transport processes. For simulating hydrologic processes, however, the HSPF model will run with a 1-hour time step. This section describes the sources of input data and estimation methods used for those data that were unavailable for the study basin.

Precipitation data were obtained from the Twin Lakes NRCS SNOTEL station located in the study basin center near Twin Lakes (Figure 3-2). Data available from the Twin Lakes SNOTEL station were 3-hour precipitation totals in 0.1-inch increments. Since the HSPF model requires a minimum of hourly precipitation input data for model runs, the 3-hour values were converted to 1-hour precipitation. The 3-hour precipitation totals were divided by 3, holding the smallest hourly value equal to 0.1 inches. For example: if there were only 0.1 inches of precipitation in a 3-hour period, then only one of the 3 hours
would have a precipitation value in the hourly dataset. Glasbey et al. (1995) describe a method to disaggregate precipitation from daily data. Unfortunately, hourly data from a station with similar characteristics are required to perform this type of analysis.

The HSPF model requires hourly temperature data for partitioning precipitation into snow and for actual evapotranspiration calculations. The Twin Lakes SNOTEL station dataset includes minimum and maximum daily temperature data. To convert these data to hourly, I developed an algorithm that fits a sine curve to the daily minimum and maximum temperatures. The algorithm disaggregates the temperature data into hourly values and assumes that the minimum daily temperature occurs at 4 AM and daily maximum at 4 PM. A computer program written in FORTRAN accomplished this task (Appendix J). Figure 3-8 illustrates the results of disaggregating min/max data in this fashion.
Figure 3-8. Example of disaggregating daily minimum and maximum temperature data into hourly values for observed and simulated data at the Twin Lakes SNOTEL station in the upper Lost Horse basin.

Dewpoint temperature is required by HSPF and was not available for the site. A common surrogate for dewpoint temperature is the daily minimum temperature, since cooling is usually arrested at the dewpoint due to the release of latent heat during condensation. Since the minimum daily temperature was available for the Twin Lakes site, it was used in place of dewpoint temperature (Linacre, 1992).

Solar radiation data were available from the US Bureau of Reclamation AgriMet station at Corvallis, Montana in the Bitterroot Valley approximately 20 miles away. According to Finklin (1983), locations in the Selway-Bitterroot Mountains should receive about 135,000 Langleys per year. Langleys are the units of incoming solar radiation used by the HSPF model (1 Langley = 41.88 KJ/m²). At Corvallis the average incoming solar...
radiation for the period 1994 through 1996 was 118,000 Langleys per year. In the higher
mountains one would expect higher incoming radiation because of the increased
elevation, but also an increased cloud cover compared to a valley station such as at
Corvallis, thereby causing a reduction in incoming solar radiation.

As a check, the Mountain Microclimate Simulation Model (MTCLIM) was used to
calculate incoming solar radiation for the Twin Lakes area from site data (Hungerford et
al., 1989). The model uses the site elevation and aspect, minimum and maximum
temperature and precipitation to calculate daily incoming solar radiation. Results of the
model runs produced an average value of 116,000 Langleys per year, somewhat less than
that estimated by Finklin (1983), but quite similar to values from the Corvallis station.
Solar radiation data from the Corvallis station were used in the final model runs.

As with the temperature data, incoming solar radiation were disaggregated to hourly
values for input to the HSPF model. Values were set to zero from 19:00 hours to 07:00
hours the following day. Total incoming solar radiation was partitioned throughout the
day, with the maximum occurring at solar noon.

Daily wind movement is required input to the HSPF model. These data are used in the
snow section of the model and to calculate actual evapotranspiration. Again, these data
were not available at the study site. Data from the U.S. Bureau of Reclamations Agrimet
station at Corvallis, Montana were used in model runs.

Typically, evapotranspiration potential or demand is supplied to the model as an input
times series using U.S. Weather Bureau Class A pan records with an adjustment factor.
Actual ET is calculated internal to the model, as a function of available moisture in various storage components and the potential. Since evaporation data were not available at the site, potential ET was calculated using data from the Twin Lakes SNOTEL station.

To calculate potential ET, a simplified form of Penmans equation that requires elevation, latitude, daily mean temperature, dewpoint and wind speed was applied (Linacre, 1992):

\[ Et = \left[ 0.015 + 4 \times 10^{-4} T + 10^{-6} z \right] \times \left[ 380 \frac{(T + 0.006 z)}{(84 - A)} - 40 + 4u (T - Td) \right] \]  

(1)

Where:

- \( Et \) = potential Evapotranspiration (mm/d)
- \( T \) = daily mean temperature (°C)
- \( z \) = elevation (meters)
- \( A \) = latitude (degrees)
- \( u \) = daily mean wind speed (m/s)
- \( Td \) = daily mean dewpoint temperature (°C)

For input to the equation, the Twin Lakes SNOTEL station record provides mean daily temperature. Daily mean wind speed was available from the Corvallis, Montana AgriMet station described above. Daily minimum temperature was substituted for dew point temperature, which is described above (Linacre, 1992).
**Calibration Data**

For model calibration, the stream gage at the upper bridge was regularly monitored during the 1995 and 1996 field seasons (Figure 3-2). Near the mouth of Lost Horse Canyon, a recording gage was operated to extend the monitoring in the spring and into the fall using a simple regression relationship (Figure 3-1). Methods used for determining streamflow and the gaging site characteristics are described in detail in Chapter 2.

Model calibration requires that a year-round continuous stream discharge record be available for the study basin. This was not possible at the upper bridge due to its inaccessibility during the winter months and often at times during the field seasons due to the primitive state of the access road to the upper basin. After snowmelt and after significant rainfall events the road often became an impassable quagmire that was impassable to vehicles. For model calibration, the discharge record was extended by using records from the Lower Lost Horse Creek gaging station at the mouth of Lost Horse Creek Canyon, and from a nearby stream gage on the Lochsa River in Idaho operated by the USGS.

A regression model relating the short-term record at Lost Horse Creek and the longer record at the Lochsa River in Idaho was developed. The missing record for the Upper Lost Horse Creek basin was filled using this relationship. There are a number of problems associated with using the Lochsa River record to extend the calibration record, the least of which is adding a significant amount of uncertainty to the calibration record. Some of the concerns of record extension by these means are discussed further in the results section.
The HSPF model can also be calibrated to snow water equivalent and snow density data. Since runoff is closely tied to snowmelt in the basin, I used snow pillow data from the Twin Lakes SNOTEL station (1,950 meters elevation) to calibrate snow accumulation and snowmelt. Two manually monitored snow courses are located in the upper basin, one at Twin Lakes (1,984 meters elevation) and one called Lost Horse (1,810 meters elevation) close to the stream gage site. Each of these snow courses was measured only once in each of the two model years, thus giving only a snapshot of snow characteristics in other parts of the study basin. Visual comparisons between snow water content at the Twin Lakes SNOTEL station and the Twin Lakes snow course in earlier years with multiple measurements shows a consistent relationship between the two. As expected, the Twin Lakes snow course had slightly higher snow water content due to its higher elevation in the basin.

**Land Segments**

*Definitions*

The HSPF model allows the user to define multiple land segments, each as an area with assumed homogeneous hydrologic characteristics. I used PAMAP GIS to divide the basin into land segments based on elevation, ground surface slope, vegetation cover/exposed bedrock and water bodies. Once the final land segments were defined, model parameters were set according to a segments’ elevation, slope and vegetation cover. Tables 3-1 and 3-2 define the HSPF land segment parameters for the SNOW and PWATER sections. Some of these parameters are fixed, and some are used for calibrating the model. Discussion of model calibration is presented below.
Table 3-1. Required land segment parameters for the PWATER module in the HSPF model.

FOREST is the fraction of the PLS which is covered by forest, and which will therefore continue to transpire in winter. This is only relevant if snow is being considered (i.e., CSNOFG = 1).

LZSN is the lower zone nominal storage.

INFILT is an index to the infiltration capacity of the soil.

LSUR is the length of the assumed overland flow plane.

SLSUR is the slope of the overland flow plane.

KVARY is a parameter that affects the behavior of groundwater recession flow, enabling it to be non-exponential in its decay with time.

AGWRC is the basic groundwater recession rate if KVARY is zero and there is no inflow to groundwater; is defined as the rate of flow today divided by the rate of flow yesterday.

PETMAX is the air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series, and PETMIN is the temperature below which E-T will be zero regardless of the value in the input time series. These values are only used if snow is being considered (CSNOFG= 1).

INFEXP is the exponent in the infiltration equation, and INFILD is the ratio between the maximum and mean infiltration capacities over the PLS.

DEEPFR is the fraction of groundwater inflow which will enter deep (inactive) groundwater, and, thus, be lost from the system as it is defined in HSPF.

BASETP is the fraction of remaining potential E-T which can be satisfied from baseflow (groundwater outflow), if enough is available.

AGWETP is the fraction of remaining potential E-T which can be satisfied from active groundwater storage if enough is available.

CEPSC is the interception storage capacity

UZSN is the upper zone nominal storage.

NSUR is Manning's n for the assumed overland flow plane.

INTFW is the interflow inflow parameter.

IRC is the interflow recession parameter. Under zero inflow, this is the ratio of today's interflow outflow rate to yesterday's rate.

LZETP is the lower zone E-T parameter. It is an index to the density of deep-rooted vegetation.
Table 3-2. Required land segment parameters for the SNOW module in the HSPF model.

ICEFG A value of 0 means ice formation in the snow pack will not be simulated; 1 means it will.

LAT is the latitude of the pervious land segment (PLS). It is positive for the northern hemisphere, and negative for the southern hemisphere.

MELEV is the mean elevation of the PLS above sea level.

SHADE is the fraction of the PLS which is shaded from solar radiation, by trees for example.

SNOWCF is the factor by which the input precipitation data will be multiplied, if the simulation indicates it is snowfall, to account for poor catch efficiency of the gage under snow conditions.

COVIND is the maximum snowpack (water equivalent) at which the entire PLS will be covered with snow (see SNOW section in Functional Description).

RDCSN is the density of cold, new snow relative to water. This value applies to snow falling at air temperatures lower than or equal to 0 degrees F. At higher temperatures the density of snow is adjusted.

TSNOW is the air temperature below which precipitation will be snow, under saturated conditions. Under non-saturated conditions the temperature is adjusted slightly.

SNOEVP is a parameter which adapts the snow evaporation (sublimation) equation to field conditions.

CCFACT is a parameter which adapts the snow condensation/convection melt equation to field conditions.

MWATER is the maximum water content of the snow pack, in depth of water per depth of water.

MGMELT is the maximum rate of snowmelt by ground heat, in depth of water per day. This is the value which applies when the pack temperature is at the freezing point.

A digital elevation model was used to divide the basin into three elevation zones. These elevation bands were used for adjustments to rainfall and temperature. For rainfall and temperature adjustment a simple linear relationship between the lower Twelvemile Creek Station and the Twin Lakes climate station was used. The precipitation and temperature lapse rate adjustments were based on annual precipitation and daily mean temperatures.

Next, using the DEM as the sourced, the ground surface slope was calculated with the GIS. The results were placed into broad slope classes to form polygons (Soil Survey Staff, 1993). The polygons were further processed to incorporate the smallest polygons into larger ones.
The basin was divided into tree density polygons using 1:12,000 aerial photographs and field investigation. To minimize the number of polygons, three broad classes were used: areas that had sparse or no tree cover, thin/discontinuous tree cover, and dense/continuous tree cover. Tree cover polygons were digitized from the photos and placed on a map layer in the GIS. Areas with exposed bedrock and open scree slopes were also included on this map layer.

The 1988 fire left a considerable part of the upper basin devoid of tree cover. During the field seasons of 1995 and 1996 most of the area within the fire perimeter had only just begun to recover. Much of this area had little or no ground cover. The burn perimeter was digitized onto a map layer from 1:12,000 air photos and ground-truthed in the field (Figure 3-9).

The overlay operation resulted in a total of 211 polygons of varying size and shape. After smoothing and combining polygons with the same attributes, 23 distinct land segment types were identified in the upper basin. Further smoothing to eliminate the smallest polygons and lumping of some attributes resulted in 10 distinct land segments that adequately described the 1551 ha upper basin area.
Further GIS processing derived the average elevation of each land segment and the dominant aspect. The average elevation of each segment was used for rainfall and temperature adjustments made internal to the model. Dominant aspect was used to adjust parameters related to solar radiation and snowmelt on a land segment. Soils characteristics were then added to the database to finalize the land segment definitions. Table 3-3 provides the final land segment descriptions that were used in the HSPF model runs.
Table 3-3. HSPF land segment definitions for simulating the water balance in the upper Lost Horse basin.

