Prepared in cooperation with the Upper Elkhorn, Lower Elkhorn, Upper Loup, Lower Loup, Middle Niobrara, Lower Niobrara, Lewis and Clark, and Lower Platte North Natural Resources Districts

Streamflow Simulations and Percolation Estimates Using the Soil and Water Assessment Tool for Selected Basins in North-Central Nebraska, 1940–2005

Scientific Investigations Report 2009–5075

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. North Fork Dismal River near Lena in Hooker County, Nebraska (photograph taken by Robert Swanson, U.S. Geological Survey, November 14, 2006).

Streamflow Simulations and Percolation Estimates Using the Soil and Water Assessment Tool for Selected Basins in North-Central Nebraska, 1940–2005

By Kellan R. Strauch and Joshua I. Linard

Prepared in cooperation with the Upper Elkhorn, Lower Elkhorn, Upper Loup, Lower Loup, Middle Niobrara, Lower Niobrara, Lewis and Clark, and Lower Platte North Natural Resources Districts

Scientific Investigations Report 2009–5075

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Strauch, K.R., Linard, Joshua, 2009 Streamflow simulations and percolation estimates using the Soil and Water Assessment Tool for selected basins in North-Central Nebraska, 1940-2005: U.S. Geological Survey, Scientific Investigations Report 2009–5075, 20 p.

Contents

Figures

Tables

Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Streamflow Simulations and Percolation Estimates Using the Soil and Water Assessment Tool for Selected Basins in North-Central Nebraska, 1940–2005

By Kellan R. Strauch and Joshua I. Linard

Abstract

The U.S. Geological Survey, in cooperation with the Upper Elkhorn, Lower Elkhorn, Upper Loup, Lower Loup, Middle Niobrara, Lower Niobrara, Lewis and Clark, and Lower Platte North Natural Resources Districts, used the Soil and Water Assessment Tool to simulate streamflow and estimate percolation in north-central Nebraska to aid development of long-term strategies for management of hydrologically connected ground and surface water. Although groundwater models adequately simulate subsurface hydrologic processes, they often are not designed to simulate the hydrologically complex processes occurring at or near the land surface. The use of watershed models such as the Soil and Water Assessment Tool, which are designed specifically to simulate surface and near-subsurface processes, can provide helpful insight into the effects of surface-water hydrology on the groundwater system. The Soil and Water Assessment Tool was calibrated for five stream basins in the Elkhorn-Loup Groundwater Model study area in north-central Nebraska to obtain spatially variable estimates of percolation.

Six watershed models were calibrated to recorded streamflow in each subbasin by modifying the adjustment parameters. The calibrated parameter sets were then used to simulate a validation period; the validation period was half of the total streamflow period of record with a minimum requirement of 10 years. If the statistical and water-balance results for the validation period were similar to those for the calibration period, a model was considered satisfactory. Statistical measures of each watershed model's performance were variable. These objective measures included the Nash-Sutcliffe measure of efficiency, the ratio of the root-mean-square error to the standard deviation of the measured data, and an estimate of bias. The model met performance criteria for the bias statistic, but failed to meet statistical adequacy criteria for the other two performance measures when evaluated at a monthly time step. A primary cause of the poor model validation results was the inability of the model to reproduce the sustained base flow and streamflow response to precipitation that was observed in the Sand Hills region.

The watershed models also were evaluated based on how well they conformed to the annual mass balance (precipitation equals the sum of evapotranspiration, streamflow/runoff, and deep percolation). The model was able to adequately simulate annual values of evapotranspiration, runoff, and precipitation in comparison to reported values, which indicates the model may provide reasonable estimates of annual percolation. Mean annual percolation estimated by the model as basin averages varied within the study area from a maximum of 12.9 inches in the Loup River Basin to a minimum of 1.5 inches in the Shell Creek Basin. Percolation also varied within the studied basins; basin headwaters tended to have greater percolation rates than downstream areas. This variance in percolation rates was mainly was because of the predominance of sandy, highly permeable soils in the upstream areas of the modeled basins.

Introduction

In central and eastern Nebraska, the Elkhorn and Loup Rivers are important sources of water for irrigation, recreation, aquatic habitat, and hydropower production. As the primary sources of streamflow to the lower Platte River, the Elkhorn and Loup Rivers support in-stream flow appropriations, off-stream hydroelectric production, and municipal water systems for the Omaha and Lincoln metropolitan areas. Understanding these water resources is essential because of newly adopted state legislation that requires a sustainable balance between long-term water supplies and uses for surface- and groundwater in Nebraska (Nebraska Department of Natural Resources, 2007a). As part of the effort to identify the sustainable balance the U.S. Geological Survey (USGS), the Upper Elkhorn, the Lower Elkhorn, the Upper Loup, the Lower Loup, the Middle Niobrara, the Lower Niobrara, the Lewis and Clark, and the Lower Platte North Natural Resources Districts (NRDs) (collectively referred to as Elkhorn-Loup Groundwater Model (ELM) NRDs), agreed to cooperatively study the water resources in the Elkhorn and Loup Basins. The information is needed to aid the ELM NRDs in developing long-term strategies for management of hydrologically connected waters.

A primary component of the cooperative study is the development of a regional-scale groundwater model. The ELM study area covers approximately 30,800 square miles (mi^2), and extends from the Niobrara River in the north to the Platte River in the south (fig. 1). The western boundary coincides with the western boundary of the Upper Loup NRD, and the eastern boundary coincides approximately with the westernmost extent of glacial till in eastern Nebraska. Although groundwater models may adequately simulate subsurface hydrologic processes, they often are not designed to simulate the hydrologically complex processes occurring at or near the land surface. The use of watershed hydrologic models, designed specifically to simulate surface and near-surface processes, can provide helpful insight into the effects of surface-water hydrology on the groundwater system. The Soil and Water Assessment Tool (SWAT) was used to simulate streamflow and produce estimates of percolation. The data and information resulting from SWAT simulations can be used to improve input to, or as quality assurance for, a groundwater model developed for the underlying aquifer system.

Purpose and Scope

The purpose of this report is to describe streamflow simulations of surface-water percolation estimates using SWAT in the ELM study area. Six watershed models were constructed, one for each of five subbasins within the ELM study area, and one watershed model for the lower Loup River Basin to better model the hydrologic processes in the downstream part of the larger Loup River drainage basin. The construction, calibration, and validation of the six watershed models are presented. The model simulation period was from October 1939 through September 2005 for each basin.

Study Area

The ELM study area encompasses 30,800 mi^2 in North-Central Nebraska. About one-half of the study area is within a physiographic region known as the Sand Hills (fig. 1). The Sand Hills region in Nebraska is the largest sand dune field in the western hemisphere (Bleed and Flowerday, 1998), and dunes are stabilized by vegetation. The study area includes five stream basins: Loup River, Elkhorn River, Shell Creek, Long Pine Creek, and Plum Creek. Mean annual evapotranspiration (ET) in the study area ranges from 19 inches (in.) per year in the eastern part of the study area to 16 in. in the western part (Dugan and Zelt, 2000). Mean annual precipitation also varies spatially in the study area. Records from precipitation gages in and around the study area, from October 1940 to September 2005 (National Oceanic and Atmospheric Administration, 2006), indicate mean annual precipitation increases from west to east from 17 to 27 in. Much of the study area is undeveloped with most of that land classified as pasture or rangeland. Agriculture is an important land use in the eastern and southern parts of the study area where the soils are less sandy. Irrigation from groundwater is common. The disparity between precipitation and runoff volumes in the ELM study area implies that most of the precipitation infiltrates the soil rather than immediately contributing to streamflow (fig. 2). This mostly is because the sandy soils of the Sand Hills, which compose approximately 50 percent of the study area, have permeability rates exceeding 10 in./hour (hr). (Dugan and others, 1990).

Loup River Basin

The physical characteristics of the Loup River Basin are spatially variable. The soils in the headwaters of the Loup River Basin are associated with the Sand Hills and are characterized by excessively drained, highly permeable soils, consisting mainly of fine sand (Dugan and others, 1990). Soils in the downstream part of the basin generally consist of silty loam with moderate permeability, and are well-drained (Dugan and others, 1990). The dominant land uses in the Loup River Basin are row crops and pasture/rangeland. Land use in the headwaters of the basin is pasture, with agricultural land use along the river bottoms predominated by corn and soybeans. In the downstream part of the basin corn and soybean agriculture is the dominant land use. Mean annual precipitation in the Loup River Basin, calculated from NOAA records, is 21.3 in. (National Oceanic and Atmospheric Administration, 2006); mean annual ET is approximately 18 in. (Dugan and Zelt, 2000); and mean annual runoff is approximately 2.4 in. at the basin’s most downstream stream gage.

Elkhorn River Basin

Elkhorn River Basin soils are composed of fine sand and loamy fine sand. The soils in the upstream part of the Elkhorn River Basin are dominated by fine sand and loamy fine sand that are moderately to excessively drained and have high permeability (Dugan and others, 1990). Soils in the downstream part of the basin are composed of loamy fine sand and have high permeability soils (Dugan and others, 1990). Land use in the basin consists of pasture/rangeland and row-crop agriculture. The land use in the upstream part of the basin mainly is pasture/rangeland; the downstream part consists mainly of agricultural uses in the form of soybeans and corn being the principal crops. The mean annual precipitation in the basin is 25.6 in. (National Oceanic and Atmospheric Administration, 2006), reported mean annual ET is 18 in. (Dugan and Zelt, 2000), and mean annual runoff is 2.7 in. at the most downstream stream gage.

