Design Document: DRAFT Precipitation and snowmelt timing for areal recharge

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Design document description and purpose

The U.S. Geological Survey (USGS), in collaboration with the Idaho Department of Water Resources (IDWR) is constructing a numerical groundwater-flow model of the Wood River Valley aquifer system in order to simulate potential anthropogenic and climatic effects on groundwater and surface-water resources. This model will serve as a tool for water-rights administration and water-resource management and planning. The study will be conducted over a 3-year period from late 2012 until model and report completion in 2015. One of the goals of the modeling study is to develop the model in an open and transparent manner. To this end, a Modeling Technical Advisory Committee (MTAC) was formed to provide for transparency in model development and to serve as a vehicle for stakeholder input. Technical representation was solicited by the IDWR and includes such interested parties as water-user groups and current USGS cooperating organizations in the Wood River Valley.

The design, construction, and calibration of a groundwater-flow model requires a number of decisions such as the number of layers, model cell size, or methodologies used to represent processes such as evapotranspiration or pumpage. While these decisions will be documented in a final USGS report, intermediate decision documents will be prepared in order to facilitate technical discussion and ease preparation of the report. These decision documents should be considered preliminary status reports and not final products.

Problem statement

Precipitation is one component of recharge to the Wood River Valley aquifer system. Although recharge due to precipitation represents less than 10% of the water budget (Bartolino, 2009), it is associated with a high level of uncertainty. Precipitation data are used as the basis for estimating areal recharge across the model domain during the non-irrigation season as well as areal recharge on non-irrigated land during the irrigation season. The estimation of recharge is covered in Design Documents

(*Winter-Time Recharge and Recharge on Non-Irrigated Lands, Calculating Incidental Recharge on Irrigated Lands*).

Although weather stations report measured precipitation for all months, the precipitation reported during winter months may not be immediately available to the aquifer system. Freezing temperatures during the winter months prevent much of the precipitation from running into streams or infiltrating into the subsurface, and a method of delaying winter precipitation is needed to simulate melt-induced areal recharge and runoff.

Precipitation data are needed for the calibration period of 1995-2010 for the entire model domain. Four sources of data were considered for use in the model; however, each of these sources has limitations in spatial and temporal coverage.

The first of these four data sources is AgriMet data. AgriMet is a satellite-telemetry network of automated agricultural weather stations, operated and maintained by the U.S. Bureau of Reclamation, that collect weather data for use in crop water-use modeling, and other weather-related research and monitoring (USBR, 2013). There is one AgriMet station within the study area located near Picabo on the Silver Creek Nature Conservancy property. The Picabo AgriMet station has precipitation data for the entire calibration period.

The National Oceanic and Atmospheric Administration (NOAA) provides another source for precipitation datasets (NOAA, 2013). NOAA precipitation data are available from local National Weather Service Cooperative Observer weather stations (NWS) for the entire calibration period at the Ketchum Ranger Station (Ketchum NWS) and Picabo (Picabo NWS), and for the period 2005-2010 at the Hailey Ranger Station (Hailey NWS). Both the AgriMet and NWS data sets are collected at discrete points and the data must be spatially interpolated across the model domain.

The National Resources Conservation Service (NRCS) provides a source for snowpack datasets through the SNOTEL system of automated snow telemetry sites (NRCS, 2013). SNOTEL sites are located at higher elevations outside of the model area, and as such, are not suitable for data concerning precipitation directly on the model domain. However, the data available from these sites can be useful for estimating the timing of snowmelt and runoff.

The fourth considered source of data is Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation data. PRISM uses data collected at discrete points, a land-surface digital elevation model, and other spatial data sets (coastal proximity, slope aspect and orientation, vertical atmospheric later, topographic position, and orographic effectiveness of the terrain) to generate spatially distributed estimates of several spatial and temporal climatic parameters, including precipitation. These data are available for the entire calibration period; however, the gridded estimates are too course and must be refined to fit into the model domain.

Options considered

The options considered for estimating precipitation are:

1) Calculate the average monthly precipitation from the Picabo AgriMet and Picabo NWS stations and apply to the entire model domain as was done by Bartolino (2009).
2) Refine the PRISM estimates to a finer resolution.
3) Apply precipitation from the Ketchum Ranger Station (104845) NWS, Hailey 3NNW (103942) NWS, and Picabo (PICI) AgriMet weather stations to zones within which the weather stations are located.

