West Plains Hydrogeology

Groundwater Recharge Estimate

June 30, 2013

Prepared by Spokane County Water Resources

Washington Department of Ecology

Grant G1200159

SPOKANE COUNTY
WATER RESOURCES

Table of Contents

Figures

Tables

Appendix A - Monthly Water Budget Components

Introduction

This report describes the work completed for the *West Plains Recharge Assessment* (project). The project was funded by grant G1200159 from the Washington Department of Ecology's (Ecology) Watershed Planning Program. The project scope was developed from recommendations included in the Water Resource Inventory Area (WRIA 54) Watershed Plan and WRIA 54 Detailed Implementation Plan (DIP). The WRIA 54 DIP includes the following recommendation

> **Recommendation TI-1: West Plains Hydrogeology Study**
> *Basalt Aquifer Groundwater Study-The Columbia River Basalt Group aquifers that underlie the West Plains area are used for water supply. Groundwater levels have declined in some areas, indicating the groundwater resource is potentially strained. These aquifers are not well understood. Elsewhere in the Pacific Northwest, basalt aquifers are used extensively for water supply, indicating that a better understanding of the Columbia River Basalt Group aquifers in the West Plains area would be beneficial to understand how this resource can be used in a sustainable way. (Tetra Tech, 2010)*

Groundwater recharge is fundamental to understanding how a groundwater resource can be used in a sustainable way and is therefore an important component to understanding the hydrogeology of the West Plains area.

The identification of the geographic area the "West Plains" is used frequently in the region, yet the boundaries of this area are

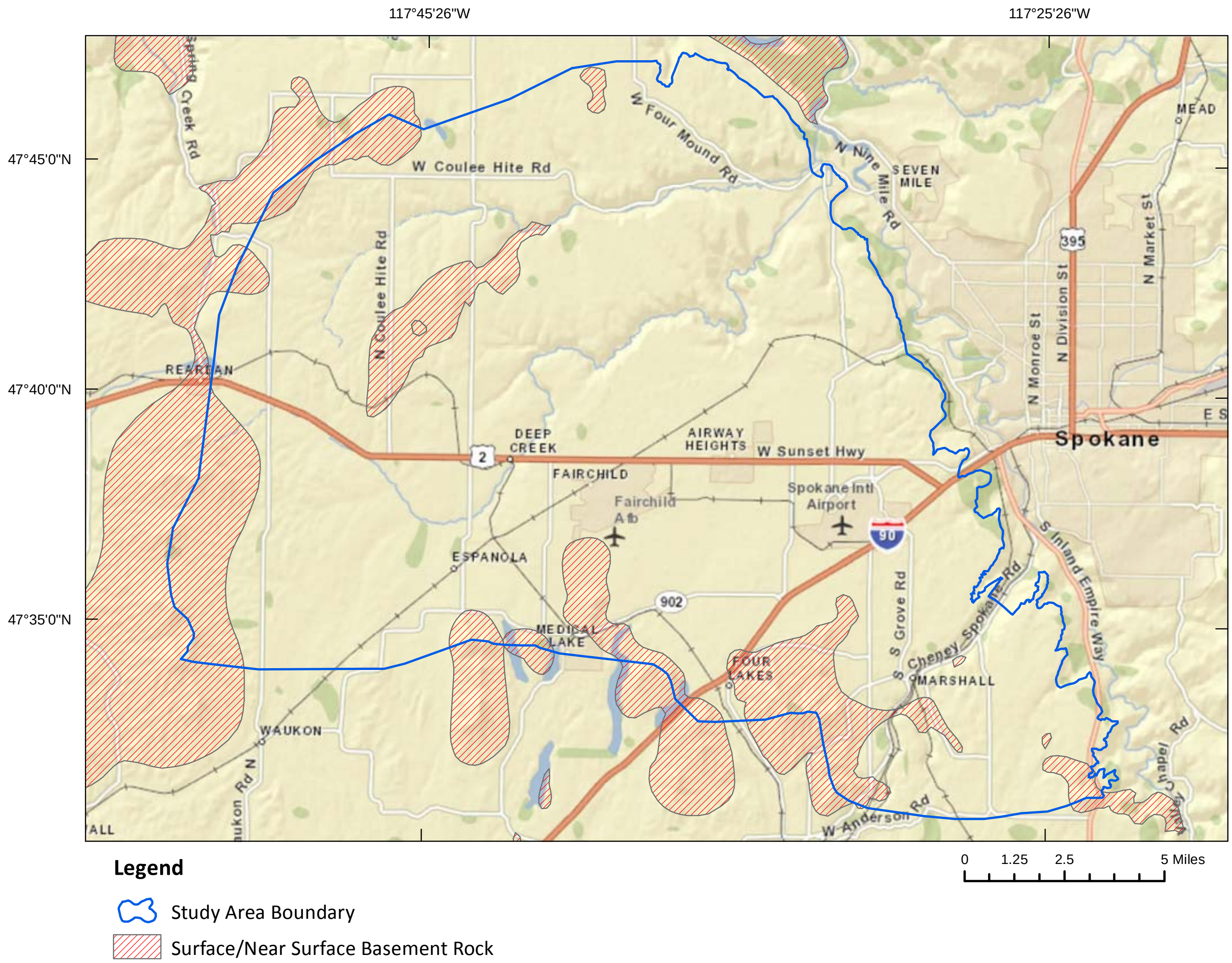

Figure 1—West Plains Groundwater Flow and Recharge Assessment Study Area

not well defined. It is often used to describe the area west of the Spokane River, south of Deep Creek, north of Interstate 90, and west of Lincoln County. The study area for this project, herein after referred to as the West Plains, includes the area described above plus additional area to the north and south. The study area was defined by outcrops of crystalline basement rock that act as a barrier to ground water flow in the basalt aquifers of the West Plains. The boundaries of the basement outcrops has been shown on surficial geology maps in the past, but a more complete boundary has been mapped by McCollum and others and is included in the soon to be released paper entitled *A reinterpretation of the pre-Neogene geology of the north eastern Columbia Plateau: A view from the steptoes*. Figure 1 shows the study area boundaries and the basement rock mapped by McCollum.

The West Plains is located in the northeast corner of the Columbia Plateau Regional Aquifer System (CPRAS). The West Plains, though, is essentially cut off from the larger CPRAS by the basement rock to the west and south, as shown in Figure 1. Groundwater on the western and southwestern side of the basement rock flows south west towards the Columbia River, and groundwater on the east and north east side of the basement rock flows east and north east towards the Spokane River. As a result recharge to the West Plains groundwater system is limited to precipitation that falls within the study area. This is a relatively small area in comparison to areas that recharge other groundwater systems in the region, found in watersheds such as the Latah, Middle Spokane, and Little Spokane River Basins.

Groundwater recharge, often called deep percolation, is water that moves through soil beyond the root zone and eventually to groundwater. Groundwater recharge is difficult to quantify because it is dependent on many factors that vary widely both temporally and spatially. The United States Geologic Survey (USGS) Groundwater Resources Program states the following on its website:

> *"Recharge has been defined as the process of addition of water to the saturated zone. Because it is almost impossible to measure directly, recharge is usually estimated by indirect means." (http://water.usgs.gov/ogw/gwrp/methods/)*

Various methods have been developed to estimate groundwater recharge that utilize chemical tracers, analysis of stream flow gains and losses to groundwater (seepage runs), and water table fluctuations . Mathematical groundwater flow models are also utilized to estimate recharge. The method utilized in this study utilizes soil-water budget calculations that are based on mathematical models of physical processes

Soil-water budget methods takes a specified quantity of water, such as precipitation, and directs components of the specified quantity to different elements of the hydrologic cycle based on mathematical models of the physical processes. For example, when precipitation falls onto land surface a certain portion of the precipitation runs off. The amount of runoff can be estimated with a mathematical model if the land slope, land cover, and soil type is known. A soil-water budget method represents each of the processes that occurs as precipitation falls from the atmosphere and makes it's way to groundwater. Such processes as interception by vegetative canopy, evaporation from land surface, runoff, and transpiration by plants are included in the soil-water budget method.

The Deep Percolation Model, a soil-water budget method developed by the USGS, was utilized for this study. This model was chosen because it is appropriate for the study area size and the time interval of interest (multiple years). It was also chosen because it has been utilized for recharge estimates by the USGS in the CPRAS and the Yakima Basin, both of which have similar climate and hydrogeologic setting to the study area.

Precipitation Recharge Analysis

Recharge was estimated for the water years 1997 through 2012 with the USGS Deep Percolation Model (DPM) Version 3.0 (Vaccaro, 2007). The DPM is a physically based model that simulates the processes of soil-moisture accumulation, evaporation from soil, evaporation of intercepted moisture, transpiration, surface runoff, snow accumulation, sublimation and melting to estimate the amount of moisture that percolates beyond the root zone (deep percolation) and eventually to the water table (Bauer and Vaccaro, 1990). Figure 2 shows the conceptual framework of the DPM.

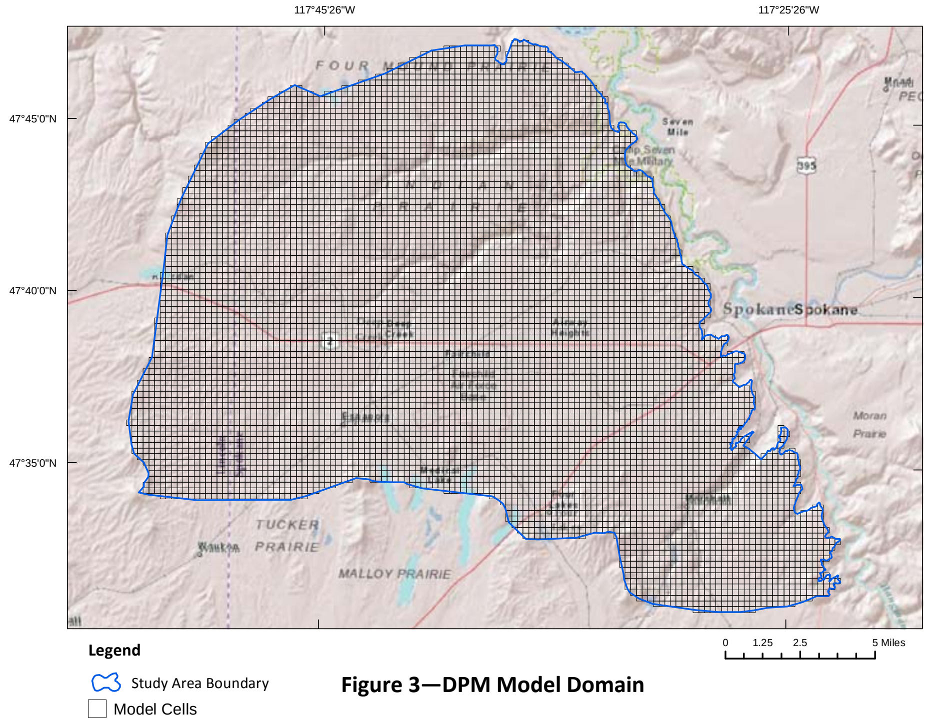

Figure 3—DPM Model Domain

The model is discretized both temporally and spatially. The model is driven by daily values for precipitation and for maximum and minimum temperature. The modeled area is segregated into model cells of a specified area. For each model cell daily water-budget calculations accounting for all fluxes of water into and out of and changes within a volume extending from the top of the foliage to the bottom of the root zone are made. For each cell, unique values for the following parameters are used:

- Longitude, latitude, & elevation;
- Land surface slope & aspect;
- Land use;
- Soil parameters;
- Long-term average annual precipitation; and
- Saturated vertical conductivity of material beneath soil layer.