Shell Creek Basin

Soils in the Shell Creek Basin are dominated by silty loam and silty clay loam. Most of the basin consists of silty loam that has moderate permeability (Dugan and others, 1990). Land use in the Shell Creek Basin mostly is row-crop

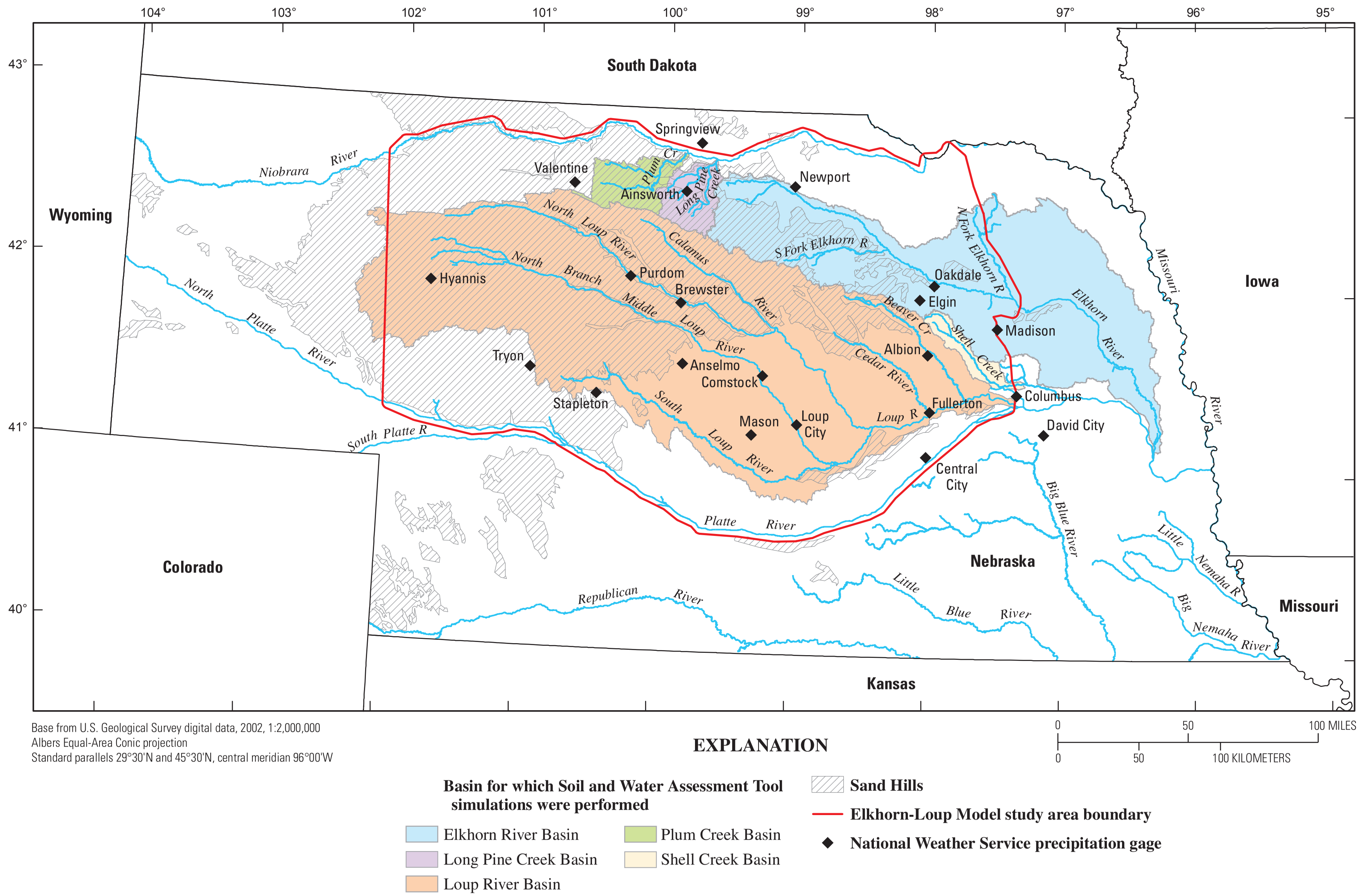

Figure 1. Elkhorn-Loup Groundwater Model study area, basins for which the Soil and Water Assessment Tool simulations were performed, and precipitation gages used as input in the models.

agriculture and pasture/rangeland. Headwater land use mainly consists of row-crop agriculture, but pasture/rangelands also are present. Land use in the downstream part of the basin is uniformly corn and soybean agriculture. Mean annual precipitation in the Shell Creek Basin is 25 in. (National Oceanic and Atmospheric Administration, 2006), reported mean annual ET is 18 in. (Dugan and Zelt, 2000), and mean annual runoff is 2.1 in. at the most downstream stream gage.

Long Pine Creek Basin

Soils in the Long Pine Creek Basin mainly are composed of fine sand and silty loam that are well-drained and have high permeabilities (Dugan and others, 1990). The fine sand mainly is located in the headwaters of the basin and in a small section near the outlet. Silty loam soils mainly are located in the lower one-half of the basin, but are absent at the outlet. Land use in the Long Pine Creek Basin mainly consists of pasture/rangeland and row crop agriculture. The subbasins in the headwaters and near the outlet are predominately pasture/rangeland. The primary land use in the middle part of the basin, where silty loam soils exist, is row-crop agriculture. Mean annual precipitation for the basin is 22.4 in. (National Oceanic and Atmospheric Administration, 2006), mean annual ET is 17 in. (Dugan and Zelt, 2000), and mean annual runoff is 4.8 in. at the most downstream stream gage.

Plum Creek Basin

Soils in the Plum Creek Basin mainly consist of fine sand and fine sandy loam. Most of the soils in the basin are composed of fine sand, with the exception of areas along the stream bottoms in the downstream part of the basin, which mainly consist of fine sandy loam. Both soil types are excessively drained, and have high permeability. Land use in the basin is dominated by pasture/rangeland, although there is some row-crop agriculture on the eastern edge of the basin. The mean annual precipitation in the basin is 22 in. (National Oceanic and Atmospheric Administration, 2006), ET is 17 in. (Dugan and Zelt, 2000), and runoff at the most downstream stream gage is 3.1 in.

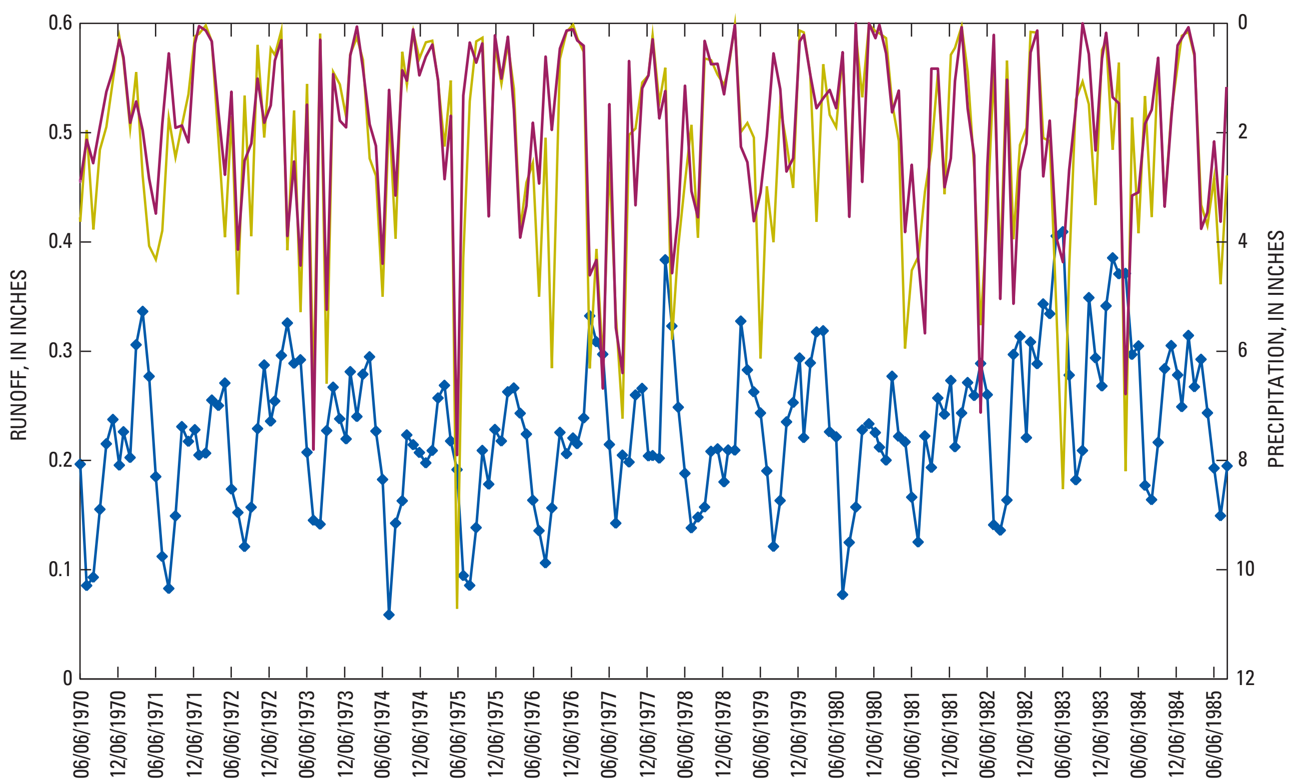

Figure 2. Lack of correspondence in the Elkhorn-Loup Groundwater Model study area between recorded precipitation and streamflow.