<table>
<thead>
<tr>
<th>Land Segments</th>
<th>Land Segment Area (hectares)</th>
<th>Average Slope (%)</th>
<th>Vegetation Density</th>
<th>Dominant Aspect</th>
<th>Mean Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW ELEVATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>279</td>
<td>25</td>
<td>dense</td>
<td>E</td>
<td>1864</td>
</tr>
<tr>
<td>102</td>
<td>77</td>
<td>35</td>
<td>sparse</td>
<td>E</td>
<td>1909</td>
</tr>
<tr>
<td>MIDDLE ELEVATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>201</td>
<td>201</td>
<td>25</td>
<td>dense</td>
<td>W</td>
<td>2022</td>
</tr>
<tr>
<td>202</td>
<td>93</td>
<td>34</td>
<td>moderate</td>
<td>E</td>
<td>2049</td>
</tr>
<tr>
<td>203</td>
<td>263</td>
<td>28</td>
<td>sparse</td>
<td>E</td>
<td>2032</td>
</tr>
<tr>
<td>401</td>
<td>31</td>
<td>Lakes</td>
<td></td>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>UPPER ELEVATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>301</td>
<td>62</td>
<td>35</td>
<td>dense</td>
<td>W</td>
<td>2180</td>
</tr>
<tr>
<td>302</td>
<td>201</td>
<td>35</td>
<td>moderate</td>
<td>W</td>
<td>2229</td>
</tr>
<tr>
<td>303</td>
<td>263</td>
<td>50</td>
<td>sparse</td>
<td>W</td>
<td>2199</td>
</tr>
<tr>
<td>304</td>
<td>77</td>
<td>50</td>
<td>Scree</td>
<td>W</td>
<td>2258</td>
</tr>
</tbody>
</table>

Model Calibration

 Calibration Procedure

Calibration of the HSPF model first requires agreement between the observed and simulated runoff for the period of record. On an annual basis this is achieved by satisfying the following equation:

\[
\text{Precipitation} - \text{Actual Evapotranspiration} +/\text{- Storage Changes} = \text{Runoff} \quad (2)
\]

Once adequate agreement in long-term runoff is achieved, annual and seasonal runoff is calibrated. After this, an attempt is made to match observed and simulated stream discharge for individual events.
Model calibration is an iterative and interactive procedure. Each model calibration parameter must be adjusted for each of the land segments used in the model run. In addition, each parameter has a different effect on the process that it primarily affects. As in nature there is considerable interaction between the model parameters.

Calibration involves the initial estimation of parameters. The HSPF user manuals, other studies, notes from training sessions were used to select initial parameter values (Hydrocomp, 1995; Crawford, 1995 personal communication). After the initial model run, calibration of annual flows, seasonal/monthly flows, snow accumulation and snowmelt proceeds. Table 3-4 lists the HSPF parameters used in the water balance calibration, and Table 3-5 lists calibration parameters for snow simulation.
Table 3-4. HSPF model water balance calibration parameters and descriptions.

<table>
<thead>
<tr>
<th>Watershed Water Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>LZSN</td>
</tr>
<tr>
<td>UZSN</td>
</tr>
</tbody>
</table>

Soil Moisture Storage, Actual ET

| INFILT                  | Index to the mean infiltration rate on a land segment |
| LZETP                   | Lower zone evapotranspiration - an index to the density of deep rooted vegetation |

Seasonal and Low Flows

| AGWRC                   | Active groundwater recession constant |
| KVARY                   | Affects the behavior of the groundwater recession flow |

Hydrograph Shape, Peak Flows

| INTFW                   | Interflow parameter - trades interflow for surface runoff |
| IRC                     | Interflow recession parameter |

Table 3-5. HSPF model snow accumulation and melt calibration parameters and descriptions.

<table>
<thead>
<tr>
<th>Snow Accumulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSNOW</td>
</tr>
<tr>
<td>SNOWCF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Snow Aging and Transformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDCSN</td>
</tr>
<tr>
<td>MWATER</td>
</tr>
<tr>
<td>COVIND</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat Exchange and Melt</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCFACT</td>
</tr>
<tr>
<td>SHADE</td>
</tr>
</tbody>
</table>

The model requires initial values for climate and storage components of the basin. When these initial values are properly adjusted, they improve the agreement between the observed and modeled runoff during the first few months of simulation. Table 3-6 describes initial parameters for the SNOW and PWATER sections used in this study.
Table 3-6. Required land segment initialization (beginning of run) parameters for the HSPF model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWATER</td>
<td>CEPS is the initial interception storage.</td>
</tr>
<tr>
<td></td>
<td>SURS is the initial surface (overland flow) storage.</td>
</tr>
<tr>
<td></td>
<td>UZS is the initial upper zone storage.</td>
</tr>
<tr>
<td></td>
<td>IFWS is the initial interflow storage.</td>
</tr>
<tr>
<td></td>
<td>LZS is the initial lower zone storage.</td>
</tr>
<tr>
<td></td>
<td>AGWS is the initial active groundwater storage.</td>
</tr>
<tr>
<td></td>
<td>GWVS is the initial index to groundwater slope; it is a measure of antecedent active groundwater inflow.</td>
</tr>
<tr>
<td>SNOW</td>
<td>PACK-SNOW is the quantity of snow in the pack (water equivalent).</td>
</tr>
<tr>
<td></td>
<td>PACK-ICE is the quantity of ice in the pack (water equivalent).</td>
</tr>
<tr>
<td></td>
<td>PACK-WATR is the quantity of liquid water in the pack.</td>
</tr>
<tr>
<td></td>
<td>RDENPF is the density of the frozen contents (snow and ice) of the pack, relative to water.</td>
</tr>
<tr>
<td></td>
<td>DULL is an index to the dullness of the snow pack surface, from which albedo is estimated.</td>
</tr>
<tr>
<td></td>
<td>PAKTMP is the mean temperature of the frozen contents of the snow pack.</td>
</tr>
<tr>
<td></td>
<td>COVINX is the current snow pack depth (water equivalent) required to obtain complete areal coverage of the PLS. If the pack is less than this amount, areal cover is prorated (PACKF/COVINX).</td>
</tr>
<tr>
<td></td>
<td>XLNMLT is the current remaining possible increment to ice storage in the pack (see Functional Description). It is relevant if ice formation is simulated (ICEFG= 1).</td>
</tr>
<tr>
<td></td>
<td>SKYCLR is the fraction of sky which is assumed to be clear at the present time.</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Model Calibration

Calibration of the HSPF model for the annual water balance had mixed results. Appendix K contains the final user control input (UCI) file for model calibration. A reasonable balance of runoff values for the entire 2 water-year period of record was achieved, but some difficulty was encountered with fit for individual years. The observed record and the simulated runoff differ by less than 1 percent for the simulation period (Figure 3-10).
Average snow water equivalent differs by approximately 4 percent for the period. During water year 1995, the model overestimated runoff by approximately 10 percent and in 1996 underestimated runoff by 6 percent. Similarly, the model overestimated snow accumulation in 1995 by 4 percent and underestimated it in 1996 by 11 percent.

Figure 3-10. HSPF model runoff and snow calibration results, water-years 1995 and 1996, upper Lost Horse basin.

The observed runoff record, partly based on the relationship between Lost Horse Creek and the Lochsa River in Idaho, shows considerable deviation from simulated runoff during the winter months in both simulation years (Figure 3-11). During water year 1995, simulated runoff is significantly higher than the observed record during the months of January, February and March. Even though discharge values from the Lochsa River matched quite well with those from Lost Horse during the summer, there were no
overlapping values to compare the records during late fall, winter and spring months (most of the year).

Figure 3-11. Monthly observed runoff vs. HSPF modeled runoff for 1995 and 1996.

Since the gage on the Lochsa River encompasses a large area in lower elevations, one would expect to encounter two separate problems with using this record to extend the Lost Horse Creek record. First, precipitation would more likely be rain than snow later into and earlier into spring. One would expect rises in the hydrograph at the Lochsa River where they wouldn’t occur at Lost Horse Creek. Secondly, the lower elevation snow accumulation in the Lochsa basin would melt off earlier than the high elevation basin at Lost Horse Creek. Figure 3-11 illustrates this during January and February of 1995. An early melt cycle occurs during January and February on the observed/infilled record, but doesn’t occur on the simulated record. Instead, the simulated record shows that the snow-
water stays in the basin during these months, retained for runoff during April and May. In water year 1996, simulated runoff is significantly higher than the observed record throughout the winter most likely due to the same problem described above. The model fit is quite well with the observed record during the summer months of June, July, August and September of both years. For model calibration, these months are the most important since they contain actual observed record at the site.

Figure 3-12 is a graphical comparison of observed snow water equivalent at the Twin Lakes SNOTEL station and simulated snow water equivalent for the land segment representing the Twin Lakes SNOTEL site. During the period of snow accumulation, roughly from October through March, the simulated snow values shadow the observed values quite closely. In water year 1995, the model simulates slightly higher accumulation than the observed record, while in 1996 the model follows the observed values reasonably well. However, during the period of snowmelt in 1996, roughly April through June, simulated snow ablation was accelerated compared to the observed record.
Figure 3-12. Plot of observed snow-water equivalent and simulated snow-water equivalent for the land segment representing the Twin Lakes SNOTEL site.

The summer low flow periods were of primary interest in this study. Figures 3-13 and 3-14 show composite plots of the infilled record, HSPF simulated runoff, and the actual discharge values at the upper basin gage and precipitation for the summer period in each of the two water years. Figure 3-13 illustrates that the simulated hydrograph from the HSPF model matches the measured values at the upper gage very closely during the period from July through September of 1995. A large peak occurred on about July 3 in response to a significant rainfall event during the previous days. The magnitude of this peak was due to the high water storage in the upper basin from recent snowmelt. Rain during the following week caused two other small peaks before the hydrograph receded during the remainder of July. The model was not sensitive enough to pick up the small peak that occurred on July 28.
Figure 3-13. Water-year 1995 HSPF calibration results for the upper Lost Horse basin.

In mid August, four consecutive days of rain caused a sharp peak in the discharge record. The peak occurred after a particularly heavy storm event dumped 3.8 centimeters of rain in the upper basin on August 16th. The recession that followed this series of storms was simulated quite accurately compared to the observed discharge values at the upper gage. There was little response in the hydrograph during the days following September 1 where 0.25 to 0.50 centimeters of precipitation fell at the Twin Lakes SNOTEL station.

The hydrograph in Figure 3-14, for water year 1996, shows that the HSPF simulated runoff fit quite well with the observed values at the upper gage. The peaks in the simulated record during the first half of July are from snowmelt. In mid-August, water was released from storage from both the upper and lower Twin Lakes. This caused an unexpected peak in stream discharge on August 17th. There were a number of other
storage releases later in the summer that made the measured values useless for model calibration.

Figure 3-14. Water-year 1996 HSPF calibration results for the upper Lost Horse basin.

Overall, the calibration results are more convincing given that we have a reasonably good fit between the model and the most reliable segment of the observed discharge record. Additionally, the model did a reasonably good job of partitioning precipitation between rainfall and snow. It is also evident from the results that snowmelt processes are being simulated well. In a remote basin such as this, with an incomplete data record with which to calibrate the model, there is a reasonably high level of confidence that the model is representing hydrologic processes in the study basin.
Water Balance

Overall Water Balance

Precipitation for both water years was above the average of in the study basin at the Twin Lakes climate station. Water year 1995 had a total of 178 centimeters of precipitation and water year 1996 a total of 224 centimeters, which are about 103 percent and 130 percent of the average annual precipitation for this site. These two years were preceded by a comparatively dry year in 1994 when only 128 centimeters of precipitation was recorded, or about 74 percent of average. Because of the low water year in 1994 prior to the analysis, and the high water year during the second year of the calculation in 1996, one would expect storage to increase from the beginning to the end of the period. The water budget for the study period was:

Precipitation (395 centimeters) – losses to the atmosphere (77.2 centimeters) = total stream flow (304 centimeters) + residual storage (13.7 centimeters).

Total evapotranspiration over the two-year period was equal to approximately 20 percent of the total precipitation in the basin and discharge was 77 percent. A net increase in storage occurred over the two-year period equaling 3.5 percent of the total precipitation.

Annual Water Balance

Looking at the water balance on an annual basis provides more insight into the changes in basin water storage over the two year period (Table 3-7). In water-year 1995, approximately 22 percent (39 centimeters) of the total precipitation was lost to
evapotranspiration and 66 percent (114 centimeters) to runoff. This left about 12 percent or 20.8 centimeters of the total precipitation as an increase to basin storage. This seems rather high, but can be explained in part by the low water year in 1994, causing storage to be depleted just prior to the study period. Very high precipitation late in the 1995 water year caused additional water to be in storage at the end of the period.

In 1996, approximately 17 percent (38.4 centimeters) of the total precipitation amount went into evapotranspiration and 86 percent (189.7 centimeters) into runoff. Total runoff and ET add up to more than 100 percent because some of the streamflow was taken from storage from the previous water year. By the end of the second water year, storage decreased by approximately 3 percent (7.1 centimeters) from the beginning of the year in part due to a dry late summer period, even though annual precipitation was above normal for the water-year.

Monthly Water Balance

Table 3-7 shows the monthly water balance for the upper Lost Horse Creek basin, illustrating the variability of the water budget components over the course of each year. Basin precipitation is divided into the monthly total, end of month snow water equivalent, and total snowfall in inches of water equivalent. The column “total ET” includes sublimation from snow, evaporation from land and water, and transpiration from vegetation. Three components of runoff are listed as surface flow, interflow and baseflow. Storage shows the net change in storage per month of the snowpack in the study basin, and the net change in total basin water storage.
Table 3-7. HSPF modeled monthly water balance totals in centimeters for the Upper Lost Horse Creek Watershed, Water Years 1995 and 1996.