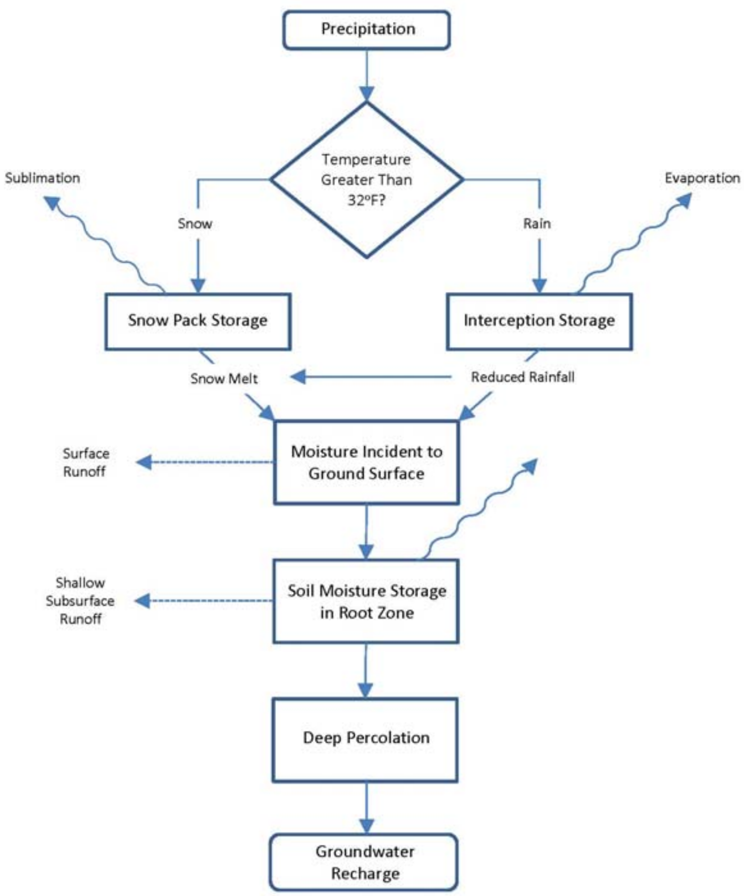

Figure 2—Deep Percolation Model Conceptual Framework

Data Used in Model

The modeled area is 279.32 square miles represented by 7,737 cells that are 1,000 by 1,000 ft. Figure 3 shows the model domain. Most of the data sources are at a higher resolution than the model cells, and none conform exactly to the spatial location of the model cells; polygon data in GIS shape files do not align with model cells, and grid data does not align on the boundary of the model cells, as shown in Figure 4. Therefore the data was resampled. Resampling was done one of two ways; either the mean of values within a model

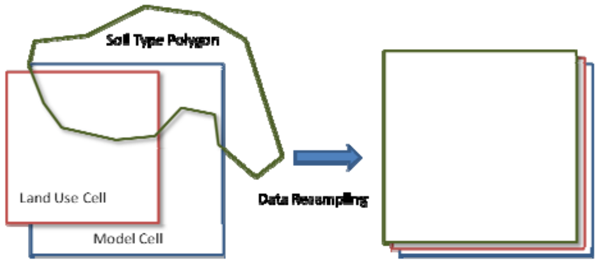

Figure 4—Data Resampling

cell was used or the majority value that was found within the model cell was used. For example, if three available water capacity values were located within a model cell, the mean of those values would be used; if two land use types were found within a model cell, the land use that occupied the most area within the cell would be used. The mean value method was used for elevation, slope, aspect, and rainfall. The majority value method was used for soil parameters, land use, and geology beneath the soil layer.

Landscape Characteristics

The latitude and longitude of the center of the cell and cell elevation, slope, and aspect are all required by the model. Values used in the model represent the mean over the area of the model cell. Elevation was determined from USGS digital elevation models (DEMs) from the USGS National Elevation Dataset (USGS, 2007). Slope and aspect were derived from the DEMs.

Soil Data

The DPM allows up to 24 different soil classifications with unique values for the following five required parameters:

- soil depth;
- soil texture;
- available water capacity;
- specific yield; and
- lateral hydraulic conductivity.

Table 1 - DPM Soil Characteristics

DPM Soil Group No.	Number of DPM Cells	Soil Depth (in.)	Soil Texture			Available Water Capacity[1]	Specific Yield[1]	Lateral Hydraulic Conductivity (ft/day)
			% Sand	% Silt	% Clay			
1	371	51.59	0.00	0.00	0.00	0.00	0.00	0.00
2	705	16.00	15.38	17.25	4.13	0.03	0.16	0.98
3	348	60.57	82.98	12.92	2.73	0.03	0.31	94.69
4	726	36.00	30.99	26.44	7.81	0.05	0.18	10.49
5	78	48.00	47.22	22.24	6.68	0.05	0.20	8.34
6	248	60.00	86.38	12.03	1.33	0.05	0.35	36.66
7	170	62.21	50.34	39.29	12.82	0.07	0.16	2.60
8	156	45.77	41.64	19.97	6.42	0.06	0.20	9.04
9	223	60.00	80.81	15.48	4.45	0.08	0.28	19.03
10	235	41.84	36.15	27.19	9.45	0.10	0.18	5.75
11	1731	60.00	55.39	33.15	7.91	0.11	0.20	59.22
12	528	60.00	74.58	17.25	7.55	0.12	0.25	15.80
13	401	58.78	43.55	40.40	11.68	0.15	0.16	4.23
14	112	38.63	21.00	38.39	15.26	0.12	0.07	1.93
15	23	60.00	22.63	39.63	35.63	0.16	0.03	2.45
16	42	60.96	20.32	55.10	24.80	0.17	0.05	1.35
17	450	60.00	14.22	60.09	23.75	0.19	0.05	1.97
18	652	60.01	19.20	62.56	17.88	0.21	0.07	2.58
19	283	61.00	60.37	28.28	9.08	0.06	0.19	38.93
20	685	56.35	0.00	0.00	21.91	0.19	0.001	2.39
21	131	60.00	34.88	46.33	18.91	0.14	0.09	3.05
22	97	57.00	24.21	46.05	9.00	0.14	0.15	2.14

1 Decimal fraction by volume

Soil data from the United States Department of Agriculture Soil Survey Geographic Database (SSURGO) for Lincoln County and Spokane County was used to develop 22 soil classifications and assign each cell to the appropriate classification.

The SSURGO database includes soil depth, texture of the soil (as percent sand, silt, and clay), and available water capacity. Specific yield was estimated from the soil texture based on a relationship developed by the USGS (Johnson, 1966). Soil permeability from the SSURGO database was used to estimate lateral hydraulic conductivity. Permeability is a measure of the saturated vertical hydraulic conductivity of the soil. The soils were assumed to be isotropic; therefore the lateral and vertical hydraulic conductivities are equal.

The study area includes 178 different SSURGO soil classifications. The 22 soil classifications used in the DPM were developed by grouping soils of similar characteristics. Parameters for each DPM soil classification were estimated from a depth and area weighted average of each of the SSURGO soil classifications that comprised a DPM soil classification. Parameter values for each DPM soil classification are presented in Table 1.

Land Use & Cover Type Data

The 2001 USGS National Land Cover Database (NLCD) was used to determine the dominant land cover type within each

Table 2—Land Use and Cover Type Descriptions

NLCD Description	DPM Code	DPM Description	Growing Season
Evergreen Forest	1	Conifer Forest	Full Year
Shrubland	3	Sagebrush & associated scrub	Full Year
Alfalfa	208	Alfalfa	February 28 to October 31
Grassland Herbaceous	2	Grass-native or irrigated; evapotranspiration estimated using Priestly-Taylor method	Full Year
Open Water	10	Water	
Winter Wheat	204	Winter wheat-harvested in summer and planted in autumn, each year; smaller maximum water demand than cover type identifier 4 based on more recent information	September 4 to July 4
Pasture/Grass	28	Pasture (mid-latitudes)	February 28 to October 31
Developed/Low Intensity	2	Grass-native or irrigated; evapotranspiration estimated using Priestly-Taylor method	Full Year
Fallow/Idle Cropland	3	Sagebrush & associated scrub	Full Year
Lentils	214	Lentil	April 30 to August 15
Developed/Med Intensity	16	Impervious	
Spring Wheat	215	Spring wheat-planted in spring and harvested in autumn, each year; smaller maximum water demand than cover type identifier 15 based on more recent information	
Peas	30	Pea	April 13 to July 24
Barley	209	Row crops (mid latitudes)-undifferentiated; annual crop water use of about 28 inches.	February 28 to October 31
Developed/Open Space	3	Sagebrush & associated scrub	Full Year
Other Hay/Non Alfalfa	209	Row crops (mid latitudes)-undifferentiated; annual crop water use of about 28 inches.	February 28 to October 31
Developed/High Intensity	16	Impervious	
Canola	209	Row crops (mid latitudes)-undifferentiated; annual crop water use of about 28 inches.	February 28 to October 31

model cell. The DPM includes 40 unique land use and cover types. Each cell is assigned a land use and cover type which is then used within the DPM. Not every NLCD cover type has a corresponding DPM land use and cover type. Table 2 presents the NLCD cover types and the DPM land use and cover type to which it was matched.

