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Assessment of Areal Recharge to the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho

Scientific Investigations Report 2007–5038

U.S. Department of the Interior
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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

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Conversion Factors

Multiply	By	To obtain
cubic foot per second (ft³/s)	0.02832	cubic meter per second (m³/s)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
inch (in.)	25.4	millimeter (mm)
inch per day (in/d)	25.4	millimeter per day (mm/d)
inch per month (in/mo)	25.4	millimeter per day (mm/mo)
joule (J)	0.0000002	Kilowatt hour (kWh)
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
meter per second (m/s)	3.281	foot per second (ft/s)
mile (mi)	1.609	kilometer (km)
square mile (mi²)	2.590	square kilometer (km²)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

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Assessment of Areal Recharge to the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho

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Abstract

A numerical flow model of the Spokane Valley-Rathdrum Prairie aquifer currently (2006) being developed requires the input of values for areally-distributed recharge, a parameter that is often the most uncertain component of water budgets and ground-water flow models because it is virtually impossible to measure over large areas. Data from six active weather stations in and near the study area were used in four recharge-calculation techniques or approaches; the Langbein method, in which recharge is estimated on the basis of empirical data from other basins; a method developed by the U.S. Department of Agriculture (USDA), in which crop consumptive use and effective precipitation are first calculated and then subtracted from actual precipitation to yield an estimate of recharge; an approach developed as part of the Eastern Snake Plain Aquifer Model (ESPAM) Enhancement Project in which recharge is calculated on the basis of precipitation-recharge relations from other basins; and an approach in which reference evapotranspiration is calculated by the Food and Agriculture Organization (FAO) Penman-Monteith equation, crop consumptive use is determined (using a single or dual coefficient approach), and recharge is calculated.

Annual recharge calculated by the Langbein method for the six weather stations was 4 percent of annual mean precipitation, yielding the lowest values of the methods discussed in this report, however, the Langbein method can be only applied to annual time periods. Mean monthly recharge calculated by the USDA method ranged from 53 to 73 percent of mean monthly precipitation. Mean annual recharge ranged from 64 to 69 percent of mean annual precipitation. Separate mean monthly recharge calculations were made with the ESPAM method using initial input parameters to represent thin-soil, thick-soil, and lava-rock conditions. The lava-rock parameters yielded the highest recharge values and the thick-soil parameters the lowest. For thin-soil parameters, calculated monthly recharge ranged from 10 to 29 percent of mean monthly precipitation and annual recharge ranged from 16 to 23 percent of mean annual precipitation. For thick-soil parameters, calculated monthly recharge ranged from 1 to 5 percent of mean monthly precipitation and mean annual recharge ranged from 2 to 4 percent of mean annual precipitation. For lava-rock parameters, calculated mean monthly recharge ranged from 37 to 57 percent of mean monthly precipitation and mean annual recharge ranged from 45 to 52 percent of mean annual precipitation.

Single-coefficient (crop coefficient) FAO Penman-Monteith mean monthly recharge values were calculated for Spokane Weather Service Office (WSO) Airport, the only station for which the necessary meteorological data were available. Grass-referenced values of mean monthly recharge ranged from 0 to 81 percent of mean monthly precipitation and mean annual recharge was 21 percent of mean annual precipitation; alfalfa- referenced values of mean monthly recharge ranged from 0 to 85 percent of mean monthly precipitation and mean annual recharge was 24 percent of mean annual precipitation. Single-coefficient FAO Penman-Monteith calculations yielded a mean monthly recharge of zero during the eight warmest and driest months of the year (March-October).

In order to refine the mean monthly recharge estimates, dual-coefficient (basal crop and soil evaporation coefficients) FAO Penman-Monteith dual-crop evapotranspiration and deep-percolation calculations were applied to daily values from the Spokane WSO Airport for January 1990 through December 2005. The resultant monthly totals display a temporal variability that is absent from the mean monthly values and demonstrate that the daily amount and timing of precipitation dramatically affect calculated recharge. The dual-coefficient FAO Penman-Monteith calculations were made for the remaining five stations using wind-speed values for Spokane WSO Airport and other assumptions regarding missing data. For the six stations, monthly recharge (totaled from daily values, 1990-2005) ranged from 0 to 94 percent of monthly precipitation.

Without *a priori* knowledge of probable values of areal recharge, choosing between values of recharge calculated by different methods is a challenging decision. Thus, the larger context provided by water budgets and ground-water flow model calibration is crucial in determining reasonable values.

Introduction

The approximately 370 mi² Spokane Valley-Rathdrum Prairie (SVRP) aquifer straddles the Idaho-Washington state line northeast of the City of Spokane (fig. 1). Because the aquifer serves as the sole source of drinking water for more than 400,000 people and the area is experiencing rapid population growth, a better understanding of the aquifer characteristics and its interaction with the Spokane River is necessary to guide the development and management of the resource. To this end, a multi-year study began in 2003 to gather data necessary to construct a ground-water flow model of the SVRP aquifer that both states could use to evaluate potential water-development and management alternatives.

Currently (2006), a ground-water-flow model that simulates ground-water/surface-water interaction is under construction by a joint team from the Idaho Department of Water Resources, University of Idaho, Washington State University, and the U.S. Geological Survey. This model requires values for areally-distributed recharge from precipitation, but such values are commonly the most uncertain components of water budgets and ground-water flow models because it is virtually impossible to measure recharge over large areas. In previous flow models of the SVRP aquifer, various approaches or techniques have been used to estimate areal recharge, ranging from assigning a uniform recharge to the entire model domain to calculating evapotranspiration for each model cell. An examination of previously developed recharge-calculation methods and their limitations is therefore needed to allow the SVRP aquifer modeling team to select and apply the most appropriate technique.
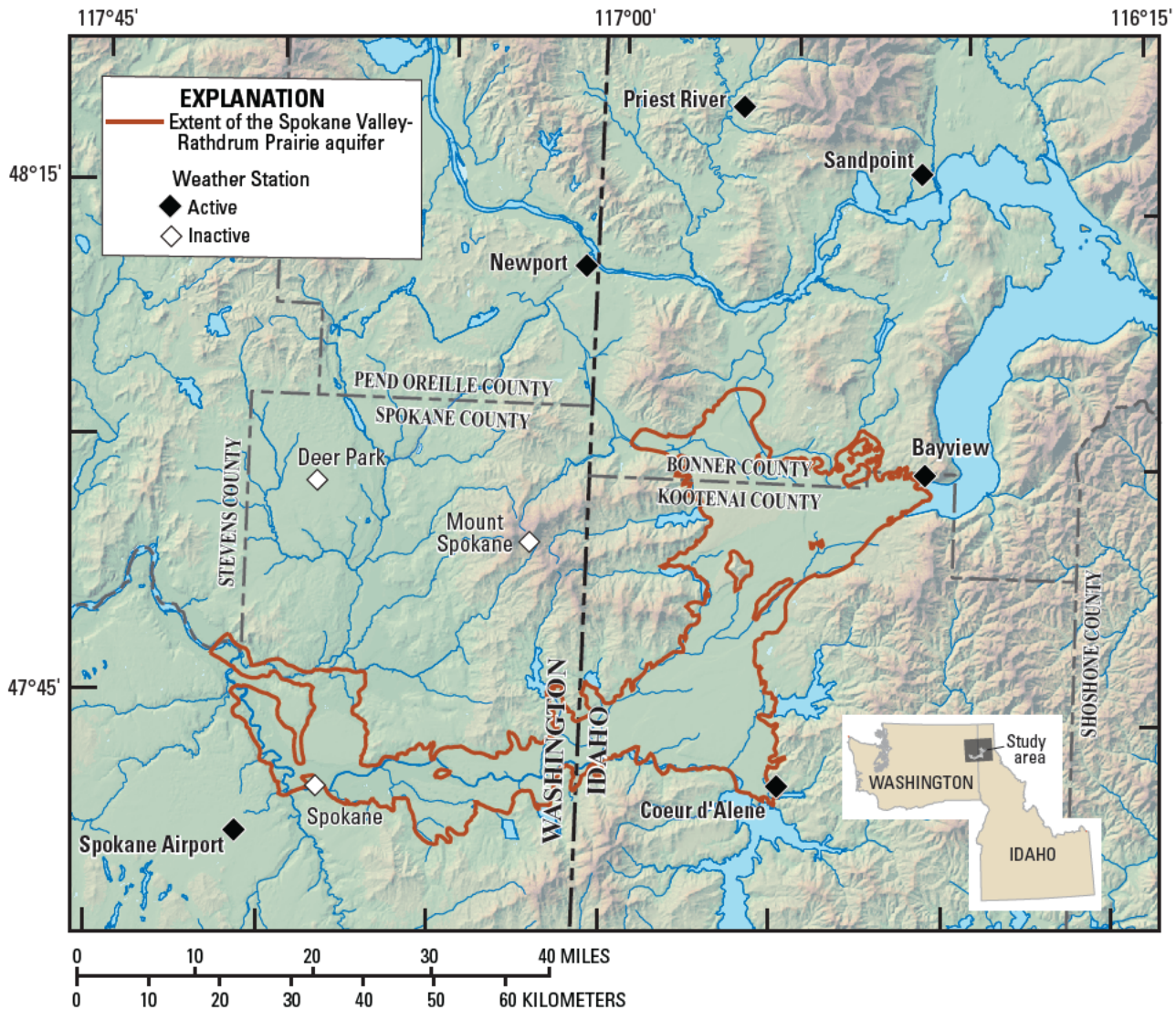
Figure 1.   Location of the Spokane Valley-Rathdrum Prairie aquifer and National Weather Service stations in and near the study area.

Purpose and Scope

This report describes four main methods for estimating areal recharge to the Spokane Valley-Rathdrum Prairie aquifer and provides recharge estimates for each method using data from weather stations in and near the study area. The limitations of each of the methods and the reliability of the recharge estimates are discussed. Because areal recharge is affected by soil hydrologic properties, those properties of the soils overlying the aquifer are briefly described in appendix A. The results of this analysis will be used by the SVRP aquifer modeling team to select an appropriate method for determining areal recharge for use in the flow model of the aquifer.

Description of Study Area

The Spokane Valley-Rathdrum Prairie aquifer underlies a relatively flat valley bottom with land-surface altitudes ranging from about 1,500 to nearly 2,600 ft. Ten lakes are located along the margins of the aquifer, the largest of which are Coeur d'Alene Lake and Lake Pend Oreille. Because the sediments of the valley floor are highly permeable, few distinct surface-drainage channels have developed other than the Spokane and Little Spokane Rivers.

Bedrock highlands of Precambrian metamorphic, Mesozoic and Cenozoic intrusive, and Tertiary basaltic rocks surround the valley. The valley is filled with Quaternary-age glaciofluvial sediments deposited during several catastrophic flood events from glacial Lake Missoula. The Spokane Valley-Rathdrum Prairie aquifer straddles the boundary between the Northern Rocky Mountain and Columbia Plateau physiographic provinces (Fenneman, 1931).

Ground water is the primary source for public-supply, domestic, irrigation, and industrial water use in the area, which led to the U.S. Environmental Protection Agency (USEPA)

giving the aquifer "sole source" designation in 1978 (Kahle and others, 2005). Currently (2006), the aquifer is the source of drinking water for as many as 400,000 people.

A more complete description of the study area may be found in Kahle and others (2005).

Climate

Spokane has a mild, arid climate during the summer months but cold, coast-like conditions in the winter (U.S. Department of Commerce, 2005). Approximately 70 percent of the total annual precipitation falls between the first of October and the end of March and about one-half of that falls as snow. The growing season usually extends over nearly six months from mid-April to mid-October (U.S. Department of Commerce, 2005).

The entire study area is classified as *Dsb* under a modified Köppen system in which *D* indicates a mean temperature of the warmest month greater than 10°C (40°F) and of the coldest month 0°C (32°F) or less; *s* indicates that precipitation in the driest month of the summer half of the year is less than 40 mm (1.6 in.) and less than one-third of the precipitation amount in the wettest winter month; and *b* indicates that the mean temperature of each of the four warmest months is 10°C (40°F) or greater and the mean temperature of the warmest month is less than 22°C (72°F) (Critchfield, 1983; Godfrey, 2000).

The National Weather Service (NWS) has nine weather stations in or within 20 mi of the study area, although only six are active (table 1). Of these, only three are within or adjacent to the SVRP aquifer study area: Bayview Model Basin, Coeur D'Alene 1E, and Spokane Weather Service Office (WSO) Airport. Currently (2006), the closest AgriMet station to the study area is the Seven Bays Marina, Washington, (SBMW), near the confluence of the Spokane and Columbia Rivers, approximately 50 mi west of Spokane (Bureau of Reclamation, 2006).

Table 1.   National Weather Service stations in or near the study area.

[Western Regional Climate Center (2006a, 2006b). **Abbreviations**: ID, Idaho, WA, Washington; WSO, Weather Service Office. **Symbols:** –, currently (2006) in operation]

Station name	Station number	Elevation (feet above vertical datum)	Latitude	Longitude	Dates in operation	
					Starting	Ending
Bayview Model Basin, ID	100667	2,070	47°59'N	116°33'W	08-01-48	–
Coeur D'Alene 1E, ID	101956	2,160	47°41'N	116°45'W	08-01-1895	–
Deer Park 2E, WA	452066	2,200	47°58'N	117°26'W	07-04-48	03-31-77
Mount Spokane Summit, WA	455674	5,890	47°55'N	117°07'W	07-01-53	12-31-72
Newport, WA	455844	2,140	48°11'N	117°03'W	01-02-27	–
Priest River Experiment Station, ID	107386	2,380	48°21'N	116°50'W	12-07-11	–
Sandpoint Experiment Station, ID	108137	2,100	48°17'N	116°34'W	10-01-10	–
Spokane WSO Airport, WA	457938	2,360	47°37'N	117°32'W	01-01-1890	–
Spokane, WA	457933	1,880	47°40'N	117°25'W	11-19-53	10-31-83

Table 2.   Summary of data from active weather stations in and near the Spokane Valley-Rathdrum Prairie area.

[Western Regional Climate Center (2006a, 2006b). Mean values are through December 31, 2005. **Abbreviations:** Exp. Stat., experiment station; WSO, Weather Service Office;   F, degrees fahrenheit; in., inch; max., maximum; min., minimum]

	Station name and number					
	Bayview Model Basin 100667	Coeur D' Alene 1E 101956	Newport 455844	Priest River Exp. Stat. 107386	Sandpoint Exp. Stat. 108137	Spokane WSO Airport 457938
Mean July max. temperature (°F)	79.6	85.0	85.3	82.6	81.9	83.9
Mean January min. temperature (°F)	21.0	21.8	18.2	18.1	20.3	21.6
Mean January max. temperature (°F)	34.7	34.6	31.8	30.4	32.3	33.0
Mean annual temperature (°F)	50.3	53.4	51.8	50.3	51.1	52.8
Mean annual precipitation (in.)	24.1	25.2	26.2	31.1	32.0	16.1
Mean annual snowfall (in.)	37.9	46.0	58.0	81.8	70.5	41.0
Mean snow depth (in.)	1.0	1.0	3.0	5.0	2.0	1.0

Mean annual temperatures at the six active NWS stations in and near the study area range from 44.9°F at Bayview Model Basin to 48°F at Coeur D'Alene 1E and at Spokane WSO Airport. The coldest month in the area is January, with mean low temperatures ranging from 18.1°F at Priest River Experiment Station to 21.8°F at Coeur D'Alene 1E. The warmest month is July, with mean high temperatures ranging from 79.6°F at Bayview Model Basin to 85.3°F at Newport (table 2; Western Regional Climate Center, 2006a, 2006b). Mean annual precipitation ranges from 16.1 in. at Spokane WSO Airport to about 32 in. at Sandpoint Experiment Station (Western Regional Climate Center, 2006a, 2006b). July and August are typically the driest months and November, December, and January the wettest.

Of the six active stations, only Spokane WSO Airport collects meteorological parameters beyond temperature, precipitation, and snow depth. This limits the ability to calculate evapotranspiration and recharge at each of the other stations by methods requiring such data as wind speed or relative humidity. Table 3 summarizes the meteorological data necessary to calculate recharge by each of the four main methods discussed in this report.

None of the three currently active stations in or adjacent to the study area have mean maximum temperatures of less than 32°F for any month (table 2). Therefore, recharge probably occurs throughout the winter and no adjustment is needed to winter recharge timing due to melting snowpack.

Types of Evapotranspiration

Any calculation of areal recharge must account for evapotranspiration as well as precipitation. Because the methods discussed in this report use different definitions of evapotranspiration, short definitions are given here:

Potential evapotranspiration (*PET*) is the "*evapotranspiration rate of short, actively transpiring vegetation (e.g., grass) that: completely covers the ground; is well-supplied with water; and exerts negligible resistance to water movement through the plant*" (Tindall and others, 1999). If sufficient water were available, *PET* indicates the amount of water that could undergo evapotranspiration. *PET* is a climatic parameter because it denotes the evaporation power of the atmosphere. In order to determine actual evapotranspiration, a crop coefficient must be included.

Table 3.   Summary of meteorological data necessary for recharge calculations.

[**Abbreviations**: USDA, U.S. Department of Agriculture; ESPAM, Eastern Snake Plain Aquifer Model; FAO, Food and Agriculture Organization; max., maximum; min., minimum]

Data	Recharge calculation method			
	Langbein	USDA	ESPAM	FAO Penman-Monteith
Precipitation	○	●	●	●
Potential evapotranspiration	○	●		
Temperature, mean		●		●
Temperature, max.				●
Temperature, min.				●
Altitude				●
Latitude				●
Relative humidity, min.				●
Relative humidity, max.				●
Percent of possible sunshine				●
Wind speed				●
Dew point				●
Annual data only	○			
Variable time period	●			

Consumptive use (or actual evapotranspiration), as defined in U.S. Department of Agriculture (USDA; 1970), is "*the amount of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil or intercepted precipitation on the plant foliage in any specified time.*"

Reference crop evapotranspiration (ET_0) is the evapotranspiration rate from a reference surface (a hypothetical grass reference crop with specific characteristics) that is not short of water. It also denotes the evaporation power of the atmosphere and thus is a climatic parameter (Allen and others, 1998). As with *PET*, in order to determine actual evapotranspiration, a crop coefficient must be included.

Crop evapotranspiration under standard conditions (ET_c) is the evapotranspiration rate from "*disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions*" (Allen and others, 1998).