<table>
<thead>
<tr>
<th></th>
<th>PRECIPITATION</th>
<th>EVAP</th>
<th>RUNOFF</th>
<th>STORAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TOTAL PPT</td>
<td>EOM</td>
<td>SNOW FALL</td>
<td>TOTAL ET</td>
</tr>
<tr>
<td>WY-1995</td>
<td>173.7</td>
<td>88.3</td>
<td>38.9</td>
<td>22.3</td>
</tr>
<tr>
<td>Oct-94</td>
<td>19.0</td>
<td>5.8</td>
<td>11.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Nov-94</td>
<td>25.0</td>
<td>31.0</td>
<td>25.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Dec-94</td>
<td>16.8</td>
<td>47.0</td>
<td>14.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Jan-95</td>
<td>20.0</td>
<td>62.1</td>
<td>15.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Feb-95</td>
<td>20.0</td>
<td>69.6</td>
<td>11.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Mar-95</td>
<td>15.8</td>
<td>74.7</td>
<td>8.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Apr-95</td>
<td>12.0</td>
<td>57.4</td>
<td>1.8</td>
<td>1.3</td>
</tr>
<tr>
<td>May-95</td>
<td>8.8</td>
<td>18.6</td>
<td>0.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Jun-95</td>
<td>9.3</td>
<td>3.0</td>
<td>0.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Jul-95</td>
<td>13.3</td>
<td>0.0</td>
<td>10.6</td>
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</tr>
<tr>
<td>Aug-95</td>
<td>7.5</td>
<td>0.0</td>
<td>8.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Sep-95</td>
<td>6.3</td>
<td>0.0</td>
<td>5.3</td>
<td>0.0</td>
</tr>
<tr>
<td>1995 TOTAL</td>
<td>173.7</td>
<td>88.3</td>
<td>38.9</td>
<td>22.3</td>
</tr>
<tr>
<td>WY-1996</td>
<td>221.0</td>
<td>120.5</td>
<td>38.3</td>
<td>51.4</td>
</tr>
<tr>
<td>Oct-96</td>
<td>18.5</td>
<td>1.8</td>
<td>7.8</td>
<td>0.9</td>
</tr>
<tr>
<td>Nov-96</td>
<td>52.8</td>
<td>31.8</td>
<td>36.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Dec-96</td>
<td>20.5</td>
<td>47.1</td>
<td>15.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Jan-96</td>
<td>25.3</td>
<td>71.5</td>
<td>22.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Feb-96</td>
<td>35.3</td>
<td>95.5</td>
<td>25.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Mar-96</td>
<td>9.3</td>
<td>97.1</td>
<td>4.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Apr-96</td>
<td>25.0</td>
<td>83.9</td>
<td>5.6</td>
<td>1.7</td>
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<tr>
<td>May-96</td>
<td>18.3</td>
<td>55.1</td>
<td>1.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Jun-96</td>
<td>3.0</td>
<td>9.1</td>
<td>0.0</td>
<td>8.4</td>
</tr>
<tr>
<td>Jul-96</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Aug-96</td>
<td>3.5</td>
<td>0.0</td>
<td>0.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Sep-96</td>
<td>8.5</td>
<td>0.0</td>
<td>0.5</td>
<td>4.1</td>
</tr>
<tr>
<td>1996 TOTAL</td>
<td>221.0</td>
<td>120.5</td>
<td>38.3</td>
<td>51.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>394.7</td>
<td>208.8</td>
<td>77.3</td>
<td>73.7</td>
</tr>
</tbody>
</table>

* SWE – snow water equivalent

In both water years, 1995 and 1996, precipitation inputs were greatest at the beginning of the water year and taper off as they reach a minimum late in the water year. During November 1995, the Twin Lakes SNOTEL station measured an astounding 53.3 centimeters of precipitation (water equivalent). This is quite noteworthy considering Bitterroot Valley weather stations average less precipitation than this on an annual basis.
Although some studies have concluded that approximately 70 percent of annual precipitation falls as snow at the higher elevation sites in Montana, the amount of measurable snow on the ground at any one time in the upper Lost Horse Creek basin was closer to 50 percent of total precipitation during the study period. Nevertheless, seasonal snowpack in the study basin had an overwhelming effect on basin outflow processes during the study period.

Figure 3-15 shows cumulative precipitation data and snow water equivalent from the nearby Twelvemile Creek SNOTEL station for water years 1994 through 1996. The site is located about 2-miles east and down-valley from the upper Lost Horse Creek gage site, and is about 50-meters lower in elevation. The plots illustrate that even though water years 1995 and 1996 were above normal in total precipitation, the snow water equivalent was well below normal throughout the winter season. The data suggest that temperatures were relatively high during these two winters and that the partitioning of precipitation into snow was less than expected. Figure 3-16 shows the same plots for the Twin Lakes SNOTEL station. Water-year 1994 shows below average precipitation and snowpack, 1995 shows roughly average precipitation and below average snowpack, and 1996 shows considerably above average precipitation and above average snowpack.
Figure 3-15. Cumulative precipitation and snow water equivalent at the Twelvemile Creek SNOTEL station. Water-years 1994 – 1996.
Figure 3-16. Cumulative precipitation and snow water equivalent at the Twin Lakes SNOTEL station. Water-years 1994 – 1996.
Maximum snow water equivalent occurred at the end of March in both water years (Table 3-7). At that time, the change in SWE is negative while runoff shows a significant increase and Total ET shows only a modest increase. In both water years the maximum decline in SWE coincides with maximum runoff. A decline in total basin water storage was delayed from the onset of snowmelt by two months in 1995 and one month in 1996. Maximum ET occurred in July of both years, when the maximum water availability coincided with maximum demand. ET tapers off in August and September due to a decrease in available water.

Finklin (1983) estimates that potential evapotranspiration (PET) in the lower elevations of the Idaho/Montana area is between 63.5 and 89 centimeters per year. Actual evapotranspiration is always less than potential due to limited water availability, especially in western Montana where dry summer conditions coincide with the highest PET. This effect increases at higher elevations where there are lower temperatures and higher relative humidity. The low actual evapotranspiration values at the study site, averaging 38.6 centimeters per year, are partly a result of the factors described above, and reduced transpiration from trees burned in the 1988 fire. Results from a previous study in the upper Lost Horse basin demonstrate that water yield increased considerably after the 1988 fire. Dixon and Potts (1996) showed that some of the increase was due to increased snow accumulation, but most came from a decline in evapotranspiration. Results from the previous study show that due to the burn, there was a 22 percent decrease in evapotranspiration, and a 13 percent increase in basin outflow from the fire.
Table 3-8 shows how the HSPF model partitions surface, interflow and baseflow runoff components for the study period and each model year. For the entire two-year study period, most of the runoff was generated by stored groundwater as baseflow (42%), next by interflow (34%) and the least by direct surface runoff (24%). Interflow runoff includes intermediate flow path lengths such as soil macropores and flow along impervious surfaces, while surface runoff includes direct precipitation to channels or water bodies and water that makes it directly to the channel from the ground surface. Sources of direct runoff from the ground surface may include precipitation on bedrock, frozen ground, or any time when the rate of precipitation exceeds the rate of infiltration.

Table 3-8. Modeled runoff pathways by volume and percent of total flow in the upper Lost Horse Creek basin.

<table>
<thead>
<tr>
<th>RUNOFF PATH</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface</td>
<td>Interflow</td>
<td>Baseflow</td>
<td>Total</td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>22</td>
<td>33</td>
<td>58</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>29%</td>
<td>51%</td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>51</td>
<td>69</td>
<td>69</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>27%</td>
<td>37%</td>
<td>36%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>74</td>
<td>103</td>
<td>128</td>
<td>304</td>
</tr>
<tr>
<td></td>
<td>24%</td>
<td>34%</td>
<td>42%</td>
<td></td>
</tr>
</tbody>
</table>

In water-year 1995, the lower of the two years in terms of precipitation, baseflow accounted for 51 percent of the total outflow compared to 36 percent in 1996. In 1995, however, baseflow accounted for 58.4 centimeters of runoff compared to 68.6 centimeters in 1996, just a little more. Alternatively, surface and interflow runoff depth more than doubled even though the percentage of total runoff increased only modestly. This illustrates how the variation in the annual precipitation affects baseflow component than the other two runoff pathways.
Sources of Error

There are essentially three sources of error associated with the approach used in this study: 1) Measurement or estimation error of time-series data used to drive and calibrate the model, 2) Error in estimating model parameters that represent physical basin characteristics, and 3) Error associated with using a computer model to simulate complex hydrologic processes.

Time-Series Measurement or Estimation Error

Measurement error of meteorological and hydrologic time-series can vary widely depending on the type of instrumentation and the maintenance or calibration of equipment. In this study, some time-series data were used as input to estimate other time-series data, so error in the derived time-series include the error of the original data set plus the error associated with the estimating algorithm. Some time-series data measured "off-site" introduce additional error associated with the spatial separation of the measurement site and the study site. Potential sources of error for individual components are:

Precipitation: error from the effect of wind on rain gage catch efficiency, (Dingman, 1993), larger error for cylindrical gages such as those used at SNOTEL sites, precipitation measurement error of 5 percent to 15 percent for annual or longer data, and up to 75 percent for single storm events (Winter, 1981), a 3 to 30 percent under measurement of annual precipitation for standard precipitation gages with larger errors during snowstorms (Rodda 1985), error from low data resolution, which is limited to
tenths of an inch at SNOTEL sites, error from interpolating hourly data from 3-hour data, error from having the basin represented by only one precipitation gage.

**Snow Water Equivalent:** SNOTEL station snow pillow measurement error, snow course measurement error, extrapolation of point data to encompass an entire HSPF land segment.

**Temperature:** SNOTEL site instrumentation measurement error, interpolation of hourly data from Min-Max daily data for input to the HSPF model, corrections for land segments by HSPF based on elevation.

**Dew Point Temperature:** error from using a measured minimum temperature.

**Stream Discharge:** measurement error, error in conversion of stage to discharge, error from interpolating missing values from relationships with other gaging stations, and error from loss of water from the basin via groundwater.

**Potential or Pan Evapotranspiration:** measurement and estimation, error associated with using data from outside the study area having differing meteorological conditions.

**Wind:** measurement error, data from an off-site valley station, mountain wind patterns would be very different from those at the open valley station, no directional component is required in the HSPF model.

**Solar Radiation:** difference in incoming radiation from the measurement station at an elevation of 1,097 meters compared to the study site elevation at about 1,981 meters,
increased cloud cover at the study site located in the mountains compared to the measurement site.

**Basin Parameter Error**

**Catchment Size**: error from assuming the contributing area of the basin is the same as the basin derived from the topographic map.

**Land Segment Definitions**: Although past studies were used as a rough guide to defining land segments in HSPF, choosing the correct attributes for separating the basin into land segments could introduce a considerable amount of error.

**Model Parameterization**: Within each land segment there are initial values to set for flux variables, and fixed values that do not change. For example, upper zone initial storage affects how much water is available for ET, transfer to the lower zone, and runoff at the beginning of the model run. However, the effect tapers off as the model comes into its own equilibrium with subsequent precipitation inputs and outflows. On the other hand, upper zone storage capacity is set at the beginning of the model run and does not change during the simulation. Upper zone storage capacity affects how much water can potentially be stored, how much can be transpired by vegetation, how much goes directly to runoff, and how much accretes to the water table in the lower zone.

**Computer Model Error**

Another source of error is the ability of the computer model to simulate complex hydrologic processes. Since the model is essentially a compilation of mathematical
simplifications of real world processes, error is associated with both the conceptual framework of the model and with each algorithm simulating a specific hydrologic function. Additionally, the interaction of the algorithms in the model is a possible source for error. An in-depth discussion of these issues is beyond the scope of this study. However, it is important to know that these sources of error exist, and that comprehensive watershed modeling is still in its infancy.

CONCLUSIONS

Using the HSPF model to derive a monthly water balance for two years in the upper Lost Horse Creek basin provides a comprehensive look at hydrologic inputs, storages, and outputs at a remote subalpine basin in western Montana. Since little is known about the relative magnitude of water budget components from this type of basin, results from this study provide a baseline for future work. The improved understanding of the hydrologic flow paths in high elevation subalpine basins should provide a basis for further understanding the effects of traditional management activities such as road building and timber harvest, in addition to more recent issues such as the reintroduction of a historic fire regime on forested lands. Although it is outside the scope of this study to analyze the long-term tradeoffs between management activities and environmental effects, we can conclude that without a solid understanding of both we risk compromising the resource in the end.

Results from this study show that higher elevation areas such as the upper Lost Horse Creek basin provide a considerable amount of runoff per land area per unit of precipitation. The low evapotranspiration rate in the basin, especially with recent fire,
shows the importance of a basin this type for generating surface water runoff to the semi-arid lowlands. Moreover, since high elevation areas in this region receive much more precipitation, they are of primary importance to supporting ecological communities that depend on sustained streamflow in the downstream direction.