Weather Data

Daily precipitation and maximum and minimum temperature data for the period October 1996 to September 2012 was used for the recharge analysis. The data was collected from the National Weather Service (NWS) Spokane Forecast Office at 2601 N. Rambo Rd., Spokane, Washington and from the Spokane International Airport (NOAA, 2012). Locations are shown in Figure 5. In addition to daily precipitation data, long-term average annual precipitation for each model cell is required. Average annual precipitation from the period 1981-2010 from the PRISM Climate Group, Oregon State University was used (http://www.ocs.orst.edu/prism/products). This data set is in a gridded format at a 2,000 by 3,000 ft. resolution Data for the study area is shown in Figure 5.

Groundwater Recharge Estimates

The estimated mean annual recharge for the study area over the period from October 1996 to September 2012 from precipitation is 2.58 in, and the estimated annual precipitation for the study area is 16.94 in; therefore the estimated recharge rate is approxi-

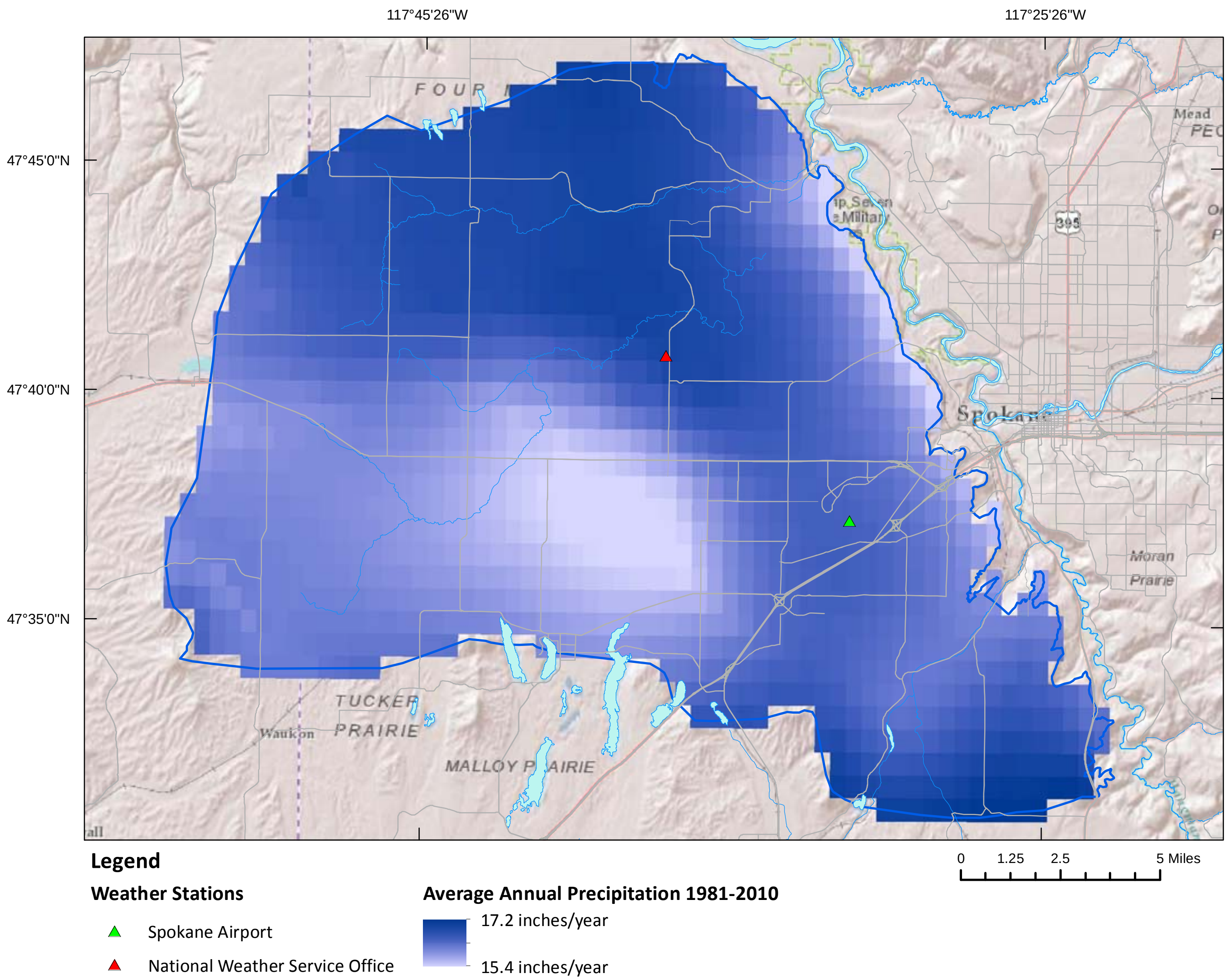

Figure 5—Weather Statins & Annual Average Precipitation

mately 15%. During the study period annual recharge ranged from 5.71 in. to 0.38 in, annual precipitation ranged from 9.89 in. to 23.40 in., and recharge rates ranged between 4% and 28% of precipitation.

The average annual volume of precipitation and recharge is 252,356 acre-feet and 38,434 acre-feet respectively. Table 4 presents the precipitation and recharge for each water year during the study period. DPM output includes water budget components on a monthly basis over the entire study period. Table 3 shows the average for each month over the course of the study period. Appendix A includes the monthly water budget component output for each year.

Temporal Distribution of Recharge

As expected, the amount of recharge is directly related to the amount of precipitation. Timing of precipitation is also a very important factor that impacts the amount of precipitation that becomes recharge. The relative standard deviation of precipitation for water years 1998, 2002, 2004, 2005, 2007, and 2008 is 2%, while the relative standard deviation of the recharge estimates for the same years is 30%. The precipitation for the 2005 and 2007 water years differed by only 4% while the recharge estimate differed by 82%. Figure 6 shows the cumulative precipitation for each of the five water years and the yearly recharge. For water years in which half of the precipitation occurred after mid-April, recharge was significantly less. This is likely because precipitation that occurs after April is more likely to remain in the soil zone during times that evaporation and transpiration are more significant, while precipitation that occurs prior to April is more likely to travel beyond the root zone before evaporation and transpiration is significant. The water budget components for 2005 and 2007 show that the sum of the actual soil evaporation and actual plant transpiration for 2005 are 1.32 in. greater than 2007.

Recharge and Groundwater Level

The DPM estimates the quantity of water that percolates beyond the root zone and presumably reaches the water table. The time it takes for the water to reach the water table and show any effect on groundwater elevation is dependent on many factors; therefore a correlation between groundwater levels and estimated recharge is often not seen. Some aquifers, though, do show changes in response to recharge in a relatively short period of

Table 3—Monthly Water Budget Components

Month	Precipitation	Recharge	Actual Bare Soil Evaporation	Direct Evaporation of Snow	Actual Plant Transpiration	Change in Soil Moisture	Change in Snow Pack
October	1.22	0.03	0.04	0.00	0.24	0.53	0.00
November	2.28	0.13	0.03	0.04	0.05	1.36	0.27
December	2.54	0.41	0.01	0.12	0.00	1.30	0.24
January	1.98	0.58	0.00	0.14	0.00	0.74	-0.07
February	1.34	0.43	0.05	0.07	0.06	0.34	-0.18
March	1.80	0.54	0.20	0.03	0.49	-0.05	-0.26
April	1.31	0.18	0.24	0.00	1.35	-1.13	-0.01
May	1.75	0.10	0.20	0.00	1.92	-1.19	0.00
June	1.36	0.09	0.17	0.00	1.56	-1.06	0.00
July	0.38	0.04	0.07	0.00	0.56	-0.49	0.00
August	0.49	0.03	0.04	0.00	0.35	-0.11	0.00
September	0.48	0.02	0.03	0.00	0.30	-0.06	0.00
TOTALS							
Inches	16.94	2.58	1.08	0.4	6.88	0.17	0.00
Acre-feet	252,356	38,434	16,089	5,959	102,492	2,533	-
Billions of Gallons	82.23	12.52	5.24	1.94	33.40	0.83	-

Table 4 - Annual Estimated Precipitation and Recharge

Water Year	Precipitation			Recharge		
	inches	acre-feet	Billions of gallons	inches	acre-feet	Billions of gallons
1997	23.41	348,740	113	4.52	67,335	22
1998	15.76	234,778	76	1.68	25,027	8
1999	16.9	251,760	82	3.2	47,671	15
2000	17.61	262,337	85	2.25	33,518	11
2001	9.9	147,481	48	0.38	5,661	2
2002	15.58	232,096	75	1.89	28,155	9
2003	16.08	239,545	78	2.41	35,902	12
2004	15.98	238,055	77	1.26	18,770	6
2005	15.11	225,095	73	0.94	14,003	5
2006	19.92	296,750	96	3.37	50,203	16
2007	15.71	234,033	76	2.24	33,369	11
2008	15.88	236,565	77	2.06	30,688	10
2009	16.99	253,101	82	2.35	35,008	11
2010	17.58	261,890	85	3.26	48,564	16
2011	20.49	305,241	99	5.72	85,211	28
2012	18.13	270,084	88	3.86	57,503	19
Average	16.94	252,356	82	2.58	38,434	12

