Estimating Tributary Basin Underflow to the Eastern Snake Plain Aquifer

Idaho Water Resources Research Institute

Stacey L. Taylor

Bryce A. Contor

Greg L. Moore

Idaho Department of Water Resources

Mike W. McVay

IWRRI Technical Completion Report 201103

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ABSTRACT

While groundwater withdrawals in the Eastern Snake River Plain Aquifer increase, the number of recharge sources to the aquifer remains the same. These sources of recharge include precipitation, stream and river losses, irrigation percolation, canal seepage, and subsurface flow from tributary basins. Most sources of recharge can be measured or closely approximated since they occur on the surface. However, flow that is underground from surrounding basins (also called tributary underflow) is much more difficult to quantify since it occurs beneath the surface. The Eastern Snake River Plain is surrounded by 23 tributary basins and is believed to receive recharge from each one. Tributary underflow is a key component of recharge in the Eastern Snake Plain Aquifer Model, representing approximately 20% of the water budget.

Several techniques have been developed to estimate underflow from tributary basins of the Eastern Snake Plain. This investigation pursues use of the Langbein method, published in a report on the Raft River Basin by Nace et al. (1961). The Langbein method estimates water yield for a basin based on relationships between temperature and potential evapotranspiration. Water yield for a basin is the manageable part of the water supply that is potentially available for consumptive use. Improved methods of estimating precipitation and temperature data have become available since the Langbein studies were completed. For the Eastern Snake Plain tributary basins, resulting values of basin yield were partitioned to three fates: irrigation ET, surface outflow, and tributary underflow. Tributary underflow was calculated as the difference between basin yield and water leaving the basin as streamflow and ET from irrigated lands.

Tributary underflow was calculated annually for each basin as a depth and a volume for 1980 – 2009. Results showed that some estimates may have been incorrect and potential sources of error were reviewed. When quality streamflow data were present for a basin, calculated values of underflow appeared reasonable. It was assumed that all basins discussed contribute some underflow to the Eastern Snake Plain, thus negative values may indicate a temporary cessation of underflow or an error in the calculation.

While the Langbein method has been previously used to estimate basin yield in basins tributary to the Eastern Snake River Plain (Little Lost, Raft), this work suggests the values for basin yield may be underestimated and the method of choice not be optimal for use in an arid climate. Other potential concerns for estimating underflow from basin yield are related to the limited information for streamflow and imprecision in the application of METRIC ET data. For future studies of basin yield, each individual basin should be analyzed based on the amount of information available for that basin and the type of climate.

INTRODUCTION

Background and Study Area

Prior to the initiation of farming practices in the 1800s on the Eastern Snake River Plain, precipitation and percolation from rivers and streams were the main source of recharge to the Eastern Snake Plain Aquifer (ESPA). Once farming was fully established on both sides of the Snake River along the eastern edge of the plain boundary, surface-water irrigation became the main source of recharge to the aquifer. As the population on the plain continued to grow larger and water use increased on a seemingly exponential scale, recharge to the aquifer became an important issue to consider. Over time, several groundwater models have been developed to better understand the aquifer and a groundwater model of the Eastern Snake Plain aquifer (called ESPAM) continues to be updated today.

While groundwater withdrawals in the Eastern Snake River Plain continued to increase, the number of recharge sources to the aquifer remained the same. These sources of recharge include precipitation, stream and river losses, irrigation percolation, canal seepage, and subsurface flow from tributary basins. Figure 1 shows the location of the study area in southeastern Idaho. The Eastern Snake River Plain extends from Ashton, Idaho, on the northeastern end to King Hill, Idaho, on the southwestern end and covers approximately 11,000 square miles.

Most sources of recharge can be measured or closely approximated since they occur on the surface. However, flow that is underground from surrounding basins (often called tributary underflow) is much more difficult to quantify since it occurs beneath the surface. The Eastern Snake River Plain is surrounded by 23 tributary basins and is believed to receive recharge from each one. Some of the surface-water tributaries flow directly into the Snake River and are found along the eastern and southern margins of the plain. Other tributaries, many located along the northern margin of the plain, disappear through seepage prior to reaching the Snake River. Figure 2 shows the location of all these tributary basins. Flows in the northern margin from the Big and Little Wood Rivers, Silver Creek (tributary to the Little Wood River), and Camas Creek may eventually reach the Snake River.

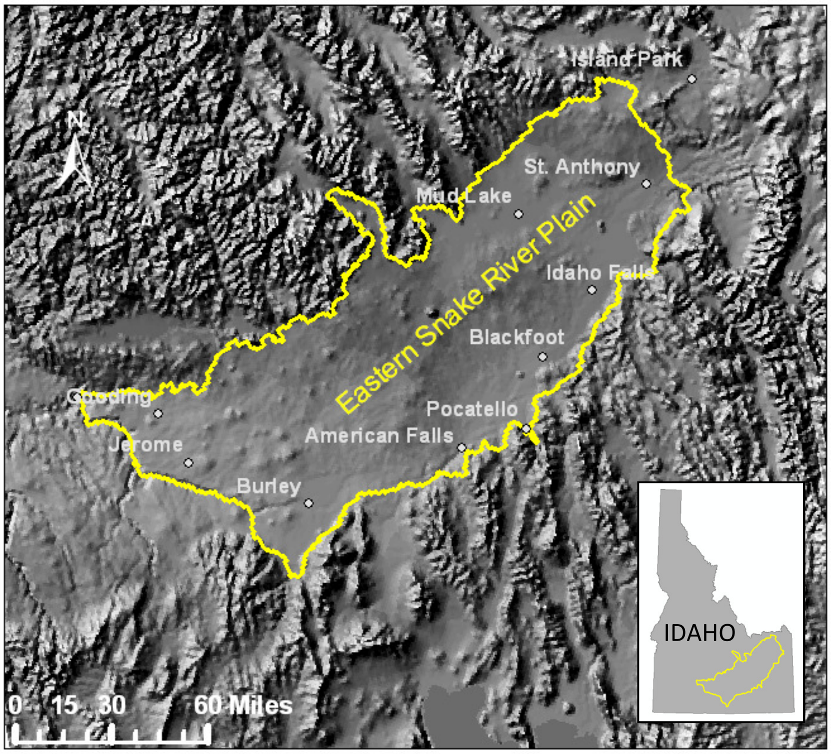

Figure 1. Eastern Snake River Plain Aquifer Boundary for the current aquifer model, ESPAM version 2.0.

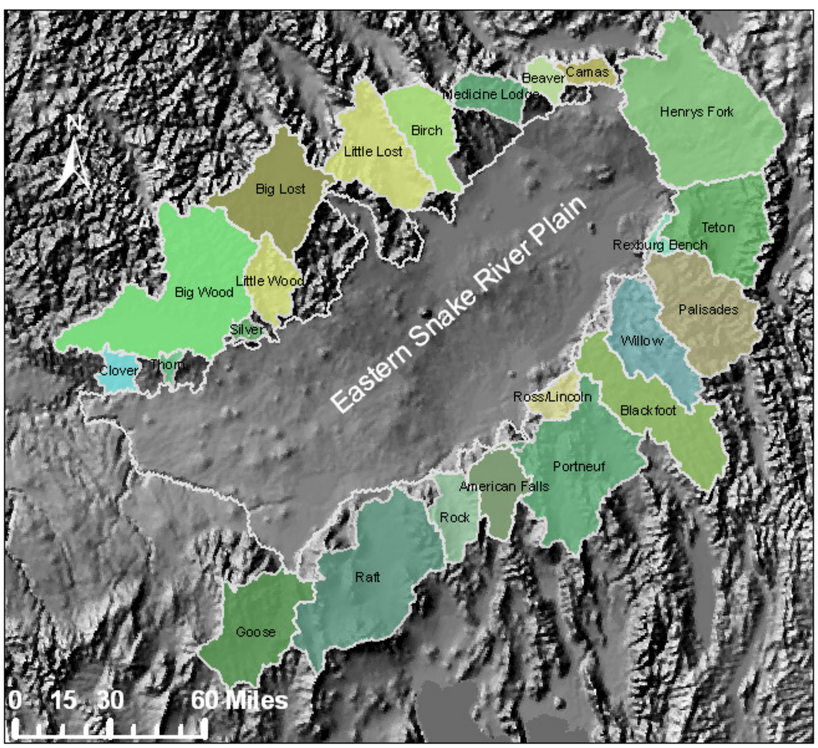

Figure 2. Tributary basin areas considered for estimating groundwater underflow.

Purpose

Tributary underflow is a key component of recharge in the Eastern Snake Plain Aquifer Model (hereafter referred to as ESPAM), representing approximately 20% of the water budget. Underflow discharge from adjoining basins is simulated as a specified flux boundary. Specified flux is used in the model to represent flow to and from the aquifer at a specified rate. Individual model cells are assigned with a flux pertaining to the underflow associated with the adjacent tributary basin.

Several techniques have been employed to estimate underflow from tributary basins of the Eastern Snake Plain. The ESPAM is continually updated with new data and knowledge with an overall goal to make improvements that help the model more closely simulate reality. Making such improvements means that better estimation techniques must be employed to calculate the imperceptible features, such as tributary underflow. The goal of this report is to convey the following information:

(1) Provide a description of methods of previous investigations used to estimate tributary underflow for the calibrated version of the model and studies performed on individual basins,
(2) Discuss the method chosen and data used to estimate underflow for this report,
(3) Present the average annual underflow estimates for each of the 23 tributary basins to the Eastern Snake Plain Aquifer,
(4) Discuss problems that occurred during calculations, and
(5) Provide a summary and recommendations for future investigations.

PREVIOUS INVESTIGATIONS

Many studies have been performed on individual basins in the Eastern Snake River Plain to estimate the tributary underflow. One study, the USGS Regional Aquifer System Analysis (RASA) (Garabedian 1992), includes information on all the tributary basins of the Snake Plain, yet it lacks the necessary detail to provide data for a model with monthly stress periods (as required by the ESPAM version 2.0 currently being calibrated). This section of the report briefly discusses the studies performed on basins tributary to the Eastern Snake Plain Aquifer.

USGS Regional Aquifer System Analysis

The ESPAM version 1.1 (ESPAM1.1) is the most current calibrated model of the Eastern Snake River Plain and ESPAM version 2.0 (ESPAM2.0) is currently being calibrated. Both of these models employ the same values of tributary underflow which were based on estimates published in the RASA study (Garabedian 1992). These were based on Kjelstrom's (1986) basin yield equations that calculated average annual underflow rates from tributary drainage basins. These equations were based on drainage area, mean annual precipitation, and percentage of forest cover as independent variables. A basin-by-basin regression analysis was performed using available stream records to determine the coefficients of the independent variables. Underflow values were determined from the basin yield equations and were found to be about eight percent of the average water yield from tributary basins.

The underflow values were annual values that needed to be scaled for seasonal and yearly variation. For ESPAM1.1, the annual underflow values were scaled based on normalized discharges at Silver Creek. Silver Creek was selected as a proxy because it is almost entirely spring-fed, flows over bedrock, and has a long period of record for flux available. Discharge at Silver Creek is believed to be more seasonally variable than underflow; therefore, the Silver Creek discharge was dampened by 2/3 to decrease the amplitude of the variation. The average annual underflow values for each tributary were multiplied by the dampened Silver Creek normalized flow for each time period to estimate the volume of underflow each tributary basin contributed to the groundwater model for a given stress period. This method of estimation did not allow for intra-year variations in flow because the lack of knowledge about the individual basins precluded the utilization of more temporal refinement. This was listed as a model limitation in the final report on ESPAM1.1 (Cosgrove et al. 2006) due to the large degree of uncertainty.