We cannot understate the importance high elevation basins for generation of runoff during a period of possible human induced climate change. If future climate change in the intermountain west means overall warming temperatures and declining precipitation, these high elevation basins will be even more important for satisfying the demand for surface water resources.
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Chapter 2


**Chapter 3**


APPENDICES

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Appendix – A  Soil descriptions from Upper Lost Horse Creek.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Ridge top northeast of Bailey Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCATION CODE</td>
<td>BL-1</td>
</tr>
<tr>
<td>DATE</td>
<td>10/3/1996</td>
</tr>
<tr>
<td>PHYSIOGRAPHY</td>
<td>flatter area near ridge top, steeper area below with boulders and other large rocks on surface</td>
</tr>
<tr>
<td>VEGETATION</td>
<td>burn area - beargrass, whortleberry, other grasses. Veg. cover about 55% the rest is exposed soil &amp; rocks</td>
</tr>
<tr>
<td>ASPECT</td>
<td>SE</td>
</tr>
<tr>
<td>SLOPE</td>
<td>10%</td>
</tr>
<tr>
<td>GROUNDWATER</td>
<td>none</td>
</tr>
<tr>
<td>GENERAL NOTES</td>
<td>ash has been mixed with sand from decomposed granite boulders or has eroded</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>0 to 1.5</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>burned dark surface horizon</td>
</tr>
<tr>
<td>A</td>
<td>1.5 to 5</td>
<td>darker than 10 or 7.5YR 2/1</td>
<td>sandy loam</td>
<td>granular</td>
<td>abrupt</td>
<td>Sample BL-1a</td>
</tr>
<tr>
<td>Bw</td>
<td>5 +</td>
<td>10 YR 5/6</td>
<td>loamy sand</td>
<td>granular</td>
<td>gradual</td>
<td>much coarser material</td>
</tr>
</tbody>
</table>

ADDITIONAL NOTES BL-1:
This area was eroded after the 1988 fire and most likely has been eroded a number of times to some extent over the last 7,000 years since ash deposition. On the surface where there is no vegetation, coarse sand and gravel fragments occur that originate further upslope or locally from granite boulders that have shed layers over time or from the intense heat of the fire.
LOCATION: 50 meters west of Bailey Lake
LOCATION CODE: BL-2
DATE: 10/3/1996
PHYSIOGRAPHY: flat depositional area at the head of Bailey Lake
VEGETATION: grasses, forbes, sedges, large - dead subalpine fir and a few live small fir trees
ASPECT: east
SLOPE: < 4%
GROUNDWATER: near or at the surface much of the year, now it is 17.5"
GENERAL NOTES: this area burned in 1988, but not as intense as surrounding area due to wetness

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 to 2.4</td>
<td>10 YR 2/1</td>
<td>loam</td>
<td>granular</td>
<td>abrupt</td>
<td>dark surface horizon, sample BL-2A</td>
</tr>
<tr>
<td>Bw1</td>
<td>2.4 to 3</td>
<td>darker than 10 or 7.5 YR 2/1</td>
<td>silt-loam</td>
<td>granular</td>
<td>gradual</td>
<td>thin, very dark horizon, possible fire-ash deposit, no sample taken</td>
</tr>
<tr>
<td>Bw2</td>
<td>3 to 6.5</td>
<td>10 YR 5/6</td>
<td>silt-loam</td>
<td>granular</td>
<td>gradual</td>
<td>this layer and the next may be a single layer it appears to get a little darker with depth. sample BL-2B</td>
</tr>
<tr>
<td>2A</td>
<td>6.5 to 13.5</td>
<td>10 YR 4/3</td>
<td>loam</td>
<td>subangular - blocky</td>
<td>abrupt</td>
<td>this is another darker horizon, from here down, there are very coarse granitic sand particles, sample BL-2C</td>
</tr>
<tr>
<td>2B</td>
<td>13.5+</td>
<td>10 YR 5/6</td>
<td>sandy-loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>lighter color and very sandy</td>
</tr>
</tbody>
</table>

LOCATION: LB-1
LOCATION CODE: LB-1
DATE: 9/11/1996
PHYSIOGRAPHY: concave slope with flat bench features
VEGETATION: beargrass, whortleberry, subalpine fir and lodgepole
ASPECT: S-SE
SLOPE: < 4%
GROUNDWATER: this area burned in 1988, but not as intense as surrounding area due to wetness
GENERAL NOTES: up slope area from stream bottom-land, much drier than stream bottom area.

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-0.75</td>
<td>10 YR 3/2</td>
<td>Loamy Sand</td>
<td>granular</td>
<td>abrupt</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>0.75 - 2.0</td>
<td>7.5 YR 6/2</td>
<td>Sandy-Loam</td>
<td>granular</td>
<td>abrupt</td>
<td>light colored sand, elluviated</td>
</tr>
<tr>
<td>Bt</td>
<td>2.0 - 7.5</td>
<td>10 YR 4/3</td>
<td>Loamy Sand</td>
<td>subangular- blocky</td>
<td>abrupt</td>
<td>Sample LB-1</td>
</tr>
<tr>
<td>C</td>
<td>7.5+</td>
<td>10 YR 5/4</td>
<td>Loamy Sand</td>
<td>none</td>
<td>gradual</td>
<td></td>
</tr>
</tbody>
</table>

ADDITIONAL NOTES LB-1:
this is the area northwest of upper bridge, thin rocky soils without a distinguishable ash layer. took sample from B horizon. A and E horizon too thin for sample. below B horizon, very coarse compacted material.
<table>
<thead>
<tr>
<th>LOCATION CODE</th>
<th>DATE</th>
<th>LOCATION</th>
<th>PHYSIOGRAPHY</th>
<th>VEGETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB-2</td>
<td>9/11/1996</td>
<td></td>
<td>base of concave hillslope. some large boulders in the area, not as many as LB-3</td>
<td>beargrass, huckleberry, spruce and fir trees. this is on the edge of the burn area</td>
</tr>
<tr>
<td>SLOPE</td>
<td>&lt; 4%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GENERAL NOTES**

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 2</td>
<td>10 YR 2/1</td>
<td>loam</td>
<td>granular</td>
<td>abrupt</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2 - 7</td>
<td>7.5 YR 4/4</td>
<td>loam</td>
<td>granular</td>
<td>gradual</td>
<td>Sample LB-2a, volcanic ash</td>
</tr>
<tr>
<td>B2</td>
<td>7 - 10</td>
<td>7.5 YR 5/2</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>Sample LB-2b</td>
</tr>
<tr>
<td>C</td>
<td>10 +</td>
<td>10 YR 6/4</td>
<td>loamy sand</td>
<td>none</td>
<td>gradual</td>
<td>coarse sand</td>
</tr>
</tbody>
</table>

**ADDITIONAL NOTES LB-2:**

Depositional area for ash, thin surface horizon stained with OM and ash from fire. This layer has many coarse sand fragments throughout and is from 0-2". Below this is the ash layer which is about 5" thick. Beyond the ash layer is coarse sand and gravel. The boundary between the ash layer is difficult to see in the soil pit because the color of the two horizons is so similar.
### Location MB-3

**Location Code:** MB-3  
**Date:** 9/11/1996

**Physiography:** Flat terrace below steep rocky cliffs

**Vegetation:** 1988 burn area - dead standing trees, live beargrass and some surface moss

**Aspect:** E-NE

**Slope:** < 1%

**Groundwater:** Some erosion of the surface horizon here

**General Notes:**

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (inches)</th>
<th>Color (moist)</th>
<th>Texture</th>
<th>Structure</th>
<th>Boundary</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oa</td>
<td>0 to 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1 to 4.5</td>
<td>10 YR 3/2</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
<td>ash layer</td>
</tr>
<tr>
<td>Bw</td>
<td>4.5 to 11</td>
<td>7.5 YR 4/3</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>subsoil</td>
</tr>
<tr>
<td>C</td>
<td>11 +</td>
<td>10 YR 6/4</td>
<td>sandy loam</td>
<td>none</td>
<td>abrupt</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

This area is on the small glacial end moraine that forms Mud Lake. Boulders are common as is small coarse particles on the surface of the ground. This location is less steep than the upslope area or the slope below.

---

### Location ML-2

**Location Code:** ML-2  
**Date:** 9/11/1996

**Physiography:** Gentle slope slightly convex, mid-slope position between basin divide and lake

**Vegetation:** Beargrass, whortleberry, subalpine fir, some whitebark pine and eng. spruce

**Aspect:** S-SW

**Slope:** Gentle

**Groundwater:** ?

**General Notes:** Surface is bouldery although not as much as steeper area to the south and west

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (inches)</th>
<th>Color (moist)</th>
<th>Texture</th>
<th>Structure</th>
<th>Boundary</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 to 3.5</td>
<td>10 YR 3/3</td>
<td>sandy loam</td>
<td>granular</td>
<td>abrupt</td>
<td>sample BF-7, this soil has a considerable amount of sand, cannot ID as ash</td>
</tr>
<tr>
<td>Bw1</td>
<td>3.5 to 6.5</td>
<td>10 YR 3/4</td>
<td>sandy loam</td>
<td>granular</td>
<td>gradual</td>
<td></td>
</tr>
<tr>
<td>Bw2</td>
<td>6.5 to 10</td>
<td>10 YR 5/6</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>sample GNP-36</td>
</tr>
<tr>
<td>C</td>
<td>10 +</td>
<td>10 YR 4/4</td>
<td>sandy loam</td>
<td>none</td>
<td>gradual</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

This area is on the small glacial end moraine that forms Mud Lake. Boulders are common as is small coarse particles on the surface of the ground. This location is less steep than the upslope area or the slope below.
LOCATION: wetland adjacent to and north and a little west of Mud Lake


PHYSIOGRAPHY: flat area adjacent to lake, steep slope approx. 50 ft. to the northwest

VEGETATION: grasses and forbes, some sedges and stunted subalpine fir in the immediate area

ASPECT: S-SE

SLOPE: gentle

GROUNDWATER: near surface, but none in soil pit at 17" photographs of location

GENERAL NOTES: this area is similar to other areas in the upper basin such as the meadow area and area west of Bailey L.

HORIZON DEPTH COLOR TEXTURE STRUCTURE BOUNDARY NOTES

<table>
<thead>
<tr>
<th></th>
<th>(inches)</th>
<th>(moist)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>1.2 to 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0 to 3</td>
<td>10 YR 3/2</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
</tr>
<tr>
<td>E</td>
<td>3 to 3.5</td>
<td>7.5 YR 6/2</td>
<td>sand</td>
<td>granular</td>
<td>gradual</td>
</tr>
<tr>
<td>B</td>
<td>3.5 to 8</td>
<td>10 YR 4/3</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>abrupt</td>
</tr>
<tr>
<td>C</td>
<td>8 to 17+</td>
<td>10 YR 5/6</td>
<td>sandy loam</td>
<td>none</td>
<td>gradual</td>
</tr>
</tbody>
</table>

LOCATION: top of steeper slope which is at the base of a gentler slope coming from ridge top


PHYSIOGRAPHY: beargrass, subalpine fir, heath, whortleberry and other grasses

ASPECT: NE

SLOPE: gentle

GROUNDWATER: near surface, but none in soil pit at 17" photographs of location

GENERAL NOTES: this location is SW of Upper Twin Lake and is located on a relatively steep slope. This profile has a few coarse particles throughout but a definite increase with depth. I see this specific location as a depositional area, with the ash being carried by the wind from the exposed flat ridge top location above to the lee side of the ridge which is where this profile is located.

HORIZON DEPTH COLOR TEXTURE STRUCTURE BOUNDARY NOTES

<table>
<thead>
<tr>
<th></th>
<th>(inches)</th>
<th>(moist)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>1.5 to 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0 to 4</td>
<td>10 YR 3/2</td>
<td>loam</td>
<td>granular</td>
<td>gradual</td>
</tr>
<tr>
<td>Bw</td>
<td>4 to 12</td>
<td>10 YR 3/4</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>abrupt</td>
</tr>
<tr>
<td>C</td>
<td>12+</td>
<td>10 YR 6/4</td>
<td>sandy loam</td>
<td>none</td>
<td>gradual</td>
</tr>
</tbody>
</table>

ML-5 (notes continued)
LOCATION
LOCATION CODE ML-6
DATE 9/11/1996
PHYSIOGRAPHY very gentle almost flat in some spots, there are snowmelt runoff channels that dissect the area
VEGETATION same as ML-5 with some additional spruce trees.
ASPECT N-NE
SLOPE
GROUNDWATER
GENERAL NOTES little or no A horizon present at this location, possibly eroded away or non-existent

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>0 to 2</td>
<td>dry colors 10 YR 5/4</td>
<td>sandy loam</td>
<td>granular</td>
<td>gradual</td>
<td>ML-6a</td>
</tr>
<tr>
<td>B</td>
<td>2 to 5</td>
<td>dry colors 10 YR 4/4</td>
<td>silt loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>Sample ML-6b</td>
</tr>
</tbody>
</table>

LOCATION
LOCATION CODE RL-1
DATE 10/2/1996
PHYSIOGRAPHY continuous slope with some undulating patterns along the contour of the slope
VEGETATION mostly grasses with patches of sedge, between strips of alpine larch w/ understory of subalpine fir
ASPECT west with an occasional whitebark pine
SLOPE 10%
GROUNDWATER 
GENERAL NOTES

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 to 2.5</td>
<td>10 YR 3/2</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
<td>dense roots, sample RL-1A, volcanic ash</td>
</tr>
<tr>
<td>B</td>
<td>2.5 to 5.5</td>
<td>5 YR 4/4</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
<td>sample RL-1B, volcanic ash with a red tinge to the soil</td>
</tr>
<tr>
<td>B2</td>
<td>5.5 to 9</td>
<td>10 YR 4/6</td>
<td>loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>sample RL-1C, may be ash</td>
</tr>
<tr>
<td>C</td>
<td>9+</td>
<td>10 YR 5/4</td>
<td>loamy sand</td>
<td>none</td>
<td>abrupt</td>
<td>no sample - large coarse angular fragments, gravel/ cobble size</td>
</tr>
</tbody>
</table>

NOTES:
Other soil pits in this area have varying thickness of fine materials (ash) on top of a coarse granite substrate. Ash thickness varies from 3" to up to 10" in one pit. Occasional boulders and cobbles on the ground surface.
**LOCATION**
high elevation area on Kerr Peak east of lower Twin Lake

**LOCATION CODE**
RL-2

**DATE**
10/2/1996

**PHYSIOGRAPHY**
continuous slope with some undulating patterns along the contour of the slope

**VEGETATION**
alpine larch with subalpine fir understory and grasses on the ground surface

**ASPECT**
west

**SLOPE**
10%

**GROUNDWATER**
?

**GENERAL NOTES**

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (inches)</th>
<th>COLOR</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>.75 to 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0 to 2.25</td>
<td>10 YR 3/2</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
<td>sample RL-2B</td>
</tr>
<tr>
<td>E</td>
<td>2.25 to 3.25</td>
<td>10 YR 4/3</td>
<td>silt loam</td>
<td>granular</td>
<td>gradual</td>
<td>sample RL-2C</td>
</tr>
<tr>
<td>Bw</td>
<td>3.25 to 5.25</td>
<td>7.5 YR 5/2</td>
<td>loam</td>
<td>subangular - blocky</td>
<td>gradual</td>
<td>sample RL-2D, this is redder than horizon below and has some lighter concretions</td>
</tr>
</tbody>
</table>

**NOTES:**
This pit is adjacent to open area RL-1, but is within the ribbon larch forest. About 40% of the area within the forest is covered by boulders to cobble size particles. This pit is deeper than others in this area. Ash depths are generally < 3" over the remaining forested area as follows:
- 40% - boulders and cobbles on the surface
- 40% - < 3" thick ash deposit
- 20% - similar to this soil pit description