Figure 6—Groundwater Recharge and Precipitation

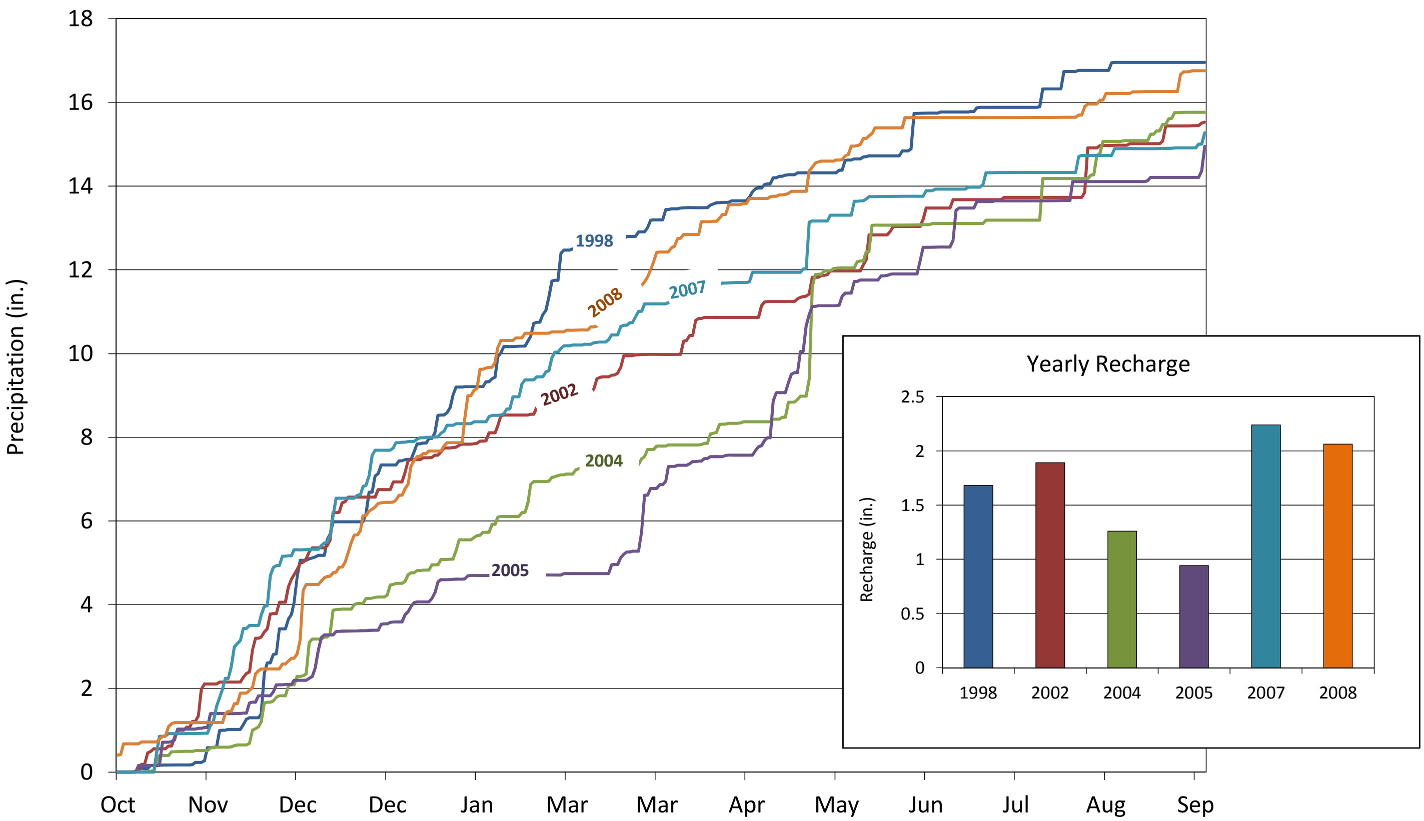

Figure 7—Groundwater Elevation & Recharge

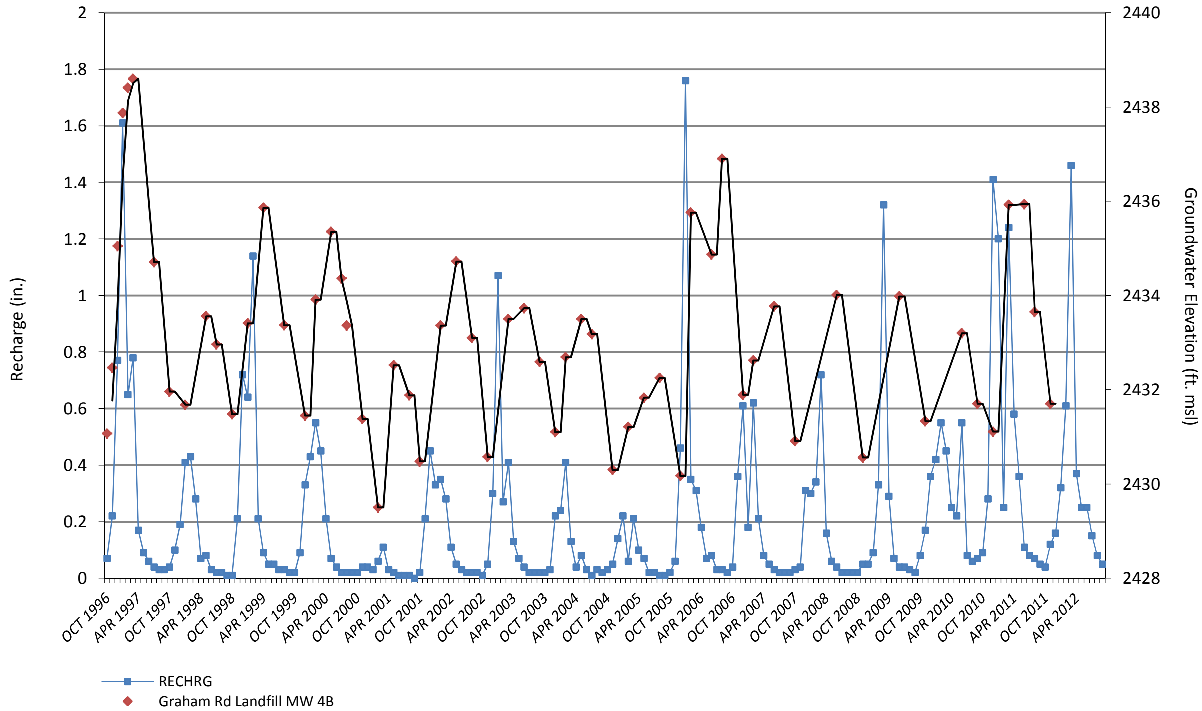

Table 5 - Recharge Rate & Soil Characteristics

DPM Soil Type	Average Annual Precipitation	Average Annual Recharge	% Recharge	Saturated Hydraulic Conductivity (ft/day)	Available Water Capacity	Soil Texture	Specific Yield
15	16.8	0.19	1%	2.45	0.16	Silty Clay	0.03
5	16.9	0.25	1%	8.34	0.05	Silty Sand	0.2
8	17.0	1.01	6%	9.04	0.06	Silty Sand	0.2
20	16.8	1.63	10%	2.39	0.19	Clay	0.001
22	17.2	1.72	10%	2.14	0.14	Sandy Silt	0.15
7	17.3	1.81	10%	2.60	0.07	Silty Sand	0.16
4	17.1	1.85	11%	10.49	0.05	Silty Sand	0.18
18	17.1	1.88	11%	2.58	0.21	Sandy Silt	0.07
17	17.1	1.97	12%	1.97	0.19	Clay Silt	0.05
13	16.9	1.95	12%	4.23	0.15	Silty Sand	0.16
2	16.9	2.20	13%	0.98	0.03	Sandy Silt	0.16
21	16.8	2.57	15%	3.05	0.14	Clay Silt	0.09
16	17.3	2.72	16%	1.35	0.17	Clay Silt	0.05
11	16.9	2.97	18%	59.22	0.11	Silty Sand	0.2
19	16.9	3.02	18%	38.93	0.06	Silty Sand	0.19
12	16.9	3.23	19%	15.80	0.12	Silty Sand	0.25
10	16.7	3.25	19%	5.75	0.10	Silty Sand	0.18
14	16.8	3.77	22%	1.93	0.12	Clay Silt	0.07
3	16.9	3.94	23%	94.69	0.03	Sand	0.31
6	16.8	4.43	26%	36.66	0.05	Sand	0.35
9	16.8	4.59	27%	19.03	0.08	Sand	0.28

time. Water levels in aquifers that are close to the ground surface and/or overlain by high hydraulic conductivity materials (sands, gravels) often show changes in response to the timing and quantity of recharge. Figure 7 shows water levels on a quarterly basis from a monitoring well completed in the wanapum basalt aquifer just west of Fairchild Air Force Base along with the DPM estimated recharge. Recharge follows the annual pattern of water level changes; and over the study period the magnitude of water level change corresponds directly with the amount of recharge.

Spatial Distribution of Recharge

Average annual recharge ranges from 0.0 to 9 in. within the study area. Figure 8 shows the distribution of recharge. Recharge is dependent on landscape characteristics, land use, soil characteristics, type of material below the root zone, precipitation and temperature. All of these parameters vary spatially within the study area, though some appear to impact recharge more than others.

The type of material found below the root zone, or subsoil material, has a significant impact on recharge rates. The saturated vertical hydraulic conductivity or infiltration rate at saturation, controls the amount of water that can move vertically beyond the root zone. Within the study area subsoil material ranged from granitic bedrock with very low infiltration rates to sand and gravel material with high infiltration rates. The distribution of recharge demonstrates the importance of this parameter. Areas with surface/near surface basement rock (Figure 1) have recharge rates from 0-1 in. Areas down gradient of the basement rock areas have recharge rates on the higher end of the range of rates found in the study area. This indicates that when recharge exceeds the infiltration capacity of the subsoil material it moves horizontally until there is an area with higher infiltration capacity.

Soil characteristics also play an important role in recharge rates. Table 5 presents soil characteristics and the associated average annual recharge rates. Higher specific yield and saturated hy-