Crop evapotranspiration under non-standard conditions ($ET_{c\,adj}$) is the evapotranspiration rate from fields with less than optimal environmental factors such as "*pests and diseases, soil salinity, low soil fertility, water shortage or water logging*" (Allen and others, 1998).

Description of Recharge-Estimation Techniques

Four potential approaches were identified for determining areal recharge for the SVRP ground-water flow model:

1. A method developed by Langbein (1961) in which recharge is estimated on the basis of empirical data from other basins;

2. A method developed by the U.S. Department of Agriculture (1970) in which crop consumptive use and effective precipitation are first calculated and then subtracted from actual precipitation to yield an estimate of recharge;

3. An approach developed by Contor (2004) for the Eastern Snake Plain Aquifer Model (ESPAM) Enhancement Project in which recharge is calculated on the basis of precipitation-recharge relations from other basins; and

4. An approach in which reference evapotranspiration is calculated by the Food and Agriculture Organization (FAO) Penman-Monteith equation (Allen and others, 1998), crop consumptive use is determined (using a single or dual coefficient approach), and the amount of water which passes through the plant root zone (and thus becomes recharge) is calculated.

These four methods will henceforth be referred to by Langbein, USDA, ESPAM, and FAO Penman-Monteith, respectively.

In the following discussion, the names of variables are reported essentially as those names are used in the original reference, both to preserve the sometimes subtle differences in the original authors' definitions and to facilitate comparison with the original work. Thus, some variable names may be duplicated between and within the equations describing the different approaches, though with different meanings. For this reason, variables are defined for each equation, thereby introducing some repetitiveness.

Previous Work

The most recent estimates of areal recharge to the SVRP aquifer system were made for application in ground-water flow models. Because the purpose, model code, and simulated area vary among the various models, recharge estimates (especially volumetric estimates) may not be directly comparable and are best viewed as approximate comparisons.

In their finite-element ground-water flow model of the Spokane area, Bolke and Vaccaro (1981) used the USDA method described below to determine effective rainfall, which was then subtracted from precipitation to determine recharge. Precipitation, evapotranspiration, and recharge values were applied uniformly over the model domain. For their steady-state, time-averaged simulation, they used values of 1.72 in/mo for precipitation and 1.31 in/mo for potential evapotranspiration (or 209 and 143 ft^3/s, respectively). For the transient simulation, Bolke and Vaccaro used monthly precipitation and potential and actual evapotranspiration values from May 1977 to April 1978; their calculated recharge ranged from 0 to about 4.5 in/mo (or maximum values of 216 and 98 ft^3/s, for precipitation and evapotranspiration, respectively).

The CH2M Hill (1998) finite-element ground-water flow model of the Spokane area redistributed the 66 ft^3/s annual steady-state recharge used by Bolke and Vaccaro (1981) to reflect spatial variation in precipitation based on the work of Olness (1993). During calibration of the CH2M Hill model, the areal recharge was adjusted, resulting in an areal-recharge volume less than half of Bolke and Vaccaro's value.

Buchanan (2000) constructed a finite-difference ground-water flow model of the entire Spokane Valley-Rathdrum Prairie aquifer. Recharge was estimated to be 25 percent of precipitation volume and was varied areally, resulting in recharge rates ranging from 0.017 to 0.028 in/d.

Golder Associates, Inc. (2004) constructed integrated ground-surface-water models of the Little Spokane (WRIA 55) and Middle Spokane (WRIA 57) watersheds using the MIKE SHE modeling program, in which the ground-water

component is calculated by the finite-difference method (DHI software, 2006). The MIKE SHE code allows precipitation and evapotranspiration to be specified separately, thus monthly potential evapotranspiration estimates were made using the Blaney-Criddle FAO method (Doorenbos and Pruitt, 1977) and precipitation was varied areally using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) data (Daly and others, 1994, 1997, 1998). Golder Associates, Inc. (2004) specified evapotranspiration as 74 percent of annual precipitation in the Middle Spokane watershed model, and 64 percent of precipitation in the Little Spokane watershed model. An approximation of these recharge rates can be made by subtracting evaporation from precipitation and applying the mean annual rainfall of 17.62 in. at the discontinued Spokane weather station for the Middle Spokane watershed and 22.44 in. at the discontinued Deer Park 2E weather station for the Little Spokane watershed, yielding recharge rates of 0.38 and 0.67 in/mo, respectively.

These and other values of areal recharge used by previous workers for water budgets and ground-water flow models of the SVRP aquifer area are described in Kahle and others (2005).

Langbein Method

The Langbein method was developed as part of a study of the water resources of the Raft River basin, Idaho and Utah (Langbein, 1961). Because the basin was largely uninstrumented, it was necessary to estimate water yield by indirect means, and the resulting method is based on empirical relations developed on the basis of data from other from drainage basins across the United States. The same methodology was later applied by Chapman and Young (1972) in the study of an area immediately east of the Raft River basin.

As applied in the Raft River basin, the derivation of basin yield was a multi-step process. First, mean annual temperatures and mean annual precipitation for the basin were calculated using relations between these parameters and elevation developed from nearby and regional weather stations; the areal distribution of precipitation was then corrected for local topographic effects. Next, using the results of earlier work by Langbein and others (1949) that defined a relation between mean annual temperature and potential evapotranspiration, values for potential evapotranspiration were derived for the basin. In the third step, the ratio of annual precipitation to potential evapotranspiration was calculated, and using relations developed for other basins across the United States (Langbein and others, 1949), the ratio of runoff to potential evapotranspiration was obtained. Finally, these values were incorporated in an equation that is solved for the value of basin yield or runoff:

$$R_a = L_a \frac{P_a}{L_a}, \qquad (1)$$

where

R_a is annual basin yield or runoff, in inches,
L_a is annual potential evapotranspiration, in inches, and
P_a is annual precipitation, in inches.

The graph relating mean annual temperature and potential evapotranspiration is available in Langbein and others (1949), Langbein (1961), and Chapman and Young (1972). The graph relating P_a/L_a to R_a/L_a is available in Langbein (1961) and Chapman and Young (1972). Alternatively, B.A. Contor (Idaho State University, written commun., March 9, 2006) derived a regression equation with a correlation coefficient (R^2) of 0.96 describing the relations in the latter graph:

$$\frac{R_a}{L_a} = (0.16534831 - 0.63978817 \left(\frac{P_a}{L_a} \right)$$
$$+ 0.772829589 \left(\frac{P_a}{L_a} \right)^2 - 0.117252503 \left(\frac{P_a}{L_a} \right)^3, \qquad (2)$$

where

R_a is annual basin yield or runoff, in inches,
L_a is annual potential evapotranspiration, in inches, and
P_a is annual precipitation, in inches.

At low values of precipitation, this equation calculates runoff values greater than precipitation, thus Contor applied an alternative linear calculation for P_a/L_a ratios less than 0.55:

$$\frac{R_a}{L_a} = \left(\frac{P_a}{L_a} \right) 0.04, \qquad (3)$$

where

R_a is annual basin yield or runoff, in inches,
L_a is annual potential evapotranspiration, in inches, and
P_a is annual precipitation, in inches.

As used here, it is assumed that basin yield is equal to ground-water recharge because the sediments that compose the SVRP valley floor are highly permeable, and little surface drainage reaches the Spokane and Little Spokane Rivers. An important limitation of the method is that it is applicable only to annual time periods. To calculate values for shorter time increments, annual values must be divided by some scheme such as simple division.

USDA Method

The USDA method is based on the Blaney-Criddle formula (Blaney and Criddle, 1962) for calculating crop consumptive use:

$$U = KF \ , \qquad (4)$$

where

    U is seasonal consumptive use of water, in inches,

    K is empirical seasonal consumptive-use crop coefficient, dimensionless, and

    F is sum of monthly consumptive use factors for the growing season, dimensionless.

Equation 4 is then restated for monthly consumptive use as:

$$u = kf \ , \qquad (5)$$

where

    u is monthly consumptive use of water, in inches,

    k is empirical monthly consumptive-use crop coefficient, dimensionless, and

    f is monthly consumptive use factors for the growing season, dimensionless.

The monthly consumptive use factor (f) is calculated with equation 6:

$$f = \frac{tp}{100} \ , \qquad (6)$$

where

    f is monthly consumptive use factors for the growing season, dimensionless,

    t is mean air temperature, °F, and

    p is percentage of daylight hours in the year.

Representative values for K and k are given in Blaney and Criddle (1962).

In order to refine the calculation of the consumptive use crop coefficient (k) for application to shorter time periods with more climatic variability, U.S. Department of Agriculture (1970) describes a modification of the Blaney-Criddle formula where k is calculated by:

$$k = k_t k_c, \qquad (7)$$

where

    k is empirical monthly consumptive use crop coefficient, dimensionless,

    k_t is climatic coefficient related to mean air temperature, dimensionless, calculated as: $k_t = 0.0173t\text{-}0.314$,

    t is mean air temperature, °F, and

    k_c is crop growth-stage coefficient, dimensionless (U.S. Department of Agriculture, 1970).

To calculate consumptive use, effective rainfall must be known, defined as the amount of precipitation that is available for crop consumptive use. The equation given in U.S. Department of Agriculture (1970) for effective rainfall is:

$$r_e = (0.70917 r_t^{0\ 82416} \text{-} 0.11556)(10)^{0\ 02426u}(f), \qquad (8)$$

where

    r_e is effective rainfall, in inches,

    r_t is mean rainfall, in inches,

    u is potential consumptive use, in inches,

    f is $0.531747 - 0.295164D - 0.057697D^2 + 0.003804D^3$, and

    D is net depth of water application, in inches.

(Note that the f in equation 8 is different than f in equations 5 and 6.)

Potential consumptive use (u) can be taken as either potential evapotranspiration or calculated with equations 5, 6, and 7, yielding:

$$u = (0.0173t - 0.314)k_c\left(\frac{tp}{100}\right), \qquad (9)$$

where

    u is potential consumptive use, in inches,

    t is mean air temperature, °F,

    k_c is crop growth-stage coefficient, dimensionless, (U.S. Department of Agriculture, 1970), and

    p is percentage of daylight hours in the year.

Values for r_t, t, and p can be specified for annual, monthly, or shorter time periods. If the calculated effective rainfall (r_e) exceeds either the mean rainfall (r_t) or mean consumptive use (u), it must be set to the lower of the latter two values.

In their transient ground-water flow model of the Spokane Valley, Bolke and Vaccaro (1981) used the USDA method to determine effective rainfall and assumed that effective rainfall was equal to actual evapotranspiration, thus yielding equation 10, the amount of recharge from precipitation:

$$R = r_t - r_e, \qquad (10)$$

where

R	is recharge from precipitation, in inches,
r_t	is precipitation, in inches, and
r_e	is effective rainfall, in inches.

Bolke and Vaccaro (1981) further assumed mean monthly consumptive use (u) was equal to potential evapotranspiration at Spokane.

In preparing data sets for the SVRP aquifer model, B.A. Contor (written commun., March 9, 2006) determined that for low values of precipitation, effective precipitation can be negative as a result of using values lower than those used to develop the non-linear regression. Consequently, for precipitation amounts less than 0.96 in., he developed equation 11 to calculate effective precipitation (r_e):

$$r_e = r_t (1 - (0.700691 - 0.02543u)), \qquad (11)$$

where

r_e	is monthly effective rainfall, in inches,
r_t	is monthly mean rainfall, in inches, and
u	is monthly mean crop consumptive use, in inches.

The central assumption in applying this method to determination of recharge is that any precipitation not necessary for plant growth (evapotranspiration) is recharged to ground water.

ESPAM Method

As part of the Eastern Snake Plain Aquifer Model Enhancement Project (ESPAM), a geographic information system (GIS)-based method was developed to calculate recharge based on the PRISM gridded maps of monthly precipitation (Daly and others, 1994, 1997, 1998) and generalized soil maps (Contor, 2004, Cosgrove and others,

2006). The calculations are based on earlier work by Rich (1951, 1952), who measured water yield from basins with forest and rangeland vegetation in the Sierra Ancha experimental forest in central Arizona. Rich (1951, 1952) plotted runoff against precipitation for several watersheds to produce a separate curve for each basin. Contor (2004) fit equations to these curves yielding:

$$U = K \times F^N, \qquad (12)$$

where

U	is basin yield or runoff, in feet per month,
K	is empirical slope parameter, dimensionless,
F	is precipitation, in feet per month, and
N	is empirical coefficient for curvature, dimensionless.

(Note that the variable names and definitions have changed from equations 1-11.)

Contor (2004) further modified Rich's method in several ways in order to apply it to the shorter time periods and geologic conditions required by the ESPAM model. Like the SVRP aquifer area, most of the eastern Snake River Plain (ESRP) has little surface-water drainage that reaches the main through-flowing river, and Contor assumed that basin yield was equal to recharge. Thus:

$$R = K \times P^N, \qquad (13)$$

where

R	is recharge from precipitation, in feet per month,
K	is empirical slope parameter, dimensionless,
P	is precipitation, in feet per month, and
N	is empirical coefficient for curvature, dimensionless.

This relation is based on the assumption that a plot of recharge against precipitation has a low slope until sufficient precipitation occurs to exceed the requirements of soil-moisture storage, ponding, evaporation, and transpiration, after which recharge occurs. At higher values of precipitation, the curve would become linear and approach a slope of 1 (however, although Rich's (1951, 1952) data were collected over 15 years, with one year exceeding 200 percent of the mean precipitation, annual precipitation was still insufficient to reach this threshold). The distance the recharge curve is offset from the 1:1 line is controlled by the potential for precipitation to be diverted to the other pre-recharge precipitation requirements mentioned above. The degree

of curvature in the early, exponential part of the curve is controlled by preferential recharge pathways within the soil profile, and any surface concentration of precipitation due to topography. The application of the method to shorter time periods changes the relative importance of each of these other pre-recharge requirements; thus the equation parameters are dependent on the time-step length selected and also are unit-dependent. Contor (2004) used annual recharge values and generalized soil types from a previous ESRP ground-water flow model (Garabedian, 1992) to develop monthly parameters for three different soil types: lava rock (K=0.69, N=1.2), thin soil (K=0.463, N=1.5), and thick soil (K=0.136, N=2), where the units are in feet per month. These parameters were calibrated to match annual volumes of recharge used in the previous modeling effort by Garabedian (1992) as well as to match the curvature and transition points suggested by theoretical monthly values of pre-recharge precipitation requirements for each of the three soil types. Garabedian (1992), in turn, based his annual recharge values on those of Mundorff and others (1964), who used a simple precipitation to water-yield ratio derived from eight basins draining to the ESRP.

Because recharge cannot exceed precipitation, the slope of the recharge-precipitation line cannot exceed one. Low values of precipitation must first satisfy the pre-recharge requirements of soil-moisture storage, ponding, evaporation, and transpiration before recharge can occur, resulting in a nonlinear recharge curve. With increasing precipitation, these pre-recharge requirements are satisfied, the curve becomes linear, and there is a one-to-one linear relation between additional precipitation and additional recharge. To automate the calculation of recharge values, Contor derived the transition point—the point where the line makes the transition from exponential to linear and the non-linear function reaches a slope of one—defined as:

$$P_T = \left(\frac{1}{NK}\right)^{\left(\frac{1}{N-1}\right)}, \tag{14}$$

where
- P_T is transition precipitation, in feet per month,
- K is empirical slope parameter, dimensionless, and
- N is empirical coefficient for curvature, dimensionless.

Thus, for precipitation amounts less than the transition precipitation (P_T), equation 13 is used to determine recharge; for amounts greater than P_T, equation 15 is used:

$$R = R_T + P - P_T, \tag{15}$$

where
- R is recharge from precipitation, in feet per month,
- R_T is recharge calculated from transition precipitation, in feet per month,
- P is precipitation, in feet per month, and
- P_T is transition precipitation, in feet per month.

Contor (2004) further modified Rich's approach by cumulatively applying precipitation for November through February as if it all occurred in February. This procedure was followed because winter-time recharge is increased owing to decreased evapotranspiration and temporal concentration of recharge resulting from episodic snow accumulation and melting. This adjustment implies that all snowfall accumulates until a single February thaw event. While this would be unrealistic in the SVRP aquifer area where thaw events are more frequent than in the ESRP, reduced evapotranspiration and episodic snow and melting events would still occur. To address these processes but to avoid applying all winter recharge in February, Contor proposed multiplying winter precipitation by four before recharge is calculated and then dividing the calculated recharge by four, resulting in precipitation/recharge ratios that are less affected by the pre-recharge factors and thus increasing recharge (B.A. Contor, written commun., September 11, 2006).

FAO Penman-Monteith Method

Another approach to the determination of recharge is to calculate actual (versus potential) evapotranspiration (accounting for processes such as soil-moisture storage and direct evaporation) and determine the amount of precipitation that passes through the root zone (and thus becomes recharge). The difficulty lies with determination of actual evapotranspiration without extensive field measurements.

Due to shortcomings in other methods for estimating reference evapotranspiration, including the earlier Blaney-Criddle FAO method, the FAO developed an approach dubbed the FAO Penman-Monteith equation (Allen and others, 1998).

The reference evapotranspiration calculated with this newer equation is then used with crop evapotranspiration coefficients to estimate crop-water requirements. The FAO Penman-Monteith equation for calculating reference evapotranspiration is:

$$ET_o = \frac{0.048\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}, \tag{16}$$

where

ET_o is reference crop evapotranspiration, in millimeters per day,

R_n is net radiation at the crop surface, in megajoules per square meter per day,

G is soil heat flux density, in megajoules per square meter per day,

T is mean daily air temperature at 2 meter height, in degrees Celsius,

u_2 is wind speed at 2 meter height, in meters per second,

e_s is saturation vapor pressure, in kilopascals,

e_a is actual vapor pressure, in kilopascals,

$e_s - e_a$ is saturation vapor pressure deficit, in kilopascals,

Δ is slope vapor pressure curve, dimensionless, and

γ is psychrometric constant, in kilopascals per degrees Celsius.

One of the characteristics of the FAO Penman-Monteith approach is an emphasis on applicability. Because most of these parameters are not commonly measured, Allen and others (1998) devoted a chapter in their paper to their calculation with commonly available meteorological data.

To calculate crop consumptive use (under standard conditions), the reference evapotranspiration (ET_o) is multiplied by a crop coefficient (K_c):

$$ET_c = K_c ET_o, \tag{17}$$

where

ET_c is crop evapotranspiration, in millimeters per day,

K_c is crop coefficient, dimensionless, and

ET_o is reference evapotranspiration, in millimeters per day.