1" of A horizon (sample RL-2A) contains some charcoal making it appear much darker than the other 1.5" (sample RL-2B, this has some of the top 1" mixed in).
**LOCATION**
northeast of Twin Lakes Campground

**LOCATION CODE** TL-1  **DATE** 8/9/1996

**PHYSIOGRAPHY**
Terrace location with steeper slope uphill and downhill

**VEGETATION**
Subalpine Fir, Eng. Spruce, Fools Huckleberry, Mt. Heath

**ASPECT**
250 degrees W-SW

**SLOPE**
4 degrees

**GROUNDWATER**
water table at 36 cm

**GENERAL NOTES**

<table>
<thead>
<tr>
<th>HORIZON</th>
<th>DEPTH (cm)</th>
<th>COLOR (moist)</th>
<th>TEXTURE</th>
<th>STRUCTURE</th>
<th>BOUNDARY (to hor. below)</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>4 to 0</td>
<td>10 YR 2/1</td>
<td></td>
<td></td>
<td></td>
<td>not very decomposed</td>
</tr>
<tr>
<td>A</td>
<td>0 to 5.5</td>
<td>10 YR 2/2</td>
<td>loam</td>
<td>granular</td>
<td>wavy</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5.5 to 14.5</td>
<td>10 YR 3/3</td>
<td>loam</td>
<td>granular</td>
<td>gradual</td>
<td>volcanic ash, sample TL-1b</td>
</tr>
<tr>
<td>B2</td>
<td>14.5 to 39</td>
<td>10 YR 3/3</td>
<td>sandy loam</td>
<td>subangular - blocky</td>
<td>abrupt</td>
<td>volcanic ash both redox conc. and mottles (7.5 YR 5/8), sample TL-1c</td>
</tr>
<tr>
<td>C</td>
<td>39 +</td>
<td>10 YR 5/6</td>
<td>loamy sand</td>
<td>none</td>
<td>gradual</td>
<td>compacted glacial till</td>
</tr>
</tbody>
</table>

**NOTES:**
This area is similar if not almost the same terrace feature as that just east of the meadow area where the wells are located. It's difficult to envision how the terrace formed. The seismic survey revealed that the terrace is most likely bedrock. Either way the area is very wet due to its location on the hillslope, a flat terrace at the base of a very steep slope. Look at the in-depth discussion on page "ash #1" and the map for its position on the slope.
### Location 1:

**LOCATION**: Upper terrace above upper Twin Lake below rock scarp  
**LOCATION CODE**: TL-6  
**DATE**: 8/9/1996  
**PHYSIOGRAPHY**: Slope moderately steep  
**VEGETATION**: Lodgepole pine and subalpine fir, beargrass, huckleberry, whortleberry  
**ASPECT**: West-southwest  
**SLOPE**: 12-14 degrees  
**GROUNDWATER**: Not near surface  

**General Notes**

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Color (moist)</th>
<th>Texture</th>
<th>Structure</th>
<th>Boundary</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>3.5 to 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0 to 4.5</td>
<td>10 YR 3/2</td>
<td>sandy loam</td>
<td>granular</td>
<td>abrupt</td>
<td>Thin layer with some coarser light granite fragments</td>
</tr>
<tr>
<td></td>
<td>0 to 4.5</td>
<td>10 YR 4/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw</td>
<td>4.5 to 19.5</td>
<td>10 YR 4/4</td>
<td>silt &amp; some coarse fragments</td>
<td>granular</td>
<td>abrupt</td>
<td>Concretions with lighter chroma and value. Sample GNP-21</td>
</tr>
<tr>
<td>C</td>
<td>19.5 +</td>
<td>10 YR 5/6</td>
<td>loamy sand</td>
<td>none</td>
<td>gradual</td>
<td>Coarse rocks mixed with sand and possibly some silt/ash</td>
</tr>
</tbody>
</table>

**Notes:**

This area has some boulders at the surface and various sizes of granite throughout the soil profile. Sample TL-8a was taken from between 1.5 and 4.5 inches depth, and sample TL-8b was taken from between 9 and 11 inches depth.

---

### Location 2:

**LOCATION**: Northeast of upper twin lake  
**LOCATION CODE**: TL-8  
**DATE**: 8/12/1996  
**PHYSIOGRAPHY**: Continuous slope  
**VEGETATION**: Beargrass, annual herbs, sparse subalpine fir, some huckleberry  
**ASPECT**: 200 degrees  
**SLOPE**: 15 degrees  
**GROUNDWATER**: None near surface  

**General Notes**

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (inches)</th>
<th>Color (moist)</th>
<th>Texture</th>
<th>Structure</th>
<th>Boundary</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oe</td>
<td>.75 to 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Root mat and some un-decomposed wood.</td>
</tr>
<tr>
<td>E</td>
<td>0 to .4</td>
<td>10 YR 4/2</td>
<td>sand</td>
<td>granular</td>
<td>abrupt</td>
<td>Very coarse and much lighter than underlying horizon</td>
</tr>
<tr>
<td></td>
<td>0 to .4</td>
<td>10 YR 5/3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bw</td>
<td>.4 to 14.9</td>
<td>10 YR 3/4</td>
<td>loam</td>
<td>noticeable</td>
<td>subangular</td>
<td>No clay, lots of sand but also silty due to ash. This layer is very uniform throughout.</td>
</tr>
<tr>
<td></td>
<td>.4 to 14.9</td>
<td>10 YR 6/4</td>
<td>silt</td>
<td>blocky</td>
<td>gradual</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>14.9 +</td>
<td>10 YR 6/4</td>
<td>loamy sand</td>
<td>subangular</td>
<td>blocky</td>
<td>Very coarse compacted material</td>
</tr>
</tbody>
</table>

**Notes:**

This area has some boulders at the surface and various sizes of granite throughout the soil profile. Sample TL-8a was taken from between 1.5 and 4.5 inches depth, and sample TL-8b was taken from between 9 and 11 inches depth.
<table>
<thead>
<tr>
<th>SITE (code)</th>
<th>ash depth</th>
<th>slope (deg.)</th>
<th>aspect</th>
<th>vegetation</th>
<th>phystography</th>
<th>texture</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCP-1</td>
<td>17 gentle</td>
<td>east</td>
<td>lodgepole pine, beargrass, annual herbs, few subalpine fir, some huckleberry</td>
<td>gentle terrain continuous slope, few bedrock outcrops visible upslope</td>
<td>silt-loam</td>
<td>we found a distinguishable ash layer that graded into a coarser granitic soil at about 16 inches.</td>
<td></td>
</tr>
<tr>
<td>BCP-2</td>
<td>5 sloping</td>
<td>east</td>
<td>lodgepole pine and subalpine fir and beargrass.</td>
<td>continuous slope with occasional boulders and bedrock up and down slope.</td>
<td>loam</td>
<td>dominated by sandy soils. This is best described as an ash affected layer.</td>
<td></td>
</tr>
<tr>
<td>BCP-3</td>
<td>10 sloping</td>
<td>east</td>
<td>small subalpine fir and bear grass</td>
<td>sloping area with small pockets of flat area bedrock visible all around.</td>
<td>sandy-loam</td>
<td>flat area adjacent to exposed granite bedrock which is decomposing, ash is mixed with coarser materials.</td>
<td></td>
</tr>
<tr>
<td>BCP-4</td>
<td>15 sloping</td>
<td>east</td>
<td>lodgepole pine, beargrass, few subalpine fir, alder and spruce nearby</td>
<td>continuous slope, some large boulders and a few bedrock outcrops upslope</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCP-5</td>
<td>0 sloping</td>
<td>east</td>
<td>Subalpine Fir, bear grass</td>
<td>continuous slope, intermittent flat areas with exposed bedrock</td>
<td>sandy-loam</td>
<td>a small draw. There was significant organic matter accumulation, poorly drained saturated almost to the surface.</td>
<td></td>
</tr>
<tr>
<td>BCP-6</td>
<td>0 sloping</td>
<td>east</td>
<td>burned, near edge of burn, trees thick burned subalpine fir, beargrass</td>
<td>continuous slope with bedrock visible upslope.</td>
<td>sandy-loam</td>
<td>exposed area, little or no ash.</td>
<td></td>
</tr>
<tr>
<td>BCP-7</td>
<td>10 gentle</td>
<td>south</td>
<td>burned sparse trees, sparse bear grass</td>
<td>low wet area</td>
<td>silt-loam</td>
<td>flat boggy area, recent burn, ash in roots of windthrown trees, thick ash layer with little mixing with granitics, saturated at the surface.</td>
<td></td>
</tr>
<tr>
<td>BCP-8</td>
<td>0 moderate</td>
<td>south</td>
<td>burned sparse trees, some bear grass exposed soil</td>
<td>continuous slope, boulder and cobble size particles at the surface.</td>
<td>sandy-loam</td>
<td>small lateral morain to the north with exposed soil at the surface, not recovered from fire, this is a good illustration of why the ash layer is not there or not apparent, very stony, rock fragments from exfoliating boulders due to fire.</td>
<td></td>
</tr>
<tr>
<td>SITE (code)</td>
<td>ash depth</td>
<td>slope (deg.)</td>
<td>aspect</td>
<td>vegetation</td>
<td>physiography</td>
<td>texture</td>
<td>notes</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------</td>
<td>------------</td>
<td>--------------</td>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>o-1</td>
<td>0</td>
<td>17 west</td>
<td>beargrass, annual herbs, sparse subalpine fir, some huckleberry</td>
<td>continuous slope, exposed</td>
<td>loamy sand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-2</td>
<td>8</td>
<td>10 west</td>
<td>Subalpine and Douglas Fir, beargrass, some huckleberry</td>
<td>continuous slope, some boulder and cobble size particles at the surface</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-3</td>
<td>6</td>
<td>15 north</td>
<td>Medium density Subalpine fir and beargrass.</td>
<td>Ridge line</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-4</td>
<td>0</td>
<td>40 west</td>
<td>burned trees, sparse bear grass</td>
<td>continuous slope, large rocks, exposed soil</td>
<td>sandy-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-5</td>
<td>5</td>
<td>9 west</td>
<td>Subalpine, Douglas Fir, few lodgepole pine, bear grass</td>
<td>continuous slope, some boulder and cobble size particles visible at the surface</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-6</td>
<td>0</td>
<td>2 north</td>
<td>grasses in open meadow</td>
<td>valley bottom near stream</td>
<td>loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-7</td>
<td>8</td>
<td>8 west</td>
<td>large doug and subalpine fir, beargrass</td>
<td>base of slope</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-8</td>
<td>0</td>
<td>12 east</td>
<td>Subalpine, Douglas Fir, few lodgepole pine, bear grass</td>
<td>continuous slope, some boulder and cobble size particles visible at the surface, very wet</td>
<td>loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-9</td>
<td>14</td>
<td>15 east</td>
<td>burned trees, sparse bear grass, bare soil</td>
<td>local depression, boulders nearby</td>
<td>silt-loam</td>
<td></td>
<td>light colored sand and gravel sized particles on surface</td>
</tr>
<tr>
<td>o-10</td>
<td>0</td>
<td>6 east</td>
<td>burned trees, sparse bear grass and bare soil</td>
<td>local depression</td>
<td>sandy-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-11</td>
<td>45</td>
<td>10 north</td>
<td>burned trees and sparse bear grass</td>
<td>valley bottom near creek</td>
<td>silt-loam</td>
<td></td>
<td>very deep ash layer with some light colored particles larger than sand</td>
</tr>
<tr>
<td>o-12</td>
<td>3</td>
<td>5 north</td>
<td>burned trees - little or no vegetation</td>
<td>ridge top</td>
<td>silt-loam</td>
<td></td>
<td>sand particles on the surface from nearby boulders, boundary between sandy sub-soil very distinct</td>
</tr>
<tr>
<td>o-13</td>
<td>0</td>
<td>12 east</td>
<td>burned trees, very sparse bear grass</td>
<td>continuous slope near eroded runoff channel</td>
<td>sandy-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-14</td>
<td>0</td>
<td>11 west</td>
<td>burned trees, med. dens. bear grass</td>
<td>continuous slope</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-15</td>
<td>0</td>
<td>21 east</td>
<td>burned trees, some bear grass and other grasses</td>
<td>continuous slope, on road-cut</td>
<td>loamy sand</td>
<td></td>
<td>huge boulders and smaller particles on the surface</td>
</tr>
<tr>
<td>o-16</td>
<td>6</td>
<td>15 north</td>
<td>very few burned trees, sparse bear grass</td>
<td>localized flat spot near bedrock outcrops</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-17</td>
<td>10</td>
<td>6 north</td>
<td>dense burned trees, sparse bear grass &amp; other pioneering grasses &amp; forbs</td>
<td>localized flat spot near bedrock outcrops</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-18</td>
<td>10</td>
<td>9 east</td>
<td>burned trees, dense bear grass, fools huckleberry</td>
<td>continuous slope with large boulders and cobbles on surface</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-19</td>
<td>12</td>
<td>9 east</td>
<td>moderate dense spruce and fir trees, labrador tea, fools huckleberry, some beargrass, and heath</td>
<td>continuous slope with occasional boulders.</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-20</td>
<td>0</td>
<td>24 south</td>
<td>grasses, fools huckleberry, dense subalpine fir</td>
<td>continuous slope, soil only exists between large boulders</td>
<td>sandy-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-21</td>
<td>14</td>
<td>6 west</td>
<td>dense douglas fir, some spruce, foels huck, grasses</td>
<td>continuous slope above creek in drier upland area</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-22</td>
<td>10</td>
<td>14 east</td>
<td>moderate density subalpine fir, beargrass, whortleberry, some other grasses</td>
<td>loam flat area near steeper slope uphill</td>
<td>silt-loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>o-23</td>
<td>0</td>
<td>21 east</td>
<td>sparse small subalpine fir w/ bear grass and other grasses</td>
<td>continuous slope with many cobble and boulder size particles</td>
<td>sandy loam</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix – B FORTRAN source code for recession segment selection program.