Raft River Basin Study

The U.S. Geological Survey conducted a study in the Raft River Basin of Idaho and Utah to estimate the total water yield in the 1,560 square mile basin (Nace et al. 1961). All water in the Raft River Basin is derived from precipitation. The method for determining basin yield, as first published in the Nace et al. (1961) report, was developed by W. B. Langbein in unpublished notes. This method uses precipitation and potential evapotranspiration (ET) depths as inputs, and gives a basin yield depth as output. The depth is then multiplied by the basin area to obtain yield volume. The calculations were applied to spatial bands determined by elevation.

To obtain band-by-band precipitation values for this method, available precipitation data were organized and plotted against station altitudes to define a trend between precipitation and altitude. Precipitation data available to define this relationship were limited. Isohyetal lines were drawn on a map of the basin to estimate precipitation at similar elevations where data were lacking.

Nomograms using the Thornthwaite (1948) method were developed using three gage stations to define a relationship between temperature and potential ET; however, this method proved cumbersome. Instead, a study involving streamflow and runoff characteristics of river basins nationwide was applied. A relationship between mean annual temperature and potential ET (water loss) was defined graphically as shown in Figure 3. Nace et al. (1961) found that values of potential ET in the Raft Basin, given by Thornthwaite (1948), plot very close to the curve as shown in Figure 3.

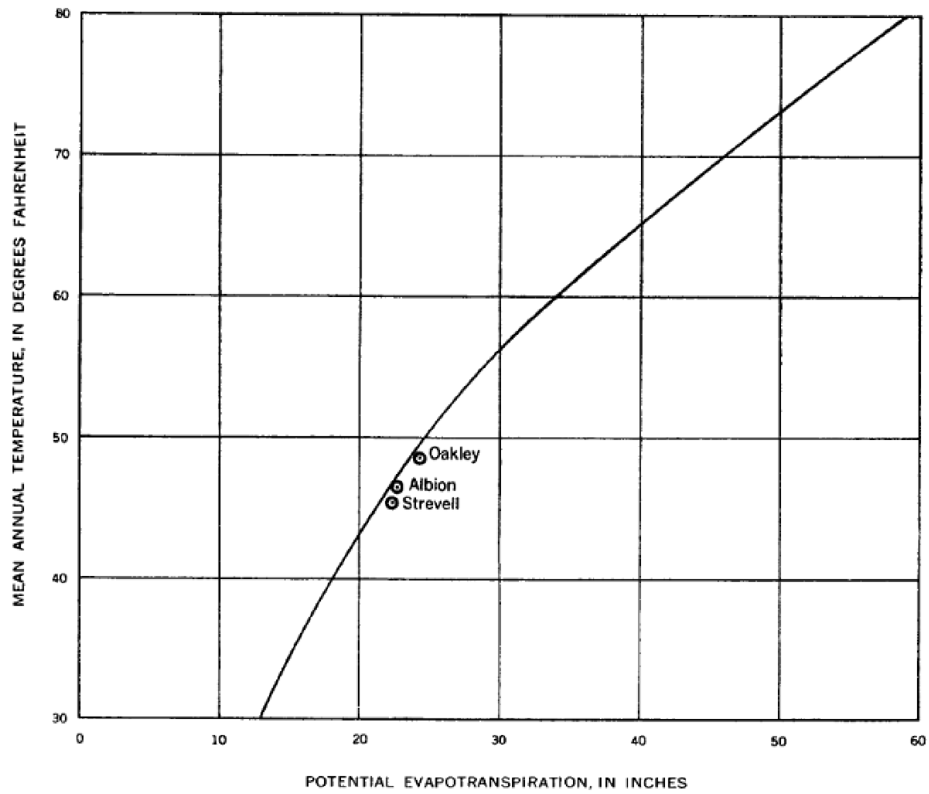

Figure 3. Defined curve between mean annual temperature and potential ET in North America. Adapted from Figure 7, Nace et al. (1961).

Data previously published in Langbein et al. (1949) based on basins where runoff equals water yield (i.e. basins where impermeable bedrock precluded subsurface outflow) allowed for a relationship to be defined between water yield (R), precipitation (P), and potential ET (L). Using a plot as shown in Figure 4 of the ratio of annual water yield to potential ET (R/L) versus the ratio of annual precipitation to potential ET (P/L), water yield could be obtained graphically. Using values of P/L, a value of R/L was found. This value (R/L) was then multiplied by the value of potential ET (L) to find the resulting annual water yield.

Figure 4 shows that the ratio of R/L quickly increases at low values of P/L. Values of P/L greater than 2 shows that R/L approaches values of (P/L – 1). The graph is not representative of a specific drainage basin and is associated with a range of climates in the U.S. Nace et al. (1961)

suggested that water yield is not completely explained by climatic variables and performed some crude analyses to check for validity.

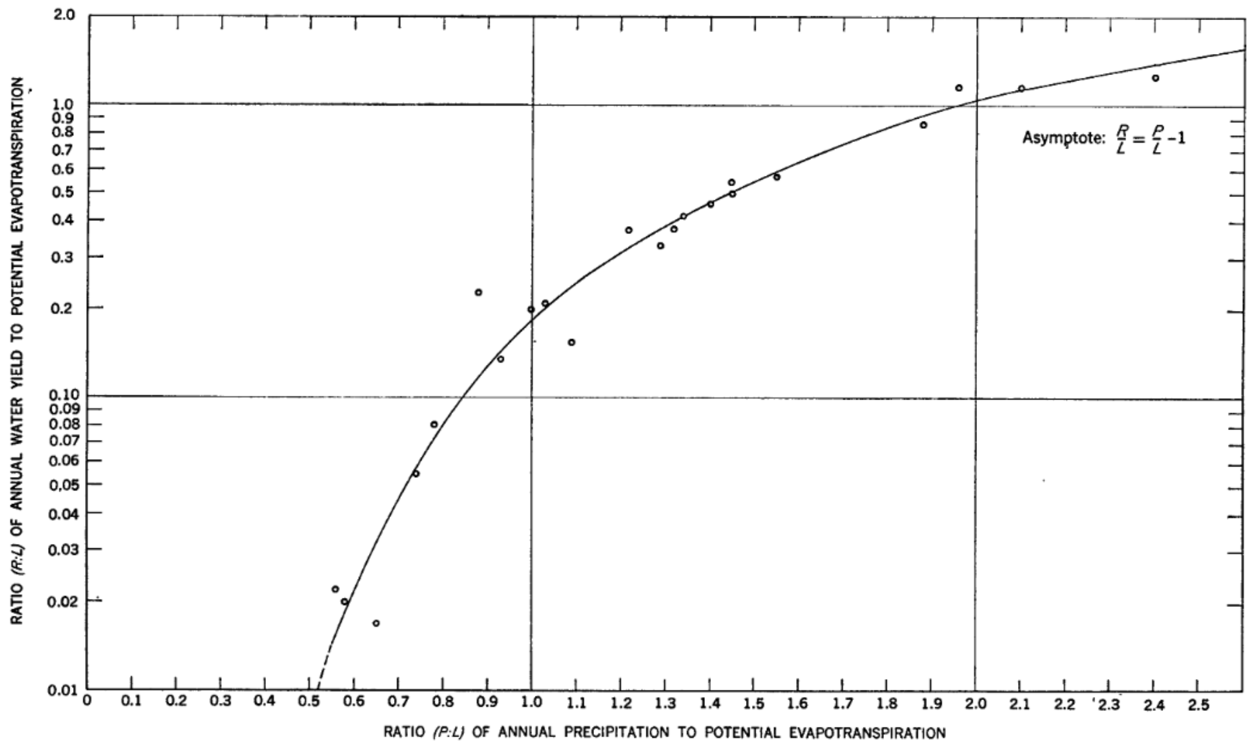

Figure 4. Relationship defined between annual water yield to precipitation and potential ET as defined by the Langbein method. Adapted from Figure 8, Nace et al. (1961).

Little Lost River Basin Study

The Idaho Department of Water Resources (IDWR) performed a study on the Little Lost River area of Idaho to estimate the availability of water in the basin (Clebsch et al. 1974). The Little Lost River Basin is a northwest trending valley that drains an area of about 900 square miles. The main source of recharge in the basin is precipitation; the average of which for the entire basin is nearly nine inches. It was assumed that there is no interbasin underflow into the basin.

An estimate of total water yield was made using three different methodologies. The first method used was a modification to the method developed by Langbein in Nace et al. (1961). For the Little Lost study, calculations were performed on individual drainage basins within the Little Lost Basin, intervening bedrock areas, and valley-floor areas. Estimates of water yield for each of these areas were made using a relation between the ratio of precipitation to potential evapotranspiration (P/L) and water yield to potential evapotranspiration (R/L). Precipitation estimates were based on a determination of mean altitude made by overlaying a grid on a contour map of the subbasin and averaging the altitude of all grid points that fall within the subbasin. Mean altitude was used to estimate the mean annual precipitation and temperature over the subbasin. Potential ET was calculated using the relationship developed by Langbein (Nace et al. 1961) between the mean annual temperatures and potential ET. A total yield of 424,000 acre-feet (8.7 inches over the basin) was found. Clebsch et al. (1974) noted that this value was relatively high and recommended this value as an upper limit to basin yield until better precipitation data are available.

The second method used streamflow measurements on tributary streams, which Clebsch et al. (1974) called the "Water Yield by Perimeter-Inflow" method. For individual streamflow sites, surface runoff was plotted against estimated precipitation and the resulting plot was used to estimate basin yield. Average precipitation for each basin was estimated using the mean altitude of the basin and the precipitation-altitude relation described by Langbein (Nace et al. 1961). From the plot of surface runoff versus precipitation, an envelope curve for the total yield of the subbasins was developed and used to estimate a yield for the 10 tributary basins where streamflow was measured periodically. Precipitation on the valley floor did not contribute to the total yield. Using this method, an annual water yield for the basin was 271,000 acre-feet.

The third method for estimating water yield in the Little Lost River basin was based on correlation with data from the Big Lost River Basin. This method assumes that the tributary drainage basins and water yield estimate for the Big Lost River are comparable to the tributaries and subbasin areas of the Little Lost River given the similarity in topographic configuration, geology, and soil and vegetation cover. In a plot of yield versus altitude, a trendline was visually fitted, placing greater emphasis on points for which gage station records were used to check the water yield of the basins. A total yield of 224,000 acre-feet for the Little Lost basin was derived using this method.

The preferred value of basin yield was 271,000 acre-feet and was derived using the second method, perimeter-inflow. The total yield derived by the Langbein method (424,000 acre-feet per year) was believed to be excessive, so the middle value was chosen to represent the basin yield.

Portneuf Basin Study

In an update to the 1993-94 water balance of the southern portion of the lower Portneuf River Valley, Welhan (2006) noted that unusually good estimates of underflow can be found due to the well-constrained bedrock geometry in the vicinity of the ESPAM2.0 model boundary. For this study, information regarding contributing watersheds, gains and losses of the Portneuf River and pumping were available allowing for good estimates of tributary underflow.

In a presentation to the Eastern Snake Hydrologic Modeling Committee, McVay (2009) of IDWR found that the calculated underflow for the year 2000 in the Portneuf Basin from Welhan's (2006) report was comparable to calculations made using Darcy's law. McVay (2009) also found that the ESPAM1.1 approach to estimating underflow in the Portneuf using Silver Creek as a proxy provided comparable values.

METHODS

For this investigation, the Langbein method used in the Raft River Basin and the Little Lost River Basin was chosen to estimate basin yield for each tributary basin of the Eastern Snake River Plain at the aquifer model boundary. This method calculates annual basin yield; therefore, only annual data was collected to estimate underflow. Improved methods of estimating precipitation and temperature data have become available since the Langbein studies were completed, and data from the PRISM Climate Group of Oregon State University have been used for this study ("PRISM precipitation data", "PRISM temperature data").

Calculations

Calculation of Water Yield. The Langbein method was used to calculate water yield for each tributary basin believed to contribute underflow to the Eastern Snake River Plain Aquifer. Calculations were performed on the individual 4000-meter square pixels of the raster grids using ESRI® software for each year from 1980 to 2009. At the time these calculations were performed, annual data for 2010 precipitation and temperature were not complete.