The crop coefficient (K_c) for specific crops may be calculated using procedures described in Allen and others (1998). To refine crop-water requirement estimates, these calculations account for growth stage. Alternatively, typical values for K_c is available in the literature. It is important to note that K_c values usually are given for either a grass or alfalfa reference crop; the coefficients given in Allen and others (1998) are for grass. To convert alfalfa-referenced K_c values to grass-referenced K_c values, K_c is multiplied by a factor ranging from 1.0 to 1.3, depending on climate. For Kimberly, Idaho, (in south-central Idaho) the conversion factor is 1.24 (Allen and others, 1998).

In this report, the initial attempt to use the FAO Penman-Monteith method to determine recharge simply subtracts crop evapotranspiration (ET_c) from precipitation. This approach is hereafter referred to as the single-coefficient FAO Penman-Monteith method.

The FAO Penman-Monteith method can be carried a step further by splitting the crop coefficient (K_c) into two components: the basal crop coefficient (K_{cb}), which accounts for crop transpiration, and the soil evaporation coefficient (K_e). This calculation of dual-crop evapotranspiration (ET_{cd}) allows estimation of the effects of specific wetting events on K_c and was intended for daily calculation of irrigation requirements. The equation for dual-crop evapotranspiration is:

$$ET_{cd} = (K_{cb} + K_e) ET_O, \tag{18}$$

where

ET_{cd} is dual-crop evapotranspiration, in millimeters per day,

K_{cb} is basal crop coefficient, dimensionless,

K_e is soil evaporation coefficient, dimensionless, and

ET_O is reference evapotranspiration, in millimeters per day.

The basal crop coefficient (K_{cb}) for specific crops is available in Allen and others (1998) or in other literature. The soil evaporation coefficient is calculated using constants and procedures described in Allen and others (1998).

Deep percolation from the soil zone can be calculated by a simple mass-balance approach that assumes deep percolation is equal to recharge. Thus, this equation yields recharge for the dual-coefficient FAO Penman-Monteith method:

$$DP_i = (P_i - RO_i) + I_i - ET_{cd,i} - D_{r,\,i-1} \qquad \geq 0, \qquad (19)$$

where

DP_i is water loss out of the root zone by deep percolation on day i, in millimeters,

P_i is precipitation on day i, in millimeters,

RO_i is runoff from the soil surface on day i, in millimeters,

I_i is net irrigation depth on day i that infiltrates the soil, in millimeters,

$ET_{cd,\,i}$ is dual-crop evapotranspiration on day i, in millimeters, and

$D_{r,\,i-1}$ is root zone depletion at the end of the previous day, $i-1$, in millimeters.

Further adjustments to crop consumptive use for non-standard conditions can be made to account for environmental stresses and constraints on crop growth such as pests, soil salinity, water-logging, or drought. These techniques are not considered in this report because they cannot be reliably applied over a large area.

Recharge Calculations and Discussion

As a first step, data from the six active NWS stations in and near the study area (Bayview Model Basin, Coeur D'Alene 1E, Newport, Sandpoint Experiment Station, Priest River Experiment Station, and Spokane WSO Airport) were used to calculate mean monthly recharge using equations and methods described above: the Langbein, USDA, ESPAM, and single-coefficient FAO Penman-Monteith methods. Annual and monthly mean temperature and precipitation values used for the recharge calculations are for each station's period of record through December 2005 (Western Regional Climate Center, 2006a, 2006b).

Apparent limitations of the mean monthly recharge calculations led to a second step in which daily recharge values for the six weather stations were calculated by using equations for the (dual-coefficient) FAO Penman-Monteith dual-crop evapotranspiration (ET_{cd}) and deep percolation. Daily observations for temperature and precipitation for the period 1990-2005 were used for each station; however, wind speed for Spokane WSO Airport was applied to all stations (U.S. Department of Commerce, 2006).

Mean Monthly Recharge

Annual recharge values for each weather station and recharge method are shown in figure 2. These annual values were calculated by summing calculated mean monthly recharge values, except for the Langbein method, for which annual means were used in the calculations.

Annual recharge values calculated by the Langbein method are shown in table 4 and figure 2. Mean annual precipitation data were obtained from published annual means (Western Regional Climate Center, 2006a, 2006b) and mean annual potential evapotranspiration values for Bayview Model Basin, Coeur D'Alene 1E, and Sandpoint Experiment Station were taken from Allen and Brockaway (1983). For the remaining three stations—Priest River Experiment Station, Newport, and Spokane WSO Airport—Allen and Brockaway's (1983) mean annual potential evapotranspiration value for Coeur D'Alene 1E was used.

The Langbein-method annual recharge for all six weather stations ranged from less than 1 percent to 11 percent of mean annual precipitation, yielding the lowest annual recharge values of the methods discussed in this report. The primary shortcoming of the Langbein method is that it can be applied only to annual time periods. For application to shorter periods, the annual values must be apportioned by some scheme, leading to further uncertainty. Furthermore, the previously stated assumption that basin yield is equal to basin recharge may not be valid: because the method was originally developed to determine runoff (as streamflow) from a basin, it does not account for subsurface underflow. Thus calculated recharge may be lower than actual recharge. In addition, basin yield does not equal recharge where there is significant surface-water runoff from lands within the study area. Finally, because independent mean annual potential evapotranspiration values were unavailable for three stations, the use of the Coeur D'Alene 1E estimate adds to the uncertainty.

The USDA-method mean monthly recharge was calculated using mean monthly crop growth stage coefficients (k_c) for alfalfa from curve number 2 in U.S. Department of Agriculture (1970). Values for potential consumptive use (u) were calculated using equation 9; however, the minimum daily value was assumed to be 1 mm/d based on the maximum measured winter evapotranspiration at Kimberly, Idaho (Wright, 1993). Because this paper is concerned with recharge from precipitation, the net depth of applied irrigation water (D) was assumed to be 0.

Calculated mean monthly recharge ranged from 53 to 73 percent of mean monthly precipitation. Annual recharge ranged from 64 to 69 percent of mean annual precipitation (table 5). The method by which potential consumptive use (u) is selected—either potential evapotranspiration or from equation 9—affects calculated recharge, with equation 9 yielding a lower value of u, thus a higher recharge value.
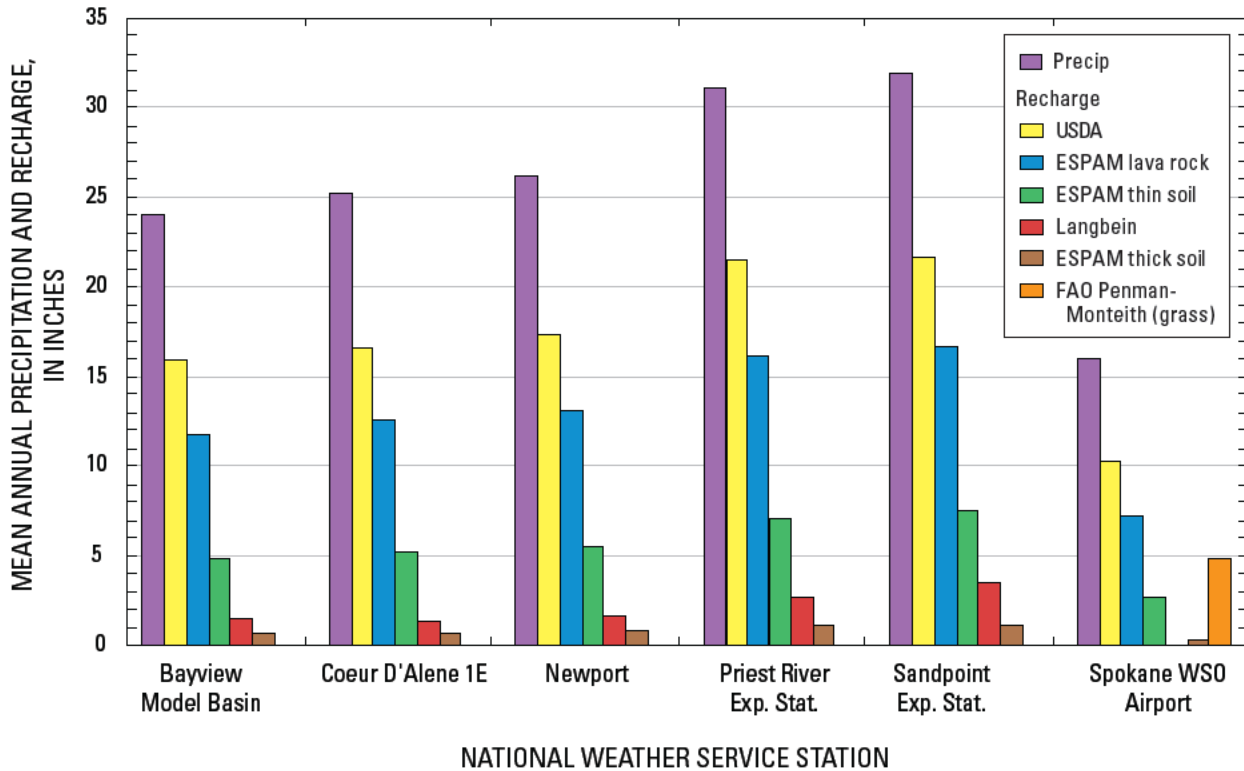
Figure 2.   Mean annual precipitation and recharge calculated by various methods at six weather stations in the study area.

Furthermore, the USDA effective rainfall equation (equation 8) was derived empirically through the "analysis of 50 years of precipitation records" at 22 weather stations representing all climatic conditions in the conterminous United States (U.S. Department of Agriculture, 1970). Thus, it is difficult to evaluate how applicable the method is to the SVRP aquifer study area.

Mean monthly recharge calculations for the ESPAM method were made using thin-soil, thick-soil, and lava-rock parameters: transition precipitation (P_T) was calculated as 2.07, 3.68, and 2.57 ft/mo, respectively. The lava-rock parameters yielded the highest recharge values; the thick-soil parameters the lowest (tables 6-8).

For thin-soil parameters, calculated monthly recharge ranged from 10 to 29 percent of monthly mean precipitation, and annual recharge ranged from 16 to 23 percent of mean annual precipitation (table 6). For thick-soil parameters, calculated monthly recharge ranged from 1 to 5 percent of monthly mean precipitation, and annual recharge ranged from 2 to 4 percent of mean annual precipitation (table 7). For lava-rock parameters, calculated monthly recharge ranged from 37 to 57 percent of monthly mean precipitation, and annual recharge ranged from 45 to 52 percent of mean annual precipitation (table 8).

Table 4.   Mean annual precipitation at active weather stations and calculated Langbein recharge.

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005.
Abbreviations: Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

		Station name					
		Bayview Model Basin	Coeur D'Alene 1E	Newport	Priest River Exp. Stat.	Sandpoint Exp. Stat.	Spokane WSO Airport
Annual	Precipitation (in.)	24	25	26	31	32	16
	Recharge (in.)	1.4	1.4	1.6	2.7	3.5	.00
	Ratio (percent)	6.0	6.0	6.0	9.0	11	0

Table 5.   Mean monthly precipitation at active weather stations and U.S. Department of Agriculture recharge.

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005. **Abbreviations:** Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

		Station name					
		Bayview Model Basin	Coeur D'Alene 1E	Newport	Priest River Exp. Stat.	Sandpoint Exp. Stat.	Spokane WSO Airport
January	Precipitation (in.)	2.8	3.4	3.2	4.0	4.1	2.0
	Recharge (in.)	1.9	2.3	2.2	2.8	2.8	1.3
	Ratio (percent)	69	69	69	70	70	68
February	Precipitation (in.)	2.1	2.5	2.4	3.0	3.1	1.5
	Recharge (in.)	1.5	1.7	1.6	2.0	2.2	1.0
	Ratio (percent)	68	68	68	69	69	67
March	Precipitation (in.)	2.0	2.3	2.3	2.7	2.8	1.4
	Recharge (in.)	1.4	1.5	1.5	1.9	1.9	.93
	Ratio (percent)	68	68	68	69	69	67
April	Precipitation (in.)	1.8	1.7	1.8	2.1	2.1	1.1
	Recharge (in.)	1.2	1.1	1.2	1.4	1.4	.72
	Ratio (percent)	66	66	66	68	66	64
May	Precipitation (in.)	2.1	2.0	2.1	2.3	2.3	1.4
	Recharge (in.)	1.3	1.3	1.3	1.6	1.5	.87
	Ratio (percent)	64	62	63	68	63	61
June	Precipitation (in.)	1.8	1.8	1.9	2.3	2.3	1.2
	Recharge (in.)	1.1	1.0	1.1	1.5	1.4	.68
	Ratio (percent)	60	58	60	68	60	57
July	Precipitation (in.)	1.0	.7	.9	1.0	1.0	.55
	Recharge (in.)	.54	.38	.52	.69	.54	.29
	Ratio (percent)	56	53	55	66	55	53
August	Precipitation (in.)	1.1	.9	1.0	1.2	1.2	.63
	Recharge (in.)	.62	.51	.57	.77	.68	.35
	Ratio (percent)	58	55	58	66	58	56
September	Precipitation (in.)	1.2	1.3	1.4	1.6	1.7	.80
	Recharge (in.)	.76	.79	.86	1.1	1.1	.49
	Ratio (percent)	63	62	63	67	64	62
October	Precipitation (in.)	2.1	2.0	2.2	2.6	2.6	1.2
	Recharge (in.)	1.4	1.3	1.5	1.8	1.8	.76
	Ratio (percent)	67	66	68	68	68	65
November	Precipitation (in.)	2.9	3.1	3.5	4.0	4.3	2.1
	Recharge (in.)	2.0	2.1	2.4	2.8	3.1	1.4
	Ratio (percent)	69	69	70	70	72	68
December	Precipitation (in.)	3.2	3.6	3.7	4.4	4.6	2.2
	Recharge (in.)	2.2	2.5	2.6	3.2	3.3	1.5
	Ratio (percent)	69	70	70	72	73	68
Annual	Precipitation (in.)	24	25	26	31	31	16
	Recharge (in.)	16	17	17	22	22	10
	Ratio (percent)	66	66	66	69	68	64

Table 6.   Mean monthly precipitation at active weather stations and calculated Eastern Snake Plain Aquifer Model recharge (thin-soil parameters).

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005. **Abbreviations**: Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

		Station name					
		Bayview Model Basin	Coeur D' Alene 1E	Newport	Priest River Exp. Stat.	Sandpoint Exp. Stat.	Spokane WSO Airport
January	Precipitation (in.)	2.8	3.4	3.2	4.0	4.1	2.0
	Recharge (in.)	.64	.82	.76	1.1	1.1	.37
	Ratio (percent)	22	24	24	27	27	19
February	Precipitation (in.)	2.1	2.5	2.4	3.0	3.1	1.5
	Recharge (in.)	.42	.51	.48	.68	.74	.26
	Ratio (percent)	20	21	20	23	24	17
March	Precipitation (in.)	2.0	2.3	2.3	2.7	2.8	1.4
	Recharge (in.)	.39	.46	.46	.60	.61	.22
	Ratio (percent)	19	20	20	22	22	16
April	Precipitation (in.)	1.8	1.7	1.8	2.1	2.1	1.1
	Recharge (in.)	.31	.30	.33	.40	.40	.16
	Ratio (percent)	18	18	18	19	19	14
May	Precipitation (in.)	2.1	2.0	2.1	2.3	2.3	1.4
	Recharge (in.)	.40	.38	.40	.48	.48	.23
	Ratio (percent)	19	19	19	20	20	16
June	Precipitation (in.)	1.8	1.8	1.9	2.3	2.3	1.2
	Recharge (in.)	.32	.32	.34	.45	.45	.18
	Ratio (percent)	18	18	18	20	20	15
July	Precipitation (in.)	1.0	.7	.9	1.0	1.0	.55
	Recharge (in.)	.13	.08	.12	.14	.13	.05
	Ratio (percent)	13	11	13	14	13	10
August	Precipitation (in)	1.1	.9	1.0	1.2	1.2	.63
	Recharge (in)	.15	.12	.13	.17	.17	.07
	Ratio (percent)	14	13	13	14	15	11
September	Precipitation (in.)	1.2	1.3	1.4	1.6	1.7	.80
	Recharge (in.)	.18	.19	.21	.26	.29	.10
	Ratio (percent)	15	15	16	17	17	12
October	Precipitation (in.)	2.1	2.0	2.2	2.6	2.6	1.2
	Recharge (in.)	.40	.37	.43	.55	.57	.17
	Ratio (percent)	19	19	20	21	22	14
November	Precipitation (in.)	2.9	3.1	3.5	4.0	4.3	2.1
	Recharge (in.)	.67	.73	.86	1.1	1.2	.40
	Ratio (percent)	23	23	25	27	28	19
December	Precipitation (in.)	3.2	3.6	3.7	4.4	4.6	2.2
	Recharge (in.)	.75	.92	.95	1.2	1.3	.43
	Ratio (percent)	24	25	26	28	29	20
Annual	Precipitation (in.)	24.1	25.2	26.2	31.1	32.0	16.1
	Recharge (in.)	4.7	5.2	5.5	7.1	7.4	2.6
	Ratio (percent)	20	21	21	23	23	16

Table 7.   Mean monthly precipitation at active weather stations and calculated Eastern Snake Plain Aquifer Model recharge (thick-soil parameters).