Applying averaged Picabo precipitation to entire model domain

Bartolino (2009) developed the water budgets for the study area in part by using calculated areal recharge values from the ET Idaho website (ET Idaho, 2013). ET Idaho only has data available for the study area at the Picabo NWS and Picabo AgriMet weather stations; therefore, data from the Picabo sites were averaged and applied to the entire study area for the Bartolino (2009) water budgets. However, the water budget is calculated differently for the model, and ET Idaho recharge calculations are not employed. This allows for the use of precipitation data from more sources.

Effect

Although applying Picabo area precipitation to the entire model domain will provide consistency with earlier water-budget work, it will likely result in too little precipitation north of Bellevue. Precipitation generally increases with elevation, and elevation increases to the north in the model domain.

PRISM precipitation

Although PRISM datasets provide contiguous precipitation data across an area and continuous precipitation data for the entire calibration period, the resolution of the data is 4 km (PRISM, 2013).

Several areas in the model are less than 500 m wide, and the coarse grid of the PRISM data results in the assignment of precipitation data that was derived for the higher elevations surrounding the model domain to the valley bottom (Figure 1). Efforts to refine the grid resulted in smaller grid cells that still assign high-elevation precipitation to the lower elevations within the model domain.

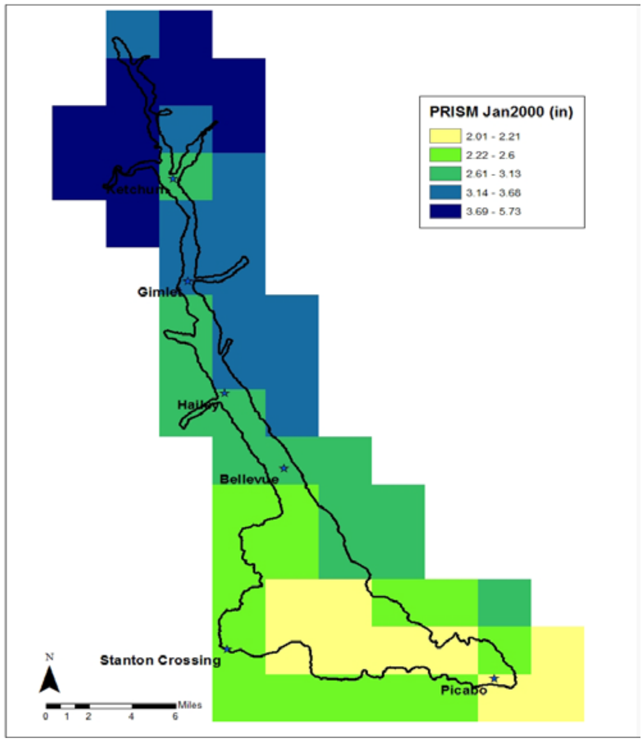

Figure 1. January 2000 PRISM precipitation and preliminary study area boundary.

Effect

Using PRISM data results in the assignment of higher-elevation precipitation values from outside the model domain to valley locations within the model. This effectively places too much precipitation in certain areas of the valley. The use of PRISM also changes the elevation-precipitation relationship within the model domain by creating an alternating high-low pattern of precipitation.

Precipitation data applied to weather-station zones

Precipitation data are available for the entire calibration period at the Ketchum NWS, Picabo NWS and Picabo AgriMet stations, and, for the period August 2005-2010, at the Hailey NWS station. The decision was made to use only the Picabo AgriMet station because both the Picabo AgriMet and Picabo NWS stations record similar precipitation amounts (6% difference), and weather data from the AgriMet station is used in calculating evapotranspiration (McVay, 2014a; McVay, 2014b).

Issues

The Hailey NWS station only has data from August 2005 – April 2013. However, analysis indicates a strong correlation ($R^2 = 0.87$) between precipitation at the Hailey NWS station and the Picabo AgriMet station during the period for which the Hailey NWS has data. Missing Hailey data have been generated by correlation with the Picabo AgriMet station.

Process

The correlated portion of the Hailey data set has been generated using a linear regression between monthly precipitation at the Hailey NWS station and monthly precipitation at the Picabo AgriMet station for the period August 2005 – April 2013, during which both stations have precipitation data (Figure 2).