Methods

Numerous commercially available surface-water runoff simulation models exist. The Soil and Water Assessment Tool (SWAT) was chosen for this study because of its common use in the agricultural research community *(http://www.brc.tamus.edu/swat/)*. SWAT is a surface-water hydrologic model designed to specifically simulate the hydrologic response of relatively flat areas of land, with patches of distinct crops, to precipitation.

Model Description

SWAT (version SWAT2005) (Neitsch and others, 2005) uses the Soil Conservation Service (SCS) Curve Number (CN) method to partition precipitation into either infiltration (water seeping into the soil profile) or to direct surface runoff (the sum of surface runoff and interflow), which is routed directly to the stream (Soil Conservation Service, 1986). Larger CNs result in more precipitation apportioned to direct runoff. Because the CN method is used to model runoff, the model does not simulate infiltration processes. To determine the amount of infiltration, the amount of direct runoff is subtracted from the amount of precipitation. Water will infiltrate unsaturated soil at a certain rate depending on the type of soil. Infiltration rates gradually decline as the soil becomes more saturated until the infiltration rate is at a steady rate. This saturated infiltration rate is an approximation of the saturated hydraulic conductivity of the soil (Neitsch and others, 2005). Infiltrated water may be held in the soil profile and later be evapotranspired, or can reach a stream or lake through shallow lateral subsurface flow or through tile drains. Evapotranspiration, or the movement of water near the earth's surface from the liquid phase to vapor phase, is calculated by the model using the Penman-Monteith method (Monteith, 1965). Infiltrated water that is not evapotranspired becomes either shallow lateral subsurface flow or deep percolation. Lateral subsurface flow is that which contributes to streamflow and is located between the saturated zone and the land surface. Lateral subsurface flow is modeled by a kinematic storage model that accounts for soil-water content, slope, and soil hydraulic conductivity (Neitsch and others, 2005), and is used to determine how water moves in each soil layer. Lateral flow is calculated concurrently with redistribution. Redistribution is the constant vertical movement of water in the soil profile after precipitation or irrigation has ceased. In the model, water content differences govern water redistribution; if the water content in the soil is uniform, redistribution is discontinued. Water percolating from the soil profile to the saturated zone can travel to the stream as shallow lateral flow or be lost to a deeper, regional groundwater system. Percolation rates are controlled by the saturated hydraulic conductivity of the soil layer. For irrigation, SWAT can draw water from several possible resources, but will use only enough water to alleviate the soil-moisture deficit. SWAT can simulate on a daily, monthly, or yearly time step. For the purposes of this study SWAT was used to simulate on a monthly time step because that was the desired time step for the existing groundwater model. Assumptions for the SWAT model are that flows in streams and reservoirs are one-dimensional and that the SCS CN approach is appropriate for the area being modeled.

Model Inputs

The model inputs used by SWAT for each subbasin in this study were topography, land use, soils, and daily precipitation. AVSWAT-X (DiLuzio and others, 2002) was used to pre-process the default parameter file sets determined for the inputs for initial simulations using SWAT for each subbasin. The spatial data required a digital elevation model (DEM), a land-use categorical grid, and a categorical grid of soil map units.

A 32.8-foot (ft) resolution DEM was used as the topographic representation *(http://seamless.usgs.gov)*. Land use was represented by a 98.4-ft-resolution grid of the National Agricultural Statistics Service's (NASS) 1:100,000-scale 2005 cropland data layer (U.S. Department of Agriculture, 2006). No attempt was made to simulate changes in land use through time; the NASS grid was used for all simulated periods. Soils were represented by the State Soil Geographic (STATSGO) Database as a 98.4-ft-resolution grid (Schwarz and Alexander, 1995) and were used to assign soil properties to each subbasin. Precipitation inputs were daily data obtained from NOAA weather stations (National Oceanic and Atmospheric Administration, 2006). This was done because several NOAA weather stations were made available to SWAT, and the model will select the weather station closest to a subbasin center and use the precipitation data from that closest weather station as model input for each subbasin. Other climatic data such as air temperature and solar radiation, and missing data in the observed precipitation record, were simulated using a weather generator module of SWAT (Neitsch and others, 2005).

For quality assurance purposes, the precipitation values used by the model were compared to data obtained from NOAA weather stations in and around the study area from October 1, 1939 through September 30, 2005 (National Oceanic and Atmospheric Administration, 2006). Mean annual values were calculated from NOAA weather stations used in the model to obtain a basin-wide mean precipitation value that was compared to the basin-wide mean precipitation value from the model. Because precipitation is spatially variable and the distribution of precipitation gages is uneven throughout the study area, the sum of SWAT precipitation for a subbasin may differ from that of the recorded precipitation.

Subbasin Delineation

Six SWAT watershed models were constructed in the ELM study area. The watershed models were constructed in the following basins:

- The Loup River watershed model—the entire Loup River drainage basin upstream from the stream gage Loup River at Columbus;
- The Lower Loup River watershed model—the downstream half of the Loup River drainage basin from the stream gages Calamus River near Burwell, North Loup River at Taylor, and Middle Loup River at Walworth to the stream gage Loup River at Columbus;
- Elkhorn River watershed model—the drainage basin upstream from the stream gages Elkhorn River at Norfolk and North Fork Elkhorn River near Pierce;
- Shell Creek watershed model—the drainage basin upstream from the stream gage Shell Creek near Columbus;
- Long Pine Creek watershed model—the drainage basin upstream from the stream gage Long Pine Creek near Riverview;
- Plum Creek watershed model—the drainage basin upstream from the stream gage Plum Creek at Meadville;

Two watershed models were developed in the Loup River Basin because of the watershed size and variance in soil types in the Loup River Basin. The Lower Loup River watershed model was built to isolate the hydrologic response of the lower subbasins, which are more responsive to precipitation, from those in the Sand Hills, which are less responsive.

Each of the watershed models were divided into subbasins. Subbasin delineation provides greater spatial resolution of hydrologic simulation for subbasins with different land uses and soils (Neitsch and others, 2005). The GIS interface for SWAT2000 (AVSWAT-X) was used to delineate basins and subbasins (DiLuzio and others, 2002) from DEM data. For some subbasins the AVSWAT-X preprocessor was unable to delineate the 32.8-ft resolution. In such cases the DEM was resampled to 98.4 ft or 328.1 ft, depending on the size of the basin being modeled.

Subbasins were further subdivided into Hydrologic Response Units (HRUs) based on crop coverage and soil types. Multiple HRUs within a subbasin were created where a land use within a subbasin occupied more than 15 percent of the subbasin area, and where a soil type composed at least 15 percent of the subbasin area. These threshold values were used because the excessive multiplication of minor HRUs could hinder model computational efficiency (Fitzhugh and Mackay, 2000). The delineated subbasins and stream gages used for calibration and validation are illustrated in figure 3; the stream gage names and period of records are given in table 1.

Model Calibration and Validation

The watershed models were calibrated and validated to ensure that the watershed model properly predicts the correct response for periods separate from the calibration period. To determine the calibration and validation periods, the total number of years in the streamflow record was divided in half; The first half of the record was the calibration period, and the second half was the validation period. During calibration, model adjustment parameters are modified to obtain the set of parameters that accurately simulates the recorded streamflow. The validation period is an independent data set from the calibration period and is used to verify that the model's calibrated parameter set accurately represents the models condition. The watershed models were evaluated statistically and visually by comparing the simulated streamflow to recorded streamflow after each simulation. Additionally, simulated values of runoff and evapotranspiration for each subbasin are compared to reported values after each simulation. Mean annual runoff values were calculated using USGS and NDNR stream-gage data (U.S. Geological Survey, 2007; Nebraska Department of Natural Resources, 2007b) from October 1, 1939 through September 30, 2005.