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005. Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

		Station name					
		Bayview Model Basin	Coeur D'Alene 1E	Newport	Priest River Exp. Stat.	Sandpoint Exp. Stat.	Spokane WSO Airport
January	Precipitation (in.)	2.8	3.4	3.2	4.0	4.1	2.0
	Recharge (in.)	.09	.13	.11	.18	.19	.04
	Ratio (percent)	3	4	4	5	5	2
February	Precipitation (in.)	2.1	2.5	2.4	3.0	3.1	1.5
	Recharge (in.)	.05	.07	.06	.01	.11	.03
	Ratio (percent)	2	3	3	3	4	2
March	Precipitation (in.)	2.0	2.3	2.3	2.7	2.8	1.4
	Recharge (in.)	.05	.06	.06	.08	.09	.02
	Ratio (percent)	2	3	3	3	3	2
April	Precipitation (in.)	1.8	1.7	1.8	2.1	2.1	1.1
	Recharge (in.)	.03	.03	.04	.05	.05	.01
	Ratio (percent)	2	2	2	2	2	1
May	Precipitation (in.)	2.1	2.0	2.1	2.3	2.3	1.4
	Recharge (in.)	.05	.05	.05	.06	.06	.02
	Ratio (percent)	2	2	2	3	3	2
June	Precipitation (in.)	1.8	1.8	1.9	2.3	2.3	1.2
	Recharge (in.)	.04	.04	.04	.06	.06	.02
	Ratio (percent)	2	2	2	3	3	1
July	Precipitation (in.)	1.0	.7	.9	1.0	1.0	.55
	Recharge (in.)	.01	.01	.09	.01	.01	.00
	Ratio (percent)	1	1	1	1	1	1
August	Precipitation (in.)	1.1	.9	1.0	1.2	1.2	.63
	Recharge (in.)	.01	.01	.01	.02	.02	.00
	Ratio (percent)	1	1	1	1	1	1
September	Precipitation (in.)	1.2	1.3	1.4	1.6	1.7	.80
	Recharge (in.)	.02	.02	.02	.03	.03	.01
	Ratio (percent)	1	1	2	2	2	1
October	Precipitation (in.)	2.1	2.0	2.2	2.6	2.6	1.2
	Recharge (in.)	.05	.04	.05	.07	.08	.02
	Ratio (percent)	2	2	2	3	3	1
November	Precipitation (in.)	2.9	3.1	3.5	4.0	4.3	2.1
	Recharge (in.)	.10	.11	.14	.18	.21	.05
	Ratio (percent)	3	4	4	5	5	2
December	Precipitation (in.)	3.2	3.6	3.7	4.4	4.6	2.2
	Recharge (in.)	.11	.15	.16	.22	.24	.05
	Ratio (percent)	4	4	4	5	5	2
Annual	Precipitation (in.)	24	25	26	31	32	16
	Recharge (in.)	.61	.71	.75	1.1	1.13	.28
	Ratio (percent)	3	3	3	3	4	2

Table 8. Mean monthly precipitation at active weather stations and calculated Eastern Snake Plain Aquifer Model recharge (lava-rock parameters).

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005. **Abbreviations:** Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

| | | Station name | | | | | |
		Bayview Model Basin	Coeur D' Alene 1E	Newport	Priest River Exp. Stat.	Sandpoint Exp. Stat.	Spokane WSO Airport
January	Precipitation (in.)	2.8	3.4	3.2	4.0	4.1	2.0
	Recharge (in.)	1.5	1.8	1.7	2.2	2.3	.95
	Ratio (percent)	52	53	53	55	56	48
February	Precipitation (in.)	2.1	2.5	2.4	3.0	3.1	1.5
	Recharge (in.)	1.0	1.2	1.2	1.5	1.7	.70
	Ratio (percent)	49	50	50	52	53	46
March	Precipitation (in.)	2.0	2.3	2.3	2.7	2.8	1.4
	Recharge (in.)	.99	1.13	1.13	1.39	1.42	.62
	Ratio (percent)	48	49	49	51	51	45
April	Precipitation (in.)	1.8	1.7	1.8	2.1	2.1	1.1
	Recharge (in.)	.82	.81	.86	1.02	1.01	.48
	Ratio (percent)	47	47	47	49	49	43
May	Precipitation (in.)	2.1	2.0	2.1	2.3	2.3	1.4
	Recharge (in.)	1.0	.97	1.0	1.2	1.2	.64
	Ratio (percent)	49	48	49	50	50	45
June	Precipitation (in.)	1.8	1.8	1.9	2.3	2.3	1.2
	Recharge (in.)	.85	.85	0.88	1.12	1.12	.52
	Ratio (percent)	47	47	48	49	49	44
July	Precipitation (in.)	1.0	.7	.9	1.0	1.0	.55
	Recharge (in.)	.41	.28	.38	.44	.41	.20
	Ratio (percent)	42	39	41	42	42	37
August	Precipitation (in.)	1.1	.9	1.0	1.2	1.2	.63
	Recharge (in.)	.46	.38	.41	.50	.51	.24
	Ratio (percent)	43	41	42	43	43	38
September	Precipitation (in.)	1.2	1.3	1.4	1.6	1.7	.80
	Recharge (in.)	.53	.56	.61	.72	.79	.32
	Ratio (percent)	44	44	45	46	47	40
October	Precipitation (in.)	2.1	2.0	2.2	2.6	2.6	1.2
	Recharge (in.)	1.0	.95	1.1	1.3	1.3	.51
	Ratio (percent)	49	48	49	51	51	43
November	Precipitation (in.)	2.9	3.1	3.5	4.0	4.3	2.1
	Recharge (in.)	1.5	1.6	1.9	2.2	2.4	1.0
	Ratio (percent)	52	53	54	55	56	49
December	Precipitation (in.)	3.2	3.6	3.7	4.4	4.6	2.2
	Recharge (in.)	1.7	2.0	2.0	2.5	2.6	1.1
	Ratio (percent)	53	54	55	56	57	49
Annual	Precipitation (in.)	24	25	26	31	32	16
	Recharge (in.)	12	13	13	16	17	7.3
	Ratio (percent)	49	50	50	52	52	45

For a given precipitation (P), paired slope parameter (K), and coefficient for curvature (N), recharge calculated by the ESPAM method will be equivalent to that calculated for the ESRP. It is difficult to evaluate the validity of this assumption: although the lowest values of mean annual precipitation on the ESRP are approximately one-half of those in the SVRP aquifer area, mean annual maximum temperatures at higher elevation stations on the ESRP are similar to those in the area of the SVRP aquifer. The range of March-October potential evapotranspiration values for the ESRP range from 46.5 to 57.4 in.; for the Bayview Model Basin, Sandpoint Experiment Station, and Coeur D'Alene 1E weather stations, the values are 39.1, 40.3, and 42.8 in., respectively (Allen and Brockaway, 1983).

The meteorological data needed for calculation of recharge using the single- or dual-coefficient FAO Penman-Monteith methods are available for only one station in the area—Spokane WSO Airport. Initially, to determine mean monthly recharge with the single-coefficient FAO Penman-Monteith method, the 15th day of each month was used to calculate the relevant radiation parameters for reference evapotranspiration (ET_o) (except percentage of possible sunshine, for which the monthly mean was used). This value was then used with mean monthly meteorological data to obtain mean monthly recharge. Crop evapotranspiration (ET_c), was calculated for grass pasture: development stages for grass pasture (L_{ini}, L_{dev}, and L_{late}) and time-averaged crop coefficients for rotated grazing pasture ($K_{c\,ini}$, $K_{c\,dev}$, $K_{c\,late}$, and maximum crop height) were taken from tables 11 and 12, respectively, in Allen and others (1998). The grass-referenced ET_c was converted to alfalfa-referenced ET_c using the Kimberly, Idaho, conversion factor of 1.24 (Allen and others, 1998). Mean monthly recharge was then calculated by subtracting the mean monthly ET_c from mean monthly precipitation. Mean monthly recharge values for both grass- and alfalfa-referenced calculations are shown in table 9.

For grass-referenced calculations, calculated mean monthly recharge ranged from 0 to 81 percent of mean monthly precipitation, and mean annual recharge was 21 percent of mean annual precipitation; for alfalfa- referenced calculations, calculated mean monthly recharge ranged from 0 to 85 percent of mean monthly precipitation, and mean annual recharge was 24 percent of mean annual precipitation (table 9). The most striking feature of these results from the single-coefficient FAO Penman-Monteith equations with mean monthly values is that calculated mean monthly recharge drops to zero during the eight warmest and driest months of the year (March-October). Such a result seems unlikely based on ground-water levels.

Table 9.　Mean monthly precipitation at active weather stations and single-coefficient FAO Penman-Monteith recharge, Spokane WSO Airport, Washington.

[Western Regional Climate Center (2006a, 2006b). Mean precipitation values are through December 31, 2005. **Abbreviations:** Exp. Stat., experiment station; WSO, Weather Service Office; in., inch; ratio, recharge to precipitation ratio]

		Spokane WSO Airport	
		Grass reference	Alfalfa reference
January	Precipitation (in.)	2.0	2.0
	Recharge (in.)	1.4	1.5
	Ratio (percent)	71	77
February	Precipitation (in.)	1.5	1.5
	Recharge (in.)	.36	.59
	Ratio (percent)	24	38
March	Precipitation (in.)	1.4	1.4
	Recharge (in.)	0	0
	Ratio (percent)	0	0
April	Precipitation (in.)	1.1	1.1
	Recharge (in.)	0	0
	Ratio (percent)	0	0
May	Precipitation (in.)	1.4	1.4
	Recharge (in.)	0	0
	Ratio (percent)	0	0
June	Precipitation (in.)	1.2	1.2
	Recharge (in.)	0	0
	Ratio (percent)	0	0
July	Precipitation (in.)	.6	.6
	Recharge (in.)	0	0
	Ratio (percent)	0	0
August	Precipitation (in.)	.6	.6
	Recharge (in.)	0	0
	Ratio (percent)	0	0
September	Precipitation (in.)	.8	.8
	Recharge (in.)	0	0
	Ratio (percent)	0	0
October	Precipitation (in.)	1.2	1.2
	Recharge (in.)	0	0
	Ratio (percent)	0	0
November	Precipitation (in.)	2.1	2.1
	Recharge (in.)	1.3	1.4
	Ratio (percent)	60	68
December	Precipitation (in.)	2.2	2.2
	Recharge (in.)	1.8	1.9
	Ratio (percent)	81	85
Annual	Precipitation (in.)	16	16
	Recharge (in.)	3.4	3.9
	Ratio (percent)	21	24

The relations of mean monthly precipitation at each weather station to mean monthly recharge values calculated by the USDA and ESPAM methods are shown in figure 3. For all stations, the lava-rock parameters yield the highest values of recharge and the thick-soil parameters the lowest among the ESPAM techniques. USDA recharge values are greater than any ESPAM values for all months. For the Spokane WSO Airport station, the single-coefficient FAO Penman-Monteith mean monthly recharge values are highest in the winter and lowest during the growing season.

Daily Recharge, 1990–2005

As mentioned in the previous section, independent evidence does not support the calculated result of no recharge during the eight warmest and driest months of the year (March-September) and suggests that the single-coefficient FAO Penman-Monteith recharge using mean monthly data does not adequately represent changes in soil-moisture storage. A similar conclusion was reached by Kafri and Ben Asher (1978) in a southern Arizona study, in which they noted, "*The conventional approach of calculating recharge by subtracting long-term averages of runoff and evapotranspiration from the total rainfall results in no apparent recharge. This result does not agree with observations of ground-water flows in the corresponding basins.*"

Such anomalous results from calculations with monthly means may result from the assumption that there is always sufficient soil moisture to satisfy evapotranspiration. However, daily soil-moisture will occasionally be insufficient to meet crop evapotranspiration (ET_c) demand, resulting in actual evapotranspiration being less than the calculated ET_c value. Thus, recharge depends on the amount and timing of individual precipitation events to replenish soil moisture and exceed ET_c, allowing deep percolation (assumed to be recharge) through the root zone.

In order to calculate a more realistic value of recharge, the dual-coefficient FAO Penman-Monteith dual-crop evapotranspiration (ET_{cd}) and deep percolation calculations in equations 18 and 19 were applied to daily values from the Spokane WSO Airport for January 1990 through December 2005. Recorded "trace" values of precipitation were assigned a value of 0.01 in. for daily calculations (although actual trace amounts were between 0.00 and 0.01 in.). As above, crop evapotranspiration (ET_c) was calculated for grass pasture: development stages and time-averaged crop coefficients were taken from tables 11 and 12, respectively, in Allen and others (1998). The key soil characteristics used were a maximum root depth of 0.8 m and an available water capacity (AWC) of 30 mm/m. The resultant monthly totals in table 10 show a temporal variability that is absent from the mean monthly

values in table 9, and demonstrate that the daily amount and timing of precipitation dramatically affect calculated recharge. Daily values of precipitation and dual-coefficient FAO Penman-Monteith recharge for the Spokane station are shown in figure 4.

For a given month, there is little consistency between the amount of precipitation and recharge from year to year. The examination of daily values for such "anomalous" months as March 1993, when precipitation was near normal yet no recharge occurred, show a soil-moisture deficit early in the month that needed replenishment by daily precipitation later in the month before deep percolation could occur. Furthermore, significant precipitation on a given day can paradoxically result in calculated value of deep percolation for the following day being greater than precipitation as a result of soil-moisture storage.

Because the daily dual-coefficient FAO Penman-Monteith recharge better represents natural processes than do the mean monthly techniques discussed previously, daily calculations were made for the five remaining weather stations. Unfortunately, the required meteorological data for these stations is limited to maximum and minimum daily temperature and precipitation. To calculate recharge for these stations, two main assumptions were made: (1) wind-speed values for Spokane WSO Airport were used for all weather stations, and (2) dewpoint temperatures were assumed to equal the daily minimum temperature. As with Spokane WSO Airport, trace amounts of precipitation were assigned a value of 0.01 in. Missing precipitation values of six or fewer days were assumed to equal zero. Missing temperature values of six or fewer consecutive days were interpolated. For longer periods of missing data, values for a station were assumed to equal those at a station with similar mean values: (1) data from the Priest River Experiment Station were used for Newport from December 1995 through January 1996, and (2) data from Newport were used for Bayview Model Basin for February 1992, March-April 2004, and July 2005. Because the Coeur d'Alene 1E station was missing a substantial amount of data (January 1990 through October 1995, March 1996, March 1998, February 2004, April 2004, June 2005, and November 2005) deep percolation for these periods was not calculated. Monthly summaries for these five weather stations, 1990-2005, are shown in tables 11-15. Daily values of precipitation and dual-coefficient FAO Penman-Monteith recharge, 1990-2005, are shown in figures 5-9. The occasional days with large amounts of precipitation (and correspondingly high recharge) are very noticeable on these graphs. In areas with a thin unsaturated zone such events may be reflected in ground-water levels, however, for much of the area, processes in a thick unsaturated zone probably dampen these events into a fairly constant recharge rate.
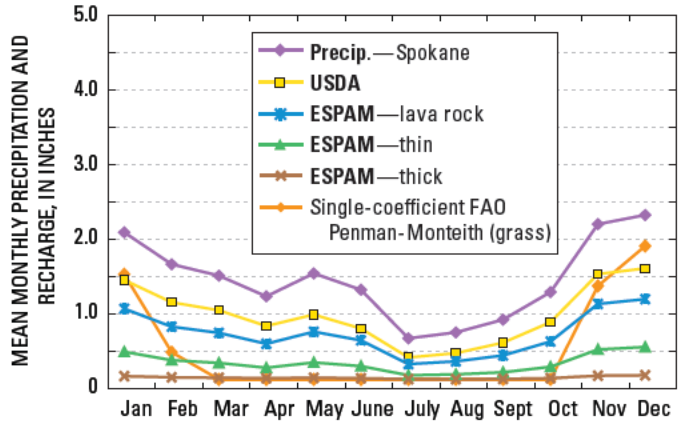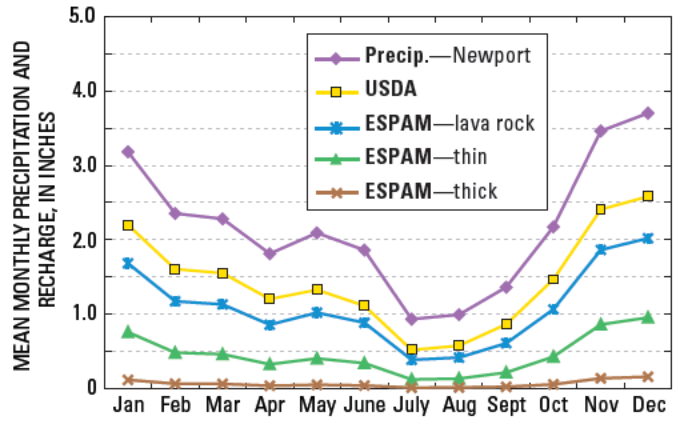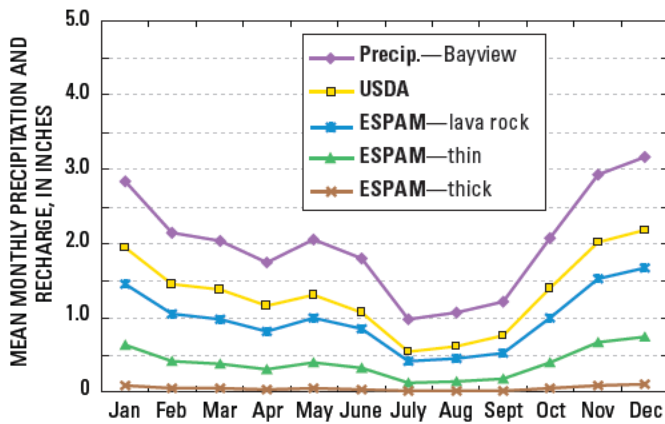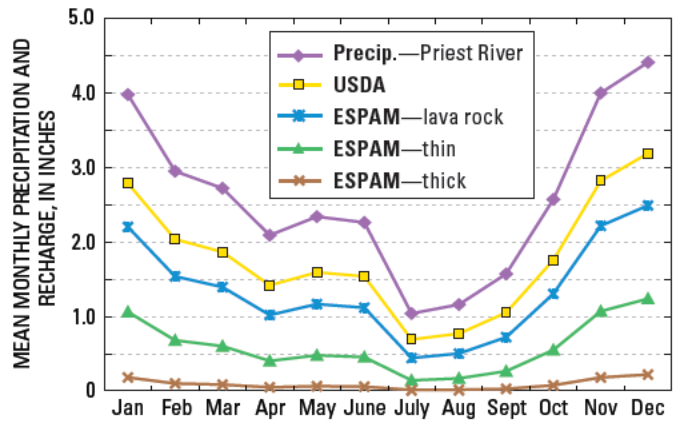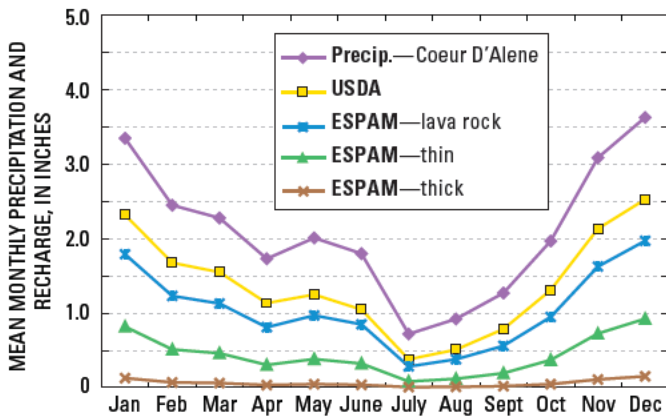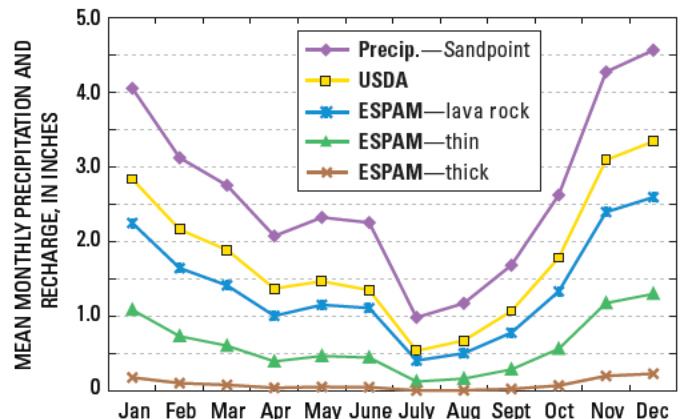
Figure 3. Mean monthly precipitation and rechargeat each weather station, Idaho and Washington.