c-----------------------------------------------
c
  variables:
c  q: discharge read from input file (array)
c  nq: next days discharge read from input file (array)
c  logq: log10 transformed value of current days discharge (array)
c  XMIN,YMIN,XMAX,YMAX,XW,YW: variables used in plotting section
c  month, day, year: date fields read from input file (array)
c  cnt: variable to keep track of the recession day number (array)
c  i, j: do loop variables
  count: variable to check minimum recession length
  recsum: variable to keep track of the recession number
  ILEN, JLEN, N, IPOS, JPOS: used in the plotting section
  m(6): stores months selected for analysis (array)
c  nm: user can choose the number of months used in analysis
  mc: month counter
  front: reduces days from the high end of the recession
  back: reduces days from the low end of the recession
  DIAG(20): used in plotting section
  filnam*12: input and output file names
  decide*1: choice of what to do with data from a recession
c
c
Real q(500), nq(500), logq(500)
REAL XMIN,YMIN,XMAX,YMAX,XW,YW
integer month(500), day(500), year(500), cnt(500)
integer i, j, count, recsum, ILEN, JLEN, N, IPOS, JPOS
integer m(6), nm, front, back, mc

CHARACTER*60 DIAG(20)
PARAMETER (ILEN=20,JLEN=60)

Character filnam*12, decide*1
Data in,iout/l,2/

c------------------------ INTRO SCREEN ------------------------
segments from USGS streamflow data files available from their web site. The readme.txt file explains the conditions of use for this program, input and output file format and some of the details about how the program looks at stream discharge data and assumptions about baseflow recession. (Use CTRL+C to exit now)

```
c query for input/output files

Write(*,10)
10 Format(' Enter input file name: ')
Read(*,15) filnam
15 Format(a12)
Open(unit=in,file=filnam,status='old')

Write(*,20)
20 Format(' Enter output file name: ')
Read(*,15) filnam
Open(unit=iout,file=filnam,status='unknown')

c**** change the months used in the analysis here (7 = July, etc.)***

write(6,*),
write(6,*),
write(6,*),
write(6,*), ' Number of months to be used (1-6): '
read(5,*) nm
write(6,*),
write(6,*),
write(6,*),
write(6,*),
write(6,*), ' Choose the calendar year month for this run'
write(6,*),
write(6,*), ' For example:'
write(6,*), ' January = 1, February = 2 etc... '
write(6,*),

do 21 i=1, nm
   mc = mc + 1
   write(*,22) mc, nm
22 format(' Enter month', i2, ' of', i2, ': ') read(5,*) m(i)
21 continue
```

```
c**************************************************************************
recsum = 1
```
c--- choose length of recession period -------------------------------
write(6,*) ' Choose the minimum recession length (days): :
read(5,*) lgth

WRITE(iout,*) 'REC DATE DIS DAY LOG-DIS'

c---- example data--- 1 7-16-1947 75.0 1 1.875

c---- begin do loop to test consecutive days of recession ----------

25 continue

do 50 j = 1, 100000
If (count.ge.lgth) then
  count = count - front - back
  write(*,8) month(1+(front)),day(1+(front)),year(1+(front)),count
8 format ( ' RECESSION BEGIN DATE: ',i2,'-',i2,'-',i4,4x, & i2,' DAYS LENGTH')

C ************** BEGIN GRAPHING DATA HERE ***********************

N = count
xmin = cnt(1+(front))
xmax = cnt((front)+(count))
ymin = logq((front)+(count))
ymax = logq(1+(front))

1 fit write (6,*) 'N and count = ', N, count
1 fit write (6,*) 'xmin = ', xmin
1 fit write (6,*) 'xmax = ', xmax
1 fit write (6,*) 'ymin = ', ymin
1 fit write (6,*) 'ymax = ', ymax

C CALCULATING SCALING CONSTANTS

XW = (XMAX-XMIN)/(JLEN-1)
YW = (YMAX-YMIN)/(ILEN-1)

C INITIALISE THE CHARACTER STRING TO ALL BLANKS

DO 1 I=1,ILEN
   DIAG(I)=' '
1 CONTINUE

DO 2 I=1,N

189
\[ J\text{POS} = \frac{(\text{cnt}(i + \text{front}) - \text{XMIN})}{\text{XW} + 1} \]
\[ I\text{POS} = \frac{(\log_2(i + \text{front}) - \text{YMIN})}{\text{YW} + 1} \]
\[ \text{DIAG}(21 - I\text{POS})(J\text{POS}:J\text{POS}) = 'O' \]

2. \text{CONTINUE}

\text{C NOW WRITE OUT THE COMPLETED DIAGRAM}

\begin{verbatim}
DO 3 I=1,ILEN
    WRITE(UNIT=6,FMT='(1X,'''|'',A)') DIAG(I)
3    CONTINUE

WRITE(UNIT=6,FMT='(1X,60('''''))')

write(6,*) 'Q TIME -->'
\end{verbatim}

\text{C********** END GRAPHING PROGRAM ******************************************}

\text{c-----begin do statement to write array to file--------------------------}

write (6,*) 'Write recession', recsum, ' to file ? (y/n/c/x) '

read (5,*) decide

if (decide.eq.'y') then

DO 70 i = 1, count
    WRITE(iout,60) recsum, month(i+(front)), day(i+(front))
    & year(i+(front)), q(i+(front)), cnt(i),
    & logq(i+(front))
60    Format(i2,4x,i2,'-',i2,'-',i4,2x,f7.1,4x,i3,4x,f6.3)

70    CONTINUE

recsum = recsum + 1
front = 0
back = 0

elseif(decide.eq.'c') then

write(6,*) 'how many days to subtract from the high end ?'
read(5,*) front
write(6,*) 'how many days to subtract from the low end ?'
read(5,*) back

endif

elseif(decide.eq.'x') then

goto 110
endif

\text{c-----reset day counter -----------------------------------------------}

cnt(i) = 1
count = 0

190
do loop to tally days, read in values from file, test whether nq > q, calculate logq

do 30 i = 1, 100000
    count = count + 1
    Read(in, 40, end=110) month(i), day(i), year(i), q(i), nq(i)
    40    Format(i2,1x,i2,1x,i4,6x,f7.0,/,16x,f7.0)
    backspace in

c------filter out unwanted months of data ---------------------

    If(month(i).ne.m(1).and.month(i).ne.m(2)
    & .and.month(i).ne.m(3).and.month(i).ne.m(4)
    & .and.month(i).ne.m(5).and.month(i).ne.m(6))
    & goto 25
    logq(i) = log10 (q(i))
    cnt(i+1) = cnt(i) + 1
    If(nq(i).ge.q(i)) goto 25

30 continue
50 continue

c-----------------------------------------------

110 stop
end
Appendix – C  Plots of individual recession segments for each of the Bitterroot study streams.

BEAR CREEK
BURNT FORK CREEK

Stream Discharge (cfs)

Time from beginning of Recession (days)
FRED BURR CREEK

Time from beginning of recession (days)

Stream Discharge (cfs)
LOLO CREEK

![Graph showing stream discharge over time from the beginning of recession.](image-url)

Stream Discharge (cfs) vs. Time from beginning of recession (days)
Appendix – D FORTRAN source code for recession segment regression program.

c--------------------------------------------------------------------------
c
Program to take output files from the program recess and fit
c a regression model to each individual recession segment.
c
--------------------------------------------------------------------------

integer day(100)
real logdis(100)
integer rec, recfile, n
real a, b, r, mnflow, rsqr
character filnam*12
real s1, s2, s3, s4, s5
Data in,iout/1,2/

rec = 1

query for input/output files

Write(*,10)
10 Format(' Enter input file name: ')
Read(*,15) filnam
15 Format(al2)
Write(*,20)
20 Format(' Enter output file name: ')
Read(*,15) filnam
Open(unit=in,file=filnam,status='old')
Write(*,20)
Write(*,20)

Colum Headings in output file----------------------

WRITE(iout,*) ' Seg Y-Int Constant R**2
$Days Mean Flow'

main do loop for regression calculations-------------
do 100 j = 1, 1000

c
nested do loop for reading data--
do 110 i = 1, 100

read( in, 30, end=130) recfile, day(i), logdis(i)
30 format (i2, 28x, i2, 5x, f7.3)

n = n + 1

check if we're at the end of block i--

if (recfile.ne.rec) then
goto 40

199
endif

110 continue

c---do regression calculations on block i---.

40 continue

n = n - 1

do 120 i = 1, n
   s1 = s1 + day(i) * logdis(i)
   s2 = s2 + day(i)
   s3 = s3 + logdis(i)
   s4 = s4 + day(i)**2
   s5 = s5 + logdis(i)**2
120 continue

b = (s1 - s2 *s3 / n) / (s4 - s2**2 / n)
a = (s3 - b * s2) / n
r = (n * s1 - s2 * s3) / sqrt(n * s4 - s2**2) /
   $ sqrt(n * s5 - s3**2)
mnflow = s3/n
rsqr = r**2

c---write to screen-----

   write (*,50) rec, a, b, rsqr, n, mnflow
50 format ( i4,4x,f7.3,4x,f7.5,4x,f7.3,4x,i2,4x,f5.3)

c---write to file------

   write (iout,60) rec, a, b, rsqr, n, mnflow
60 format ( i4,6x,f7.3,6x,f7.5,6x,f7.3,6x,i2,6x,f5.3)

c---don't forget to make identical changes to calcs for last block-----
---

100 continue

c---re-initialize variables for next block---

rec = rec + 1

n = 0
s1 = 0
s2 = 0
s3 = 0
s4 = 0
s5 = 0

backspace in

100 continue

c---regression calculations for last block---
130 continue

    do 140 i = 1, n
        s1 = s1 + day(i) * logdis(i)
        s2 = s2 + day(i)
        s3 = s3 + logdis(i)
        s4 = s4 + day(i)**2
        s5 = s5 + logdis(i)**2
    140 continue

    b = (s1 - s2 * s3 / n) / (s4 - s2**2 / n)
    a = (s3 - b * s2) / n
    r = (n * s1 - s2 * s3) / sqrt(n * s4 - s2**2) / sqrt(n * s5 - s3**2)
    mnflow = s3/n
    rsqr = r**2

---write last block to screen---

    write (*,70) rec, a, b, rsqr, n, mnflow
    70 format ( i4,4x,f7.3,4x,f7.5,4x,f7.3,4x,i2,4x,f5.3)

---write last block to file---

    write (iout,80) rec, a, b, rsqr, n, mnflow
    80 format ( i4,6x,f7.3,6x,f7.5,6x,f7.3,6x,i2,6x,f5.3)

200 stop
end
Appendix – E Plots of individual recession segment slope against individual recession segment length and mean discharge for all Bitterroot study streams.

Blodgett Creek

![Graph showing recession constant vs. mean discharge and recession length](image)
Burnt Fork Creek

![Graphs showing the relationship between recession constant and mean discharge, as well as recession constant and recession length. The graphs include data points for individual recession and the average recession.](image-url)
Fred Burr Creek

![Graph showing recession constants vs. recession length and mean discharge.](image)

- **Recession Length (days)**
  - Mean Discharge (cfs)

- **Recession Constant**
  - Individual Recession
  - Average Recession

204
Kootenai Creek

![Graph 1: Recession Constant vs. Recession Length (days)]

- Recession Constant
- Individual Recession
- Average Recession

![Graph 2: Recession Constant vs. Mean Discharge (cfs)]

- Recession Constant
- Individual Recession
- Average Recession

205
Lolo Creek

![Graph 1: Recession Length vs. Recession Constant](image1)

![Graph 2: Mean Discharge vs. Recession Constant](image2)
Bear Creek

Diagram 1: Recession Length vs. Recession Constant

Diagram 2: Mean Discharge vs. Recession Constant
Sleeping Child Creek

![Graph showing recession constants and mean discharge for Sleeping Child Creek.]
Skalkaho Creek

![Graph 1: Recession Length vs. Recession Constant](image1)

![Graph 2: Mean Discharge vs. Recession Constant](image2)
Lost Horse Creek

![Graph 1: Mean Discharge vs. Recession Constant](image1)

- Individual Recession
- Average Recession

![Graph 2: Recession Length vs. Recession Constant](image2)

- Individual Recession
- Average Recession
Appendix – F  Stage- discharge rating curves for Lost Horse Creek Stream Gages.
Lost Horse Creek - Falls Gauging Station
Stage/Discharge Rating Curve

Discharge (cfs)

Stage (inches)
Lost Horse Creek - Upper Bridge Gauging Station
Stage/Discharge Rating Curve

Stage (inches)

Discharge (cfs)
Lost Horse Creek - Meadow Gauging Station
Stage/Discharge Rating Curve

Discharge (cfs)

Stage (inches)
Appendix – G Potentiometric maps of the upper meadow area of Lost Horse Creek on July 15, August 11, August 19 and August 29, 1995.
July 15, 1995

Groundwater Surface
1-foot contour interval
Water Measurement Points
Piezometer
Access Road
Streams
August 29, 1995

Groundwater Surface

Water Measurement Points

· Piezometer

Access Road

Streams

1-foot contour interval
Appendix – H  Lost Horse Creek seismic line data.