At each stream gage the calibration and validation process was performed. Calibration started at the most upstream stream gage in each basin and continued downstream to the basin outlet. Basin outlet stream gages, time periods, and basin characteristics are shown in table 2. During calibration at the most upstream stream gage all subbasins that contribute flow to that stream gage were calibrated through manual parameter adjustment. After calibration at a stream gage the next downstream gage was calibrated. At this gage only the subbasins that contribute flow between the previous stream gage and the current gage are calibrated. This process continued until the stream gage at the outlet of the basin was calibrated. The primary parameters that were adjusted as determined by previous model calibration experience were the curve number, soil available-water capacity, soil evaporation-compensation factor (Neitsch and others, 2005), groundwater revaporation coefficient (water being drawn up from the saturated zone to the unsaturated zone) (Neitsch and others, 2005), the minimum, or threshold, depth for revaporation occurrence (Neitsch and others, 2005), the depth of water in the shallow aquifer required for base flow to occur, base flow alpha factor (a constant in the base flow recession function), and crack volume or other preferential routing of water into the soil profile. Calibration began by adjusting the surface-runoff parameters including the curve number, soil-available water capacity, and soil evaporation-compensation factor. When the simulated streamflow peaks were similar to the recorded streamflow, the authors considered the surface flow calibrated. Subsurface flow was then calibrated by adjusting the groundwater revaporation coefficient, the minimum depth for revaporation to occur, the depth of water in the shallow aquifer required for base flow to occur, base flow alpha, and crack volume. After each model simulation, the simulated streamflow was compared visually and statistically to the recorded streamflow, and simulated basin-wide mean annual values of the water balance were also compared to recorded mean annual values for each watershed model. After this comparison model parameters were adjusted,

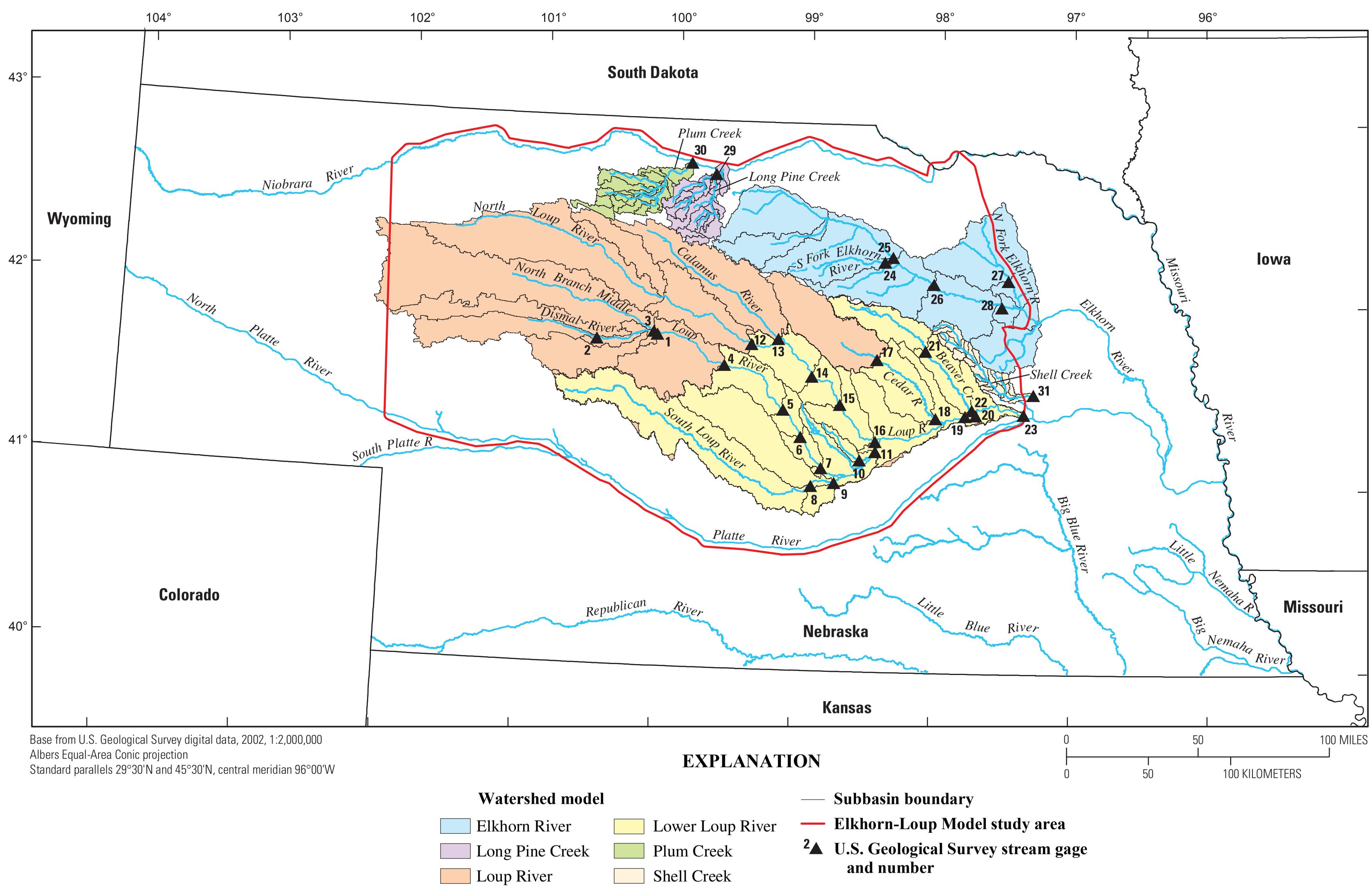

Figure 3. Basins, delineated subbasins, and U.S. Geological Survey stream gages located at subbasin outlets.

Table 1. Calibration/validation stream gages and period of record.

[All stations are located in Nebraska; period of record is for streamflow; ID, identifier]

Stream gage number (fig. 3)	Station name	Station ID	Period of record
	Loup River Basin		
1	Middle Loup River at Dunning	06775500	10/01/1945–09/30/2004
2	Dismal River near Thedford	06775900	10/01/1966–09/30/2004
3	Dismal River at Dunning	06776500	10/01/1945–09/30/1995
4	Middle Loup River at Walworth	06777500	10/01/1940–09/30/1960
5	Middle Loup River at Arcadia	06779000	07/01/1937–09/30/1994
6	Middle Loup River at Loup City	06779500	01/01/1937–09/30/1956
7	Middle Loup River at Rockville	06780000	10/01/1955–10/01/1975
8	South Loup River at Ravenna	06782500	10/01/1940–09/30/1975
9	South Loup River at St. Michael	06784000	10/01/1943–09/30/2004
10	Turkey Creek near Dannebrog	06784800	05/01/1966–09/30/1994
11	Middle Loup River at St. Paul	06785000	09/01/1928–09/30/2004
12	North Loup River at Taylor	06786000	12/01/1936–09/30/2004
13	Calamus River near Burwell	06787500	10/01/1940–09/30/1995
14	North Loup River at Ord	06788500	07/01/1952–09/30/1994
15	North Loup River at Scotia	06789000	12/01/1936–01/31/1970
16	North Loup River near St. Paul	06790500	09/01/1928–09/30/2004
17	Cedar River near Spalding	06791500	10/01/1944–09/30/1994
18	Cedar River near Fullteron	06792000	10/01/1940–09/30/1995
19	Loup River Power Canal near Genoa	06792500	01/01/1937–09/30/2004
20	Loup River near Genoa	06793000	04/01/1929–09/30/2004
21	Beaver Creek at Loretto	06793500	10/01/1944–09/30/1991
22	Beaver Creek at Genoa	06794000	10/01/1940–09/30/2004
23	Loup River at Columbus	06794500	04/01/1934–09/30/2004
	Elkhorn River Basin		
24	Elkhorn River at Ewing	06797500	08/01/1947–09/30/2004
25	South Fork Elkhorn River near Ewing	06798000	08/01/1947–09/30/1991
26	Elkhorn River at Neligh	06798500	10/01/1930–09/30/1993
27	North Fork Elkhorn River near Pierce	06799100	08/01/1960–09/30/2004
28	Elkhorn River at Norfolk	06799000	08/01/1896–09/30/2004
	Long Pine Creek Basin		
29	Long Pine Creek near Riverview	06463500	05/01/1948–09/30/2005
	Plum Creek Basin		
30	Plum Creek at Meadville	06462500	01/01/1948–09/30/1994
	Shell Creek Basin		
31	Shell Creek near Columbus	06795500	09/01/1947–10/24/2005

and another model simulation was performed. This process of parameter adjustment was continued until the model was deemed calibrated, that is, when additional parameter changes did not result in improved model performance in regards to both visual, statistical, and water-balance evaluations.

The corresponding parameter set was then used to simulate the validation period, which ranged in length from 23 to 29 years. If the performance of the model for the validation period was similar to that of the calibration period with respect to visual and statistical comparisons to streamflow and ET, the model was deemed satisfactory; if the model did not perform similarly to the calibration period the process of calibration was repeated. When the model was deemed satisfactory, the percolation values for each subbasin could be extracted. Initial and calibrated model parameter values are listed in table 3. For five of the six models, the calibration period included years in the early part of the period of record, and the validation period included years in the later part of the period of record (table 2). For the Shell Creek watershed model, however, the calibration (October 1976–September 2005) and validation (October 1947–September 1976) were switched relative to the other models to determine if a more acceptable model could be developed by using the drier conditions in the early part of the record.

After the model was calibrated/validated, the percolation from the output files were examined for how percolation responded to precipitation and for the effects of soil texture, land use, and ET. To analyze the response of percolation, basin-wide annual mean values for the time period from 1940–2005 of both precipitation and simulated percolation were compared. 10-year moving average plots were used to help visualize the results.