Table 10. Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Spokane WSO Airport, Washington.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005. **Abbreviations:** in., inch; ratio, recharge to precipitation ratio]

|		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	2.5	1.8	2.3	1.6	1.5	2.8	2.3	1.7	2.2	1.9	2.1	0.72	1.2	3.5	1.5	1.2	2.0
	Recharge (in.)	1.5	1.5	1.6	1.0	1.0	1.9	1.8	1.1	1.6	1.5	1.5	.42	.66	2.9	1.2	.73	
	Ratio (percent)	59	85	72	67	68	70	78	65	73	75	73	58	55	84	77	62	
February	Precipitation (in.)	1.1	.84	1.9	.95	.97	1.7	3.0	1.5	1.7	3.3	1.7	.70	1.1	.56	1.5	.1	1.5
	Recharge (in.)	.36	.00	1.0	.62	.00	1.1	2.4	.73	.43	1.9	.73	.20	.43	.00	.85	.00	
	Ratio (percent)	33	0	56	65	0	65	81	50	25	59	44	29	40	1	58	0	
March	Precipitation (in.)	.91	2.4	.47	1.2	.54	3.8	1.7	2.5	1.3	.76	1.7	1.4	1.1	2.2	.70	2.1	1.4
	Recharge (in.)	.00	1.3	.00	.00	.00	2.3	.63	.84	.05	.00	.28	.00	.00	.05	.00	.57	
	Ratio (percent)	0	53	0	0	0	61	38	34	4	0	17	0	0	2	0	27	
April	Precipitation (in.)	1.3	1.4	.71	2.0	1.7	1.0	2.2	2.6	1.0	.44	2.2	1.8	.94	1.5	.60	.80	1.1
	Recharge (in.)	.00	.00	.00	.00	.00	.00	.30	.51	.00	.00	.92	.00	.00	.00	.00	.00	
	Ratio (percent)	0	0	0	0	0	0	13	19	0	0	41	0	0	0	0	0	
May	Precipitation (in.)	3.2	1.8	.31	1.4	1.4	1.4	1.8	2.3	3.1	.76	2.3	.82	1.2	1.6	3.8	3.6	1.4
	Recharge (in.)	.13	.00	.00	.00	.00	.05	.00	.27	.79	.00	.04	.00	.00	.33	1.9	.41	
	Ratio (percent)	4	0	0	0	0	3	0	12	25	0	2	0	0	21	50	11	
June	Precipitation (in.)	2.0	1.2	1.6	.55	.95	2.2	1.2	.53	.90	1.4	.98	1.1	1.5	.27	1.1	1.4	1.2
	Recharge (in.)	.08	.00	.21	.00	.00	.36	.00	.00	.00	.08	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	4	0	13	0	0	16	0	0	0	6	0	0	0	0	0	0	
July	Precipitation (in.)	2.4	.61	1.1	2.2	.02	1.1	.34	.82	.28	.18	.36	.32	.28	.02	.11	1.1	.6
	Recharge (in.)	1.2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.05	
	Ratio (percent)	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
August	Precipitation (in.)	1.1	.22	.36	1.3	.10	.64	.83	.26	.28	1.1	.05	.29	1.3	.46	1.9	.49	.6
	Recharge (in.)	.15	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.36	.00	.28	.00	
	Ratio (percent)	14	0	0	0	0	0	0	0	0	0	0	0	28	0	15	0	
September	Precipitation (in.)	.00	.02	.41	.30	.47	1.9	.83	.97	.24	.05	1.2	.18	.56	.61	.72	.86	.8
	Recharge (in.)	.00	.00	.00	.00	.00	.38	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	
October	Precipitation (in.)	3.1	.38	.85	.50	2.8	1.6	3.3	1.7	.30	.93	.71	2.1	.25	.57	1.1	1.1	1.2
	Recharge (in.)	1.2	.00	.00	.00	1.0	.15	1.9	.00	.00	.00	.00	.31	.00	.00	.00	.21	
	Ratio (percent)	40	0	0	0	36	9	59	0	0	0	0	14	0	0	0	19	
November	Precipitation (in)	.90	3.1	3.1	.80	2.3	1.4	4.1	2.0	3.8	2.1	1.2	2.6	1.7	1.6	1.2	2.0	2.1
	Recharge (in)	.00	2.0	2.17	.00	1.54	.00	3.43	.92	2.0	.58	.20	1.6	.39	.41	.00	.91	
	Ratio (percent)	0	64	71	0	66	0	84	46	53	28	17	61	24	25	0	46	
December	Precipitation (in.)	1.8	1.3	2.2	2.0	1.7	2.7	4.1	1.1	3.3	2.3	1.1	2.1	3.4	2.3	1.4	3.0	2.2
	Recharge (in.)	.73	.66	1.8	1.1	1.1	2.0	3.8	.52	2.6	1.7	.71	1.6	2.6	1.8	.85	2.7	
	Ratio (percent)	40	50	81	59	67	74	92	49	79	75	67	75	77	80	61	90	
Annual	Precipitation (in.)	20	15	15	14	15	22	26	18	18	15	15	14	14	15	15	18	16.1
	Recharge (in.)	5.3	5.5	6.9	2.8	4.7	8.3	14	4.9	7.5	5.7	4.4	4.1	4.4	5.5	5.0	5.6	
	Ratio (percent)	26	36	45	19	33	38	56	27	41	38	28	29	31	37	32	31	
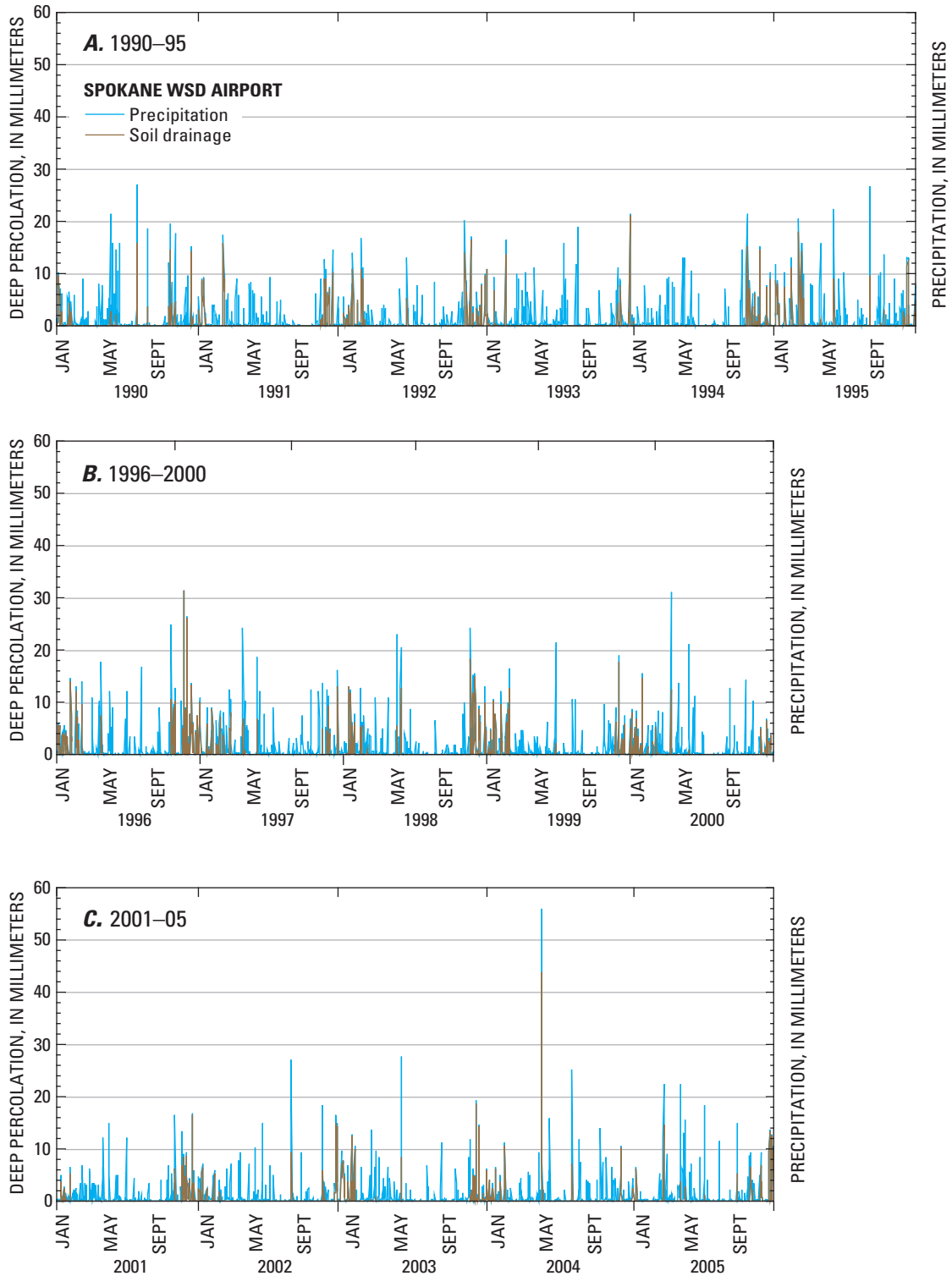
Figure 4.   Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1990–2005, Spokane WSO Airport, Washington.

Table 11. Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Bayview Model Basin, Idaho.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005. **Abbreviations:** in., inch; ratio, recharge to precipitation ratio]

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	5.4	1.0	1.3	1.9	1.8	3.4	3.8	3.6	2.4	2.8	1.0	0.10	1.6	5.1	3.3	2.4	2.8
	Recharge (in.)	4.	.77	.56	1.4	1.32	2.5	3.0	2.8	1.4	1.8	.33	.00	.42	4.1	2.2	1.8	
	Ratio (percent)	80	75	43	78	72	74	80	77	59	64	33	0	27	81	69	76	
February	Precipitation (in.)	2.5	1.0	1.8	.67	1.5	2.7	4.3	2.1	1.7	3.6	.20	.06	.59	1.0	2.4	.22	2.1
	Recharge (in.)	1.6	.45	1.2	.18	.55	2.2	3.1	.97	.63	2.0	.00	.00	.00	.41	1.2	.00	
	Ratio (percent)	64	43	69	26	36	79	73	47	37	57	0	0	0	40	47	0	
March	Precipitation (in.)	1.0	3.1	.47	1.6	1.7	3.0	2.3	4.3	2.5	1.5	2.2	.28	.77	3.1	1.1	2.9	2.0
	Recharge (in.)	.18	1.8	.00	.19	.24	1.4	.88	1.9	.89	.00	.31	.00	.00	.86	.00	1.1	
	Ratio (percent)	18	57	0	12	14	47	39	43	35	0	14	0	0	28	0	38	
April	Precipitation (in.)	2.3	2.8	1.7	4.3	1.6	2.0	3.2	2.8	.27	.86	2.1	2.4	1.7	1.9	1.4	.80	1.8
	Recharge (in.)	1.0	.62	.00	.66	.00	.05	.33	.05	.00	.00	.99	.04	.17	.00	.00	.00	
	Ratio (percent)	44	22	0	15	0	3	10	2	0	0	47	2	10	0	0	0	
May	Precipitation (in.)	2.3	4.4	.9	1.7	2.0	1.7	3.6	2.2	2.4	1.6	4.0	1.5	2.0	2.0	3.4	1.8	2.1
	Recharge (in.)	.00	.75	.00	.00	.26	.11	1.5	.00	.65	.00	1.2	.22	.26	.00	.48	.00	
	Ratio (percent)	0	17	0	0	13	6	43	0	27	0	30	14	13	0	14	0	
June	Precipitation (in.)	2.3	2.2	2.3	1.6	1.9	3.3	2.4	2.2	.5	.7	1.1	1.8	1.8	.8	1.1	2.9	1.8
	Recharge (in.)	.22	.00	1.12	.00	.11	.70	.62	.11	.00	.00	.00	.00	.01	.00	.00	.21	
	Ratio (percent)	9	0	48	0	6	21	26	5	0	0	0	0	1	0	0	7	
July	Precipitation (in.)	1.6	.25	3.3	5.3	.16	1.2	.19	1.2	.57	.83	.65	.42	1.2	.02	.06	1.4	1.0
	Recharge (in.)	.61	.00	1.0	1.0	.00	.00	.00	.00	.00	.04	.00	.00	.44	.00	.00	.10	
	Ratio (percent)	39	0	31	19	0	0	0	0	0	5	0	0	37	0	0	7	
August	Precipitation (in.)	1.9	1.0	3.0	1.3	.03	1.5	.64	.28	.50	1.5	.03	.00	.90	.27	3.3	.51	1.1
	Recharge (in.)	.56	.00	1.50	.00	.00	.00	.00	.00	.00	.34	.00	.00	.03	.00	.88	.00	
	Ratio (percent)	30	0	49	0	0	0	0	0	0	24	0	0	3	0	27	0	
September	Precipitation (in.)	.00	.05	2.6	.99	1.1	1.6	1.1	2.5	.34	.29	1.2	.45	.92	1.3	2.6	.97	1.2
	Recharge (in.)	.00	.00	.64	.00	.00	.44	.00	.41	.00	.00	.00	.00	.00	.09	.92	.00	
	Ratio (percent)	0	0	24	0	0	28	0	16	0	0	0	0	0	8	35	0	
October	Precipitation (in.)	3.7	.05	.85	1.7	3.9	3.8	3.5	3.1	.00	2.3	3.5	3.5	.39	1.6	2.5	2.8	2.1
	Recharge (in.)	1.2	.00	.00	.09	1.9	1.7	1.8	.69	.00	.41	1.6	1.5	.00	.00	.80	1.0	
	Ratio (percent)	33	0	0	6	50	45	52	22	0	18	47	41	0	0	32	36	
November	Precipitation (in.)	3.5	.47	5.4	.76	2.6	4.1	4.6	1.5	3.8	3.4	1.0	2.9	3.1	4.2	2.9	2.2	2.9
	Recharge (in.)	2.0	.00	4.2	.00	1.5	2.4	3.7	.35	2.0	1.8	.20	1.4	1.6	2.6	1.0	1.1	
	Ratio (percent)	59	0	77	0	57	58	80	23	52	55	20	47	52	61	35	51	
December	Precipitation (in.)	2.9	.69	3.7	2.0	3.5	3.4	5.1	1.8	4.1	3.4	1.3	3.2	3.6	2.9	1.8	3.3	3.2
	Recharge (in.)	1.9	.00	2.9	.91	2.7	2.5	4.2	.97	3.1	2.5	.69	2.3	2.4	2.0	.87	2.7	
	Ratio (percent)	67	0	77	46	78	76	84	54	74	74	53	72	67	68	49	82	
Annual	Precipitation (in.)	29	17	27	24	22	32	35	28	19	23	18	17	19	24	26	22	24
	Recharge (in.)	14	4.4	13	4.5	8.6	14	19	8.2	8.6	8.9	5.4	5.3	5.47	10	8.4	8.1	
	Ratio (percent)	47	26	48	19	39	44	56	30	45	40	29	32	29	42	33	36	

Table 12. Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Coeur D'Alene 1E, Idaho.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005. **Abbreviations**: in., inch; ratio, recharge to precipitation ratio; –, missing data or value not calculated]