LOCATION: Near Well 2-A
TIME: milliseconds
DISTANCE: feet

<table>
<thead>
<tr>
<th>distance 1</th>
<th>time 1</th>
<th>distance 2</th>
<th>time 2</th>
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</tr>
<tr>
<td>70</td>
<td>16.8</td>
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<td></td>
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LOCATION: Near Well N-1
TIME: milliseconds
DISTANCE: feet

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<tr>
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<th>time 2</th>
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</tr>
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<td>65</td>
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<td>70</td>
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</table>
**LOCATION:** Near Well 2-E  
**TIME:** milliseconds  
**DISTANCE:** feet  

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**LOCATION:** Near Well N-2  
**TIME:** milliseconds  
**DISTANCE:** feet  

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**LOCATION:** Near Well N-3  
**TIME:** milliseconds  
**DISTANCE:** feet  

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LOCATION: Near Well 2-C  
TIME: milliseconds  
DISTANCE: feet

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Appendix – 1  Groundwater well and tensiometers hydrographs from the upper meadow area of Lost Horse Creek.
Upper Meadow Well Levels and Stream Stage - 1995
Transect #2

Well 2-a
Well 2-f
Precipitation

Well 2-b
Well 2-c
Well 2-e
Staff gauge #1
Precipitation

Julian Day
Elevation (inches)
Precipitation (inches)
Upper Meadow Well Levels and Stream Stage - 1995
Transect #3

Julian Day
190 200 210 220 230 240 250 260 270

Elevation (inches)
4850 4860 4870 4880 4890 4900 4910

Precipitation (inches)
0 1 2 3

Well 3-a
Well 3-b
Well 3-c
Well 3-d
Precipitation

Julian Day
190 200 210 220 230 240 250 260 270

Elevation (inches)
4820 4825 4830 4835 4840 4845

Precipitation (inches)
0 1 2 3

Staff gauge #1
Well 3-c
Well 3-d
Precipitation
Upper Meadow Well Levels and Stream Stage - 1995
Transect #4

Julian Day

Elevation (inches)

Precipitation (inches)

Well 4-a
Well 4-e
Precipitation

Staff gauge #2
Well 4-b
Well 4-c
Well 4-d
Precipitation

Elevation (inches)

Precipitation (inches)

Julian Day
Upper Meadow Well Levels and Stream Stage - 1995
Transect #5

Julian Day

Elevation (inches)

Precipitation (inches)

well 5-a
well 5-b
well 5-e

precipitation

well 5-c
well 5-d
well 5-f
staff gauge #3
precipitation
Upper Meadow Well Levels and Stream Stage - 1996
Transect #1

Elevation (inches)

200 210 220 230 240 250
Julian Day

Precipitation (inches)

200 210 220 230 240 250
Julian Day

well 1-b
well 1-e
well 1.5-b

precipitation

228
Upper Meadow Well Levels and Stream Stage - 1996
Transect #2

[Graph showing well levels and stream stage over Julian Day, with data points for different wells and precipitation levels.]
Upper Meadow Well Levels and Stream Stage - 1996
Transect #5

![Graph showing well levels and stream stage over Julian Day]
Appendix – J Fortran source code for disaggregating minimum / maximum temperature into hourly temperature.

This program takes values of minimum and maximum daily temperature and returns hourly temperature. Input file format is fixed as follows:

```
123456789*123456789*123456789*123456789*123456789*123456789*
yyyy mm dd  tmin  tmax
1994 01 01  18.0  31.6
1994 01 02  24.8  29.5
1994 01 03  23.5  31.5
```

---declare variables-----------------------------------------------

```
Real  hrtemp, amp1, amp2, avg1, avg2, tmin1, tmax1, tmin2
integer year1, month1, day1
integer year2, month2, day2
integer i, j, k, l, hour
Character filnam*12
```

query for input/output files

```
write(*,10)
10 Format(' Enter input file name: ')
```

This program disaggregates daily minimum and maximum temperature into hourly values. The input file is fixed format as follows:

```
123456789*123456789*123456789*123456789*123456789*
yyyy mm dd  tmin  tmax
1994 01 01  18.0  31.6
1994 01 02  24.8  29.5
1994 01 03  23.5  31.5
```

24 hourly values are output to a file for each day, one hourly value per line.

(CTRL-C to exit now)
Read(*,15) filnam
15 Format(a12)
   Open(unit=in,file=filnam,status='old')

Write(*,20)
20 Format(' Enter output file name: ')
   Read(*,15) filnam
   Open(unit=iout,file=filnam,status='unknown')

c--------this section does first 3 hours of first day--------
   Read(in, 30, end=35) year1, month1, day1, tmin1, tmax1
30 Format(i4,1x,i2,1x,i2,2x,f6.1,2x,f6.1)
   avg1 = (tmax1 + tmin1) / 2
   ampl = avg1 - tmin1
   hour = 1
   DO 25 j = 1, 3
      hrtemp = ampl*cos((3.1416/12)*(hour-16)) + avg1
      WRITE(iout,40) year1, month1, day1, hour, hrtemp
40 Format(i4,' . ',i2,' . ',i2,' . ',i2,6x,f5.1)
      hour = hour + 1
   25 CONTINUE
35 CONTINUE

rewind in

c--------read in values from file and do calculations--------

   DO 45 i = 1, 10000
      Read(in, 50, end=100) year1, month1, day1, tmin1, tmax1,
      $ year2, month2, day2, tmin2
50 Format(i4,1x,i2,1x,i2,2x,f6.1,2x,f6.1,/,i4,1x,i2,1x,i2,2x,f6.1)
      avg1 = (tmax1 + tmin1) / 2
      ampl = avg1 - tmin1
      avg2 = (tmax1 + tmin2) / 2
      amp2 = avg2 - tmin2
      hour = 4
   c--------calculate hours 4 to 16 of current day-------------
   DO 55 j = 1, 13
hrtemp = amp1*cos((3.1416/12)*(hour-16)) + avg1
WRITE(iout,60) year1, month1, day1, hour, hrtemp
60 Format(i4,'.',i2,'.',i2,'.',i2,'.',i2,6x,f5.1)

hour = hour + 1
55 CONTINUE

c-------calculate hours 17 to 24 of current day-------------------

hour = 17
DO 65 k = 1, 8
hrtemp = amp2*cos((3.1416/12)*(hour-16)) + avg2
WRITE(iout,70) year1, month1, day1, hour, hrtemp
70 Format(i4,'.',i2,'.',i2,'.',i2,'.',i2,6x,f5.1)

hour = hour + 1
65 CONTINUE

c-------calculate hours 1 to 3 of next day----------------------

hour = 1
DO 75 l = 1, 3
hrtemp = amp2*cos((3.1416/12)*(hour-16)) + avg2
WRITE(iout,80) year2, month2, day2, hour, hrtemp
80 Format(i4,'.',i2,'.',i2,'.',i2,'.',i2,6x,f5.1)

hour = hour + 1
75 CONTINUE

write(6,*) year1
backspace in
45 CONTINUE
100 CONTINUE

c-------calculate last 21 hours on the final day---------------

DO 85 j = 1, 21
hrtemp = amp1*cos((3.1416/12)*(hour-16)) + avg1
WRITE(iout,90) year1, month1, day1, hour, hrtemp
90 Format(i4,'.',i2,'.',i2,'.',i2,'.',i2,6x,f5.1)
hour = hour + 1

85 CONTINUE

110 stop
   end
Appendix – K  User control input (UCI) file for final HSPF model run.

RUN

GLOBAL
2/8/1999 Lost Horse Creek:PERLND w/ SNOW, PWATER, COPY, DISPLY
START  1994 10 1 0 0 END  1996 9 30 24 0
RUN INTERP OUTPUT LEVEL 4
RESUME 0 RUN  1

END GLOBAL

FILES
<FILE> <UN#> *** <---- FILE NAME ------------------------------->
WDM 21 LOST3.WDM
MESSU 22 output\RUN.ECH
62 output\SIMFLOW.DIS
70 output\SIMSSEQ.DIS
92 SIMOUT.PLT
INFO 23 c:\models\hspfl0\HSPINF.DA
ERROR 24 c:\models\hspfl0\HSPERR.DA
WARN 25 c:\models\hspfl0\HSPWRN.DA

END FILES

OPN SEQUENCE

INGRP INDELT 01:00
PERLND 101
PERLND 102
PERLND 201
PERLND 202
PERLND 203
PERLND 301
PERLND 302
PERLND 303
PERLND 304
PERLND 401
COPY 1
COPY 2
COPY 3
COPY 4
COPY 5
COPY 6
COPY 7
COPY 8
COPY 9
DISPLY 1
DISPLY 2
PLTGEN 1

END INGRP

END OPN SEQUENCE

PERLND

ACTIVITY
<PLS > Active Sections (1=Active; 0=Inactive) ***
# - # ATMP SNOW PWAT SED PST PWG PQAL MSTL PEST NITR PHOS TRAC ***
101 401 1 1 1

END ACTIVITY

PRINT-INFO
<PLS > Print-flags *** PIVL PYR
# - # ATMP SNOW PWAT SED PST PWG PQAL MSTL PEST NITR PHOS TRAC ***
101 401 6 4 4

END PRINT-INFO
GEN-INFO

<PLS ><-------Name------->NBLKS Unit-systems Printer ***
# - #  User  t-series Engl Metr ***
in out ***

*** Elev: 100=low, 200=mid, 300=high. 400=water/mid elev.***
101 ComStp,dense,unburn 1 1 1 1 1. 0
102 steep, sparse 1 1 1 1 1 0
201 ComStp,dense,unburn 1 1 1 1 1 0
202 steep,modveg,unburn 1 1 1 1 1 0
203 ComStp,sparse veg. 1 1 1 1 1 0
301 steep,dense,unburn 1 1 1 1 1 0
302 steep,modveg,unburn 1 1 1 1 1 0
303 steep-vsteep,sparse 1 1 1 1 1 0
304 steep-vsteep,scree 1 1 1 1 1 0
401 Water (lakes) 1 1 1 1 1 0
END GEN-INFO

*** SECTION ATEMP ***

ATEMP-DAT

<PLS > El-diff Airtmp ***
# - # (ft) (DegF) ***
101 -287. 35.
102 -138. 35.
201 233. 35.
202 321. 35.
203 267. 35.
301 751. 35.
302 911. 35.
303 812. 35.
304 1006. 35.
401 163. 35.
END ATEMP-DAT

*** Section SNOW ***

ICE-FLAG

<PLS > 0= Ice formation not simulated; 1= Simulated ***
# - #ICEFG ***
101 401 0
END ICE-FLAG

SNOW-PARM1

<PLS > Snow input info: Part 1 ***
# - # LAT MELV MELEV SHADE SNOWCF COVIND ***
101 46. 6114. .90 1.02 0.5
102 46. 6263. .55 1.02 0.5
201 46. 6634. .85 1.07 0.5
202 46. 6722. .80 1.07 0.5
203 46. 6668. .60 1.07 0.5
301 46. 7152. .85 1.12 0.5
302 46. 7312. .80 1.12 0.5
303 46. 7213. .50 1.12 0.5
304 46. 7407. .40 1.12 0.5
401 46. 6564. .30 1.00 0.5
END SNOW-PARM1

SNOW-PARM2

<PLS > Snow input info: Part 2 ***
# - # RDCSN TSNOW SNOEVP CCFACT M WATER MGMELT ***
101 102 0.15 32.0 0.10 0.45 0.30 0.005
201 203 0.15 32.0 0.10 0.45 0.30 0.005
301 304 0.15 32.0 0.10 0.45 0.30 0.005
401 0.15 32.0 0.10 0.45 0.30 0.005
END SNOW-PARM2

238
SNOW-INIT1

<PLS> Initial snow conditions: Part 1

<# - # PACKSNOW PACKICE PACKWATER RDENPF DULL PAXTMP #>

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END SNOW-INIT1

SNOW-INIT2

<PLS> Initial snow conditions: Part 2

<# - # COVINX XINMLT SKYCLR #>

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END SNOW-INIT2

*** Section PWATER ***

PWAT-PARM1

<PLS> PWATER variable monthly parameter value flags

<# - # CSNO RTOP UZFG VCS UZ VNN VIFW VIRC VLE #>

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END PWAT-PARM1

PWAT-PARM2

<PLS> PWATER input info: Part 2

<# - # ***FOREST LZSN INFILT LSUR SLSUR KVARY AGWRC #>

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<td>0.060</td>
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<td>0.070</td>
<td>250.0</td>
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<td>0.060</td>
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END PWAT-PARM2

PWAT-PARM3

<PLS> PWATER input info: Part 3

<# - # ***PETMAX PETMIN INEXP INFILD DEEPFR BASETP AGMETP #>

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END PWAT-PARM3
PWAT-PARM4

<PLS> PWATER.input info: Part 4 ***
# - # CEPSC UZSN NSUR INTFW IRC LZETP ***
101 0.200 2.200 0.35 2.300 0.600 0.900
102 0.130 1.000 0.35 1.500 0.600 0.600
201 0.200 2.000 0.35 2.000 0.600 0.800
202 0.180 1.000 0.35 1.500 0.600 0.500
203 0.130 1.200 0.35 1.000 0.600 0.300
301 0.200 1.600 0.35 1.700 0.600 0.800
302 0.180 1.100 0.35 1.500 0.600 0.500
303 0.120 0.700 0.35 1.000 0.600 0.200
304 0.120 0.500 0.35 1.000 0.600 0.000
401 0.100 1.000 0.001 1.000 0.010 0.000
END PWAT-PARM4

PWAT-STATE1

<PLS> *** Initial conditions at start of simulation
# - # *** CEPS SURS UZS IFWS LZS AGWS GWVS
101 0.10 0.0 0.25 0.0 13.0 0.80 0.05
102 0.10 0.0 0.25 0.0 13.0 0.80 0.05
201 0.10 0.0 0.20 0.0 15.0 0.80 0.05
202 0.10 0.0 0.20 0.0 14.0 0.80 0.05
203 0.10 0.0 0.20 0.0 13.0 0.80 0.05
301 0.10 0.0 0.20 0.0 11.0 0.80 0.05
302 0.10 0.0 0.20 0.0 13.0 0.80 0.05
303 0.10 0.0 0.20 0.0 12.0 0.80 0.05
304 0.10 0.0 0.20 0.0 13.0 0.80 0.05
401 0.00 0.0 0.05 0.0 11.5 0.00 0.05
END PWAT-STATE1
END PERLAND