Figure 3 (same as Figure 7 from Nace et al. (1961)) was applied to calculate potential ET in inches using mean annual temperature in degrees Fahrenheit. In order to do this, an equation derived from Figure 3 was used to acquire a value for potential ET for each individual 4000-meter square pixel within a basin. This equation was defined as follows:

$$y = 0.0109x^2 - 0.2966x + 12.24, \qquad \text{Equation 1}$$

where y is the potential ET in inches and x is the mean annual temperature in degrees Fahrenheit. Equation 1 was used for each year (1980 – 2009) resulting in a raster grid of potential ET for each tributary basin.

Using the mean annual precipitation grids and the previously calculated potential ET rasters, the ratio of precipitation and potential ET (P/L) was found. The ratio of annual water yield to potential ET was found by using the equation derived from Figure 4 (same as Figure 8 from Nace et al. (1961)):

$$y = -0.1154x^3 + 0.7497x^2 - 0.58x + 0.1252, \qquad \text{Equation 2}$$

where y is the ratio of annual water yield to potential ET (R/L) and x is the ratio of annual precipitation to potential ET (P/L). After solving for y, water yield was found by multiplying the ratio (R/L) by L (or potential ET). This calculation was performed on each pixel. Given the individual pixel values of water yield, a mean value of water yield was found for each tributary basin.

Calculation of ET on Irrigated Lands. The data used to develop the relationships of the Langbein method empirically incorporate naturally-occurring ET associated with direct use of precipitation, as well as some riparian ET in the basins from which data were derived. Irrigation, either from groundwater or surface water, represents an additional use of water not implicit in the Langbein methodology. For this reason, ET on irrigated lands was calculated as an additional deduction to be made from the basin yield in calculation of tributary underflow.

The 1992 irrigated lands polygons from the ESPAM2.0 data set (the only data set that covered all the tributary basins) was intersected with a GIS data set of 1000-foot elevation bands. Using the METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) remotely-sensed ET estimates, a relationship between elevation and irrigated ET depth was derived for each month of the three years of available METRIC data, 2000, 2002 and 2006. The relationship was not strong.

Actual METRIC ET depths were applied to all parcels that were fully covered by METRIC data, and elevation-based depths were applied to parcels lying outside the METRIC coverage. For each parcel, depth was multiplied by area to obtain a volume of ET associated with irrigation.

Calculation of Tributary Underflow. The water supply of a basin is the total amount of water available from any source, which can include precipitation, runoff, and interbasin flow. The water yield of a basin, or how much water a basin can produce, is precipitation plus inflow (from streams or nearby basins) minus ET (or water consumptively used). The Langbein method incorporates precipitation and naturally-occurring ET. The resulting basin yield must then be partitioned to three fates: irrigation ET, surface outflow, and tributary underflow. If there are no surface inflows to the basin, the following equation should result in the estimate of tributary underflow:

Tributary Underflow =

Water Yield – Surface Flow Exiting the Basin – ET from Irrigation Lands Equation 3

For the purpose of calculating tributary underflow at the model boundary, *Surface Flow Exiting the Basin* is defined as the flow at the gage station at or near the model boundary within the tributary basin.

In the Palisades Basin, other considerations were made for calculating underflow. The Palisades Reservoir receives inflow from three different sources: (1) the Snake River, (2) the Greys River, and (3) the Salt River. The reservoir has one outflow (the Snake River) and the closest measurement location is the USGS gage on the Snake River at Heise. Changes in storage and inflows and outflows in the reservoir were added to Equation 3 above when calculating tributary underflow for the Palisades Basin. The following equation was used for Palisades:

Tributary Underflow =

Water Yield – Outflow from the Basin + Inflow to the Basin –
Change in Storage of the Reservoir – ET from Irrigated Lands Equation 4

Data Collection

PRISM. Oregon State University has developed a climate mapping system, known as PRISM (Parameter-elevation Regressions on Independent Slopes Model), to produce continuous spatial data set of climactic factors. A large majority of the data were collected from the PRISM website. Data available on the website are available as ASCII grids with 4000-meter square pixels which were later converted to raster grids using ESRI® software. Data acquired from PRISM include minimum temperature data, maximum temperature data, and precipitation data. Since mean annual temperature data were needed for calculation of basin yield, the average between the minimum and maximum temperature grids was calculated (Allen et al. 1998).

METRIC. The University of Idaho and IDWR have developed a computer model, known as METRIC, to calculate and map ET through the use of Landsat satellite data. METRIC data are currently available for the years 2000, 2002, and 2006 for the months April through October. Since data are not available for the entire calibration period of ESPAM2.0 (1980 - 2008), an average of the METRIC data was assumed when calculating tributary underflow. These data were only used to estimate ET lost from irrigation.

Irrigated Area. ET on irrigated lands was applied to the calculation of tributary underflow. IDWR has developed ESRI shapefiles of irrigated lands for the Eastern Snake River Plain. Several years are available (1992, 2000, 2002, and 2006); however, the 1992 ESRI shapefile was the only one used since it covered more area within the tributary basins than the other years available.

Streamflow and Reservoir Storage. Streamflow data were acquired for several gages in the Eastern Snake Plain from the United States Geological Society (USGS) National Water Information System ("Idaho streamflow data") and the United States Bureau of Reclamation (USBR) Hydromet Historical Database ("Hydromet historical data"). Gages were selected based on location relative to the ESPAM2.0 boundary and the amount of data available during the ESPAM2.0 model calibration period (1980 – 2008). Figure 5 shows the location of the gages relative to the model boundary.

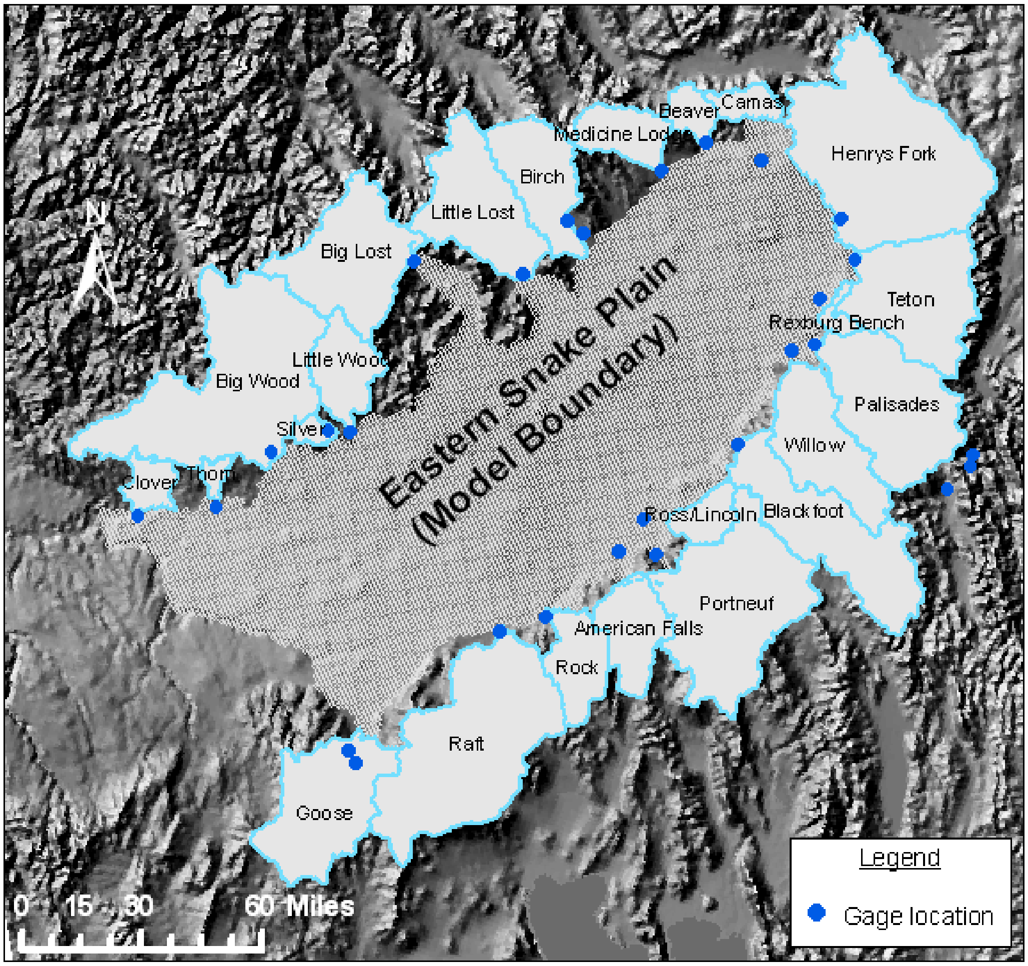

Figure 5. Gaged flow locations near the model boundary.

Some tributary basins only have gages with limited data. In such a case, average values were substituted for the missing years. Table 1 shows the gages acquired and the associated tributary basin.

Reservoir storage data were also collected from the USBR Historical Hydromet Data ("Hydromet historical data"). Daily data were used to calculate total change in reservoir storage for each year from 1980 through 2009.

Table 1. Gage sites used in the calculations of tributary underflow.

Gage Sites	Gage Number	Associated Basin
Clover Creek near Bliss, ID	13154000	Clover
Thorn Creek Watermaster record (no gage number)	(Watermaster Record)	Thorn
Big Wood River below Magic Reservoir	13142500	Big Wood
Silver Creek at Sportsmans Access near Picabo, ID		Silver
Little Wood River near Carey, ID	13148200	Little Wood
Big Lost below Mackay Reservoir near Mackay, ID		Big Lost
Little Lost River near Howe	13119000	Little Lost
Birch Creek at 8-Mile Canyon Rd near Reno, ID (1980-1987); Birch Creek Hydropower Plant Records (1987-present)	13117030	Birch
Medicine Lodge near Small, ID	13116500	Medicine Lodge
Beaver Creek near Spencer	13112500	Beaver
Camas Creek at Red Rd near Kilgore	13108900	Camas
Henrys Fork near Ashton	13046000	Henrys Fork
Teton River near St. Anthony	13055000	Teton
Moody Creek near Rexburg	13055319	Rexburg Bench
(1) Snake River near Heise, ID; (2) Greys River above Palisades Reservoir near Alpine, WY; (3) Salt River above Reservoir near Etna, WY; (4) Snake River above Palisades Reservoir near Alpine, WY	(1) 13037500; (2) 13023000; (3) 13027500; (4) 13022500	Palisades
Willow Creek near Ririe	13058000	Willow
Blackfoot River near Shelley	13066000	Blackfoot
Ross Fork Creek at Rio Vista Rd near Fort Hall	13075958	Ross/Lincoln
Portneuf River at Pocatello	13075500	Portneuf
Bannock Creek near Pocatello	13076200	American Falls
Rock Creek near American Falls	13077650	Rock
Raft River near mouth at Yale at Raft River, ID	13079901	Raft
(1) Goose Creek above Trapper Creek near Oakley; (2) Trapper Creek near Oakley	(1) 13082500; (2) 13083000	Goose

<u>RESULTS</u>

Basin Yield

A value for basin water yield was estimated as a depth and a volume for each year. Figure 6a shows the depth of the yield calculated for some of the tributary basins and Figure 6b shows the results for the remaining tributary basins. Note that the years are annual values for calendar years (January through December), not water years (October through the following September). The values were presented in this way since the annual PRISM data were already calculated in this fashion.

Figures 6a and 6b show values that range from a low of 0.02 feet of water yield depth in the Clover Creek Basin to a high water yield depth of 2.02 feet in the Camas Creek Basin. On average, the Henrys Fork Basin generally has the largest values of yield which is expected since this basin has high elevations and receives more precipitation relative to the other basins. Water yield depth in the Camas Creek Basin peaked in 1983 and 1996. These two years were characterized by large amounts of precipitation in the winter months. On average, the Silver Creek Basin has the smallest values of yield depth due to the size and elevation of this basin. The Thorn and Clover Creek basins follow Silver with small values of water yield depth due to the amount of precipitation and the low elevations relative to the remaining basins.