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	–	–	–	–	–	–	1.4	3.7	8.7	3.6	3.9	1.2	2.6	3.6	3.8	1.8	3.4
	Recharge (in.)	–	–	–	–	–	–	.65	2.8	7.7	2.8	3.2	.70	1.6	2.8	3.2	1.1	
	Ratio (percent)	–	–	–	–	–	–	47	76	88	78	82	57	63	78	83	62	
February	Precipitation (in.)	–	–	–	–	–	–	3.9	2.3	1.2	5.8	3.2	1.9	1.7	.90	–	.04	2.5
	Recharge (in.)	–	–	–	–	–	–	2.6	1.2	.01	4.4	2.0	.94	.89	.31	–	.00	
	Ratio (percent)	–	–	–	–	–	–	66	53	1	75	63	49	53	34	–	0	
March	Precipitation (in.)	–	–	–	–	–	–	–	4.4	–	1.1	2.4	1.5	2.2	3.1	1.3	2.8	2.3
	Recharge (in.)	–	–	–	–	–	–	–	2.6	–	.00	.55	.01	.44	.55	.18	.49	
	Ratio (percent)	–	–	–	–	–	–	–	60	–	0	23	1	20	17	14	17	
April	Precipitation (in.)	–	–	–	–	–	–	3.3	3.2	–	1.1	3.0	1.8	2.0	1.5	–	1.1	1.7
	Recharge (in.)	–	–	–	–	–	–	.48	.08	–	.00	.59	.00	.00	.00	–	.00	
	Ratio (percent)	–	–	–	–	–	–	14	2	–	0	20	0	0	0	–	0	
May	Precipitation (in.)	–	–	–	–	–	–	2.2	3.0	3.7	1.0	2.6	2.6	2.1	3.1	2.8	2.4	2.0
	Recharge (in.)	–	–	–	–	–	–	.00	.00	.63	.00	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	–	–	–	–	–	–	0	0	17	0	0	0	0	0	0	0	
June	Precipitation (in.)	–	–	–	–	–	–	2.1	3.0	.8	1.3	1.5	1.8	1.7	.8	.8	–	1.8
	Recharge (in.)	–	–	–	–	–	–	.00	.00	.00	.00	.00	.00	.00	.00	.00	–	
	Ratio (percent)	–	–	–	–	–	–	0	0	0	0	0	0	0	0	0	–	
July	Precipitation (in.)	–	–	–	–	–	–	.82	2.7	.88	.26	.12	.38	.26	.22	.12	1.5	.7
	Recharge (in.)	–	–	–	–	–	–	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	–	–	–	–	–	–	0	0	0	0	0	0	0	0	0	0	
August	Precipitation (in.)	–	–	–	–	–	–	.45	.53	.64	2.5	.01	.05	.38	.58	2.0	.63	.9
	Recharge (in.)	–	–	–	–	–	–	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	–	–	–	–	–	–	0	0	0	0	0	0	0	0	0	0	
September	Precipitation (in.)	–	–	–	–	–	–	1.2	1.2	.98	.14	2.0	.48	.37	1.6	1.4	.65	1.3
	Recharge (in.)	–	–	–	–	–	–	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
	Ratio (percent)	–	–	–	–	–	–	0	0	0	0	0	0	0	0	0	0	
October	Precipitation (in.)	–	–	–	–	–	–	5.0	4.5	.63	2.0	1.2	2.8	.39	1.5	1.8	3.2	2.0
	Recharge (in.)	–	–	–	–	–	–	2.0	.81	.00	.00	.00	.00	.00	.00	.00	.68	
	Ratio (percent)	–	–	–	–	–	–	39	18	0	0	0	0	0	0	0	22	
November	Precipitation (in)	–	–	–	–	–	2.8	4.5	3.0	5.2	2.9	2.4	3.3	2.3	2.9	2.2	–	3.1
	Recharge (in)	–	–	–	–	–	1.1	3.5	1.5	2.7	.88	.35	1.9	.00	.83	.18	–	
	Ratio (percent)	–	–	–	–	–	40	77	50	51	31	15	57	0	29	8	–	
December	Precipitation (in.)	–	–	–	–	–	2.9	6.3	1.4	5.4	3.9	1.8	5.2	5.3	2.8	2.0	3.3	3.6
	Recharge (in.)	–	–	–	–	–	2.0	5.5	.69	4.5	3.1	1.3	4.6	4.5	2.3	1.5	2.8	
	Ratio (percent)	–	–	–	–	–	68	88	48	83	81	75	87	84	80	74	84	
Annual	Precipitation (in.)	–	–	–	–	–	–	–	33	–	26	24	23	21	23	–	–	25
	Recharge (in.)	–	–	–	–	–	–	–	9.7	–	11	8.0	8.1	7.4	6.8	–	–	
	Ratio (percent)	–	–	–	–	–	–	–	30	–	44	33	35	35	30	–	–	

Table 13.   Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Newport, Washington.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005. **Abbreviations:** in., inch; ratio, recharge to precipitation ratio]

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	3.6	2.5	3.7	3.1	1.2	4.7	2.3	1.3	2.2	1.7	4.6	1.0	4.1	3.9	3.4	2.2	3.2
	Recharge (in.)	2.6	2.1	2.9	2.4	.67	3.9	2.0	.65	1.4	.82	3.7	.40	3.2	3.2	2.8	1.6	
	Ratio (percent)	72	85	80	78	59	84	85	49	64	50	79	40	77	82	84	73	
February	Precipitation (in.)	3.1	2.6	1.8	1.0	1.1	2.5	2.3	1.4	1.6	3.9	2.6	1.7	1.9	.9	1.8	.00	2.4
	Recharge (in.)	2.3	1.5	1.1	.84	.45	2.0	1.6	.70	.80	2.5	1.4	.75	1.1	.47	.72	.00	
	Ratio (percent)	75	57	65	85	40	80	67	51	52	63	52	45	57	53	41	0	
March	Precipitation (in.)	1.0	3.5	1.0	2.3	1.7	4.1	.6	2.8	3.5	.7	1.5	2.0	1.2	3.3	1.5	3.8	2.3
	Recharge (in.)	.00	2.3	.00	.81	.46	2.2	.00	1.7	1.7	.00	.70	.18	.00	1.3	.25	2.1	
	Ratio (percent)	0	67	0	36	27	53	0	60	49	0	46	9	0	40	16	56	
April	Precipitation (in.)	2.0	2.8	2.0	4.1	2.0	1.7	1.7	1.8	.52	.57	3.1	2.4	2.1	1.7	1.4	1.3	1.8
	Recharge (in.)	.33	.79	.15	.29	.06	.23	.00	.26	.00	.00	1.0	.56	.39	.00	.00	.07	
	Ratio (percent)	17	28	7	7	3	13	0	15	0	0	33	24	19	0	0	5	
May	Precipitation (in.)	4.5	3.3	.77	1.4	1.1	1.1	3.7	1.0	4.4	.88	2.5	1.6	1.8	2.8	3.2	3.2	2.1
	Recharge (in.)	.84	.35	.00	.00	.00	.00	1.2	.00	2.4	.00	.00	.31	.10	.30	.72	.93	
	Ratio (percent)	19	11	0	0	0	0	32	0	53	0	0	19	6	11	22	29	
June	Precipitation (in.)	2.5	2.3	1.2	1.1	1.4	3.1	2.1	2.0	3.4	1.9	2.0	1.2	1.1	.74	2.3	2.2	1.9
	Recharge (in.)	.71	.00	.04	.00	.00	.59	.91	.00	1.3	.47	.15	.00	.00	.00	.04	.00	
	Ratio (percent)	29	0	4	0	0	19	42	0	37	24	8	0	0	0	2	0	
July	Precipitation (in.)	1.3	.82	1.8	5.1	.10	.39	.24	2.1	2.8	.70	.13	.92	1.3	.00	.16	1.4	.9
	Recharge (in.)	.17	.00	.00	1.29	.00	.00	.00	.72	.98	.00	.00	.00	.00	.00	.00	.10	
	Ratio (percent)	12	0	0	25	0	0	0	34	35	0	0	0	0	0	0	7	
August	Precipitation (in.)	2.4	.45	.50	.83	.09	.76	.93	.41	.20	.37	.02	.19	.15	.88	3.2	1.5	1.0
	Recharge (in.)	.44	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	1.3	.05	
	Ratio (percent)	19	0	0	0	0	0	0	0	0	0	0	0	0	0	40	4	
September	Precipitation (in.)	.00	.00	.82	.61	1.3	1.6	.68	2.2	1.2	.65	1.1	.24	.56	2.0	1.9	.47	1.4
	Recharge (in.)	.00	.00	.00	.00	.00	.13	.00	.31	.00	.00	.00	.00	.00	.95	.80	.00	
	Ratio (percent)	0	0	0	0	0	8	0	14	0	0	0	0	0	49	42	0	
October	Precipitation (in.)	3.0	1.0	1.4	.91	1.8	3.0	5.2	1.9	.84	1.6	4.1	3.5	.16	2.0	2.8	2.3	2.2
	Recharge (in.)	1.28	.20	.00	.00	.10	.95	3.64	.33	.00	.25	2.98	1.45	.00	.20	1.68	.18	
	Ratio (percent)	42	20	0	0	6	32	70	17	0	16	73	42	0	10	60	8	
November	Precipitation (in.)	2.8	4.2	3.9	.67	4.8	3.6	3.1	2.1	3.9	2.4	.81	3.5	2.8	2.5	2.7	2.8	3.5
	Recharge (in.)	1.6	3.0	3.2	.00	4.0	2.1	2.2	1.2	2.7	1.1	.04	2.3	1.6	1.1	1.3	1.7	
	Ratio (percent)	58	71	82	0	83	59	72	54	69	46	5	64	55	43	48	60	
December	Precipitation (in.)	3.1	2.0	3.1	2.8	3.3	4.0	5.4	5.8	.00	3.6	.72	6.1	4.8	3.7	1.5	3.2	3.7
	Recharge (in.)	2.4	1.2	2.4	2.0	2.7	3.4	4.7	5.0	.00	2.9	.28	5.3	4.0	3.0	1.0	2.8	
	Ratio (percent)	77	61	78	72	82	84	88	87	92	81	40	88	83	82	62	87	
Annual	Precipitation (in.)	29	25	22	24	20	31	28	25	36	19	23	24	22	24	26	24	26
	Recharge (in.)	13	11	10	7.7	8.4	15	17	11	22	8.0	11	11	10	10	11	10	
	Ratio (percent)	43	45	45	32	43	51	57	44	61	42	44	46	47	43	41	39	

Table 14.   Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Priest River Experiment Station, Idaho.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005.
**Abbreviations:** in., inch; ratio, recharge to precipitation ratio]

|		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	7.7	3.3	4.9	2.9	3.1	4.7	3.9	4.9	4.7	4.0	4.8	1.2	4.5	4.9	3.6	2.7	4.0
	Recharge (in.)	7.0	2.9	4.2	2.2	2.6	4.1	3.4	4.2	4.0	3.3	4.1	.63	3.7	4.3	3.0	2.1	
	Ratio (percent)	90	89	86	76	85	87	86	87	85	82	85	52	83	87	84	77	
February	Precipitation (in.)	3.9	1.8	1.9	1.0	2.3	2.6	5.3	2.0	2.1	6.7	2.8	1.3	2.1	1.3	1.7	.2	3.0
	Recharge (in.)	3.3	1.0	1.1	.52	1.3	2.0	4.2	1.2	1.3	5.5	1.7	.57	1.4	1.0	.68	.00	
	Ratio (percent)	84	55	57	54	56	79	80	57	61	82	59	44	68	72	40	0	
March	Precipitation (in.)	1.3	2.3	.7	2.4	2.0	4.9	1.4	5.4	3.3	1.7	3.2	2.3	1.7	4.9	1.6	5.0	2.7
	Recharge (in.)	.44	1.6	.00	.64	.85	3.2	.23	3.7	1.2	.15	1.6	.05	.40	3.0	.40	3.1	
	Ratio (percent)	34	72	0	27	42	65	17	69	37	9	50	2	24	62	24	62	
April	Precipitation (in.)	1.8	2.9	2.0	3.9	2.2	1.9	4.5	2.9	1.2	1.0	2.8	4.5	2.1	1.7	1.7	1.5	2.1
	Recharge (in.)	.23	.89	.10	.31	.06	.20	1.3	.18	.00	.00	.70	2.0	.55	.00	.00	.16	
	Ratio (percent)	13	30	5	8	3	11	28	6	0	0	25	44	26	0	0	11	
May	Precipitation (in.)	4.6	2.3	.8	1.9	2.0	1.8	4.4	3.6	7.2	2.0	2.3	1.9	2.4	2.5	4.0	3.6	2.3
	Recharge (in.)	.53	.00	.00	.00	.02	.20	1.3	1.2	3.7	.00	.00	.47	.49	.00	.82	.63	
	Ratio (percent)	11	0	0	0	1	11	29	35	52	0	0	25	20	0	21	17	
June	Precipitation (in.)	3.7	1.7	4.5	1.7	2.5	4.2	3.3	1.8	1.8	2.3	3.6	2.6	2.0	1.8	1.8	3.0	2.3
	Recharge (in.)	1.4	.00	2.7	.00	.00	1.4	1.4	.06	.00	.00	.76	.14	.13	.00	.00	.10	
	Ratio (percent)	38	0	60	0	0	33	42	3	0	0	21	6	6	0	0	4	
July	Precipitation (in.)	1.2	.89	2.3	4.0	.06	.77	.63	2.0	2.2	.53	.81	1.0	.71	.00	.55	1.6	1.0
	Recharge (in.)	.09	.00	.39	.54	.00	.00	.00	.00	.35	.00	.00	.00	.00	.00	.00	.14	
	Ratio (percent)	7	0	17	14	0	0	0	0	16	0	0	0	0	0	0	9	
August	Precipitation (in.)	1.7	.85	.53	1.1	.23	1.5	.89	.55	.86	1.7	.29	.35	.23	.64	4.1	.84	1.2
	Recharge (in.)	.18	.00	.00	.00	.00	.00	.00	.00	.11	.00	.00	.00	.00	.00	1.7	.00	
	Ratio (percent)	11	0	0	0	0	0	0	0	13	0	0	0	0	0	42	0	
September	Precipitation (in.)	.01	.17	1.3	1.3	1.1	1.6	1.4	3.5	1.4	.35	1.6	.42	.79	2.1	1.8	.86	1.6
	Recharge (in.)	.00	.00	.00	.01	.00	.01	.00	1.70	.00	.00	.09	.00	.00	.44	.34	.00	
	Ratio (percent)	0	0	0	1	0	1	0	48	0	0	6	0	0	22	19	0	
October	Precipitation (in.)	3.4	1.0	1.3	.79	2.9	4.0	4.7	3.9	.99	2.5	2.0	3.9	.72	2.7	2.9	2.8	2.6
	Recharge (in.)	1.4	.30	.00	.00	1.0	2.1	2.9	1.6	.00	.65	.52	1.8	.00	.55	1.1	.47	
	Ratio (percent)	41	29	0	0	35	54	62	40	0	26	27	45	0	20	39	17	
November	Precipitation (in.)	3.1	3.7	3.5	1.3	5.0	4.3	8.2	2.4	6.6	4.4	2.4	5.0	3.3	3.9	3.4	2.9	4.0
	Recharge (in.)	2.1	2.7	2.9	.31	4.2	2.8	7.5	1.4	5.0	3.4	1.7	4.0	2.2	2.7	2.2	2.2	
	Ratio (percent)	69	74	83	23	85	65	91	59	75	77	73	80	65	68	65	75	
December	Precipitation (in.)	2.4	3.1	4.6	4.4	4.7	4.6	8.8	2.1	7.4	5.7	2.1	5.1	6.1	3.6	2.1	3.9	4.4
	Recharge (in.)	1.8	2.5	4.0	3.9	4.2	4.0	8.3	1.6	6.8	5.1	1.6	4.5	5.4	3.0	1.5	3.5	
	Ratio (percent)	75	80	87	90	89	87	94	78	91	90	78	88	88	83	74	90	
Annual	Precipitation (in.)	35	24	28	27	28	37	47	35	40	33	29	29	27	30	29	29	31
	Recharge (in.)	18	12	15	8.5	14	20	30	17	22	18	13	14	14	15	12	12	
	Ratio (percent)	53	50	55	32	51	54	64	48	57	55	45	48	54	50	41	43	

Table 15.   Monthly precipitation and dual-coefficient FAO Penman-Monteith recharge using daily values, 1995–2005, Sandpoint Experiment Station, Idaho.

[Western Regional Climate Center (2006a, 2006b), U.S. Department of Commerce (2006). Mean precipitation values are through December 31, 2005. **Abbreviations:** in., inch; ratio, recharge to precipitation ratio]