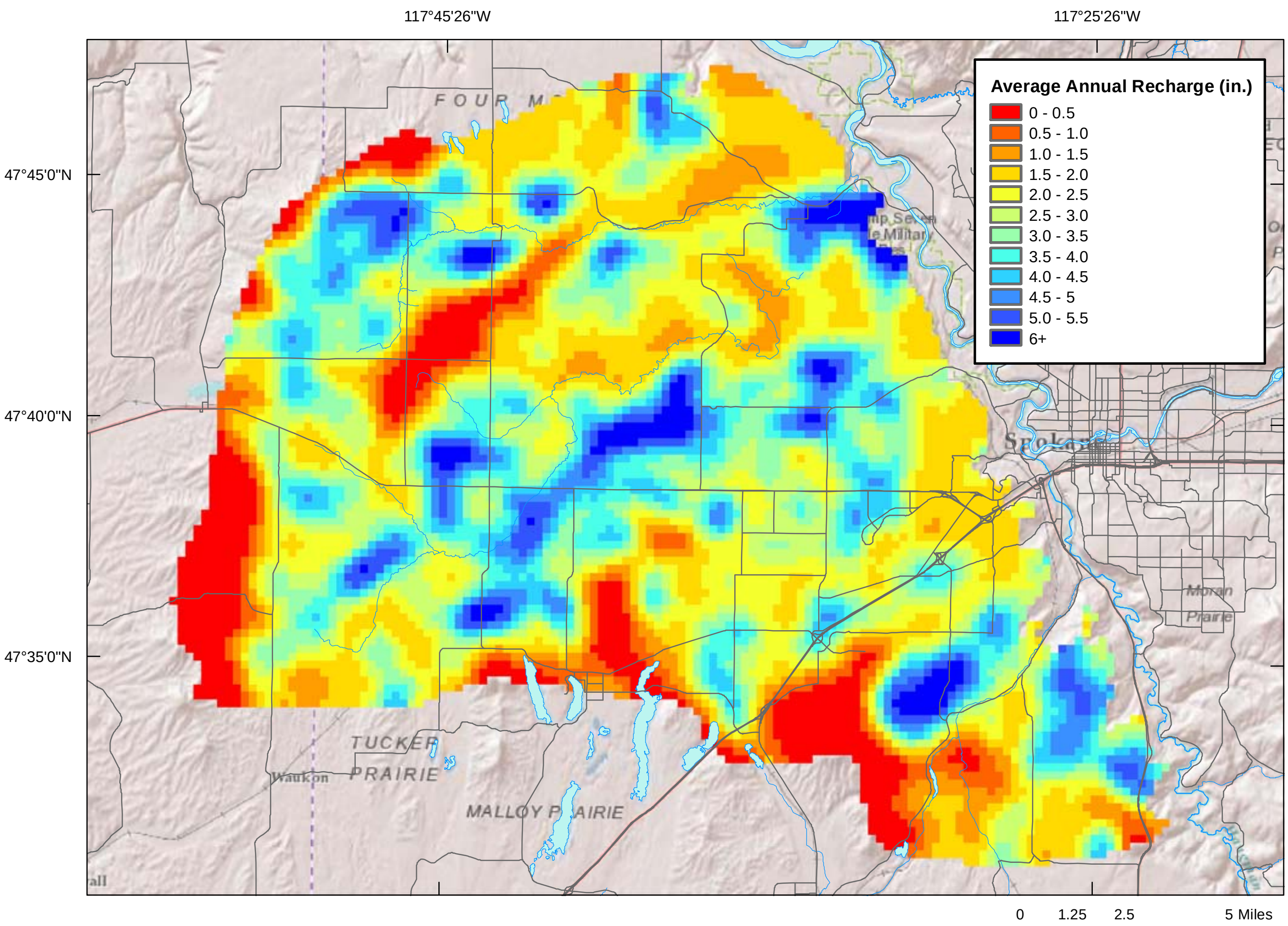

Figure 8—Spatial Distribution of Annual Recharge

draulic conductivity, parameters related to the capacity of a soil type to transmit water, correlate with higher recharge rates.

Table 6-Land Use & Recharge Rates

Land Use Classification	Recharge Rate
Sagebrush & associated scrub	12.36%
Winter wheat-harvested in summer and planted in autumn, each year	12.37%
Conifer Forest	13.73%
Alfalfa	14.03%
Grass-native	19.77%
Spring wheat-planted in spring and harvested in autumn, each year	21.30%
Row crops (mid latitudes)-undifferentiated	23.48%
Pasture (mid-latitudes)	25.59%

Available water capacity does not correlate with recharge rates.

Land use also correlates with recharge rates. As shown in Table 2 each land use has a specified growing season in the DPM. Areas with land use types, such as Conifer Forest, that have a full year growing season have on average lower recharge rates. Conversely areas with land use types that do not have full year growing seasons have, on average, lower recharge rates. There are two exceptions to this, winter wheat and native grass; these land use types are associated with soil types with recharge rates that are counter to the recharge rates associated with growing season. Therefore winter wheat, with a more limited growing season, has an average recharge rate similar to those land use types with all year growing seasons, and native grass, with an all year growing season has an average recharge rate similar to those land use types with a more limited growing season.

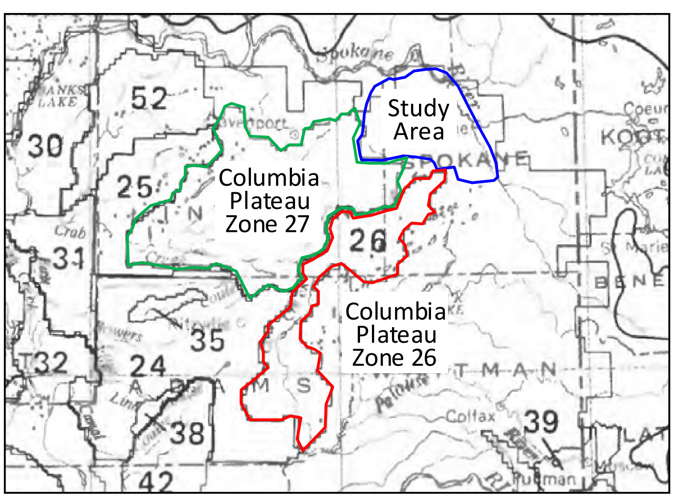

Figure 9—Adjacent Columbia Plateau Recharge Estimate Study Areas

Comparison to Other Recharge Estimates

The USGS completed recharge estimates for the Columbia Plateau Regional Aquifer System including areas just west and south of the study area (Bauer and Vaccaro, 1988) using the DPM. Recharge estimates were developed for discrete zones within the Columbia Plateau, two of which are adjacent to the study area (Figure 9) and have similar geology, land use and climate and are therefore a good comparison. The Columbia Plateau study included irrigation in addition to precipitation, but irrigation in zones 26 and 27 was minimal, 0.77 and 0.27 in. respectively. In Zone 27 estimated precipitation was 12.61 in. and estimated recharge was 2.11 in. which is a recharge rate of 15.8%. In Zone 26 estimated precipitation was 12.54 in. and estimated recharge was 1.35 in. which is a recharge rate of 10.5%. These estimates are consistent with the estimates developed in this study given the differences in annual precipitation. Estimates for Zone 27 more closely align with the study estimates likely because it is at similar latitude.

Summary and Conclusions

The USGS Deep Percolation model was used to estimate groundwater recharge for the period October 1996 to September 2012 for the West Plains area of Spokane County, Washington. The average precipitation over this period was 16.94 in. and the average groundwater recharge was 2.58 in. The annual recharge varied between 5.71 in and 0.38 in. As expected the largest determinant in the amount of recharge was the amount of precipitation. Some years, though, with similar precipitation amounts showed a wide variance in recharge. This was due to the timing of the precipitation events; when precipitation occurs in late spring it is more likely to leave the system via evapotranspiration than percolate to groundwater. This indicates that long term changes in weather patterns could impact the amount of recharge, even if the annual precipitation does not change substantially.

Recharge varied spatially with a range of over 6 in. to less than 0.5 inches depending on the location within the study area. The amount of recharge was dependent on the underlying geology, the soil type, and land use. Factors such as the permeability of the underlying geologic materials, permeability of the soils, and type of vegetative cover all impacted recharge rates. The amount of groundwater recharge is an important component in land use planning. Areas with low recharge rates may not be able to sustain withdrawals from underlying aquifers and development in these areas may require water from other sources. Recharge rates are also an important consideration in evaluating potential water quality impacts from land use changes. The impact of some groundwater containments is less in areas of high recharge, such as with nitrates from onsite septic systems. High recharge rates, though, indicate a shorter travel time for some contaminants, such as petroleum hydrocarbons that are detrimental to water quality at low concentrations.

References

Bauer, H.H., Vaccaro, J.J., Estimates of Ground-Water Recharge to the Columbia Plateau Regional Aquifer System, Washington, Oregon, and Idaho, for Predevelopment and Current Land-Use Conditions: U.S. Geological Survey Scientific Investigations Report 88-4108, 37p.

Gesch, D.B., 2007, The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, p. 99-118.

Homer, C., Dewitz, J., Fry, J., Coan, M., Hossain, N., Larson, C., Herold, N., McKerrow, A., VanDriel, J.N., and Wickham, J. 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States. Photogrammetric Engineering and Remote Sensing, Vol. 73, No. 4, pp 337-341.

Johnson, A.I.,1966, Specific Yield-Compilation of Specific Yields for Various Materials: U.S. Geological Survey Open-File Report 63-59, 112 p.

NOAA. 2012. http://www.wrh.noaa.gov/otx. National Oceanic and Atmospheric Administration web page. Accessed December 2012.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for Spokane County, WA and Lincoln County, WA. Available online at http://soildatamart.nrcs.usda.gov. Accessed 7/24/2012.

Tetra Tech, 2010, WRIA 54-Lower Spokane Wateshed Detailed Implementation Plan, prepared under grant no. G1000326 from the Washington Department of Ecology, variously paginated.

Vaccaro, J.J., 2007, A deep percolation model for estimating ground-water recharge: Documentation of modules for the modular modeling system of the U.S. Geological Survey: U.S. Geological Survey Scientific Investigations Report 2006-5318, 30 p.