Figures 7a and 7b display the basin yields as acre-feet per year. As expected, the basins covering the largest areas have the highest volumetric basin yields. The smallest basins, Thorn and Silver, have the smallest basin yield volumes. Note that the basin yield volumes for the Little Lost in Figure 7a range from approximately 96,000 acre-feet to 453,000 acre-feet (average volume is 244,000 acre-feet) . Clebsch et al. (1974) calculated values of 474,000 acre-feet (for 1959-1966 data) using the Langbein method and believed that this value was an overestimate for the Little Lost River Basin. Basin yield volumes for the Raft River Basin range from 58,000 acre-feet to about 555,000 acre-feet, as shown in Figure 7b. Nace et al. (1961) calculated a value of 83,000 acre-feet for the basin yield of the Raft River Basin.

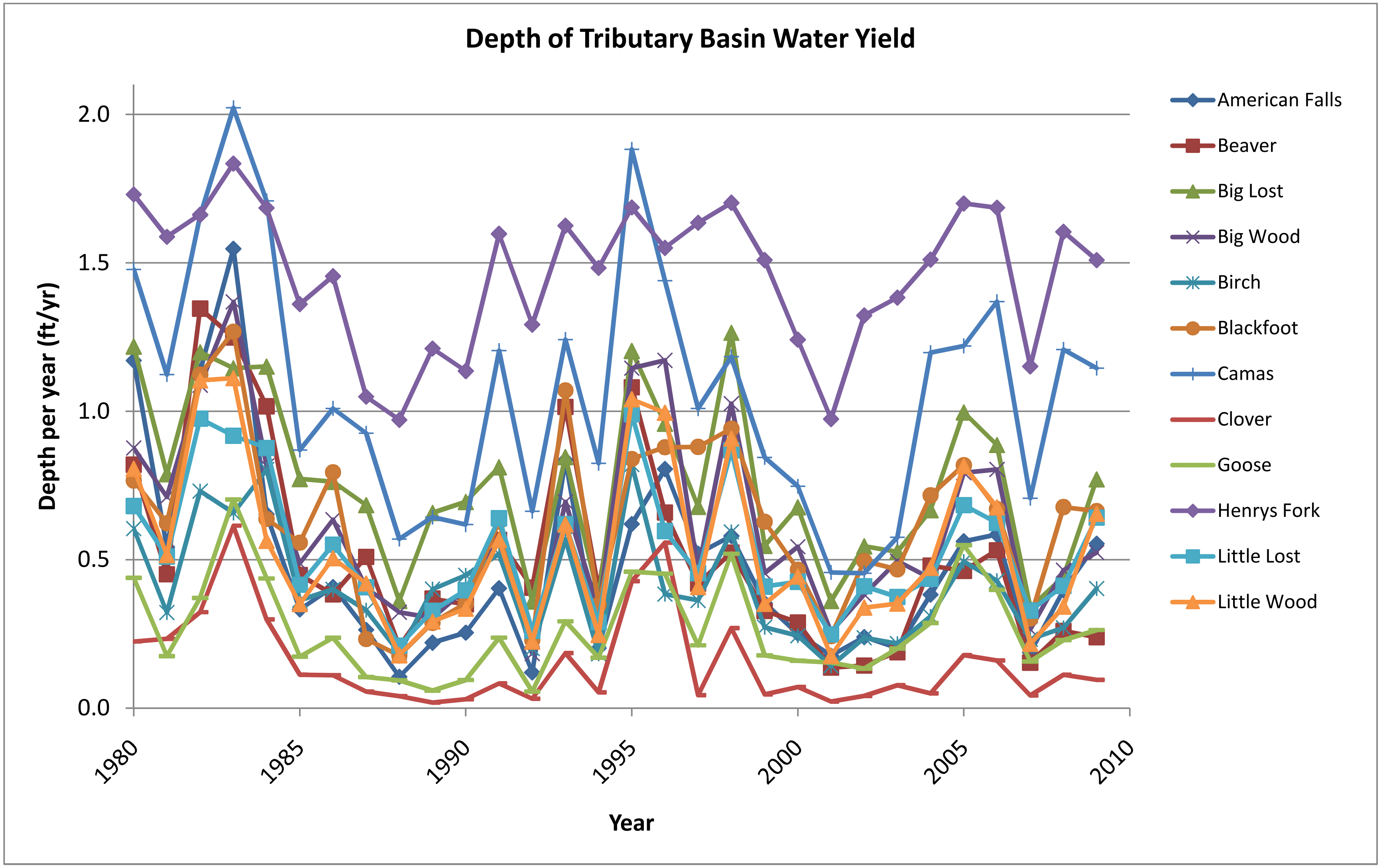

Figure 6a. Water yield depth for basins tributary to the Eastern Snake River Plain aquifer. Water yield calculated using the Langbein method (Nace et al. 1961).

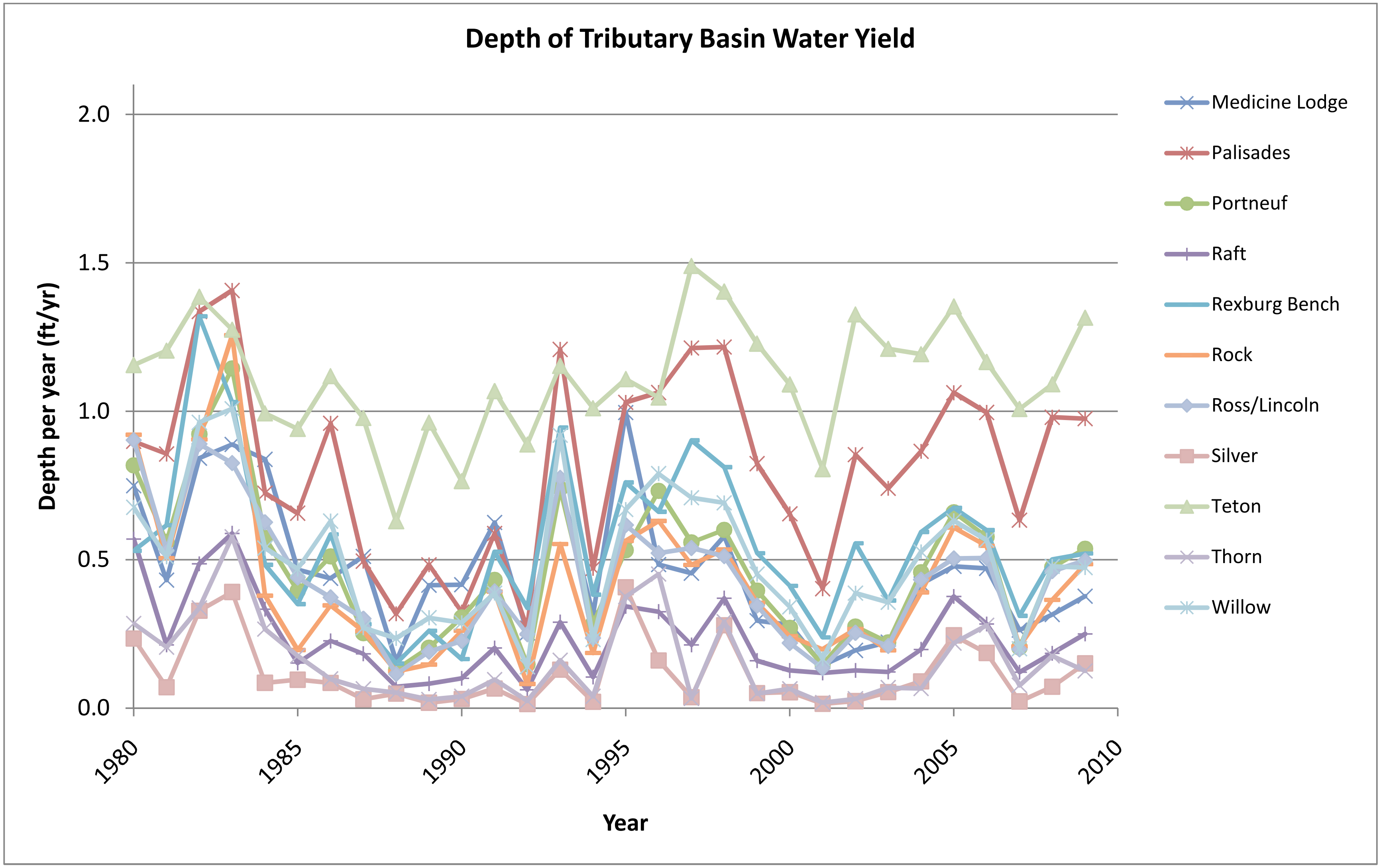

Figure 6b. Water yield depth for basins tributary to the Eastern Snake River Plain aquifer. Water yield calculated using the Langbein method (Nace et al. 1961).

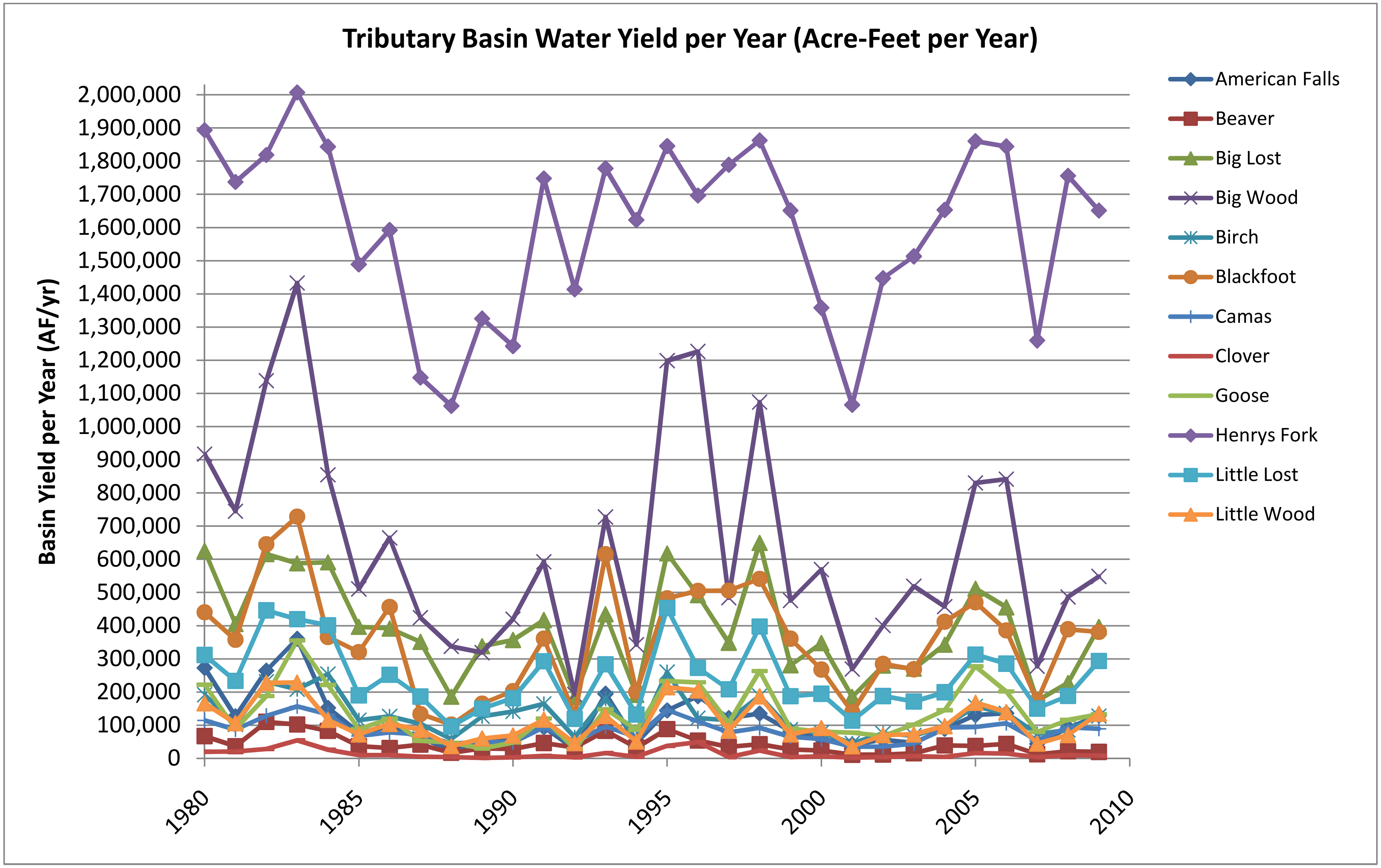

Figure 7a. Volume of water yield for tributary basins of the Eastern Snake River Plain aquifer. Water yield calculated using the Langbein method (Nace et al. 1961).