To compare the effects of soil texture, land use, and ET on percolation the STATSGO (Schwarz and Alexander, 1995) and the NASS (U.S. Department of Agriculture, 2006) coverages were used to determine the percentages of land use and soil texture that composed the area of the watershed model. The soils and landuses were generalized into the most prevalent categories in each basin. Soils were grouped into the soil textures: silty loam, silty clay loam, fine sandy loam, loamy fine sand, and fine sand. Land use categories were: medium density urban, range-shrubland, hay, alfalfa, soybeans, corn, and pasture. These values were then compared graphically with basin-wide mean annual simulated values from 1940–2005 of ET and percolation to illustrate the effects. The error bars on the graphs are one standard deviation above and below the mean (Helsel and Hirsch, 2002).

Model Error Assessment

Statistics used to evaluate model performance included the Nash-Sutcliffe measure of efficiency (NSE), the ratio of the root-mean-square error of simulated streamflow to the standard deviation of the measured data (RSR), and the percent bias (PBIAS) of simulated streamflow to recorded

Table 2. Basin-outlet stream gages, basin characteristics, and periods used for model calibration and validation.

[All gaging stations are in Nebraska; mi^2, square miles; HRU, hydrologic response unit; USGS, United States Geological Survey; ID, identifier; basins are as shown in figure 3]

Basin	Basin area (mi^2)	Number of subbasins	Number of HRUs	Mean subbasin area (mi^2)	Station ID	Stream gage at basin outlet	Calibration period	Validation period
Loup River[1]	14,444	27	5	535	06794500	Loup River at Columbus, USGS stream gage	October 1939–September 1976	October 1976–September 2004
Elkhorn River	6,502	19	12	342	06799000	Elkhorn River at Norfolk, USGS stream gage	October 1947–September 1976	October 1976–September 2004
Shell Creek	305	27	7	11	06795500	Shell Creek near Columbus, USGS stream gage	October 1976–September 2005	October 1947–September 1976
Long Pine Creek	489	25	5	20	06463500	Long Pine Creek near Riverview, USGS stream gage	October 1948–September 1977	October 1977–September 2005
Plum Creek	514	19	5	27	06462500	Plum Creek at Meadville, USGS stream gage	January 1948–September 1971	October 1971–September 1994

[1] Calibration and validation periods used for Lower Loup River and Loup River models.

Table 3. Initial and calibrated model parameter values for six watershed models.

[--, initial parameter was variable and was determined on the basis of basin characteristics; mm, millimeter; m, meter; hr, hour; SCS, Soil Conservation Service; parameter ranges refer to values in multiple subbasins; ravap, revaporation or water drawn up from the saturated zone to the unsaturated zone]

Parameter code	Parameter definition	Initial value	Calibrated model					
			Loup River	Lower Loup River	Elkhorn River	Shell Creek	Long Pine Creek	Plum Creek
GW_DELAY	Groundwater delay (days) - time between water exiting soil profile and entering the shallow aquifer.	31.00	220.00	220.00–365.00	300. 00	300.00	200.00	300.00
ALPHA_BF	Base-flow alpha factor (days).	.0480	.0001–.9000	.0002–.9000	.0006	.0005	.0001	.0001
GWQMN	Threshold depth of water in the shallow aquifer required for base flow to occur (mm).	.00	.000–1.000	.000–10.000	1.00	1.00	1.00	.00
GW_REVAP	Groundwater “revap” coefficient.	.02	.02–2.00	.020–.200	0.020–0.080	.04	.02	.02
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur (mm).	1.00	.0–10.0	.00	.00	.00	.00	1.00
RCHRG_DP	The fraction of percolation from the root zone which recharges the deep aquifer.	.05	.0–7.0	0–.6	.05	.05	.10	.05
OV_N	Manning’s “n” value for overland flow.	.14–.15	.540–.550	.540–.550	.540–.550	.54	.55	.55
LAT_TTIME	Lateral flow travel time (days).	.00	180.00	0–120	7–20.0	10.00	10.00	5.00
SLSOIL	Slope length for lateral subsurface flow (m).	.00	150.00	0–150	11.0–40.0	3.00	850.00	775.00
ESCO	Soil evaporation compensation factor.	.00	.80	0–.75	.75–.80	.87	.70	.70
CN2	SCS runoff curve number for moisture condition II.	--	40–61	50	44–78	54–63	27–75	27–82
SOL_CRK	Potential or maximum crack volume of the soil profile expressed as a fraction of the total soil volume.	.00	.0–1.0	0–1.0	.1–.7	.00	.00	.00
SOL_AWC	Available water capacity of the soil layer (mm/mm soil).	--	.04–.290	.04–.290	.04–.260	.22–.260	.08–.243	.07–.20
SOL_K	Saturated soil hydraulic conductivity (mm/hr).	--	.340–1550	.340–1050	.280–1050	2.8–21	25–1050	28–1050

streamflow (Moriasi and others, 2007). Each model also was evaluated on the basis of how well the model simulations of runoff, ET, and percolation conformed to a water balance equation. As groundwater is the main source of water to streams in most of the simulated basins, an effort was made to calibrate to base-flow conditions. The watershed models were evaluated on a monthly time step.

The NSE assesses the ability of a model to correctly simulate streamflow during periods when recorded streamflow deviates largely from the measured mean monthly streamflow and is calculated as:

$$NSE = 1 - \left[\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2 / \sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2 \right] \quad (1)$$

where

Y_i^{obs} is the measured streamflow for the ith time step,

Y_i^{sim} is the simulated streamflow at the ith time step, and

Y^{mean} is the measured mean monthly streamflow.

The total number of time steps is indicated by n. As defined, NSE ranges from minus infinity to 1.0, a perfect model would produce an NSE of 1; however, Moriasi and others (2007) suggest that the performance of a model is considered to be "good" if the NSE is between 0.65 and 0.75 and "satisfactory" when the NSE is above 0.5.

The RSR statistic evaluates the error associated with model performance and is determined from the root-mean-square error (RMSE) and standard deviation (STDEV) in the simulated data compared to the measured data:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2} \right]} \quad (2)$$

where the factors are as defined in equation 1. A model performing with no error would produce an RSR of 0.0. The criteria presented by Moriasi and others (2007) would designate model performance as "good" if the RSR is between 0.5 to 0.6 and "unsatisfactory" if the RSR was more than 0.7.

To evaluate the ability of a model to produce an unbiased estimate of the streamflow component of the mass balance for an entire simulation, the PBIAS statistic was used and is calculated as:

$$PBIAS = \frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})}{\sum_{i=1}^{n} (Y_i^{obs})} * 100 \quad (3)$$

where the factors are as defined in equation 1. The PBIAS statistic can be positive or negative. The closer to zero the PBIAS value is, the more equally balanced are the overpredictions and the underpredictions of streamflow for the period being evaluated. A positive PBIAS value indicates on average a model is underpredicting streamflow, whereas negative values indicate overprediction. PBIAS values between 0 and +/-10 percent indicate a "very good" model simulation, values between +/-10 and +/-15 percent indicate a "good" model simulation, whereas values greater than +/-25 percent indicate an "unsatisfactory" model (Moriasi and others, 2007).

To evaluate how well a model estimated percolation from each of the basins, each model was evaluated on how well it conformed to the water balance equation:

Precipitation (in.) = ET (in.) + Runoff (in.) +/- Change in Storage (in.) (4)

Because of the small number of surface reservoirs in the ELM study area, it was assumed that any changes in storage would occur in the subsurface. Soil moisture not lost to ET was assumed to percolate past the root zone to the saturated zone where it could contribute to groundwater storage or groundwater discharge to streamflow. Therefore substituting percolation in equation 4 for the change in storage and rearranging equation 4:

Percolation (in.) = Precipitation (in.) - ET (in.) - Runoff (in.) (5)

If simulated runoff was similar to measured runoff, and simulated ET was similar to reported ET (Dugan and Zelt, 2000), the authors assumed that the simulated values for percolation were reasonable. Equation 5 was not used to calculate percolation; the SWAT model simulates percolation, and the water balance was used to check the simulated components with recorded values. With this in mind, an effort was made to calibrate the models to base-flow conditions to ensure that the simulated groundwater contribution was reasonable through visually comparing hydrographs of simulated and measured streamflow.

Streamflow Simulation Results

When the recorded streamflow and precipitation in the study area were examined it was apparent that most precipitation infiltrates the soil rather than directly contributing to streamflow. This observation was more apparent when examining streamflow in headwater areas that are underlain by sandy soils such as those in the Sand Hills region. Peaks evident in the recorded hydrographs indicate that infiltrating water may reach streams through preferential flow paths before contacting the saturated zone. With this in mind, the parameter sets were adjusted to simulate the hypothesized processes. Even with the parameter adjustments the model was unable to simulate the correct response of the hydrologic system to precipitation that was observed in the headwater areas.

Visual comparison of the simulated and recorded streamflow indicates that the watershed models adequately simulated the base-flow conditions of the stream, but was unable

Table 4. Statistical validation results for performance of the Soil and Water Assessment Tool model simulations of streamflow.

[NSE: Nash-Sutcliffe coefficient of efficiency, RSR: ratio of the root-mean-square error to the standard deviation of the measured data, PBIAS: percent bias.]