Appendix A

Monthly Water Budget Components for West Plains Recharge Estimate

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 1997**													
October	1996	3.15	1.70	0.01	0.07	0.30	0.04	0.00	0.80	0.49	1.89	0.51	0.00	44.90	0.14
November	1996	4.09	0.45	0.04	0.22	0.07	0.07	0.10	0.11	0.11	1.74	0.16	1.42	32.40	0.23
December	1996	4.40	0.22	0.00	0.77	0.00	0.00	0.22	0.00	0.00	2.18	0.19	0.31	23.70	0.72
January	1997	1.60	0.30	0.00	1.61	0.01	0.01	0.18	0.00	0.00	0.39	0.21	-1.71	27.20	0.91
February	1997	1.33	0.63	-0.04	0.65	0.09	0.09	0.06	0.08	0.08	-0.23	0.30	-0.03	30.70	0.44
March	1997	2.37	1.61	-0.01	0.78	0.27	0.25	0.01	0.48	0.46	-0.34	0.62	0.00	38.50	0.59
April	1997	2.25	2.66	0.02	0.17	0.60	0.37	0.00	1.40	1.32	-0.44	0.57	0.00	42.60	0.25
May	1997	2.05	4.58	-0.02	0.09	1.06	0.36	0.00	2.98	2.55	-1.71	0.62	0.00	55.90	0.15
June	1997	0.68	5.10	0.00	0.06	1.23	0.19	0.00	3.70	2.32	-2.30	0.35	0.00	58.70	0.06
July	1997	0.50	6.56	0.00	0.04	1.56	0.03	0.00	4.64	0.75	-0.70	0.35	0.00	65.90	0.03
August	1997	0.17	6.11	0.00	0.03	1.48	0.02	0.00	4.09	0.06	-0.07	0.11	0.00	69.70	0.01
September	1997	0.82	3.62	0.00	0.03	0.81	0.04	0.00	2.14	0.33	0.04	0.36	0.00	60.70	0.03
TOTALS		**23.40**	**33.54**	**0.00**	**4.51**	**7.47**	**1.45**	**0.57**	**20.43**	**8.48**	**0.45**	**4.37**	**0.00**	**46.00**	**3.56**
Month	**Year**	**Water Year 1998**													
October	1997	1.74	1.72	0.01	0.04	0.32	0.06	0.00	0.86	0.40	0.74	0.44	0.00	46.3	0.05
November	1997	1.93	0.62	0.00	0.10	0.10	0.09	0.00	0.14	0.13	1.27	0.22	0.00	37.6	0.11
December	1997	1.25	0.25	0.02	0.19	0.02	0.02	0.11	0.00	0.00	0.65	0.17	0.00	28.3	0.09
January	1998	2.18	0.35	-0.02	0.41	0.01	0.01	0.11	0.00	0.00	1.17	0.28	0.00	29.7	0.23
February	1998	1.80	0.73	0.00	0.43	0.07	0.07	0.02	0.09	0.09	0.49	0.43	0.01	36.8	0.26
March	1998	1.29	1.74	-0.01	0.28	0.38	0.33	0.00	0.74	0.71	-0.55	0.37	-0.01	40.2	0.16
April	1998	0.86	3.34	0.00	0.07	0.80	0.15	0.00	2.24	1.98	-1.82	0.41	0.00	46.8	0.07
May	1998	3.25	4.35	0.00	0.08	0.94	0.31	0.00	2.63	1.90	-0.03	0.85	0.00	54.7	0.14
June	1998	0.78	5.53	0.00	0.03	1.31	0.11	0.00	4.04	2.07	-1.89	0.43	0.00	61.4	0.03
July	1998	0.32	7.38	0.00	0.02	1.77	0.03	0.00	5.38	0.34	-0.27	0.20	0.00	73.3	0
August	1998	0.24	6.46	0.00	0.02	1.57	0.03	0.00	4.33	0.08	0.01	0.10	0.00	70	0
September	1998	0.12	4.25	0.00	0.01	1.03	0.01	0.00	2.78	0.11	-0.12	0.10	0.00	63.8	0
TOTALS		**15.75**	**36.72**	**0.00**	**1.68**	**8.30**	**1.20**	**0.24**	**23.24**	**7.84**	**-0.35**	**3.99**	**0.00**	**49.1**	**1.15**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	Year	Water Year 1999													
October	1998	0.32	1.82	0.00	0.01	0.41	0.01	0.00	1.12	0.09	-0.04	0.24	0.00	45.2	0.01
November	1998	3.65	0.47	0.05	0.21	0.01	0.01	0.00	0.02	0.02	2.83	0.34	0.00	39.3	0.2
December	1998	3.45	0.24	-0.01	0.72	0.01	0.01	0.08	0.00	0.00	1.92	0.18	0.00	28.5	0.56
January	1999	1.81	0.34	-0.04	0.64	0.01	0.01	0.12	0.02	0.02	0.47	0.23	0.00	31.7	0.38
February	1999	3.24	0.64	0.02	1.14	0.04	0.04	0.00	0.04	0.04	0.86	0.42	0.00	34.7	0.71
March	1999	0.59	1.74	-0.02	0.21	0.37	0.28	0.00	0.75	0.71	-1.25	0.41	0.00	39.8	0.25
April	1999	0.36	3.11	0.00	0.09	0.80	0.11	0.00	2.29	1.92	-2.03	0.17	0.00	44.9	0.12
May	1999	0.72	4.48	0.00	0.05	1.05	0.02	0.00	3.19	1.75	-1.74	0.58	0.00	50	0.06
June	1999	1.57	5.29	0.00	0.05	1.25	0.16	0.00	3.77	1.33	-0.52	0.49	0.00	59.3	0.06
July	1999	0.26	6.64	0.00	0.03	1.63	0.02	0.00	4.86	0.42	-0.39	0.17	0.00	65.3	0.01
August	1999	0.93	5.99	0.00	0.03	1.41	0.06	0.00	3.84	0.42	0.11	0.28	0.00	69.6	0.03
September	1999	0.00	3.98	0.00	0.02	1.01	0.01	0.00	2.71	0.15	-0.18	0.00	0.00	57.9	0
TOTALS		**16.91**	**34.74**	**0.00**	**3.20**	**7.99**	**0.73**	**0.20**	**22.60**	**6.86**	**0.02**	**3.50**	**0.00**	**47.3**	**2.4**
Month	Year	Water Year 2000													
October	1999	0.93	1.81	0.00	0.02	0.40	0.02	0.00	1.11	0.08	0.52	0.25	0.00	46.8	0.03
November	1999	2.08	0.60	0.05	0.09	0.05	0.04	0.01	0.09	0.08	1.39	0.33	0.00	40.9	0.1
December	1999	2.30	0.25	0.00	0.33	0.01	0.01	0.02	0.00	0.00	1.36	0.17	0.18	32	0.22
January	2000	2.12	0.30	-0.02	0.43	0.00	0.00	0.17	0.00	0.00	0.97	0.24	-0.01	28.1	0.34
February	2000	1.72	0.61	0.00	0.55	0.02	0.02	0.07	0.04	0.04	0.55	0.37	-0.17	33.5	0.29
March	2000	1.71	1.66	-0.04	0.45	0.30	0.28	0.00	0.57	0.56	-0.37	0.57	0.00	39.4	0.26
April	2000	2.23	3.38	0.00	0.21	0.78	0.38	0.00	2.04	1.91	-0.95	0.48	0.00	48.5	0.19
May	2000	2.16	4.41	0.01	0.07	0.99	0.19	0.00	2.85	2.32	-1.29	0.76	0.00	53.1	0.1
June	2000	1.01	5.62	-0.01	0.04	1.37	0.19	0.00	4.15	2.25	-1.81	0.30	0.00	60.7	0.04
July	2000	0.35	6.81	0.00	0.02	1.66	0.02	0.00	4.94	0.36	-0.27	0.20	0.00	67.2	0.01
August	2000	0.01	6.14	0.00	0.02	1.53	0.02	0.00	4.20	0.01	-0.05	0.01	0.00	66.9	0
September	2000	0.99	3.14	0.00	0.02	0.70	0.04	0.00	1.82	0.40	0.11	0.38	0.00	55.5	0.03
TOTALS		**17.62**	**34.74**	**0.00**	**2.25**	**7.82**	**1.21**	**0.27**	**21.81**	**8.01**	**0.18**	**4.09**	**0.00**	**47.8**	**1.6**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2001**													
October	2000	0.66	1.73	0.00	0.02	0.40	0.04	0.00	1.10	0.26	0.15	0.17	0.00	46	0.02
November	2000	1.31	0.41	0.05	0.04	0.05	0.03	0.10	0.06	0.03	0.64	0.19	0.20	27.1	0.03
December	2000	1.02	0.20	0.01	0.04	0.00	0.00	0.22	0.00	0.00	0.02	0.17	0.55	24.6	0.02
January	2001	0.71	0.31	-0.04	0.03	0.00	0.00	0.22	0.00	0.00	0.09	0.25	0.16	26.6	0.01
February	2001	0.78	0.58	-0.01	0.06	0.00	0.00	0.19	0.00	0.00	0.71	0.30	-0.51	26.9	0.04
March	2001	1.32	1.70	0.02	0.11	0.31	0.28	0.04	0.66	0.63	0.09	0.50	-0.40	38.7	0.05
April	2001	1.62	2.68	0.00	0.03	0.55	0.17	0.00	1.40	1.09	-0.48	0.77	0.00	43.7	0.04
May	2001	0.72	5.22	-0.01	0.02	1.31	0.15	0.00	4.03	1.72	-1.35	0.17	0.00	55.3	0.01
June	2001	0.98	5.26	0.00	0.01	1.23	0.04	0.00	3.77	0.57	-0.21	0.55	0.00	58.1	0.01
July	2001	0.17	6.96	0.00	0.01	1.71	0.02	0.00	5.15	0.13	-0.10	0.13	0.00	67.3	-0.01
August	2001	0.43	6.37	0.00	0.01	1.52	0.02	0.00	4.18	0.13	0.07	0.21	0.00	70.6	-0.01
September	2001	0.18	4.23	0.00	0.00	1.03	0.01	0.00	2.79	0.10	-0.02	0.09	0.00	62.5	-0.01
TOTALS		**9.89**	**35.65**	**0.00**	**0.38**	**8.13**	**0.78**	**0.76**	**23.14**	**4.66**	**-0.40**	**3.49**	**0.00**	**45.7**	**0.2**
Month	**Year**	**Water Year 2002**													
October	2001	2.10	1.69	0.04	0.02	0.29	0.03	0.00	0.78	0.16	1.26	0.53	0.00	45.5	0.06
November	2001	2.77	0.58	0.01	0.21	0.07	0.06	0.02	0.12	0.12	1.65	0.26	0.28	39.9	0.14
December	2001	2.29	0.25	-0.02	0.45	0.00	0.00	0.19	0.00	0.00	1.24	0.19	-0.13	28.2	0.37
January	2002	1.31	0.32	0.01	0.33	0.00	0.00	0.13	0.00	0.00	0.41	0.26	-0.04	30.5	0.21
February	2002	1.07	0.68	-0.05	0.35	0.09	0.09	0.07	0.06	0.06	0.14	0.34	-0.10	31.4	0.17
March	2002	1.21	1.32	0.00	0.28	0.22	0.21	0.06	0.43	0.42	-0.30	0.43	-0.01	34.7	0.12
April	2002	1.01	2.85	0.00	0.11	0.69	0.30	0.00	1.81	1.67	-1.47	0.32	0.00	45.6	0.08
May	2002	1.42	4.16	0.00	0.05	0.95	0.09	0.00	2.79	2.09	-1.52	0.67	0.00	51.5	0.05
June	2002	1.10	5.79	0.00	0.03	1.35	0.06	0.00	4.18	1.47	-1.07	0.58	0.00	61.9	0.03
July	2002	0.28	7.26	0.00	0.02	1.77	0.03	0.00	5.34	0.30	-0.20	0.14	0.00	70.5	0
August	2002	0.60	5.90	0.00	0.02	1.43	0.06	0.00	3.88	0.25	0.09	0.16	0.00	66	0.02
September	2002	0.42	3.74	0.00	0.02	0.90	0.02	0.00	2.39	0.24	-0.04	0.17	0.00	58.3	0.01
TOTALS		**15.59**	**34.54**	**0.00**	**1.90**	**7.77**	**0.95**	**0.47**	**21.78**	**6.77**	**0.19**	**4.05**	**0.00**	**47.1**	**1.26**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2003**													
October	2002	0.24	1.88	0.00	0.01	0.47	0.01	0.00	1.25	0.16	-0.05	0.11	0.00	42.6	0.01
November	2002	1.86	0.61	0.00	0.05	0.07	0.02	0.00	0.03	0.01	1.40	0.30	0.00	36.6	0.08
December	2002	3.23	0.25	0.05	0.30	0.01	0.01	0.04	0.01	0.01	1.76	0.16	0.72	33.8	0.18
January	2003	3.50	0.35	-0.01	1.07	0.01	0.01	0.05	0.00	0.00	2.11	0.27	-0.72	33.9	0.73
February	2003	0.67	0.72	-0.05	0.27	0.12	0.12	0.00	0.08	0.08	-0.24	0.28	0.00	33.5	0.22
March	2003	1.91	1.72	0.00	0.41	0.32	0.30	0.00	0.60	0.59	-0.17	0.54	0.00	41.2	0.23
April	2003	1.55	2.75	0.00	0.13	0.58	0.35	0.00	1.39	1.32	-1.08	0.69	0.00	45.5	0.14
May	2003	1.69	4.44	0.00	0.07	1.05	0.09	0.00	3.19	2.42	-1.45	0.46	0.00	53.4	0.1
June	2003	0.25	6.24	0.00	0.04	1.54	0.12	0.00	4.82	1.98	-2.09	0.18	0.00	63.1	0.02
July	2003	0.01	7.69	0.00	0.02	1.90	0.03	0.00	5.77	0.11	-0.16	0.01	0.00	71.4	0
August	2003	0.39	6.27	0.00	0.02	1.50	0.03	0.00	4.12	0.14	0.00	0.19	0.00	69.4	0.01
September	2003	0.78	3.86	0.00	0.02	0.92	0.07	0.00	2.43	0.45	0.05	0.16	0.00	61.3	0.02
TOTALS		**16.09**	**36.78**	**0.00**	**2.42**	**8.50**	**1.15**	**0.08**	**23.70**	**7.27**	**0.08**	**3.34**	**0.00**	**48.9**	**1.75**