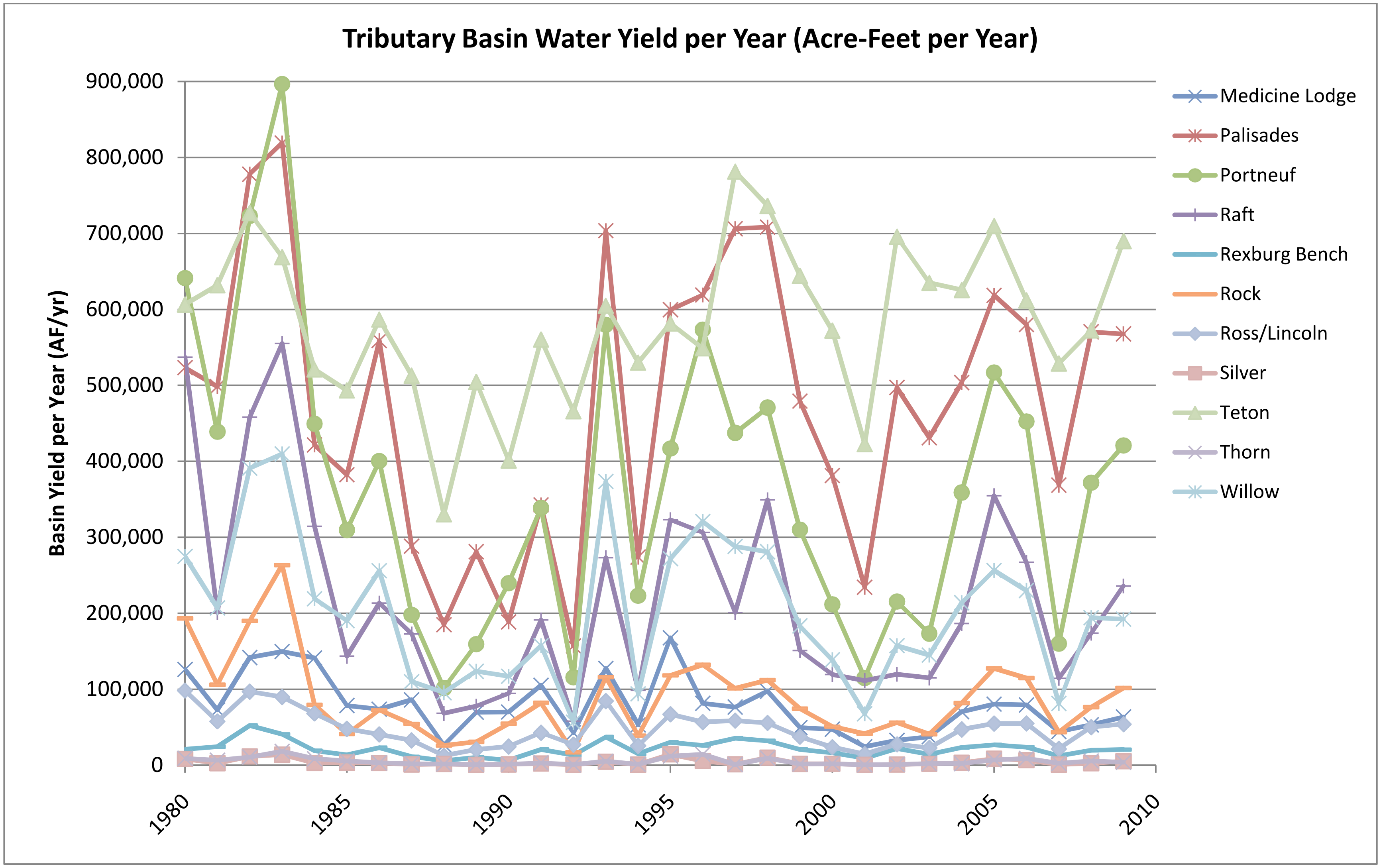

Figure 7b. Volume of water yield for tributary basins of the Eastern Snake River Plain aquifer. Water yield calculated using the Langbein method (Nace et al. 1961). Note that the vertical scale in this figure is smaller than the scale used in Figure 7a for the purpose of showing all basins clearly.

Figure 8 shows the average basin yield depths per year for 1980 - 2009 for each tributary basin. For comparison, the average basin elevation was plotted on a secondary axis. Average elevation is not a strong component in determining the magnitude of basin yield depth as can be seen in Figure 8, but it does have an impact on some basins. The Henrys Fork Basin has some of the highest elevations in the basin, which is one reason why it has a high basin yield.

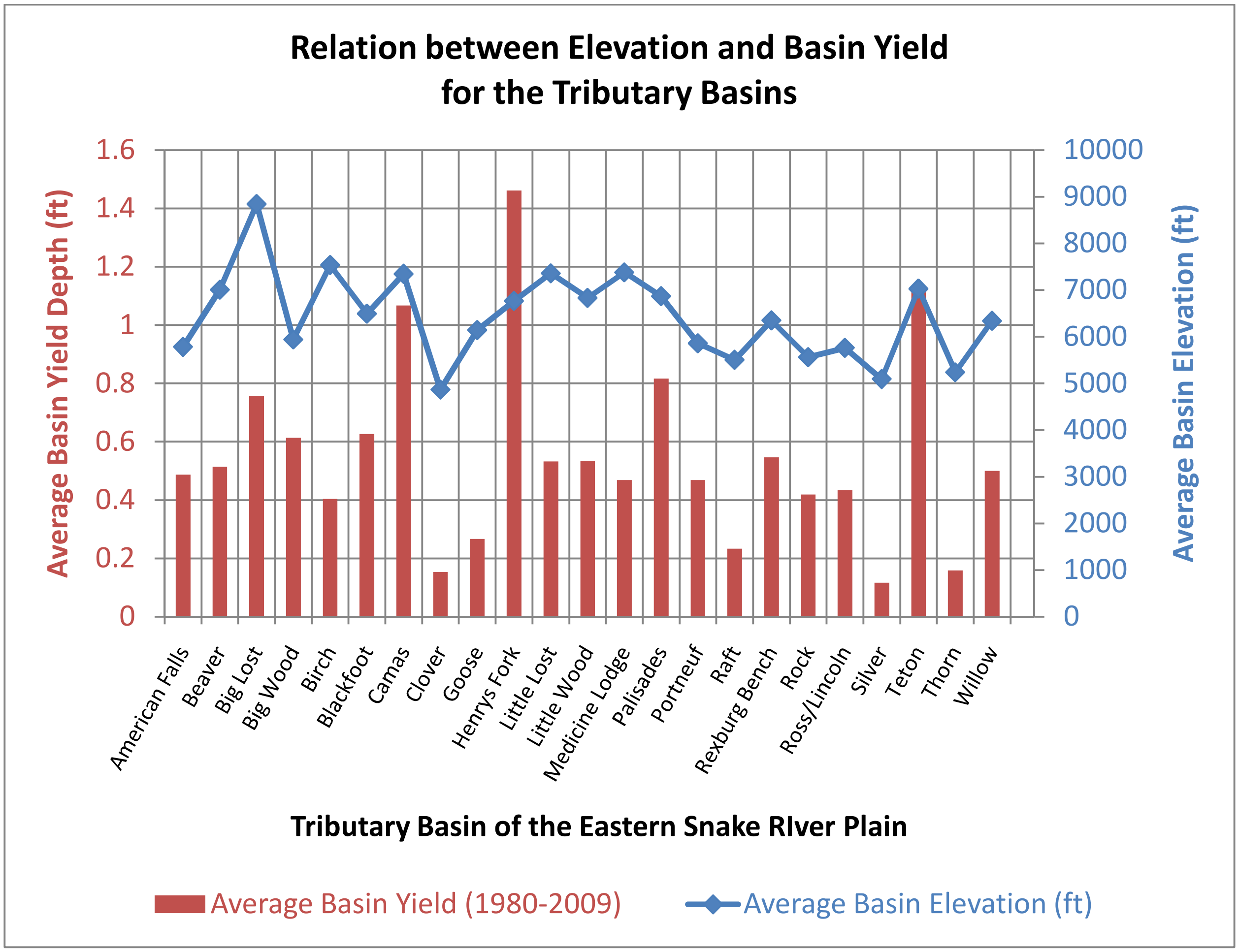

Figure 8. Tributary basin yield averages for 1980 - 2009.

Figure 9 shows the average basin yield by basin on a map. The tributary basins located around the northeastern end of the Eastern Snake Plain have some of the highest depths for basin yield, while the lowest basin yield depths are located on the northwestern margin (Clover, Thorn, and Silver).

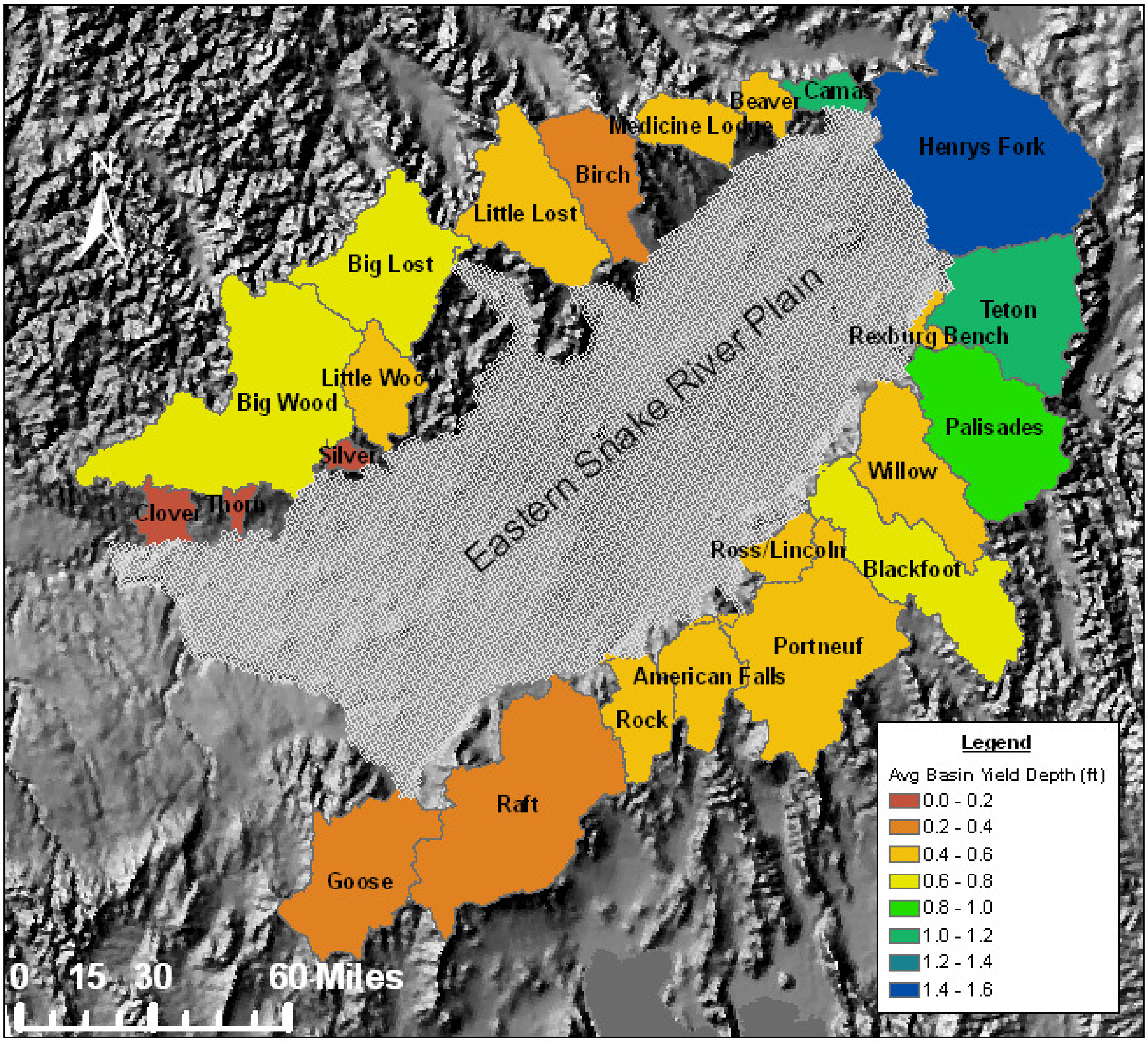

Figure 9. Average basin yield depths in feet for 1980 – 2009.