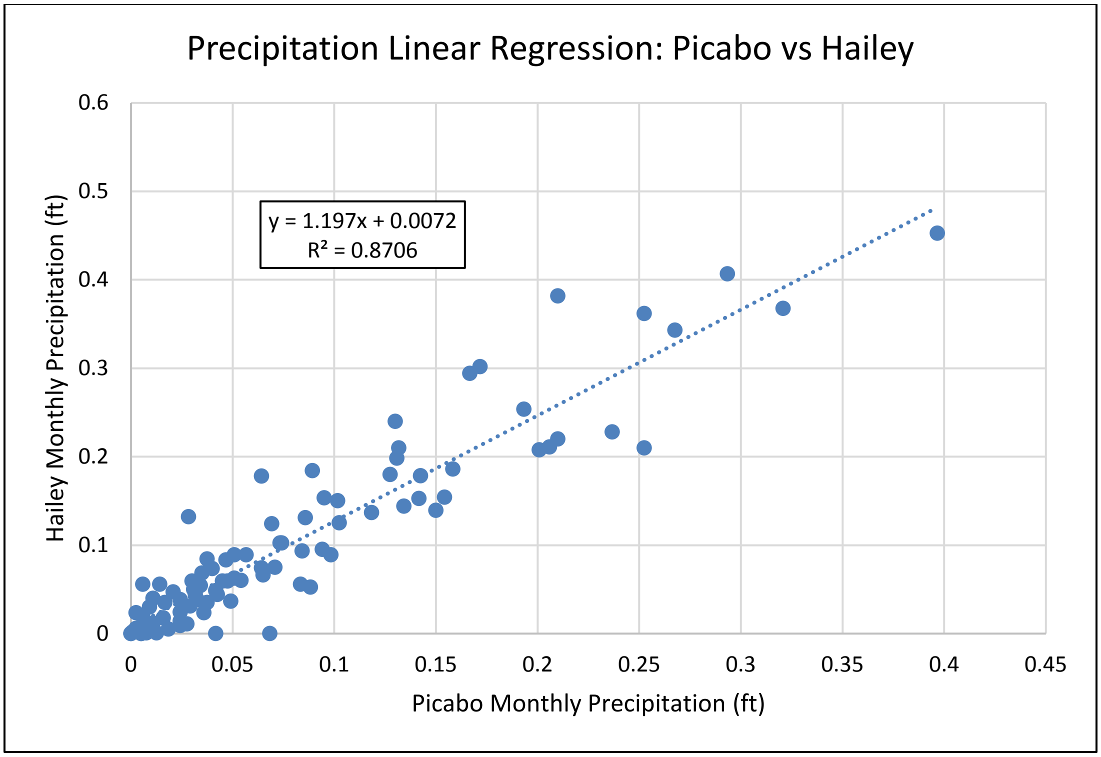

Figure 2. Linear regression relating precipitation at Picabo and Ketchum to precipitation at Hailey for the years 2005-2010.

The equation to calculate precipitation for missing months at the Hailey NWS weather station is:

$$HaileyPrecip_{month} = (PicaPrecip_{month}\ x\ 1.197) + 0.0072 \qquad \text{Equation 1}$$

Where:

$HaileyPrecip_{month}$ = Monthly precipitation at the Hailey NWS weather station [L]

$PicaPrecip_{month}$ = Monthly precipitation at the Picabo AgriMet weather station [L]

Effect

The use of correlated data at the Hailey station for the period 1995-2005 results in data that both preserve the elevation-precipitation relationship and have a similar temporal shape as the data from the Ketchum and Picabo stations. Figures 3 and 4 illustrate how the Hailey data generally fit between the Ketchum and Picabo data, and how the Hailey data track the same general weather patterns as at Ketchum and Picabo.