Month	**Year**	**Water Year 2004**													
October	2003	0.64	2.02	0.00	0.02	0.44	0.03	0.00	1.22	0.24	0.07	0.26	0.00	50.8	0.02
November	2003	1.61	0.47	0.04	0.03	0.05	0.00	0.09	0.05	0.01	1.12	0.25	0.01	29.1	0.06
December	2003	2.33	0.22	0.01	0.22	0.00	0.00	0.15	0.00	0.00	1.54	0.18	0.07	29.2	0.16
January	2004	1.72	0.27	-0.01	0.24	0.00	0.00	0.22	0.00	0.00	0.62	0.22	0.34	26	0.1
February	2004	1.65	0.66	-0.04	0.41	0.05	0.05	0.12	0.07	0.07	0.79	0.38	-0.42	31.6	0.29
March	2004	0.75	2.13	0.00	0.13	0.46	0.27	0.01	1.07	1.01	-1.15	0.40	0.00	43	0.09
April	2004	0.52	3.48	0.00	0.04	0.84	0.03	0.00	2.49	1.89	-1.82	0.34	0.00	49.1	0.04
May	2004	3.12	4.20	0.00	0.08	0.94	0.27	0.00	2.62	1.44	0.42	0.75	0.00	53.7	0.16
June	2004	0.95	5.55	0.00	0.03	1.32	0.14	0.00	4.06	1.97	-1.59	0.38	0.00	62.4	0.03
July	2004	0.08	7.04	0.00	0.01	1.72	0.02	0.00	5.22	0.16	-0.18	0.07	0.00	70.8	-0.01
August	2004	1.75	5.62	0.00	0.03	1.30	0.18	0.00	3.43	0.81	0.35	0.35	0.00	69.9	0.04
September	2004	0.86	3.11	0.00	0.02	0.70	0.05	0.00	1.84	0.45	0.00	0.32	0.00	57	0.02
TOTALS		**15.96**	**34.77**	**0.00**	**1.26**	**7.83**	**1.04**	**0.58**	**22.08**	**8.04**	**0.15**	**3.90**	**0.00**	**47.8**	**0.99**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2005**													
October	2004	1.16	1.73	0.00	0.03	0.37	0.07	0.00	0.99	0.29	0.47	0.27	0.00	48.5	0.03
November	2004	1.27	0.48	0.05	0.05	0.05	0.04	0.01	0.08	0.07	0.71	0.25	0.05	35.6	0.04
December	2004	1.50	0.24	0.00	0.14	0.01	0.01	0.08	0.00	0.00	0.94	0.18	0.06	31.4	0.09
January	2005	1.32	0.34	-0.04	0.22	0.01	0.01	0.17	0.03	0.03	0.73	0.24	-0.11	27.8	0.08
February	2005	0.04	0.91	-0.01	0.06	0.25	0.20	0.00	0.31	0.29	-0.57	0.04	0.00	34	0.03
March	2005	2.08	1.84	0.00	0.21	0.39	0.14	0.00	0.93	0.86	0.36	0.42	0.00	41.5	0.09
April	2005	0.70	3.08	0.00	0.10	0.72	0.23	0.00	2.00	1.67	-1.71	0.38	0.00	47.6	0.04
May	2005	3.53	4.24	0.00	0.07	0.89	0.49	0.00	2.28	1.88	-0.05	1.02	0.00	56	0.12
June	2005	1.47	4.88	0.00	0.02	1.13	0.11	0.00	3.37	1.47	-0.77	0.61	0.00	59	0.03
July	2005	0.93	6.75	0.00	0.02	1.62	0.11	0.00	4.78	0.91	-0.38	0.27	0.00	68.6	0.01
August	2005	0.36	6.13	0.00	0.01	1.50	0.04	0.00	4.12	0.20	0.03	0.08	0.00	68.1	0
September	2005	0.75	3.33	0.03	0.01	0.80	0.01	0.00	2.14	0.11	0.42	0.15	0.00	56.1	0.01
TOTALS		**15.11**	**33.96**	**0.03**	**0.93**	**7.73**	**1.46**	**0.26**	**21.02**	**7.77**	**0.17**	**3.91**	**0.00**	**47.9**	**0.58**
Month	**Year**	**Water Year 2006**													
October	2005	1.17	1.46	0.01	0.02	0.25	0.08	0.00	0.66	0.43	0.16	0.43	0.00	48	0.03
November	2005	1.99	0.43	0.01	0.06	0.02	0.02	0.02	0.02	0.02	1.13	0.30	0.35	33.5	0.08
December	2005	3.11	0.22	0.00	0.46	0.00	0.00	0.15	0.00	0.00	2.40	0.14	-0.35	23.2	0.3
January	2006	4.87	0.35	0.00	1.76	0.00	0.00	0.01	0.00	0.00	1.72	0.27	0.00	35.2	1.11
February	2006	1.16	0.66	-0.02	0.35	0.11	0.10	0.04	0.07	0.07	0.02	0.26	0.00	30.8	0.35
March	2006	1.35	1.44	-0.01	0.31	0.23	0.22	0.05	0.42	0.41	-0.39	0.50	0.00	38.3	0.26
April	2006	1.64	2.80	-0.02	0.18	0.58	0.40	0.00	1.37	1.30	-1.13	0.72	0.00	46.7	0.19
May	2006	0.97	4.70	0.00	0.07	1.09	0.09	0.00	3.31	2.60	-2.44	0.58	0.00	55.4	0.09
June	2006	2.87	5.35	0.00	0.08	1.22	0.44	0.00	3.40	2.41	-0.92	0.73	0.00	62.1	0.13
July	2006	0.13	7.30	0.00	0.03	1.78	0.02	0.00	5.41	0.61	-0.66	0.10	0.00	72	0.01
August	2006	0.18	6.05	0.00	0.03	1.49	0.02	0.00	4.09	0.04	0.01	0.07	0.00	67.3	0.01
September	2006	0.48	3.88	0.00	0.02	0.92	0.02	0.00	2.46	0.27	-0.05	0.19	0.00	59.7	0.02
TOTALS		**19.93**	**34.66**	**-0.03**	**3.37**	**7.69**	**1.42**	**0.27**	**21.20**	**8.16**	**-0.15**	**4.31**	**0.00**	**47.8**	**2.57**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2007**													
October	2006	1.21	1.70	0.00	0.04	0.39	0.10	0.00	1.00	0.30	0.52	0.19	0.00	46	0.05
November	2006	4.13	0.50	0.05	0.36	0.01	0.01	0.05	0.01	0.01	2.69	0.37	0.33	35.3	0.27
December	2006	2.47	0.23	-0.02	0.61	0.00	0.00	0.15	0.00	0.00	1.35	0.18	-0.27	27.7	0.47
January	2007	0.68	0.30	-0.02	0.18	0.00	0.00	0.16	0.00	0.00	-0.10	0.24	0.05	23.7	0.16
February	2007	1.81	0.53	0.03	0.62	0.02	0.02	0.09	0.03	0.03	0.40	0.37	-0.01	33.3	0.26
March	2007	1.05	1.70	-0.04	0.21	0.31	0.28	0.02	0.61	0.59	-0.60	0.53	-0.09	41.6	0.15
April	2007	0.61	2.87	0.00	0.08	0.69	0.17	0.00	1.91	1.71	-1.75	0.33	0.00	45.6	0.07
May	2007	1.55	4.94	0.00	0.05	1.18	0.15	0.00	3.57	2.50	-1.67	0.45	0.00	54.9	0.07
June	2007	0.81	5.32	0.00	0.03	1.29	0.06	0.00	4.01	1.28	-0.91	0.31	0.00	60.9	0.03
July	2007	0.35	7.54	0.00	0.02	1.81	0.03	0.00	5.52	0.27	-0.15	0.17	0.00	73.7	0.01
August	2007	0.52	5.78	0.00	0.02	1.39	0.04	0.00	3.81	0.20	0.08	0.17	0.00	66.9	0.01
September	2007	0.52	3.71	0.03	0.02	0.90	0.01	0.00	2.40	0.12	0.20	0.13	0.00	57.9	0.01
TOTALS		**15.70**	**35.13**	**0.03**	**2.23**	**8.02**	**0.88**	**0.47**	**22.89**	**7.03**	**0.07**	**3.43**	**0.00**	**47.4**	**1.56**
Month	**Year**	**Water Year 2008**													
October	2007	1.01	1.54	-0.03	0.03	0.29	0.10	0.00	0.73	0.50	-0.01	0.40	0.00	45.8	0.03
November	2007	1.50	0.56	0.04	0.04	0.06	0.01	0.04	0.15	0.04	0.87	0.27	0.14	34.1	0.05
December	2007	3.44	0.23	0.00	0.31	0.00	0.00	0.15	0.00	0.00	1.99	0.19	0.57	27.9	0.22
January	2008	2.96	0.31	0.01	0.30	0.00	0.00	0.21	0.00	0.00	0.68	0.26	1.27	23.8	0.23
February	2008	0.74	0.63	-0.05	0.34	0.00	0.00	0.20	0.11	0.11	0.55	0.25	-0.86	31	0.19
March	2008	1.84	1.30	0.01	0.72	0.09	0.08	0.10	0.28	0.28	0.58	0.71	-1.02	35.6	0.36
April	2008	1.23	2.59	-0.01	0.16	0.56	0.40	0.01	1.22	1.17	-1.21	0.66	-0.10	41.2	0.15
May	2008	0.77	4.68	0.00	0.06	1.10	0.06	0.00	3.42	2.63	-2.48	0.45	0.00	55.6	0.06
June	2008	1.21	5.35	0.00	0.04	1.25	0.05	0.00	3.76	1.46	-1.00	0.62	0.00	59	0.04
July	2008	0.01	6.88	0.00	0.02	1.71	0.02	0.00	5.16	0.16	-0.21	0.01	0.00	68.4	0
August	2008	0.68	5.67	0.00	0.02	1.33	0.03	0.00	3.63	0.17	0.13	0.30	0.00	67	0.01
September	2008	0.49	3.76	0.00	0.02	0.90	0.03	0.00	2.41	0.30	-0.04	0.17	0.00	58.9	0.01
TOTALS		**15.88**	**33.48**	**-0.03**	**2.07**	**7.29**	**0.79**	**0.70**	**20.88**	**6.81**	**-0.13**	**4.29**	**0.00**	**45.7**	**1.37**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2009**													
October	2008	0.26	1.74	0.00	0.02	0.39	0.01	0.00	1.11	0.15	-0.12	0.20	0.00	46.4	0.01
November	2008	1.79	0.51	0.05	0.05	0.04	0.03	0.02	0.07	0.05	1.19	0.29	0.03	37.7	0.07
December	2008	3.73	0.21	0.00	0.05	0.00	0.00	0.16	0.00	0.00	0.23	0.18	3.07	21.3	0.03
January	2009	1.24	0.28	-0.05	0.09	0.00	0.00	0.22	0.00	0.00	0.47	0.15	0.32	25	0.05
February	2009	1.19	0.52	0.01	0.33	0.00	0.00	0.20	0.00	0.00	1.35	0.26	-1.11	29.6	0.15
March	2009	3.00	1.22	0.01	1.32	0.11	0.10	0.10	0.18	0.18	2.01	0.70	-2.31	34.2	0.88
April	2009	1.04	2.76	-0.01	0.29	0.66	0.35	0.01	1.67	1.57	-1.76	0.35	0.00	44.5	0.26
May	2009	1.12	4.86	0.00	0.07	1.15	0.10	0.00	3.47	2.58	-2.26	0.54	0.00	54.3	0.09
June	2009	1.55	5.65	0.00	0.04	1.34	0.15	0.00	4.03	1.72	-0.96	0.53	0.00	61.9	0.06
July	2009	0.72	6.96	0.00	0.04	1.66	0.05	0.00	4.96	0.48	-0.18	0.31	0.00	70.5	0.03
August	2009	0.91	5.77	0.00	0.03	1.33	0.04	0.00	3.62	0.35	0.07	0.39	0.00	69	0.03
September	2009	0.44	4.05	0.00	0.02	0.97	0.02	0.00	2.59	0.28	-0.06	0.16	0.00	62.3	0.02
TOTALS		**16.99**	**34.53**	**0.00**	**2.34**	**7.64**	**0.85**	**0.70**	**21.71**	**7.37**	**-0.01**	**4.06**	**0.00**	**46.5**	**1.68**
Month	**Year**	**Water Year 2010**													
October	2009	2.50	0.67	0.04	0.08	0.07	0.01	0.00	0.15	0.04	1.86	0.36	0.00	42.4	0.12
November	2009	1.34	0.31	0.00	0.17	0.01	0.01	0.03	0.01	0.01	0.82	0.23	0.00	36.2	0.09
December	2009	1.89	0.14	0.02	0.36	0.01	0.01	0.03	0.00	0.00	1.05	0.10	0.08	23.6	0.24
January	2010	1.56	0.26	-0.04	0.42	0.00	0.00	0.04	0.00	0.00	0.70	0.20	-0.08	33.1	0.31
February	2010	1.53	0.42	0.01	0.55	0.02	0.02	0.00	0.02	0.02	0.36	0.29	0.00	35.8	0.27
March	2010	1.50	0.85	-0.02	0.45	0.14	0.13	0.01	0.23	0.22	0.13	0.35	0.00	38.2	0.23
April	2010	1.43	1.33	0.00	0.25	0.20	0.18	0.00	0.40	0.39	-0.22	0.65	0.00	43.8	0.19
May	2010	1.97	1.83	0.02	0.22	0.35	0.22	0.00	0.79	0.73	0.02	0.59	0.00	47.1	0.16
June	2010	2.60	2.19	-0.03	0.55	0.41	0.36	0.00	0.87	0.85	-0.24	0.76	0.00	55.5	0.35
July	2010	0.28	2.60	0.00	0.08	0.61	0.14	0.00	1.72	1.39	-1.60	0.19	0.00	63	0.09
August	2010	0.22	2.26	0.02	0.06	0.54	0.01	0.00	1.50	0.81	-0.80	0.08	0.00	62.8	0.05
September	2010	0.76	1.39	-0.03	0.07	0.27	0.05	0.00	0.70	0.40	-0.06	0.27	0.00	55	0.05
TOTALS		**17.58**	**14.25**	**0.00**	**3.23**	**2.64**	**1.15**	**0.11**	**6.40**	**4.87**	**2.00**	**4.07**	**0.00**	**44.7**	**2.14**