Tributary Underflow

Tributary underflow was calculated for each basin using Equation 3 (Equation 4 was used for the Palisades Basin). Surface-water flow and ET from irrigated lands were essentially removed from the annual water yield values shown in Figures 6a through 7b. Figures 10a and 10b show the resulting values from 1980 to 2009 for each basin as depth in feet. Figure 11a and 11b show the underflow values as volumes in acre-feet per year.

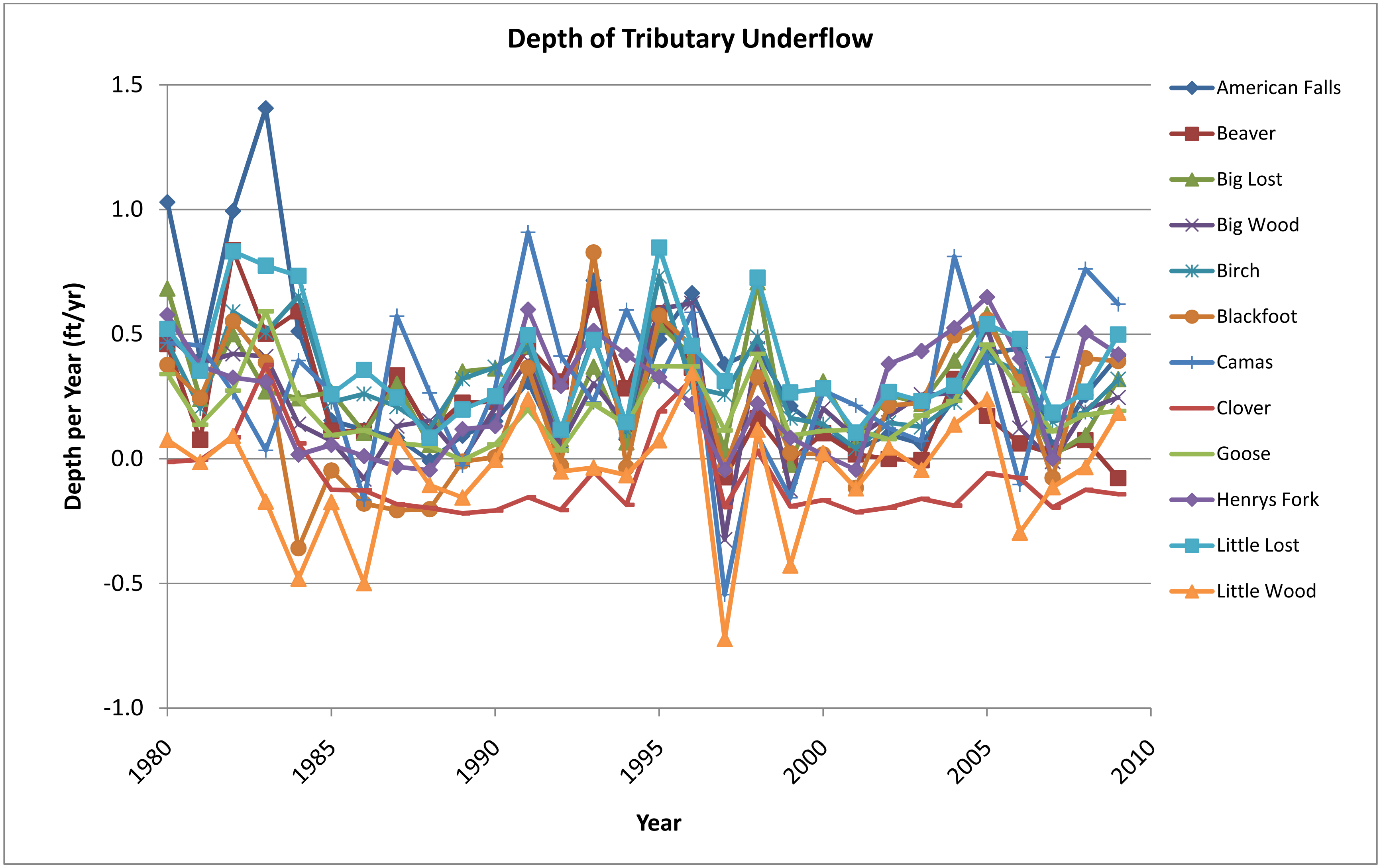

Figure 10a. Estimates of underflow as a depth for basins tributary to the Eastern Snake River Plain.

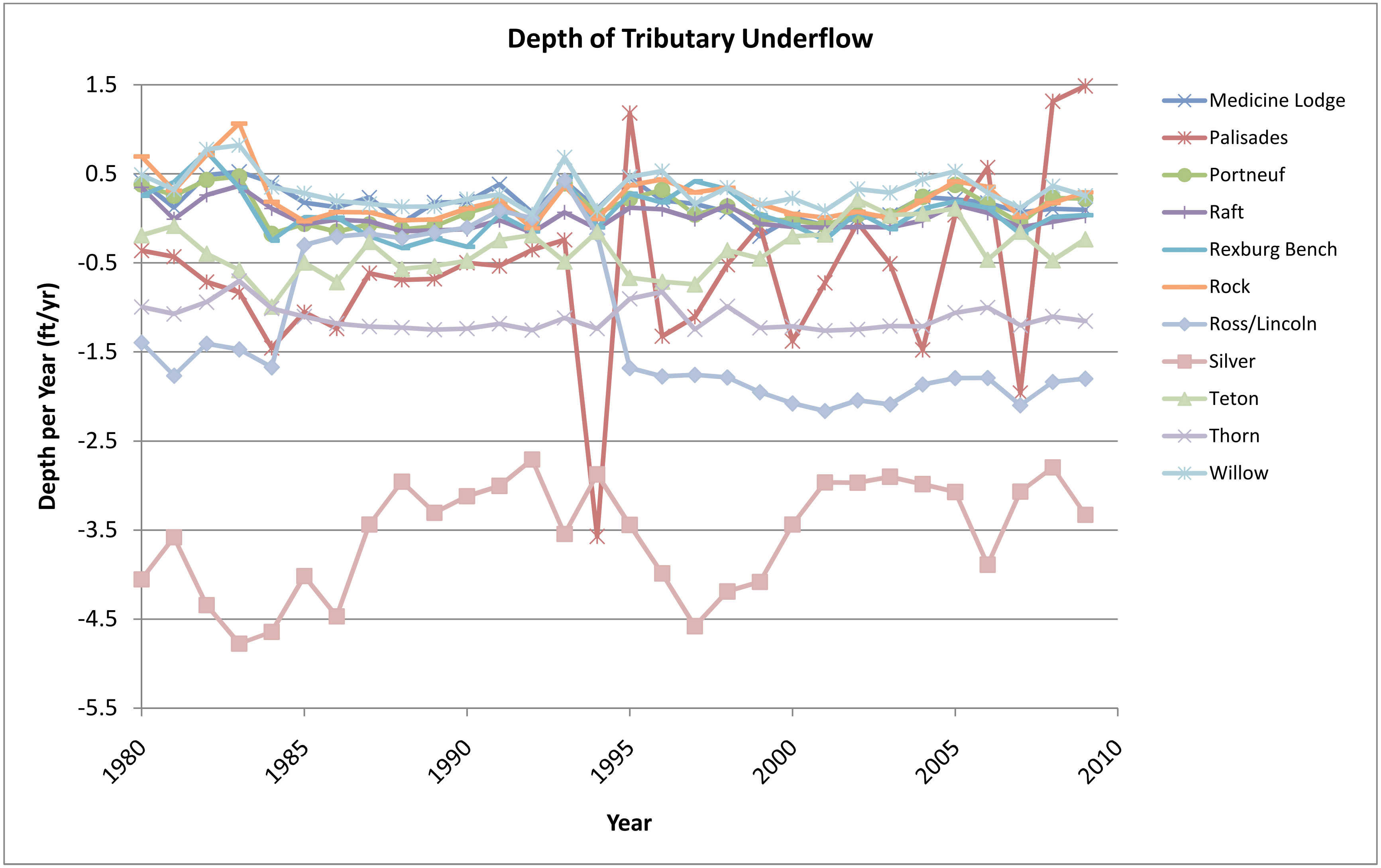

Figure 10b. Estimates of underflow as a depth for basins tributary to the Eastern Snake River Plain. Note that the vertical scale in this figure is different from Figure 10a.