Watershed model	NSE	RSR	PBIAS
Loup River	- 1.13	1.46	21.11
Lower Loup River	.22	.88	1.09
Elkhorn River	.35	.81	-13.22
Shell Creek	.24	.88	- 6.00
Long Pine Creek	.38	.79	6.48
Plum Creek	.08	.96	2.21

to consistently reproduce the peaks produced in response to precipitation (fig. 4). This resulted in poor statistical results when the simulated streamflow was evaluated for model performance.

Statistical Validation Results

For the watershed models performance to be considered satisfactory, the simulated mass balance needed to conform to reported values and to satisfy objective statistical criteria for acceptable performance (satisfactory or better) of an effective model (NSE>0.5; RSR < 0.7; and PBIAS < +/-25 percent). The statistical validation results determined by comparing simulated and recorded streamflow values, generally, were not within the satisfactory ranges (table 4). For the Loup River watershed model, it seems likely that the most important processes were not being simulated correctly because the model did not accurately simulate the streamflow response to precipitation that was observed in the recorded streamflow. Through visual comparison of the simulated and recorded streamflow hydrographs from the Loup and Lower Loup models, it is apparent that the Lower Loup model more accurately simulated the recorded streamflow, and that the important hydrologic processes were more accurately represented. The Lower Loup model also performed better as indicated by the statistical metrics. Although the Lower Loup River model performed better both visually and statistically than the Loup River model, it still failed to meet the objective criteria described in this report. All of the watershed models failed to meet the criteria for the NSE and RSR, but most performed in the acceptable range for the PBIAS statistic. Even though the NSE values were unsatisfactory, the positive values indicate that the simulated streamflow was a more effective predictor of streamflow than the mean monthly streamflow. The attainment of acceptable values for the PBIAS statistic indicated that models under- or over-estimated streamflow are almost an equivalent cumulative balance.

Mass Balance Results

Without confidence in the simulated streamflow statistical results it was unlikely that the simulated percolation values would be useful. To determine the ability of the watershed models to estimate percolation, the water balance was used (eq. 5). Components of the cumulative basin-level water balances for the six models for 1940–2005 were similar to those recorded or reported (table 5) except for ET in the Loup River, Shell Creek, and Plum Creek watershed models. The large water imbalance in the Loup River Basin model was caused by the large differences between the reported and simulated ET values. The ET value in the Loup River model (12.8 in.) was 24.7 percent lower than the reported value (17 in.). ET from the Loup River watershed model was lower than expected because up to 70 percent of precipitation was preferentially routed to the shallow aquifer in the Sand Hills region to maintain base flow, which limited the amount of water available for ET. The Lower Loup River mass balance more effectively represented the reported values of ET, because the model did not have to reproduce the strong groundwater effect on streamflow that was needed in the upstream subbasins of the Loup River model; therefore, less water was preferentially routed to the shallow aquifer, and infiltrated precipitation had a longer residence time in the soil profile. As a result, groundwater contributed less to simulated streamflow than in the model of the Loup River Basin. The increased residence time also resulted in simulated ET (16.3 in.) that was higher and more similar to the value of 18 in. estimated for the lower Loup River Basin from the map presented by Dugan and Zelt (2000) but still undersimulated the reported value by 9.4 percent. The Shell and Plum Creek basin-level models simulated mass balances varied from the reported mass balances because the simulated ET was respectively 7.8 and 8.8 percent higher than the reported ET. Model precipitation in these areas did not percolate as rapidly, creating a longer residence time in the soil and greater ET rates in these basins.

Model Limitations and Future Model Improvements

Some model limitations that hindered model performance are the limited time period that SWAT can simulate, land use that didn’t change through time, and how SWAT distributes precipitation. Currently the 2005 Soil and Water Assessment Tool can simulate only periods from the year 1900, which may not be enough time to develop a representative groundwater system in equilibrium. The model simulations for this study also did not take into account changes in land use through time which may drastically alter runoff calculations. Another limitation is the way SWAT inputs precipitation. Precipitation is used as direct input to subbasins from the closest precipitation gage, instead of applying a gradient. Because gages can be distributed unevenly throughout the basin this may cause a bias in the precipitation data.

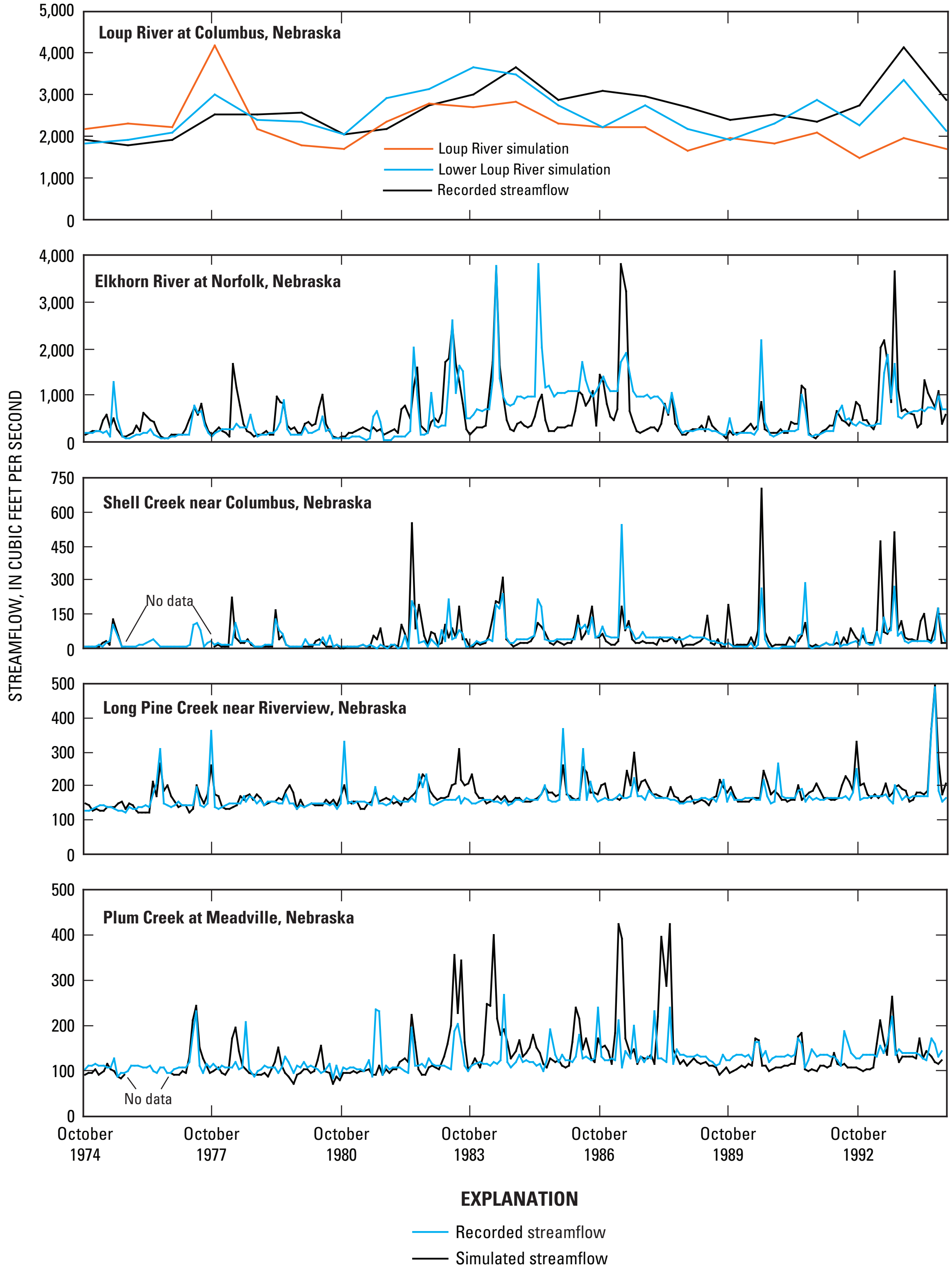

Figure 4. Simulated and recorded basin-outlet streamflows from six calibrated watershed models.

Some possible means of model improvement are to calibrate and validate at a daily time step, and allow the model a longer period of time to develop and equilibrate the groundwater system. At a daily time step, the role of surface and near-surface runoff could be examined more thoroughly. With a longer period of development, theoretically it might be easier to produce a responsive groundwater system while maintaining base flows. Also changing land use through time may resolve the difficulties of simulating the streamflow to match measured values. Admittedly, these are not absolute solutions to the problems of simulating the streamflow in the study area. A model specifically designed to estimate percolation, such as the USGS Modular Modeling System Deep Percolation Model (Vaccaro, 2007), may be more suited to obtaining spatially variable estimates of percolation.