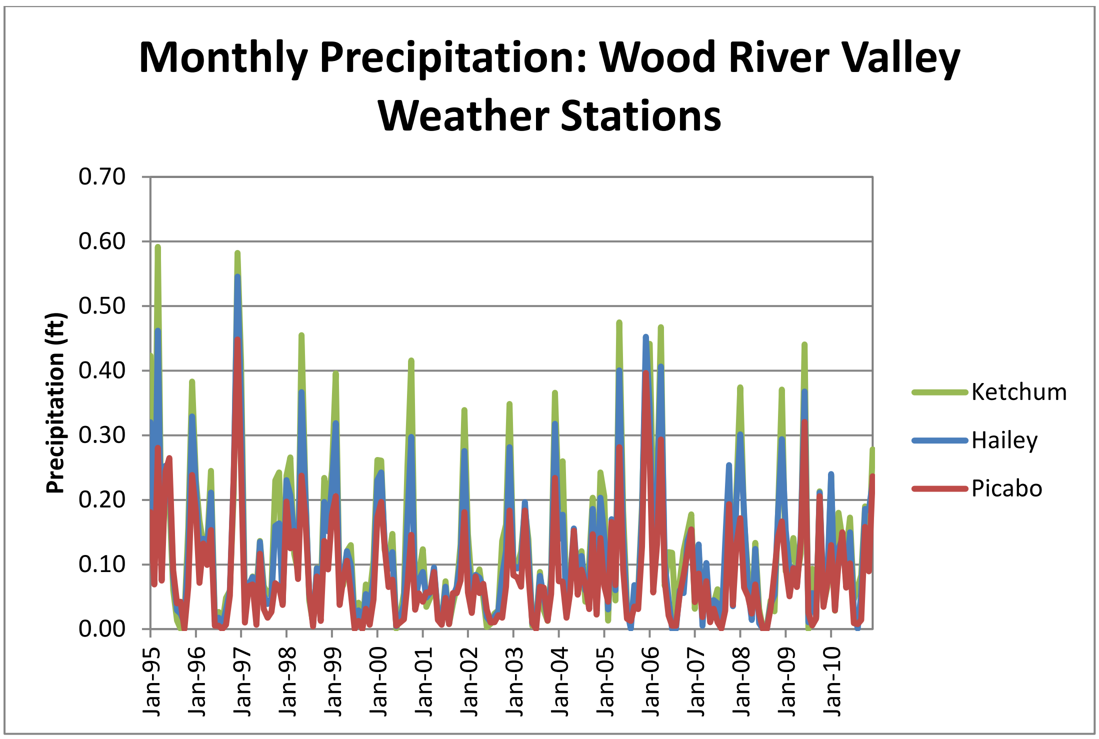

Figure 3. Monthly precipitation at Wood River area weather stations.

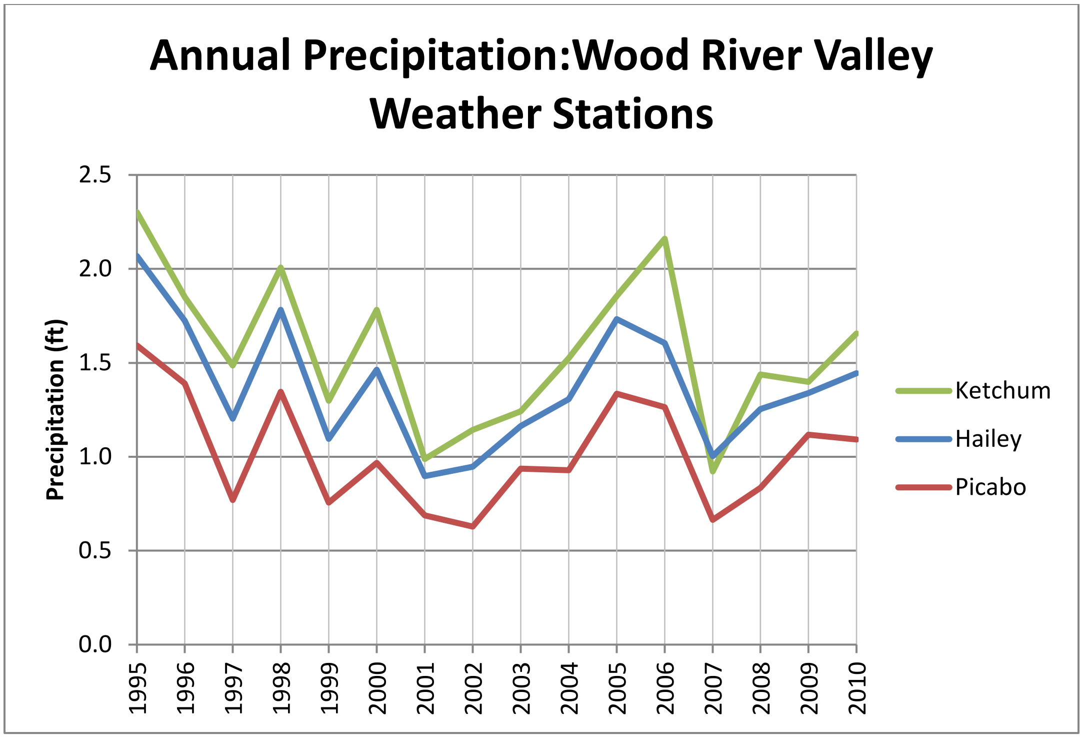

Figure 4. Annual precipitation at Wood River area weather stations.