|		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	Period of record mean
January	Precipitation (in.)	7.4	4.9	5.5	3.0	2.9	4.5	4.7	5.1	4.8	4.6	4.1	1.3	5.7	6.1	3.9	2.6	4.1
	Recharge (in.)	6.5	4.5	4.5	2.3	2.4	3.8	4.1	4.4	4.0	3.9	3.3	.55	4.8	5.4	3.2	1.8	
	Ratio (percent)	87	93	83	75	83	83	87	86	83	85	80	43	84	87	83	70	
February	Precipitation (in.)	4.0	2.6	2.1	.76	2.6	4.3	7.2	2.7	2.3	7.8	3.2	1.3	2.9	1.3	1.9	.15	3.1
	Recharge (in.)	3.1	1.4	1.0	.26	1.6	3.6	5.9	1.8	1.1	6.5	1.9	.55	2.1	.86	1.0	.00	
	Ratio (percent)	77	57	50	35	64	83	83	64	51	83	59	41	72	65	51	0	
March	Precipitation (in.)	1.2	3.1	.55	1.9	2.3	3.4	.32	6.7	3.4	1.6	3.6	2.0	1.4	5.3	2.0	4.7	2.8
	Recharge (in.)	.34	1.77	.00	.31	.90	1.58	.00	4.99	1.40	.06	1.86	.17	.17	3.32	.29	2.86	
	Ratio (percent)	28	57	0	17	39	47	0	74	41	4	51	9	12	62	14	61	
April	Precipitation (in.)	2.0	4.0	1.4	2.9	1.6	2.1	5.0	3.4	1.3	.86	2.5	2.9	2.4	1.4	2.1	1.2	2.1
	Recharge (in.)	.54	1.5	.00	.07	.00	.26	1.7	1.1	.00	.00	.58	.60	.97	.00	.13	.20	
	Ratio (percent)	28	38	0	3	0	13	33	31	0	0	23	20	41	0	6	16	
May	Precipitation (in.)	3.9	3.5	.82	1.8	2.2	1.8	4.8	3.5	6.8	1.8	2.6	2.0	2.6	2.7	4.0	3.4	2.3
	Recharge (in.)	.21	.26	.00	.00	.00	.13	1.8	1.1	3.6	.00	.00	.62	.35	.00	.95	.57	
	Ratio (percent)	5	8	0	0	0	7	38	31	52	0	0	31	13	0	24	17	
June	Precipitation (in.)	2.9	3.7	4.5	1.9	2.8	3.8	2.7	1.6	2.2	2.1	2.8	4.0	2.3	1.6	2.1	3.6	2.3
	Recharge (in.)	1.5	.18	1.9	.00	.02	1.1	.62	.18	.01	.19	.80	.67	.01	.00	.00	.00	
	Ratio (percent)	52	5	43	0	1	28	23	11	0	4	29	17	0	0	0	0	
July	Precipitation (in.)	1.2	1.1	4.0	6.6	.08	.83	.45	2.9	1.8	1.0	.64	.78	.69	.05	.50	1.6	1.0
	Recharge (in.)	.00	.00	1.2	2.8	.00	.00	.00	.16	.00	.00	.00	.00	.00	.00	.00	.36	
	Ratio (percent)	0	0	29	42	0	0	0	5	0	0	0	0	0	0	0	23	
August	Precipitation (in.)	1.0	.87	.83	1.6	.11	1.6	1.2	.38	.98	1.1	.07	.12	.48	.86	4.1	.72	1.2
	Recharge (in.)	.00	.00	.00	.00	.00	.00	.00	.00	.10	.00	.00	.00	.00	.00	1.93	.00	
	Ratio (percent)	0	0	0	0	0	0	0	0	11	0	0	0	0	0	47	0	
September	Precipitation (in.)	.00	.05	1.6	1.3	1.4	1.9	1.6	3.5	.72	.27	2.0	.37	.56	2.0	2.8	1.5	1.7
	Recharge (in.)	.00	.00	.00	.00	.18	.33	.00	1.6	.00	.00	.32	.00	.00	.28	1.0	.00	
	Ratio (percent)	0	0	0	0	12	18	0	45	0	0	16	0	0	14	37	0	
October	Precipitation (in.)	5.4	.86	1.6	1.3	3.3	4.9	4.8	4.3	1.2	2.5	1.4	4.3	.40	3.5	3.4	3.8	2.6
	Recharge (in.)	2.8	.13	.18	.00	1.4	2.8	3.1	1.8	.00	.61	.00	2.1	.00	1.0	1.6	1.3	
	Ratio (percent)	51	15	11	0	42	58	65	42	0	24	0	49	0	27	48	35	
November	Precipitation (in.)	4.6	4.8	5.0	1.5	5.4	5.3	5.5	2.8	6.3	4.1	2.1	5.1	3.6	5.4	5.3	3.4	4.3
	Recharge (in.)	3.2	3.5	4.2	.40	4.3	3.6	4.6	1.5	4.6	2.8	1.2	3.8	2.3	4.2	3.6	2.2	
	Ratio (percent)	69	74	85	27	81	68	84	55	73	69	57	75	64	78	68	66	
December	Precipitation (in.)	3.8	3.5	3.1	5.1	5.7	5.3	8.8	2.6	7.9	6.5	1.5	6.6	5.8	3.8	3.6	4.6	4.6
	Recharge (in.)	3.0	2.8	2.3	4.5	5.0	4.6	8.1	1.9	7.2	5.9	1.0	5.9	5.0	3.0	2.8	4.0	
	Ratio (percent)	79	80	74	88	88	87	92	75	91	91	65	89	86	80	77	86	
Annual	Precipitation (in.)	37	33	31	30	30	40	47	39	40	34	26	31	29	34	36	31	32
	Recharge (in.)	21	16	15	11	16	22	30	20	22	20	11	15	16	18	16	13	
	Ratio (percent)	56	49	50	36	52	55	64	52	55	58	41	49	54	53	46	43	
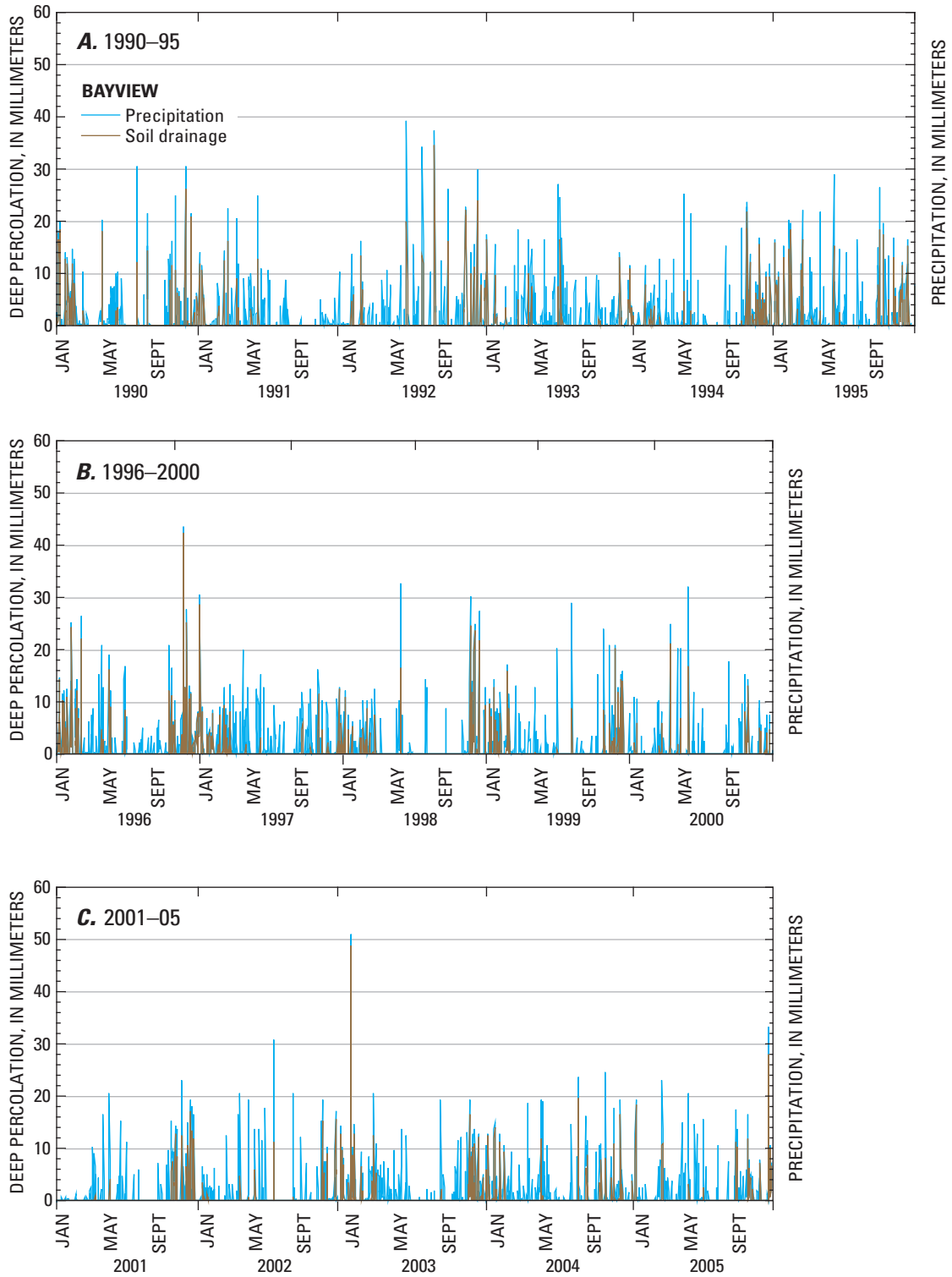
Figure 5. Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1990–2005, Bayview Model Basin, Idaho.
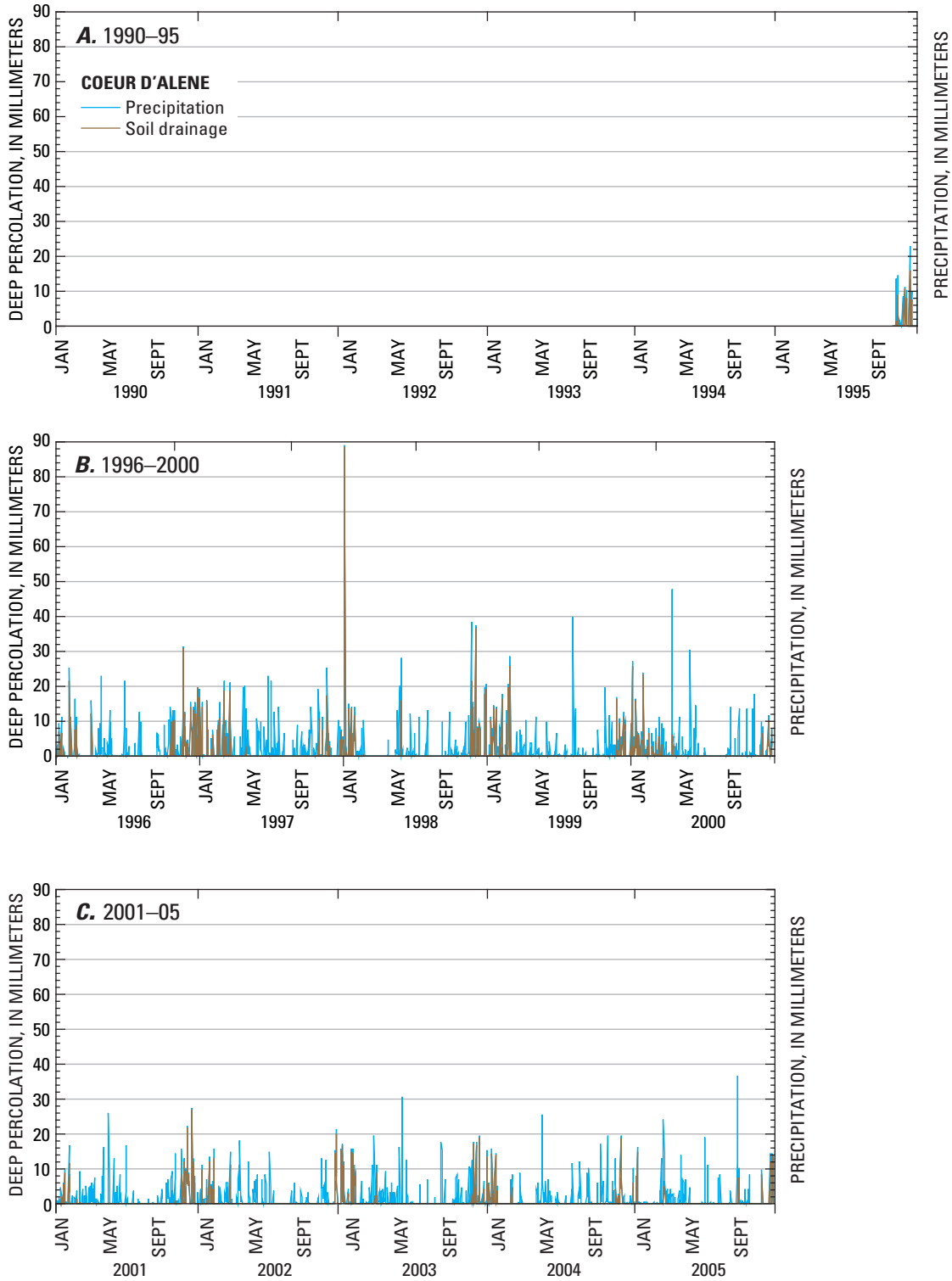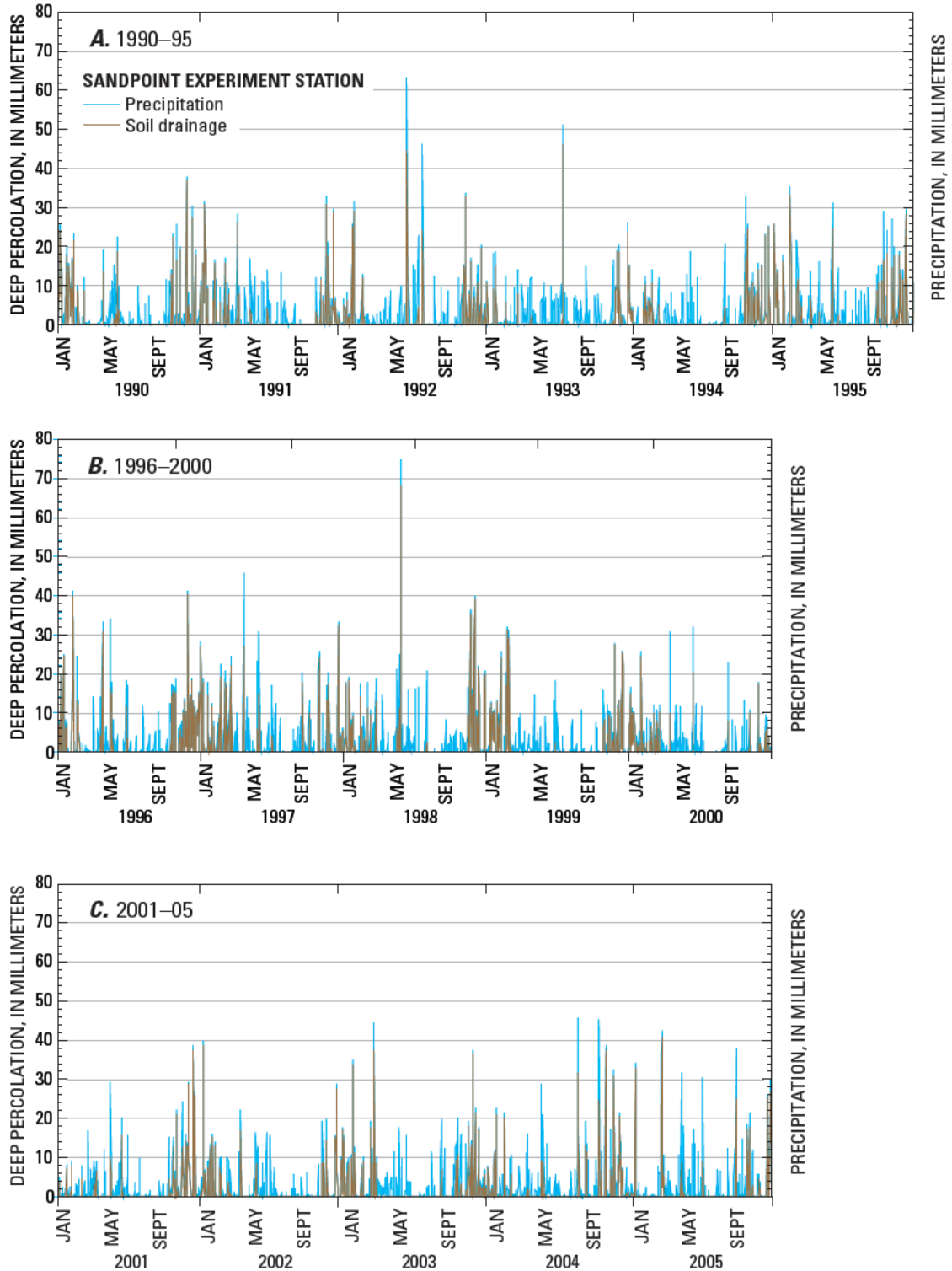
Figure 6.   Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1995–2005, Coeur D'Alene 1E, Idaho.
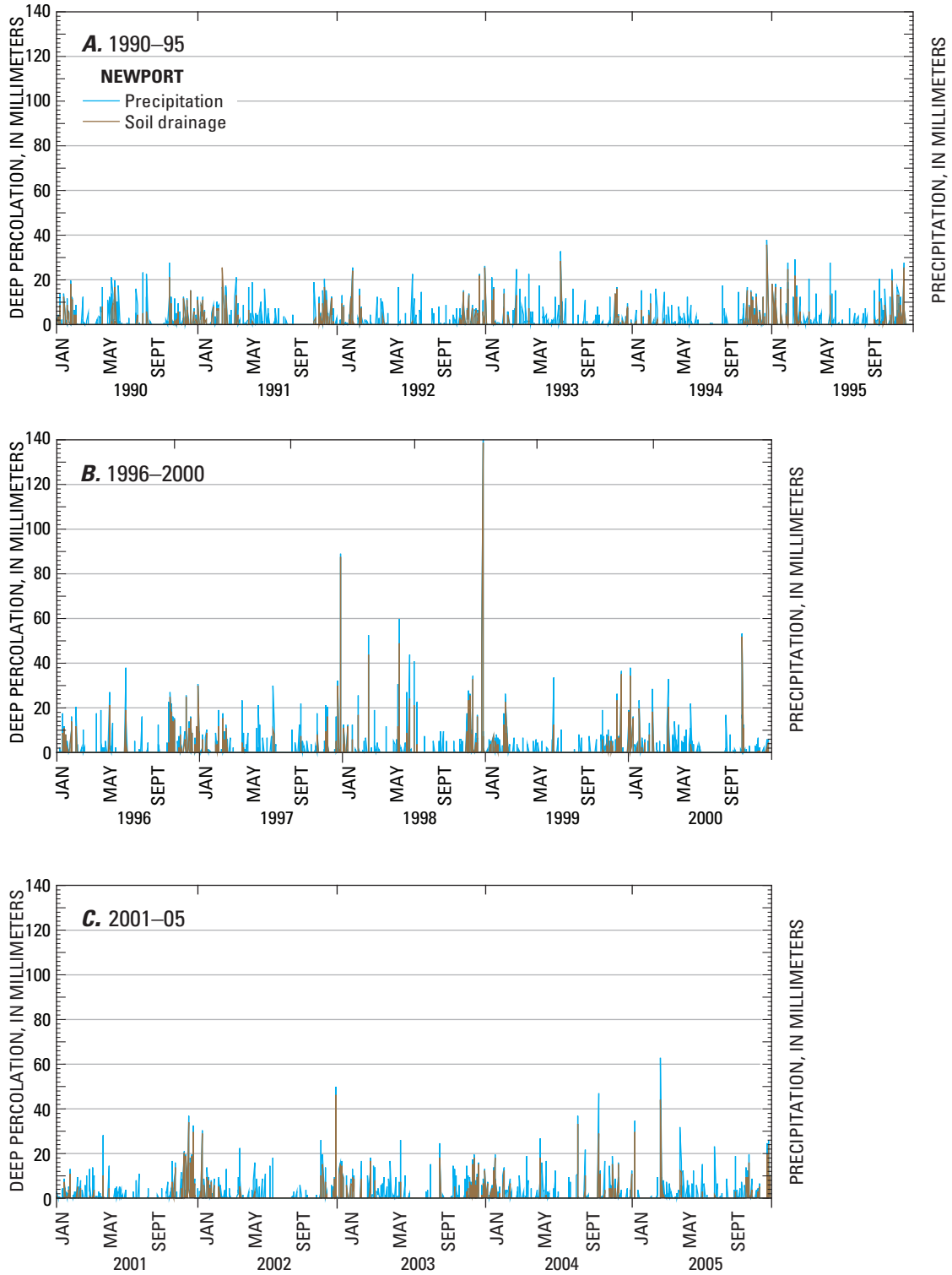
Figure 7. Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1990–2005, Newport, Washington.
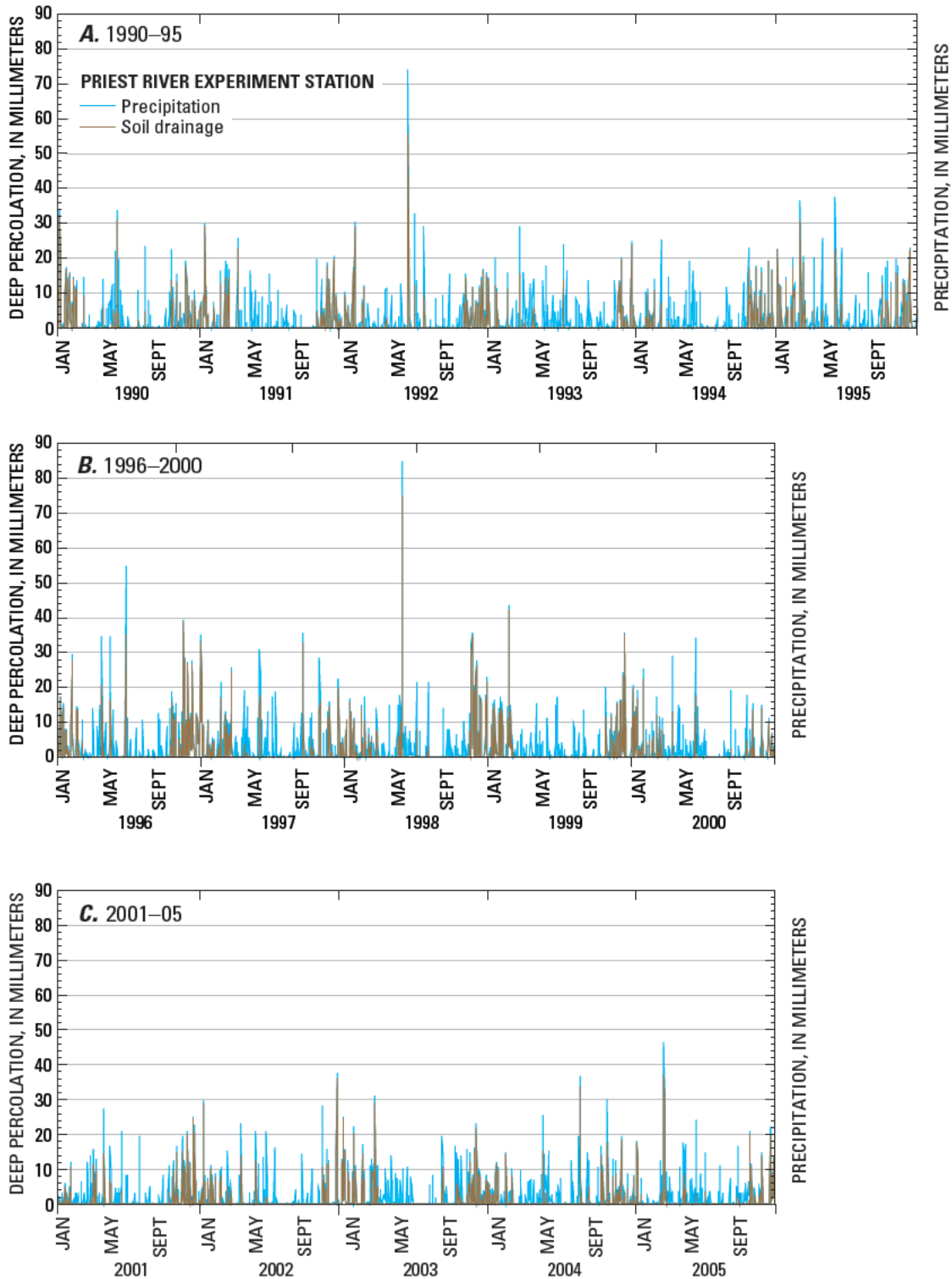
Figure 8.   Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1990–2005, Priest River Experiment station, Idaho.