Appendix A - Monthly Water Budget Components for West Plains Recharge Estimate

PRECP, measured precipitation; **POTET**, potential evapotranspiration; **CHGINT**, change in moisture stored on foliage; **RECHRG**; soil water that percolates below the root zone (recharge) **SOLPEV**, potential soil evaporation over bare soil areas; **ACTSEV**, actual bare-soil evaporation; **SNWEVP**, direct evaporation of snow; **PPLTR**, foliage-type-dependent potential transpiration; **APLTR**, actual plant transpiration; **CHGSM**, Change in soil moisture; **EVINT**, interception loss; **CHGSNW**, change in snowpack; **AVTMP**, average temperature; **SYM-RO**, DPM calculated surface runoff. All values in inches of water except AVTMP, which is in degrees Farenheit.

DATE		PRECP	POTET	CHGINT	RECHRG	SOLPEV	ACTSEV	SNWEVP	PPLTR	APLTR	CHGSM	EVINT	CHGSNW	AVTMP	SYM-RO
Month	**Year**	**Water Year 2011**													
October	2010	1.71	0.77	0.05	0.09	0.10	0.04	0.00	0.26	0.18	0.93	0.33	0.00	45.9	0.08
November	2010	3.27	0.29	0.00	0.28	0.00	0.00	0.07	0.01	0.01	0.96	0.22	1.56	31.1	0.17
December	2010	3.28	0.16	0.00	1.41	0.00	0.00	0.19	0.00	0.00	1.70	0.13	-0.99	27.4	0.84
January	2011	2.27	0.24	-0.01	1.20	0.00	0.00	0.16	0.00	0.00	0.45	0.19	-0.57	28.8	0.85
February	2011	1.02	0.35	0.00	0.25	0.03	0.03	0.04	0.02	0.02	-0.16	0.22	0.33	28.9	0.27
March	2011	2.92	0.79	-0.04	1.24	0.03	0.03	0.06	0.03	0.03	0.33	0.64	-0.33	38.7	0.96
April	2011	2.16	1.14	0.00	0.58	0.13	0.13	0.00	0.20	0.19	-0.04	0.76	0.00	40.9	0.54
May	2011	2.19	1.83	0.00	0.36	0.30	0.28	0.00	0.66	0.65	-0.24	0.76	0.00	51.3	0.39
June	2011	0.73	2.13	-0.01	0.11	0.45	0.29	0.00	1.14	1.06	-1.36	0.44	0.00	57.6	0.2
July	2011	0.51	2.45	0.00	0.08	0.55	0.12	0.00	1.58	1.28	-1.30	0.22	0.00	64.9	0.12
August	2011	0.35	2.25	0.02	0.07	0.53	0.01	0.00	1.49	0.83	-0.69	0.04	0.00	68.8	0.07
September	2011	0.08	1.53	-0.02	0.05	0.35	0.03	0.00	0.95	0.49	-0.59	0.09	0.00	63.4	0.05
TOTALS		**20.50**	**13.92**	**0.00**	**5.71**	**2.49**	**0.95**	**0.52**	**6.33**	**4.74**	**-0.02**	**4.06**	**0.00**	**45.7**	**4.53**
Month	**Year**	**Water Year 2012**													
October	2011	0.70	0.74	0.02	0.04	0.08	0.01	0.00	0.22	0.15	0.05	0.37	0.00	47.2	0.05
November	2011	1.87	0.29	-0.01	0.12	0.02	0.00	0.04	0.03	0.02	1.39	0.19	0.00	34.5	0.12
December	2011	0.95	0.16	0.03	0.16	0.02	0.02	0.02	0.00	0.00	0.55	0.08	0.00	27.6	0.09
January	2012	1.74	0.23	-0.01	0.32	0.00	0.00	0.14	0.00	0.00	0.93	0.19	0.00	28.9	0.18
February	2012	1.74	0.39	0.01	0.61	0.01	0.01	0.06	0.01	0.01	0.41	0.31	0.00	32.3	0.32
March	2012	3.96	0.80	-0.01	1.46	0.07	0.07	0.01	0.10	0.10	0.86	0.52	0.00	38.2	0.96
April	2012	1.80	1.36	-0.01	0.37	0.20	0.19	0.00	0.42	0.41	-0.24	0.65	0.00	47.5	0.42
May	2012	0.83	1.91	-0.03	0.25	0.42	0.28	0.00	1.08	1.02	-1.29	0.32	0.00	52.5	0.28
June	2012	3.20	2.15	0.00	0.25	0.37	0.32	0.00	0.75	0.73	0.72	0.91	0.00	58.2	0.27
July	2012	1.16	2.65	0.00	0.15	0.59	0.35	0.00	1.52	1.36	-1.12	0.25	0.00	70	0.17
August	2012	0.18	2.29	0.00	0.08	0.54	0.07	0.00	1.46	1.04	-1.15	0.07	0.00	69.5	0.08
September	2012	0.00	1.48	0.00	0.05	0.36	0.01	0.00	1.00	0.53	-0.63	0.00	0.00	61.5	0.05
TOTALS		**18.12**	**14.44**	**0.00**	**3.84**	**2.68**	**1.33**	**0.28**	**6.59**	**5.37**	**0.46**	**3.86**	**0.00**	**47.4**	**2.99**