Since the precipitation data are collected at discrete points, an interpolation scheme must be employed to obtain precipitation values across the model domain. In an effort to preserve the precipitation signature in the valley, the model domain has been divided into zones that were chosen by selecting areas nearest to the weather stations. Zone boundaries were chosen so that geographical characteristics similar to the weather station are maintained within a zone. The boundary between the Picabo and Hailey zones is located at latitude 43.438° and the boundary between the Hailey and Ketchum precipitation zones is located at 43.592° (Figure 5).

Figure 5. Three precipitation zones, based on weather-station location and geographic similarities.

Applying precipitation to three zones within the model domain results in precipitation data that are distributed across the entire model domain for the entire model calibration period. The use of three zones based on proximity to the weather stations and geographic similarities results in precipitation that is spatially distributed in a way that preserves the precipitation-elevation relationship seen in the data.

Application of winter precipitation

Cold temperatures during the months of November, December, January, February, and March result in frozen precipitation. Since much of the precipitation that falls during these months is not available for runoff into streams or to infiltrate into the ground during the same month, a method is needed to simulate spring-time melting.

Issues

Two issues impact the application of winter-time precipitation to the model. First, a large portion of frozen precipitation will not be available for recharge or runoff until warmer spring-time temperatures. Therefore, the percentage of winter-time precipitation that is applied to the model during the same month in which it fell must be determined. This value is very difficult to determine because it relies on complicated energy balance concepts that are typically modeled, as well as observation data like soil temperature which are not available for the model area. Therefore, a method based on other modeling efforts has been used as a template to estimate how much in-month precipitation is applied to the model during winter months. The in-month precipitation estimates have been adjusted to better represent the model area using reported snow accumulation in the form of normalized, average daily snow water equivalent (SWE) data.

The second issue is that frozen winter-time precipitation must be applied to the model in a manner that simulates spring-time melting, and time-series estimates of melting snow need to be developed. Snowmelt is an energy-exchange process, and complex models are typically employed to estimate melting; however, the necessary data (soil temperature, extent of snow cover, and snow condition) to model melting regimes are not available for the Wood River Valley. Air temperature, reported snow accumulation, groundwater levels, and anecdotal information on snow-melt have been investigated in an effort to understand the timing of spring melt. However, reported snow accumulation in the form of normalized, average daily SWE data have been used as the basis for snowmelt timing.

Process

Determining how much in-month winter-time precipitation is applied to the model is based on previous modeling efforts. The melting and infiltration of frozen precipitation is a function of air and soil temperature, wind, precipitation, snow cover, soil moisture and frozen soil moisture, and the thermal and hydrologic characteristics of the soil (Harshburger et al., 2010). Since the all of the data necessary to reliably model snowmelt are not available in the study area, soil moisture and temperature values from various locations were analyzed in an attempt to determine winter-time melting; however, soil moisture and temperature data are sparse and inconsistent in the model area. Air temperature data alone are not good indicators of snowpack ablation, and it was decided not to use air temperature as the basis for determining snowmelt. Therefore, the Enhanced Snake Plain Aquifer Model (ESPAM) versions 1.1 and 2.1 method of applying a reduced percentage of the November, December, January, February, and March precipitation to the model during the month that it occurred has been implemented (IDWR, 2013). The ESPAM assumption that at least 25% of winter-month precipitation is available for recharge or runoff has been retained for the WRV model; however, the timing of spring melt has been adjusted based on the accumulation of snow, reported as SWE depths. The use of snow accumulation relies on the assumption that snow accumulation is due to frozen precipitation that is not available for recharge, and that melting snow results in the availability of previously frozen precipitation. The Hailey NWS station reports daily snow accumulation amounts, and the Picabo AgriMet station and a SNOTEL site in Chocolate Gulch report daily SWE values. Hailey SWE has been estimated by dividing snow accumulation by 10 (Ward and Tremble, 2004). By calculating the average daily SWE for the period 1995-2010 the relative amount of snow by day-of-the-year can be plotted (Figure 6).