Figure 9. Daily values of precipitation and dual-coefficient FAO Penman-Monteith deep percolation, 1990–2005, Sandpoint Experiment station, Idaho.

The "Previous Work" section of this paper discusses earlier estimates of areal recharge and figure 10 shows a comparison between these monthly recharge rates and monthly recharge rates calculated in this study. The ranges of 1995-2005 monthly values of dual-coefficient FAO Penman-Monteith recharge are similar to those of the transient model of Bolke and Vaccaro (1988), though the ranges are larger than that of Buchanan (2000). If one considers the location and extent of these previous models and compares the Bolke and Vaccaro (1988) and the Golder Associates, Inc. (2004) recharge values to calculated recharge for Spokane WSO Airport, there is good agreement between the estimates. Similarly, if the recharge estimates from the three stations in the study area are compared to Buchanan's (2000) estimates, they fall within his range.

Although beyond the scope of this report, these recharge estimates for individual points need to be applied to the study area as a whole. A number of techniques may be appropriate for this task.

Areal recharge commonly is the most uncertain component of water budgets and ground-water flow models and is therefore usually calculated as the residual of other components. Without *a priori* knowledge of probable values, choosing between values of areal recharge calculated by different methods is difficult. Thus, the larger context provided by water budgets and ground-water flow model calibration is crucial in determining reasonable values.

Summary and Conclusions

The Spokane Valley-Rathdrum Prairie (SVRP) aquifer, which straddles the Idaho-Washington state line northeast of the City of Spokane, is the sole source of drinking water for more than 400,000 people. The area is experiencing rapid population growth, and a better understanding of the characteristics of the aquifer and its interaction with the Spokane River is necessary to guide the development and management of the resource. To this end, a multi-year study started in 2003 to gather data and construct a ground-water flow model of the SVRP aquifer that both states can use to evaluate water-management decisions.

Currently (2006), a ground-water-flow model that simulates ground-water/surface-water interaction is under construction by a joint team from the Idaho Department of Water Resources, University of Idaho, Washington State University, and the U.S. Geological Survey. This model requires values for areally-distributed recharge from precipitation, however, such values commonly are the most uncertain components of water budgets and ground-water flow models because it is virtually impossible to measure recharge over large areas. In previous flow models of the SVRP aquifer, various approaches or techniques were used to estimate areal recharge, ranging from assigning a uniform recharge to the entire model domain to calculating evapotranspiration for each model cell.
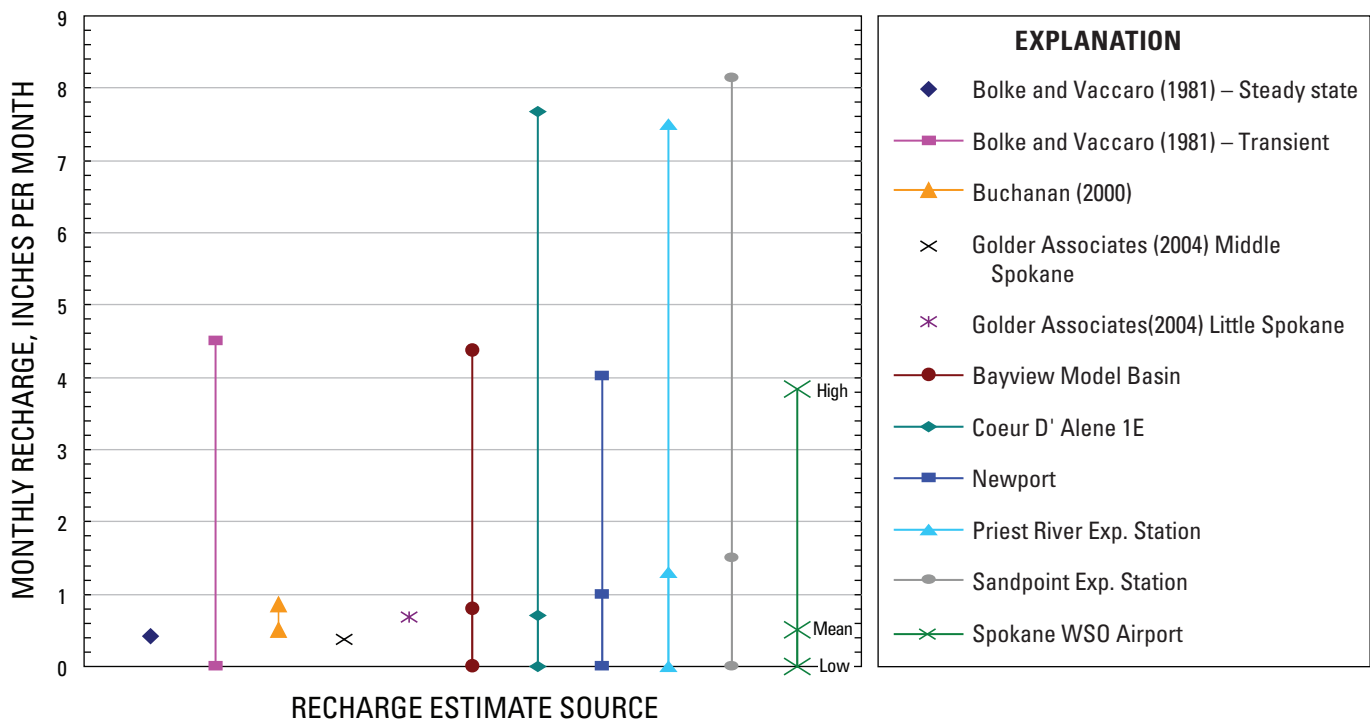
Figure 10.   Comparison of previous monthly recharge rate estimates with dual-coefficient FAO Penman-Monteith recharge, 1995–2005.

The National Weather Service has nine weather stations in or within 20 miles of the study area, although only six are active, and only three are within or adjacent to the SVRP study area. The data from these weather stations were used in the calculations of area recharge via several methods or approaches.

Four potential approaches were identified for determining areal recharge for the SVRP ground-water flow model:

1. A method (Langbein method) developed in which recharge is estimated on the basis of empirical data from other basins;

2. A method (USDA method) developed in which crop consumptive use and effective precipitation are first calculated and then subtracted from actual precipitation to yield an estimate of recharge;

3. An approach developed for the Eastern Snake Plain Aquifer Model (ESPAM) Enhancement Project in which recharge is calculated on the basis of precipitation-recharge relations from other basins; and

4. An approach in which reference evapotranspiration is calculated by the Food and Agriculture Organization (FAO) Penman-Monteith equation, crop consumptive use is determined (using a single or dual coefficient approach), and the amount of water which passes through the plant root zone (and thus becomes recharge) is calculated.

Mean annual recharge calculated with the Langbein method for the six active weather stations was 4 percent of mean annual precipitation, yielding the lowest mean annual values of the methods discussed in this report. The primary shortcoming of the Langbein method is that it can only be applied to annual time periods.

Mean monthly recharge calculated with the USDA method ranged from 53 to 73 percent of mean monthly precipitation. Mean annual recharge ranged from 64 to 69 percent of mean annual precipitation. Because the USDA effective rainfall equation was derived empirically using data from throughout the United States, it is difficult to evaluate how applicable the method is to the SVRP study area.

Mean monthly recharge calculations by the ESPAM method were made using thin-soil, thick-soil, and lava-rock parameters. The lava-rock parameters yielded the highest recharge values and the thick-soil parameters the lowest. For thin-soil parameters, calculated monthly recharge ranged from 10 to 29 percent of monthly mean precipitation and annual recharge ranged from 16 to 23 percent of mean annual precipitation. For thick-soil parameters, calculated monthly recharge ranged from 1 to 5 percent of monthly mean precipitation and annual recharge ranged from 2 to 4 percent

of mean annual precipitation. For lava-rock parameters, calculated monthly recharge ranged from 37 to 57 percent of monthly mean precipitation and annual recharge ranged from 45 to 52 percent of mean annual precipitation. Because the ESPAM method equations were derived from previous work on the ESRP, for a given precipitation (P), paired slope parameter (K), and coefficient for curvature (N), recharge calculated by the ESPAM method will be equivalent to that calculated for the ESRP.

Single-coefficient FAO Penman-Monteith mean monthly recharge values were calculated for the Spokane WSO Airport station: grass-referenced values of mean monthly recharge ranged from 0 to 81 percent of mean monthly precipitation and mean annual recharge was 21 percent of mean annual precipitation; alfalfa-referenced values of mean monthly recharge ranged from 0 to 85 percent of mean monthly precipitation and mean annual recharge was 24 percent of mean annual precipitation. The single-coefficient FAO Penman-Monteith equations used with mean monthly values yield mean monthly recharge values of zero during the eight warmest and driest months of the year (March-October). Such a result seems unlikely based on ground-water levels.

For all stations the lava-rock parameters yield the highest values of mean monthly recharge and the thick-soil parameters the lowest among the ESPAM techniques. USDA mean monthly recharge values are higher than any ESPAM values for all months. For the Spokane WSO Airport station, the single-coefficient FAO Penman-Monteith mean monthly recharge values are highest in the winter and lowest during the growing season.

The dual-coefficient FAO Penman-Monteith dual-crop evapotranspiration (ET_{cd}) and deep percolation calculations were applied to daily values from the Spokane WSO Airport for January 1990 through December 2005. The resultant monthly totals show a temporal variability lacking in the single-coefficient mean monthly values and demonstrate that the daily amount and timing of precipitation dramatically affect calculated recharge. For the remaining five weather stations, 1990-2005 daily recharge was calculated using wind speed from the Spokane WSO Airport station and assuming that dewpoint was equal to the daily minimum temperature. For all six weather stations dual-coefficient FAO Penman-Monteith monthly recharge ranged from 0 to 94 percent of monthly precipitation.

Because areal recharge is often the most uncertain component of water budgets and ground-water flow models, it is often calculated as the residual of other components. Without *a priori* knowledge of probable values of areal recharge, choosing between values of recharge calculated by different methods is a challenging decision. Thus, the larger context provided by water budgets and ground-water flow model calibration is crucial in determining reasonable values.

Acknowledgments

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Appendix A. Soils

Nearly all of the Spokane Valley-Rathdrum Prairie aquifer is overlain by two STATSGO soil mapping units: the Kootenai-Bonner-Rathdrum unit mostly north of Rathdrum and near Hayden Lake and the Garrison-Avonville-Marble Variant unit in most of the remainder of the study area (fig. A1; Soil Survey Staff, 2006a, b). Virtually all the soil series comprising these mapping units are classified in hydrologic soil groups A and B (rated on a scale from A to D, ranging from high values of saturated hydraulic conductivity and deep free-water occurrence, (A), to moderately low saturated hydraulic conductivity and shallow free-water occurrence, (D), (Weisel, 1981)). Thus, precipitation may be expected to pass readily into the root zone and beyond. Measured mean vertical permeability ranges from 1.3 to greater than 40 feet per day for both units. Golder Associates, Inc. (2004) reported that during calibration of their integrated ground-water/surface-water model of the Middle Spokane watershed, a uniform change of all soils in the model to

type D (thus decreasing vertical hydraulic conductivity by approximately four orders of magnitude) decreased mean weekly recharge by about 50 percent.

By way of comparison, Garabedian's (1992) ESRP thin soil infiltration rate group contained hydrologic soil groups A–D, but were primarily of groups A and B. His thick soil group contained hydrologic soil groups B-D, but were primarily of groups B and C.

Contor (2004) assumed that the rangeland plants of the ESRP had root systems developed throughout the entire soil profile. Because water in the root zone is available for evapotranspiration, the increased time necessary for water to pass through a thick soil results in less recharge than for a thin soil with the same hydrologic properties. Because most of the series comprising the two STATSGO mapping units in the study area are described as "very deep," no effort was made in the current report to differentiate soil depths.

Available water capacity values for the soil mapping units range from 0.01 to 0.6 in/in (10-600 mm/m) (Natural Resources Conservation Service, 2006a, 2006b, 2006c).
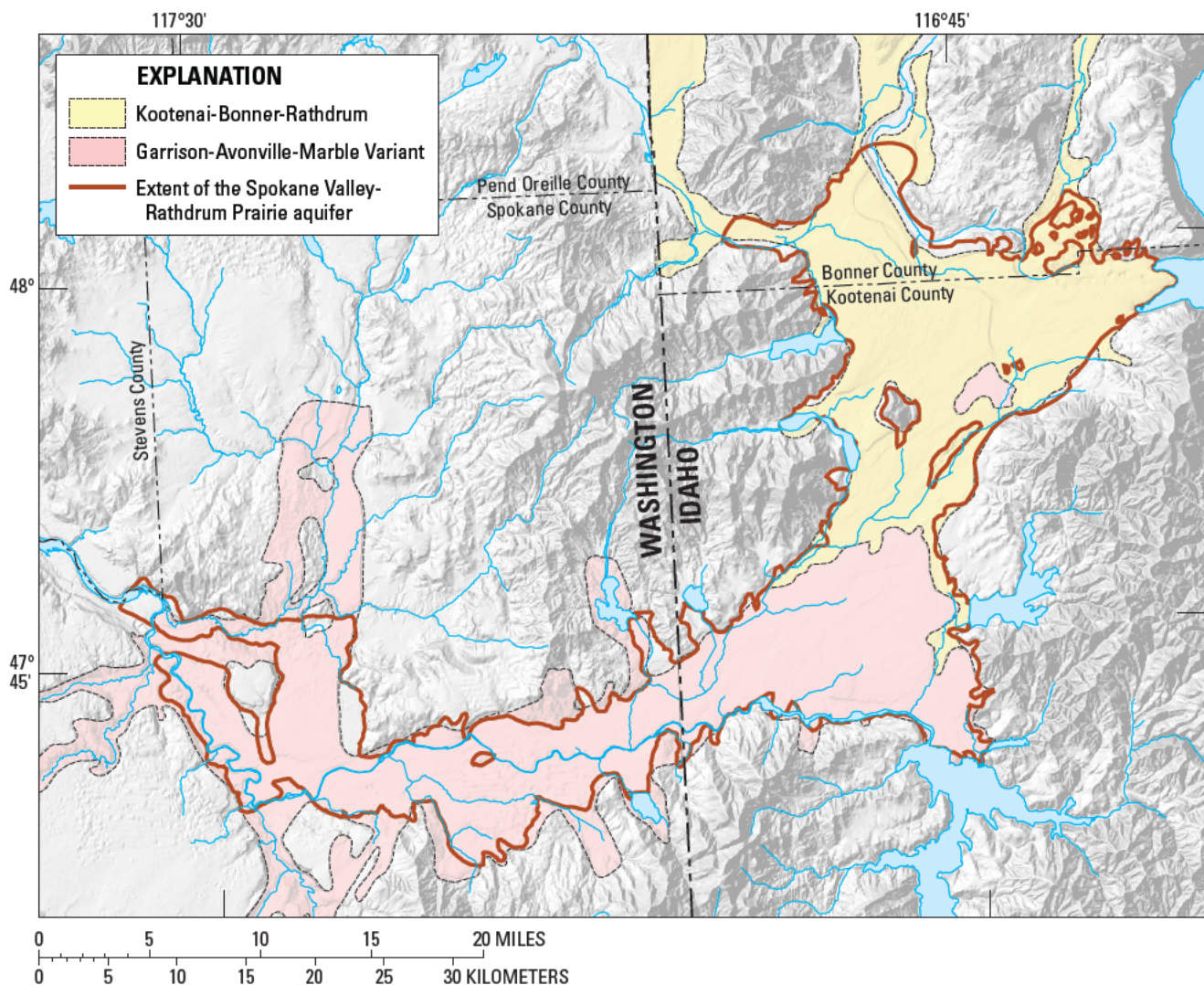

Figure A1.   Major soil mapping units in the study area.

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Bartolino

Assessment of Areal Recharge to the Spokane Valley-Rathdrum Prairie Aquifer, Spokane County, Washington, and Bonner and Kootenai Counties, Idaho

SIR 2007–5038