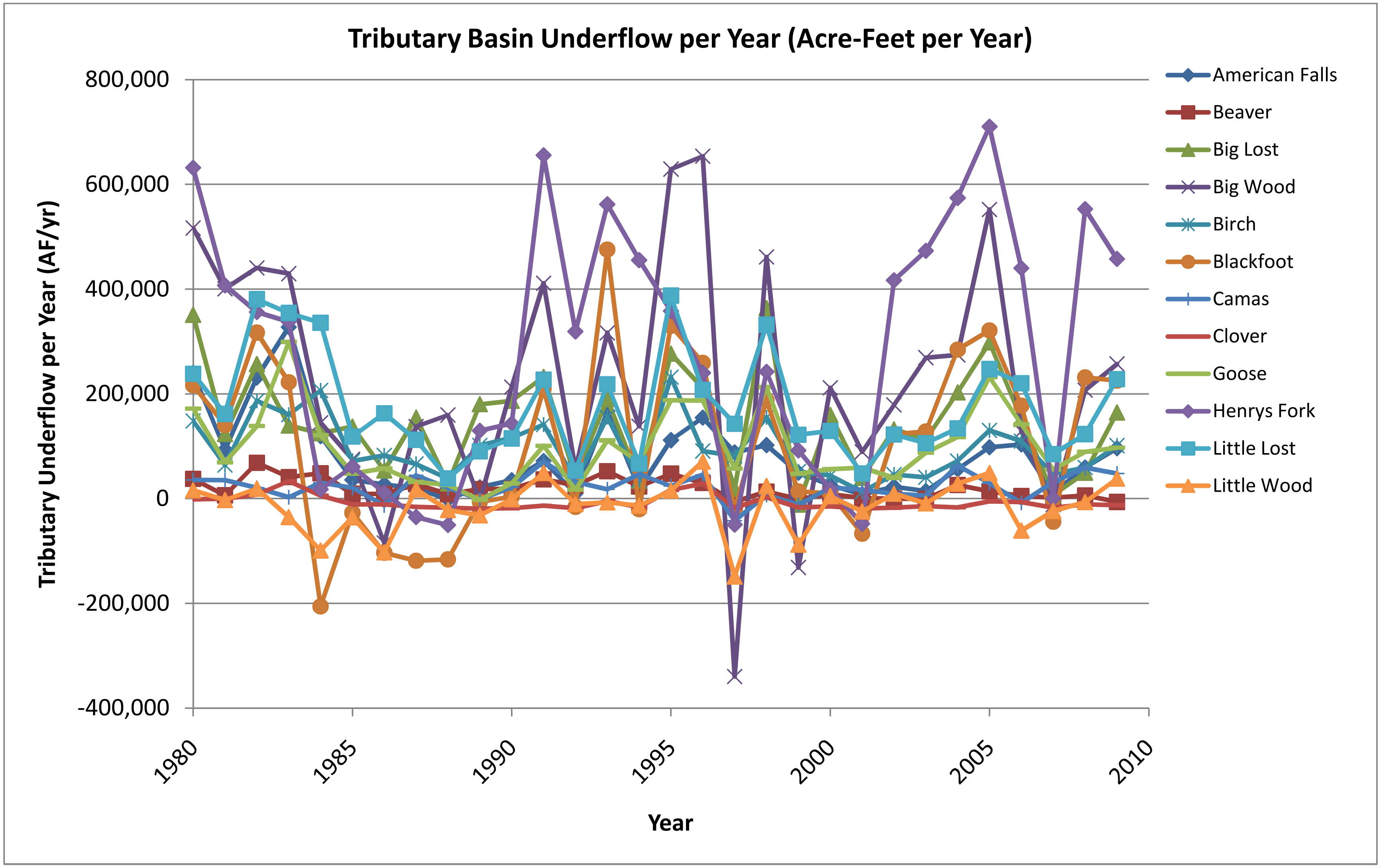

Figure 11a. Volumetric estimates of underflow for basins tributary to the Eastern Snake River Plain.

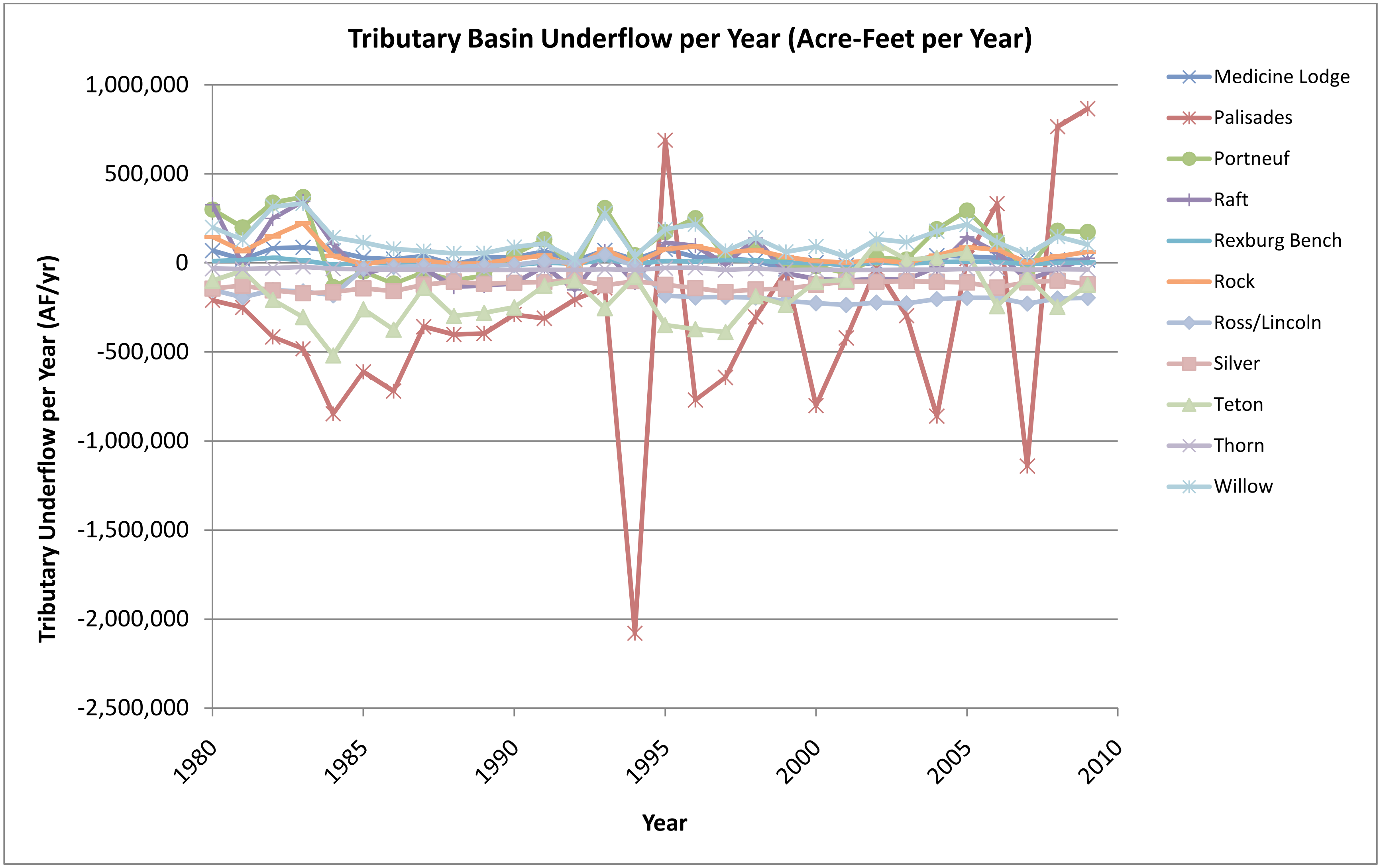

Figure 11b. Volumetric estimates of underflow for basins tributary to the Eastern Snake River Plain. Note that the vertical scale in Figure 11a is different than the scale in this figure.

Given the negative values in both Figures 10 and 11, it is apparent that some estimates are incorrect. The basins are sufficiently higher in elevation than the Eastern Snake Plain that flow from the regional aquifer into the tributary basins is highly unlikely, except perhaps in the Raft River Basin. In an attempt to reveal the cause of the negative values, sources of possible error were reviewed. Such sources of error may be found present within one or more of the following sources from Equation 3:

(1) Streamflow. Some gages that were necessary to estimate surface flow out of a basin and into the Eastern Snake Plain did not have complete records during 1980 – 2009. As a result, missing values were filled in with average values. These averages could overestimate the flow for the missing period of time causing more water to be removed from the basin yield value than appropriate. Some gages were also not in the most appropriate place. For instance, the gage Camas Creek at Red Road near Kilgore, was approximately 11 miles outside the basin boundary. Since this gage was downstream of the basin boundary, it is possible that additional inflows such as irrigation returns were also included in the gage reading suggesting a too-large flux of surface water out of the basin.

(2) Irrigated ET. There are several possible sources of error associated with irrigated ET. First, ET on irrigated lands was estimated using METRIC data. There is some overlap of ET between potential ET and METRIC ET; implicit in the Langbein yield is the naturally-occurring ET that would have resulted from precipitation, were the lands not irrigated. The METRIC ET implicitly includes ET resulting from precipitation along with ET from irrigation. The effect is not large because irrigated lands are a small fraction of total area, and typically occur at lower elevations with less precipitation and more natural ET. However, this overlap does result in the removal of slightly more ET from the basin yield than necessary, possibly resulting in a negative value for tributary underflow. Second, the METRIC data are currently only available for the years 2000, 2002, and 2006. An average of these values was used for the entire period of 1980 – 2009, which may have been an overestimate for earlier years. Third, the irrigated lands data available in the tributary basins are nearly 20 years old. Finally, the extrapolation based on elevation bands assumes that the irrigated lands outside the METRIC images have crop mix and irrigation management patterns similar to lands inside the METRIC images. If the lands outside are characterized by irrigated pastures, casual management, and junior water rights; the extrapolated ET could be over-estimated by a factor of two.

(3) The Langbein Relationship. While the Thornthwaite (1948) method is attractive due to its simplicity and few variables required, Jensen et al. (1990) warned that it is generally only applicable to areas that have climates similar to that of the east central U.S. and is

not applicable to arid and semiarid regions. The Langbein method is associated with a variety of climates in the U.S.; although, Nace et al. (1961) recognizes that water yield is not entirely explained by climatic variables (in this case, precipitation, potential ET, and temperature).

Following the assumption that the ET calculated on irrigated lands could be overestimated, irrigated ET was removed from Equation 3. Equation 5 was then used to calculate tributary underflow:

Tributary Underflow = Water Yield – Surface Flow Exiting the Basin Equation 5

This resulted in fewer negative underflow values, yet many negative values were still present. Figures 12a and 12b show the tributary underflow depths calculated. A large majority of the basins with values -0.5 feet of depth or smaller (larger negative values) include surface flow estimates from gages that are either (1) not in a desirable location relative to the model boundary or (2) have incomplete gage records. Figure 13 was constructed by removing basins with questionable gage data from Figures 10a and 10b. The tributary basins represented in Figure 13 possess the most suitable gage station records, in which "suitable" is defined as a gage located less than eight miles from the model boundary and having no more than five years missing from the gage record. Exceptions to this definition are the Beaver, Birch, Medicine Lodge, and Little Lost basins since missing flow data at these gages were estimated using gages with similar characteristics (Taylor and Moore, 2009). Negative values are still present in some underflow depths; however, the lack of gage station records of surface-water flow suggests potential for error in calculating tributary underflow using Equation 4.

A final possibility is that in water short periods, groundwater from the tributary valley aquifer sustains baseflow in streams, supporting irrigation and/or surface flows exiting the basin. Short-term indications of negative contribution to tributary underflow may in fact be accurate. Since most of the basins are physically at significantly higher elevation than the regional aquifer, if this explanation is correct, it must be that storage in the tributary aquifer buffers year-to-year differences, and that the actual tributary underflow contribution to the regional system is some multi-year average of basin yield less irrigation ET and surface outflows.