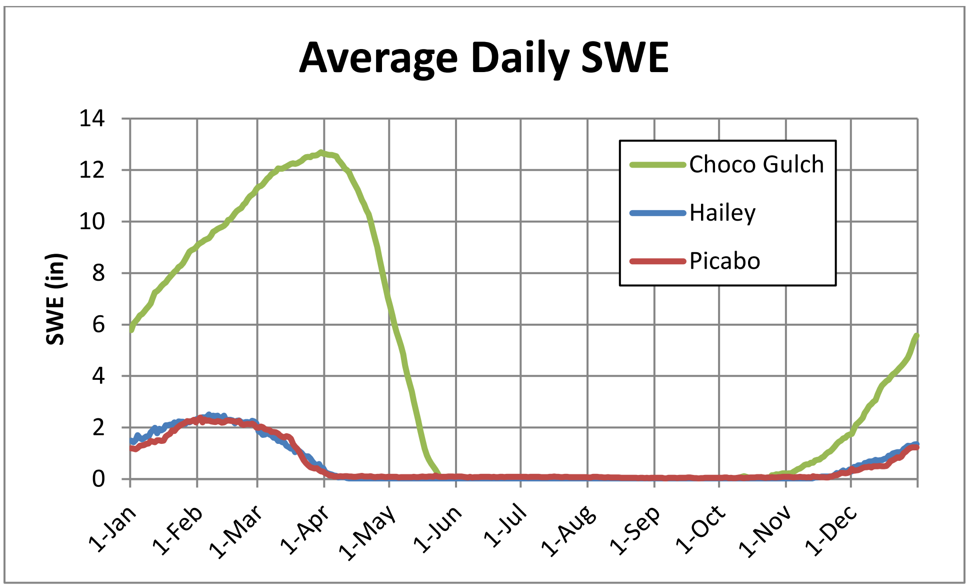

Figure 6. Normalized values of average daily SWE in the Wood River Valley.

The Chocolate Gulch SNOTEL station is used as a proxy for snow accumulation and melt in the Ketchum precipitation zone. It is important to note that the Chocolate Gulch SNOTEL site is at an elevation of 6,440 feet compared to the elevation of the Ketchum NWS weather station at 5,840 feet; therefore, snow accumulation will most likely begin at the Chocolate Gulch site somewhat earlier than in the model area, and snowmelt will most likely begin later. Snow accumulation at Chocolate Gulch begins in early October, and assuming snow starts accumulating a short time later, 25% of November precipitation at Ketchum is applied to the model. Snow begins to accumulate in mid November at the Hailey and Picabo sites; therefore, 75% of November precipitation is applied to the model at both Hailey and Picabo (Table 1).

Table 1. Application of winter-time precipitation during the month in which it fell.

Precipitation Zone	Nov	Dec	Jan	Feb	Mar	Apr
Ketchum	25%	25%	25%	25%	25%	75% Nov + 75% Dec + 75% Jan + 75% Feb + 75% Mar + 100% Apr
Hailey	75%	25%	25%	50%	25% Nov + 75% Dec + 75% Jan + 50% Feb + 100% Mar	100%
Picabo	75%	25%	25%	75%	25% Nov + 75% Dec + 75% Jan + 25% Feb + 100% Mar	100%

Visual inspection of Figure 6 indicates that the majority of snowmelt occurs in the month of March at both the Picabo and Hailey weather stations. Snowmelt in Chocolate Gulch starts to occur in the first week of April, and continues into the latter part of May; however, as stated earlier, the Chocolate Gulch SNOTEL site is at a higher elevation than the valley floor, and it is assumed that melting occurs earlier in the model area. Input from the MTAC indicated that April is more appropriate for valley-floor snowmelt in the Ketchum precipitation zone.

Effect

The use of the ESPAM2.1 method of applying a reduced percentage of winter-time precipitation to the month in which it occurred results in a reduction of the amount of precipitation that is fed into the model during the winter months. Although uncertain, this method is generally consistent with how frozen soil and frozen precipitation are theorized to behave (Contor, 2004; IDWR, 2013). The use of reported SWE values in conjunction with the input of local knowledge by MTAC members results in the application of snowmelt during the months in which it is most likely to occur. Figure 7 illustrates the redistribution of precipitation from winter months to spring melt at each of the weather stations.