DISPLY

DISPLY-INFO1

*** # - #<--------Title----------->***TRAN PIVL DIG1 FIL1 PYR DIG2 FIL2 YRND
1 SIMULATED FLOW (CFS) AVER 1 2 62 9
2 SIMULATED SWE (IN) AVER 1 2 70 9
END DISPLY-INFO1
END DISPLY

COPY

TIMESERIES

# - # NPT NMN ***
1 9 1 9
END TIMESERIES
END COPY

PLOTGEN

PLOTINFO

# - # FILE NPT NMN LABEL PYR PIVL ***
1 4 92 4 1 24
END PLOTINFO

GEN-LABELS

# - #<-----------------Title-------------------> ***<------Y axis------>
1 Observed Discharge Discharge (cfs)
2 Simulated Discharge Discharge (cfs)
3 Observed SWEQ SWEQ (in)
4 Simulated SWEQ SWEQ (in)
END GEN-LABELS

SCALING

# - # YMIN YMAX IVLIN ***
1 4 0.0 10000.0 20.
END SCALING
CURV-DATA (first curve)
   <-Curve label--> Line Intg Col Tran ***
   # - # type eqv code code ***
   1 obsflow 4 1 SUM
END CURV-DATA

CURV-DATA (second curve)
   <-Curve label--> Line Intg Col Tran ***
   # - # type eqv code code ***
   1 simflow 4 1 AVER
END CURV-DATA

CURV-DATA (third curve)
   <-Curve label--> Line Intg Col Tran ***
   # - # type eqv code code ***
   1 obsnow 4 1 SUM
END CURV-DATA

CURV-DATA (fourth curve)
   <-Curve label--> Line Intg Col Tran ***
   # - # type eqv code code ***
   1 simsnow 4 1 AVER
END CURV-DATA

END PLTGEN

END PLTGEN

EXT SOURCES
   <-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member> ***
   <Name> # <Name> # tem strg<-factor->strg <Name> # <Name> # # ***
   WDM 40 PREC ENGLZERO 0.83 PERLND 101 102 EXTNL PREC
   WDM 40 PREC ENGLZERO 0.98 PERLND 201 203 EXTNL PREC
   WDM 40 PREC ENGLZERO 1.08 PERLND 301 304 EXTNL PREC
   WDM 40 PREC ENGLZERO 1.03 PERLND 401 EXTNL PREC
   WDM 52 TEMP ENGLZERO 1.00 PERLND 101 401 EXTNL GTMP
   WDM 50 DSWP ENGL SAME PERLND 101 401 EXTNL DTMPG
   WDM 20 EVAP ENGL .70 PERLND 101 401 EXTNL PETINP
   WDM 30 WIND ENGL 0.9 PERLND 101 401 EXTNL WINMOV
   WDM 61 SOL2 ENGL 1.1 PERLND 101 401 EXTNL SOLRAD
   WDM 80 OBSF ENGL PLTGEN 1 INPUT MEAN 1
   WDM 90 SWWQ ENGL PLTGEN 1 INPUT MEAN 3
END EXT SOURCES

NETWORK
   <-Volume> <-Grp> <-Member> <-Grp> <-Member> ***
   <Name> # # <Name> # <-factor->strg <Name> # # <Name> # # ***
   *** Multiply area in acres by 1.0083 to convert from in/hr*acre to cfs
   ***input to WDM file to get flow in cfs
   PERLND 101 PWATER PERO 689.4 COPY 1 INPUT MEAN 1
   PERLND 102 PWATER PERO 191.5 COPY 1 INPUT MEAN 1
   PERLND 201 PWATER PERO 497.9 COPY 1 INPUT MEAN 1
   PERLND 202 PWATER PERO 229.8 COPY 1 INPUT MEAN 1
   PERLND 203 PWATER PERO 651.1 COPY 1 INPUT MEAN 1
   PERLND 301 PWATER PERO 153.2 COPY 1 INPUT MEAN 1
   PERLND 302 PWATER PERO 497.9 COPY 1 INPUT MEAN 1
   PERLND 303 PWATER PERO 651.1 COPY 1 INPUT MEAN 1
   PERLND 304 PWATER PERO 191.5 COPY 1 INPUT MEAN 1
   PERLND 401 PWATER PERO 76.6 COPY 1 INPUT MEAN 1
   ***total runoff in inches
   PERLND 101 PWATER PERS 0.180 COPY 2 INPUT MEAN 1
   PERLND 102 PWATER PERS 0.050 COPY 2 INPUT MEAN 1
   PERLND 201 PWATER PERS 0.130 COPY 2 INPUT MEAN 1
   PERLND 202 PWATER PERS 0.060 COPY 2 INPUT MEAN 1
   PERLND 203 PWATER PERS 0.170 COPY 2 INPUT MEAN 1
   PERLND 301 PWATER PERS 0.040 COPY 2 INPUT MEAN 1

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PERLND 302 PWWATER PERS 0.130 COPY 2 INPUT MEAN 1
PERLND 303 PWWATER PERS 0.170 COPY 2 INPUT MEAN 1
PERLND 304 PWWATER PERS 0.050 COPY 2 INPUT MEAN 1
PERLND 401 PWWATER PERS 0.020 COPY 2 INPUT MEAN 1
***surface runoff inches
PERLND 101 SNOW SNOWE 0.180 COPY 3 INPUT MEAN 1
PERLND 102 SNOW SNOWE 0.050 COPY 3 INPUT MEAN 1
PERLND 201 SNOW SNOWE 0.130 COPY 3 INPUT MEAN 1
PERLND 202 SNOW SNOWE 0.060 COPY 3 INPUT MEAN 1
PERLND 203 SNOW SNOWE 0.170 COPY 3 INPUT MEAN 1
PERLND 301 SNOW SNOWE 0.040 COPY 3 INPUT MEAN 1
PERLND 302 SNOW SNOWE 0.130 COPY 3 INPUT MEAN 1
PERLND 303 SNOW SNOWE 0.170 COPY 3 INPUT MEAN 1
PERLND 304 SNOW SNOWE 0.050 COPY 3 INPUT MEAN 1
PERLND 401 SNOW SNOWE 0.020 COPY 3 INPUT MEAN 1
***interflow inches
PERLND 101 SNOW WYIELD 0.180 COPY 4 INPUT MEAN 1
PERLND 102 SNOW WYIELD 0.050 COPY 4 INPUT MEAN 1
PERLND 201 SNOW WYIELD 0.130 COPY 4 INPUT MEAN 1
PERLND 202 SNOW WYIELD 0.060 COPY 4 INPUT MEAN 1
PERLND 203 SNOW WYIELD 0.170 COPY 4 INPUT MEAN 1
PERLND 301 SNOW WYIELD 0.040 COPY 4 INPUT MEAN 1
PERLND 302 SNOW WYIELD 0.130 COPY 4 INPUT MEAN 1
PERLND 303 SNOW WYIELD 0.170 COPY 4 INPUT MEAN 1
PERLND 304 SNOW WYIELD 0.050 COPY 4 INPUT MEAN 1
PERLND 401 SNOW WYIELD 0.020 COPY 4 INPUT MEAN 1
***baseflow inches
PERLND 101 SNOW PACKF 0.180 COPY 5 INPUT MEAN 1
PERLND 102 SNOW PACKF 0.050 COPY 5 INPUT MEAN 1
PERLND 201 SNOW PACKF 0.130 COPY 5 INPUT MEAN 1
PERLND 202 SNOW PACKF 0.060 COPY 5 INPUT MEAN 1
PERLND 203 SNOW PACKF 0.170 COPY 5 INPUT MEAN 1
PERLND 301 SNOW PACKF 0.040 COPY 5 INPUT MEAN 1
PERLND 302 SNOW PACKF 0.130 COPY 5 INPUT MEAN 1
PERLND 303 SNOW PACKF 0.170 COPY 5 INPUT MEAN 1
PERLND 304 SNOW PACKF 0.050 COPY 5 INPUT MEAN 1
PERLND 401 SNOW PACKF 0.020 COPY 5 INPUT MEAN 1
***potential ET inches
PERLND 101 PWWATER PET 0.180 COPY 6 INPUT MEAN 1
PERLND 102 PWWATER PET 0.050 COPY 6 INPUT MEAN 1
PERLND 201 PWWATER PET 0.130 COPY 6 INPUT MEAN 1
PERLND 202 PWWATER PET 0.060 COPY 6 INPUT MEAN 1
PERLND 203 PWWATER PET 0.170 COPY 6 INPUT MEAN 1
PERLND 301 PWWATER PET 0.040 COPY 6 INPUT MEAN 1
PERLND 302 PWWATER PET 0.130 COPY 6 INPUT MEAN 1
PERLND 303 PWWATER PET 0.170 COPY 6 INPUT MEAN 1
PERLND 304 PWWATER PET 0.050 COPY 6 INPUT MEAN 1
PERLND 401 PWWATER PET 0.020 COPY 6 INPUT MEAN 1
***actual ET inches
PERLND 101 PWWATER TABT 0.180 COPY 7 INPUT MEAN 1
PERLND 102 PWWATER TABT 0.050 COPY 7 INPUT MEAN 1
PERLND 201 PWWATER TABT 0.130 COPY 7 INPUT MEAN 1
PERLND 202 PWWATER TABT 0.060 COPY 7 INPUT MEAN 1
PERLND 203 PWWATER TABT 0.170 COPY 7 INPUT MEAN 1
PERLND 301 PWWATER TABT 0.040 COPY 7 INPUT MEAN 1
PERLND 302 PWWATER TABT 0.130 COPY 7 INPUT MEAN 1
PERLND 303 PWWATER TABT 0.170 COPY 7 INPUT MEAN 1
PERLND 304 PWWATER TABT 0.050 COPY 7 INPUT MEAN 1
PERLND 401 PWWATER TABT 0.020 COPY 7 INPUT MEAN 1
***upper zone storage inches
PERLND 101 PWWATER IGWI 0.180 COPY 8 INPUT MEAN 1
PERLND 102 PWWATER IGWI 0.050 COPY 8 INPUT MEAN 1
PERLND 201 PWWATER IGWI 0.130 COPY 8 INPUT MEAN 1
PERLND 202 PWWATER IGWI 0.060 COPY 8 INPUT MEAN 1
PERLND 203 PWWATER IGWI 0.170 PWWATER IGWI 8 INPUT MEAN 1
PERLND 301 PWWATER IGWI 0.040 COPY 8 INPUT MEAN 1
PERLND 302 PWWATER IGWI 0.130 COPY 8 INPUT MEAN 1
PERLND 303 PWWATER IGWI 0.170 COPY 8 INPUT MEAN 1
PERLND 304 PWWATER IGWI 0.050 COPY 8 INPUT MEAN 1
PERLND 401 PWWATER IGWI 0.020 COPY 8 INPUT MEAN 1

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***snowfall, water equivalent
PERLND 101 SNOW SNOWF 0.180 COPY 9 INPUT MEAN 1
PERLND 102 SNOW SNOWF 0.050 COPY 9 INPUT MEAN 1
PERLND 201 SNOW SNOWF 0.130 COPY 9 INPUT MEAN 1
PERLND 202 SNOW SNOWF 0.060 COPY 9 INPUT MEAN 1
PERLND 301 SNOW SNOWF 0.040 COPY 9 INPUT MEAN 1
PERLND 302 SNOW SNOWF 0.130 COPY 9 INPUT MEAN 1
PERLND 303 SNOW SNOWF 0.170 COPY 9 INPUT MEAN 1
PERLND 304 SNOW SNOWF 0.050 COPY 9 INPUT MEAN 1
PERLND 401 SNOW SNOWF 0.020 COPY 9 INPUT MEAN 1
COPY 1 OUTPUT MEAN 1 1. DISPLY 1 INPUT TIMSER
PERLND 201 SNOW PACK 1. DISPLY 2 INPUT TIMSER
COPY 1 OUTPUT MEAN 1 1. PLTGEN 1 INPUT MEAN 2
PERLND 201 SNOW PACK 1. PLTGEN 1 INPUT MEAN 4
END NETWORK
EXT TARGETS
<<-Volume-> <<-Grp <<-Member-><<-Mult--->Tran <<-Volume-> <Member> Tsys Tgap Amd ***
<Name> # <Name> # <-factor->strg <Name> # <Name> # tem strg strg***
COPY 1 OUTPUT MEAN 1 AVER WDM 81 SIMF ENGL AGGR REPL
COPY 2 OUTPUT MEAN 1 WDM 109 PERS ENGL AGGR REPL
COPY 3 OUTPUT MEAN 1 WDM 93 SUBL ENGL AGGR REPL
COPY 4 OUTPUT MEAN 1 WDM 94 WYLD ENGL AGGR REPL
COPY 5 OUTPUT MEAN 1 WDM 95 PACK ENGL AGGR REPL
COPY 6 OUTPUT MEAN 1 SUM WDM 101 PTX ENGL AGGR REPL
COPY 7 OUTPUT MEAN 1 SUM WDM 102 SBT ENGL AGGR REPL
COPY 8 OUTPUT MEAN 1 WDM 110 IGWI ENGL AGGR REPL
COPY 9 OUTPUT MEAN 1 WDM 92 snf ENGL AGGR REPL
PERLND 201 SNOW PACK AVER WDM 91 SIMS ENGL AGGR REPL
END EXT TARGETS

END RUN