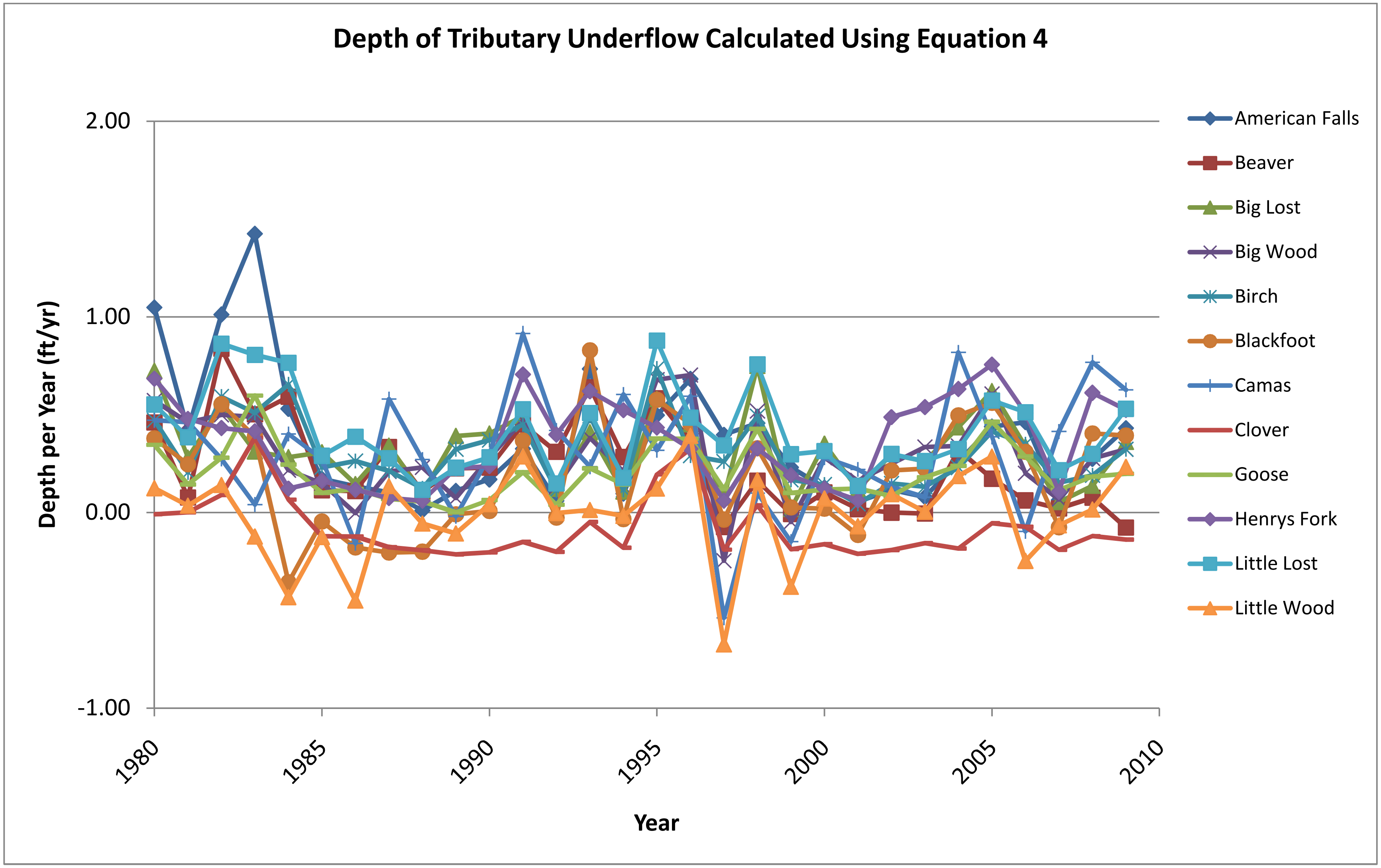

Figure 12a. Tributary underflow depths calculated using Equation 4.

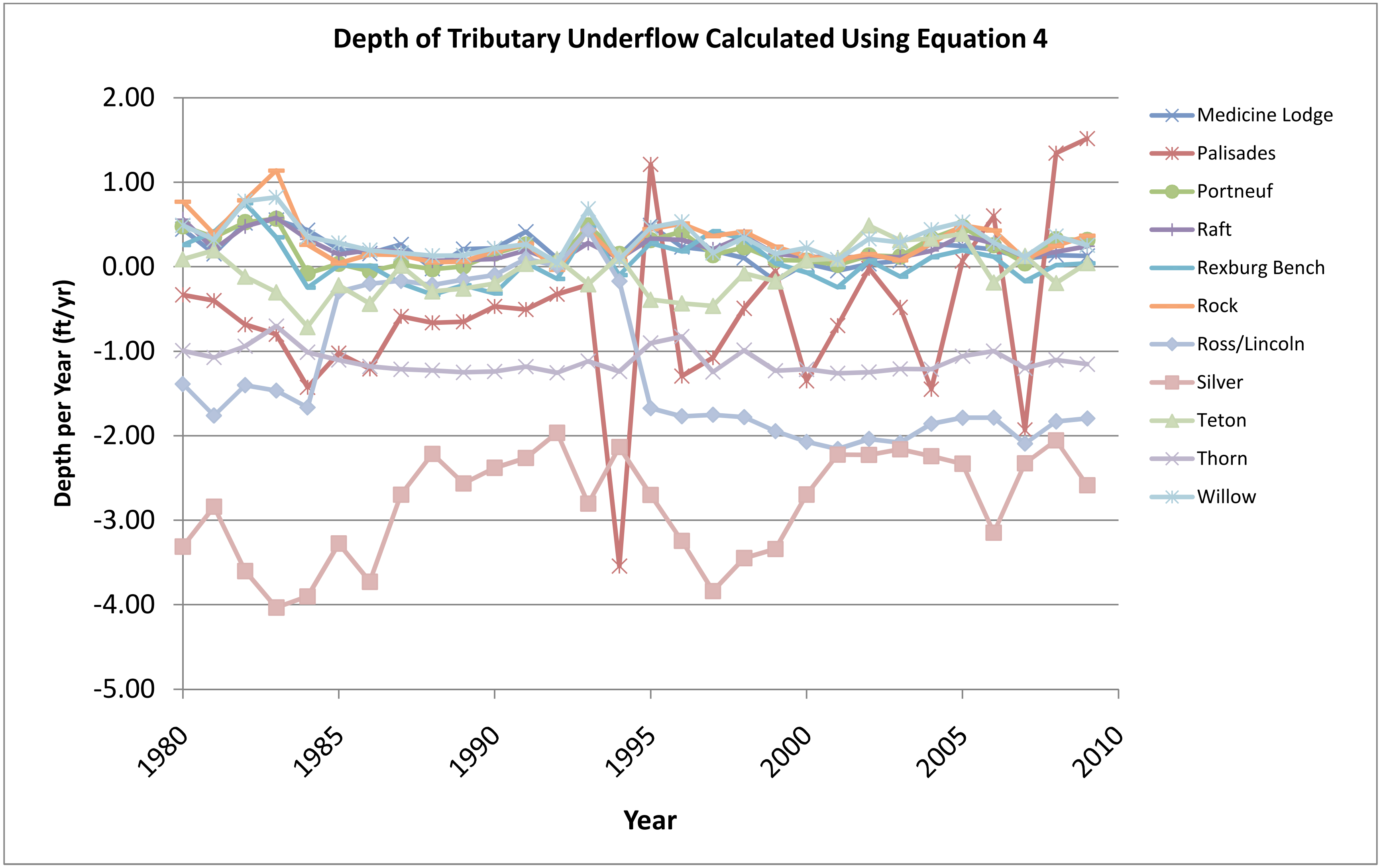

Figure 12b. Tributary underflow depths calculated using Equation 4. Note that this scale is different Figure 12a for the purpose of showing basins with larger values of depth.

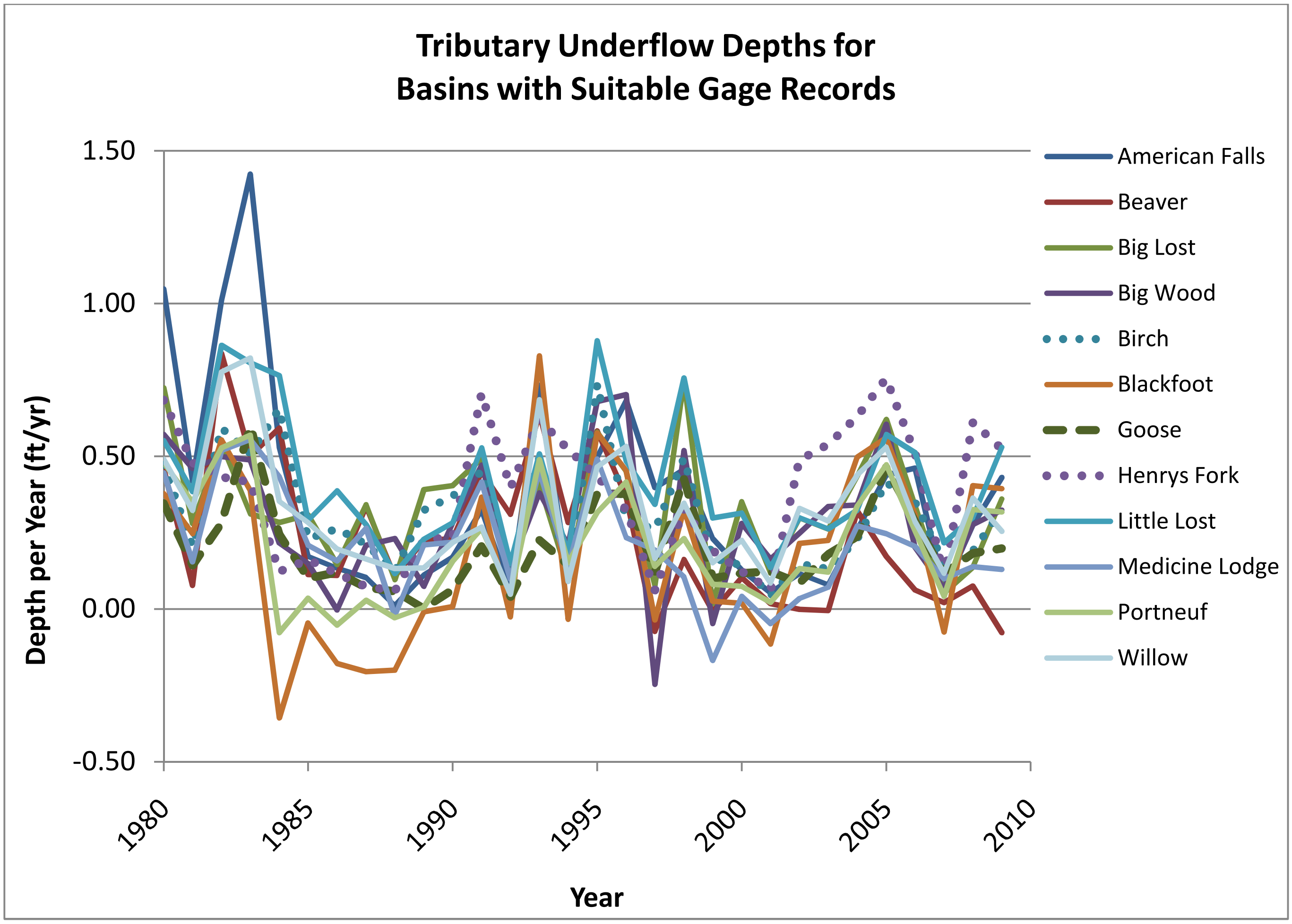

Figure 13. Tributary underflow depths for basins of the Eastern Snake Plain with suitable gage station records near the model boundary.

SUMMARY AND CONCLUSIONS

The goal of this project was to estimate the total basin yield for each tributary basin contributing groundwater underflow to the Eastern Snake Plain Aquifer. From this value, the amount of water entering the Eastern Snake Plain as underflow could be derived. The Langbein method (Nace et al. 1961) has been used to estimate total water yield for basins in North America using mean annual precipitation and temperature data. Since that report has been published, better techniques such as PRISM have been developed to estimate the climatic parameters of precipitation and temperature.

Tributary underflow was calculated in this report as the difference between basin yield and water leaving the basin as streamflow and ET from irrigated lands. When quality streamflow data were present for a basin, calculated values of underflow appeared reasonable. It is assumed that all basins discussed in this report contribute some underflow to the Eastern Snake Plain, thus negative values indicate a temporary cessation of underflow or an error in the calculation. Some of the basins with the most positive underflow values and suitable streamflow records (some records were "suitably" estimated) include the following:

(1) American Falls
(2) Beaver
(3) Big Lost
(4) Big Wood
(5) Birch
(6) Blackfoot
(7) Goose
(8) Henrys Fork
(9) Little Lost
(10) Medicine Lodge
(11) Portneuf
(12) Willow

While the Langbein method has been previously used to estimate basin yield in basins tributary to the Eastern Snake River Plain (Little Lost, Raft), this work suggests the values for basin yield may be underestimated and may not be optimal for use in an arid climate. Other potential concerns for estimating underflow from basin yield are related to the limited information available for streamflow and imprecision in the application of METRIC ET data. For future studies of basin yield, each individual basin should be analyzed based on the amount of information available for that basin and the type of climate.

ACKNOWLEDGMENTS

The authors of this report would like to thank the U.S. Geological Survey and the Idaho Department of Water Resources for providing financial support needed to complete this research opportunity.

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