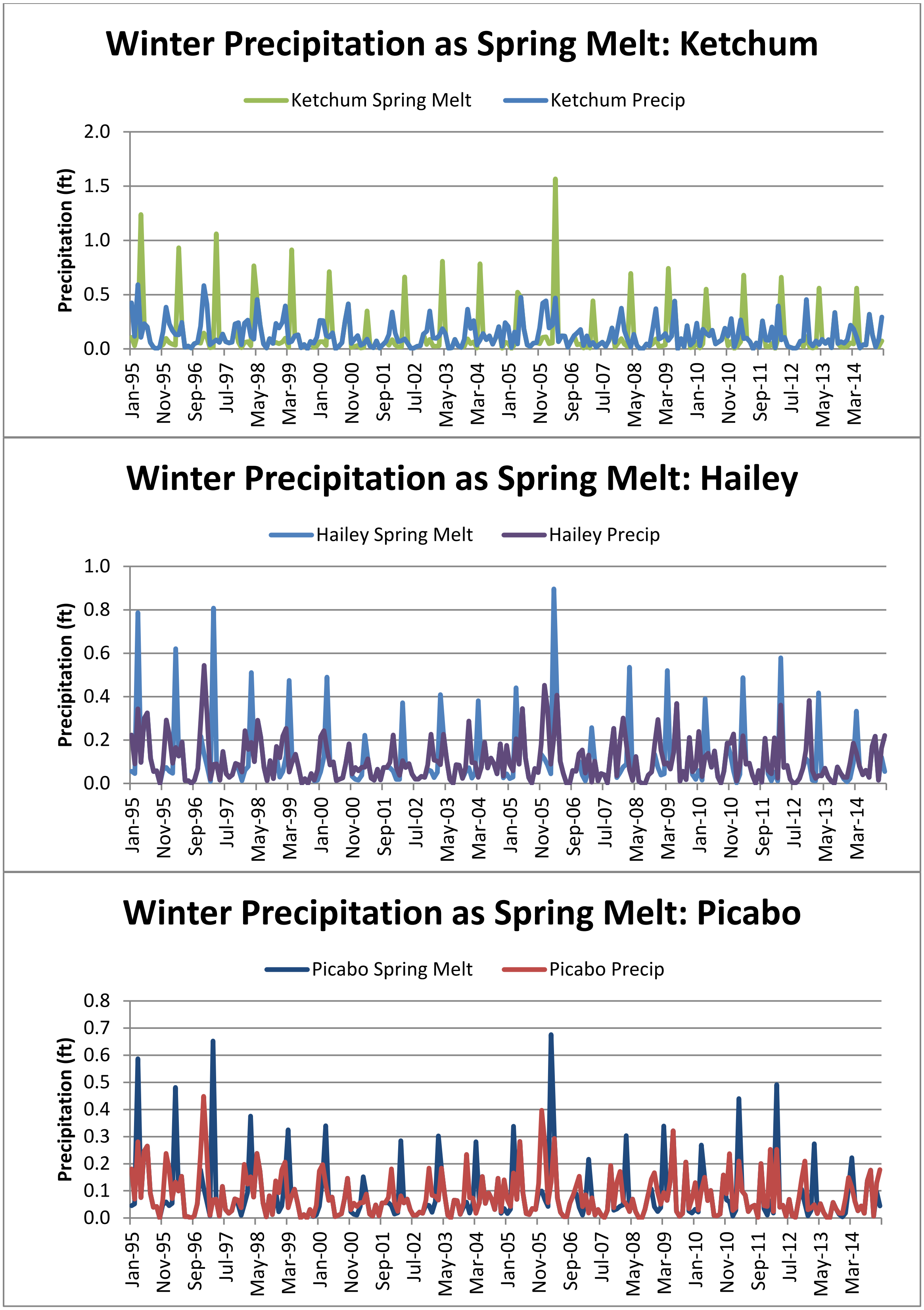

Figure 7. Wood River Valley precipitation with a portion of winter precipitation held until spring melt.

Design decision

The recommended design decision is to assign precipitation data to three precipitation zones which are based on proximity to local weather stations. Precipitation is applied to the model in the month during which it fell except for winter months, when reduced percentages of November, December, January, February, and March precipitation are assigned to simulate frozen conditions. The remaining precipitation from the winter months is applied to the model during the month of March in the Picabo and Hailey precipitation zones, and during the month of April in the Ketchum precipitation zone.

The file BigWood_PrecipWntrAdj.csv contains the monthly precipitation values for the calibration period with winter precipitation distributed as described above.

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