Percolation Estimates

Estimated percolation in the study area varied spatially within the individual basins and within the entire study area. Mean annual estimated percolation by subbasin varied from west to east within the study area. Estimated percolation ranged from a maximum of 12.9 inches per year (in/yr) in the Loup River Basin to a minimum of 1.5 in/yr in the Shell Creek Basin (fig. 5). Higher percolation values in the Loup River Basin were attributed to the permeable sandy soils that are prevalent in the headwaters and to lower ET rates, which made more water available for percolation, whereas the silty loam of the Shell Creek Basin is less permeable and had higher ET rates. The intermediate values in the Elkhorn River, Plum Creek, and Long Pine Creek Basins were attributed to less permeable soils and larger ET rates in these basins, therefore leaving less water in the soil profile to percolate to the groundwater. Results for the subbasins within each watershed model indicated that percolation in the headwaters of the basins generally was higher than percolation in downstream sections. This trend was the result of the permeable sandy soils located in the headwater basins. With less permeable soils in the downstream sections, agriculture also is more prevalent in the lower lying areas. Greater extent of agricultural land also increases ET, which then decreases the amount of water available for deep percolation. The high percolation values that were estimated for a downstream part of the Lower Loup River, resulted from a low ET that was needed to match measured streamflow.

Simulated percolation values were compared to published values to see how well the SWAT simulated percolation was modeled. Published simulated percolation values from the map in figure 37 on page 54 of Dugan and Zelt (2000, fig. 37, p. 54) (table 6) were compared. The simulated values compare favorably for all of the watershed models except the Loup River and Long Pine Creek Basins. The simulated percolation in these two basins overpredicted the previously published values; one possible reason for this is that during calibration

Table 5. Results from basin-level water balances of simulated and reported mean annual values, 1940–2005.

[all values reported in inches; ET, evapotranspiration; %, percent; reported ET from Dugan and Zelt, 2000; recorded runoff calculated from USGS and NDNR streamflow gages (U.S. Geological Survey, 2007; Nebraska Department of Natural Resources, 2007b); recorded precipitation from NOAA weather stations (National Oceanic and Atmospheric Administration, 2006)]

Watershed Model and Validation period (fig. 3)	Recorded precipitation	Model input precipitation	Percent difference precipitation	Reported ET	Simulated ET	Percent difference ET	Recorded runoff	Simulated runoff	Percent difference runoff	Simulated water balance (precipitation - ET - runoff)
Loup River (1976–2005)	21.3	22.5	5.6%	17.0	12.8	-24.7%	2.4	2.4	0.0%	7.3
Lower Loup River (1976–2005)	24.6	24.5	-0.4%	18.0	16.3	-9.4%	2.4	1.7	-29.2%	6.5
Elkhorn River (1976–2005)	25.6	25.7	0.4%	18.0	18.6	3.3%	2.7	2.6	-3.7%	4.5
Shell Creek (1947–1976)	24.5	25.1	2.4%	18.0	19.4	7.8%	2.1	2.0	-4.8%	3.7
Long Pine Creek (1977–2005)	22.4	23.0	2.7%	17.0	17.2	1.2%	4.8	4.6	-4.2%	1.2
Plum Creek (1971–1994)	21.9	22.1	0.9%	17.0	18.5	8.8%	3.1	2.8	-9.7%	0.8

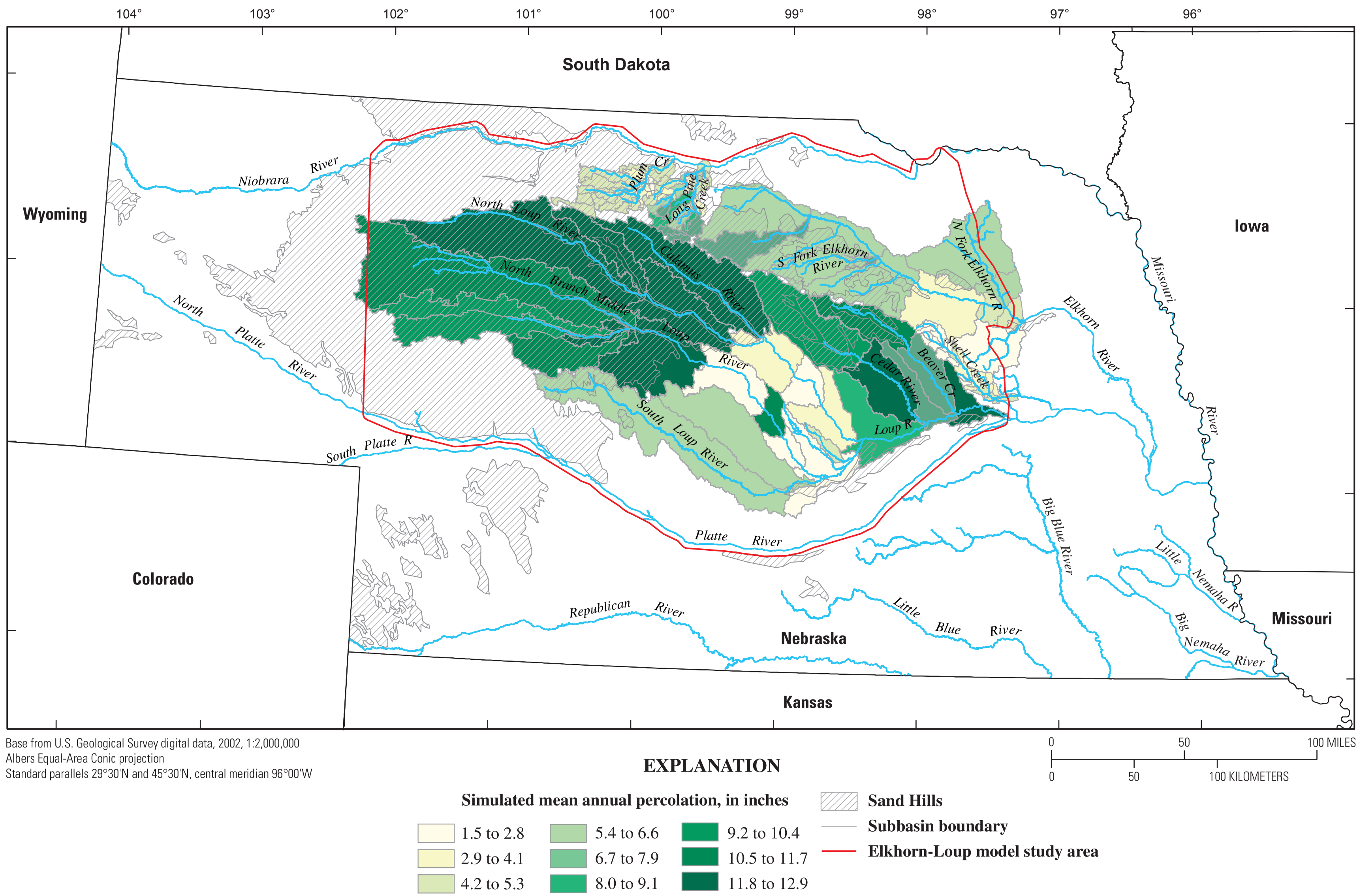

Figure 5. Spatial variablity of model-simulated percolation in the Elkhorn-Loup Groundwater Model study area.

Table 6. Mean annual model-simulated percolation and previously published values.

[Basin-wide SWAT simulated percolation mean annual values for 1940–2005; in inches; --, no value in publication; published simulated percolation values from Dugan and Zelt, 2000; published estimated percolation values from Gutentag and others, 1984]

Basin	Model-simulated percolation	Published simulated percolation for 1951–1980	Published estimated percolation
Loup River	9.8	2–5	5.0
Lower Loup River	6.4	3–5	--
Elkhorn River	5.6	4–6	5.0
Shell Creek	3.0	3–4	--
Long Pine Creek	5.4	3	--
Plum Creek	4.2	3	--

to best match the recorded streamflow, a large part of the precipitation was preferentially routed to the shallow aquifer. Published, estimated percolation values for the Sand Hill portions of the Loup River and Elkhorn River Basins (Gutentag and others, 1984) were also compared to the SWAT simulated percolation values. The simulated percolation in the Loup River Basin again was greater than the published percolation, but simulated percolation in the Elkhorn River Basin was within 0.6 inch of the published values.

To analyze how percolation responded to precipitation, simulated percolation values obtained from each model were averaged for each model area and examined at a yearly time step by 10-year moving averages (figs. 6 and 7). Simulated percolation in all of the watershed models responded to dry or wet periods, in which percolation gradually declined or increased, respectively. The watershed models that are predominately in the Sand Hills (Long Pine Creek, Plum Creek, Loup River) tended to show quicker and greater change in simulated percolation in response to precipitation. This rapid response was expected because the soils of these basins have high hydraulic conductivities and permeability rates. The watershed models that are not in the Sand Hills (Elkhorn River, Shell Creek, Lower Loup River) still showed a rapid response to precipitation, but the response was not quite as distinct. This less distinct response to precipitation was anticipated because these watershed models tend to have lower soil hydraulic conductivities and slower permeability rates than the watershed models located primarily in the Sand Hills.

Soil texture, ET, and land use all were compared to evaluate the combined effects on percolation rates (figs. 8 and 9). Error bars show one standard deviation above and below the mean on figures 8 and 9, and differences in the range in error is related to differences in the number of subbasins (table 2) and in annual results for each watershed model. Percolation was expected to be higher in the basins that have a higher percentage of fine sand and loamy fine sand. This was true for all of the watershed models except for Loup River and Lower Loup River watershed models. In these two models water was preferentially routed to the aquifer to match runoff values in the water balance. When this was done the percolation in these basins increased and ET decreased relative to the other four models. In the remaining four watershed models, percolation increased or decreased with the increase or decrease in percentages of fine sand and loamy fine sand in the basins except for in the Plum Creek watershed model, where sand percentage increased but percolation decreased. This decrease in percolation was a result of the increase in ET, leaving less water in the soil profile to percolate past the root zone.

When land use, percolation, and ET were compared, a correlation between the prevalence of pasture land and simulated percolation was observed; where pasture land was less extensive mean annual percolation was less (fig. 9). This difference in estimated percolation is not only affected by land use, but also soil type and ET. On the less permeable soils, corn and soybeans production is more common, whereas on the more permeable sandy soils, pasture is the dominant land use. The basins that have large simulated ET values also had large areal percentages of corn and soybeans, which require more water than a pasture and as a result, transpire more water (Klocke and others, 1990). In the basins of the Loup River and Lower Loup River watershed models this does not hold true and is also explained by the preferential routing of water past the root zone.

Summary and Conclusions

Six watershed models were constructed and calibrated using the Soil and Water Assessment Tool for five stream basins in the Elkhorn-Loup Groundwater Model study area in North-Central Nebraska to obtain spatially variable estimates of mean annual percolation. The study was performed by the U.S. Geological Survey in cooperation with the Upper Elkhorn, Lower Elkhorn, Upper Loup, Lower Loup, Middle Niobrara, Lower Niobrara, Lewis and Clark, and Lower Platte North Natural Resources Districts to help aid development of long-term strategies for management of hydrologically connected groundwater and surface water. Six watershed models were calibrated by adjusting parameters to iteratively improve the match between the simulated and the recorded streamflow in each subbasin. The adjustment parameter most effective for calibrating these models to streamflow were the curve number, soil available-water capacity, soil evaporation-compensation factor, groundwater revaporation coefficient (water being drawn up from the saturated zone to the unsaturated zone), the minimum depth for revaporation occurrence, the depth of water in the shallow aquifer required for base flow to occur, base flow alpha factor (a constant in the base-flow recession function), and crack volume or other preferential routing of water into the soil profile. When the final parameter sets were determined the calibrated models were used to simulate a validation period that ranged in length from 23 to 29 years. If the validation period statistical metrics results were similar to

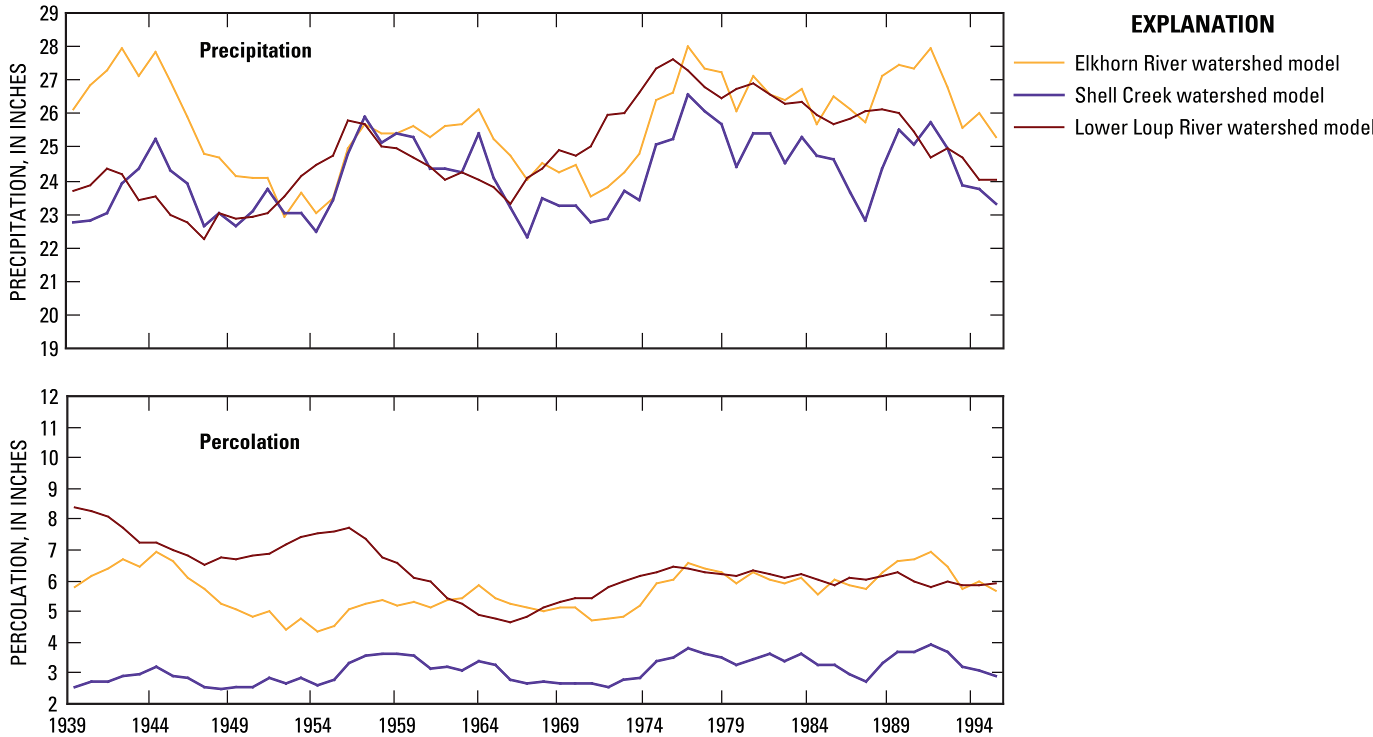

Figure 6. Watershed-wide 10-year moving averages of watershed model precipitation and simulated percolation for the Elkhorn River, Shell Creek, and Lower Loup River watershed models.

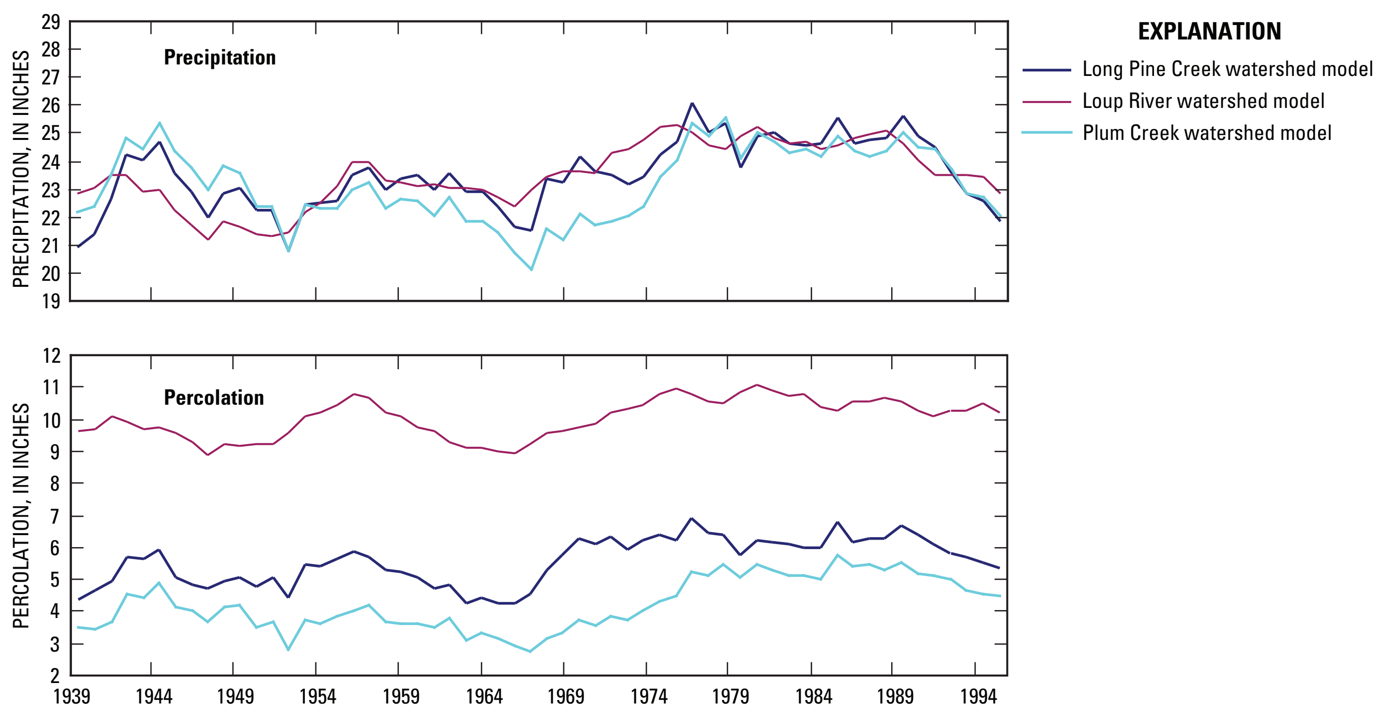

Figure 7. Watershed-wide 10-year moving averages of watershed model precipitation and simulated percolation for the Long Pine Creek, Loup River, and Plum Creek watershed models.

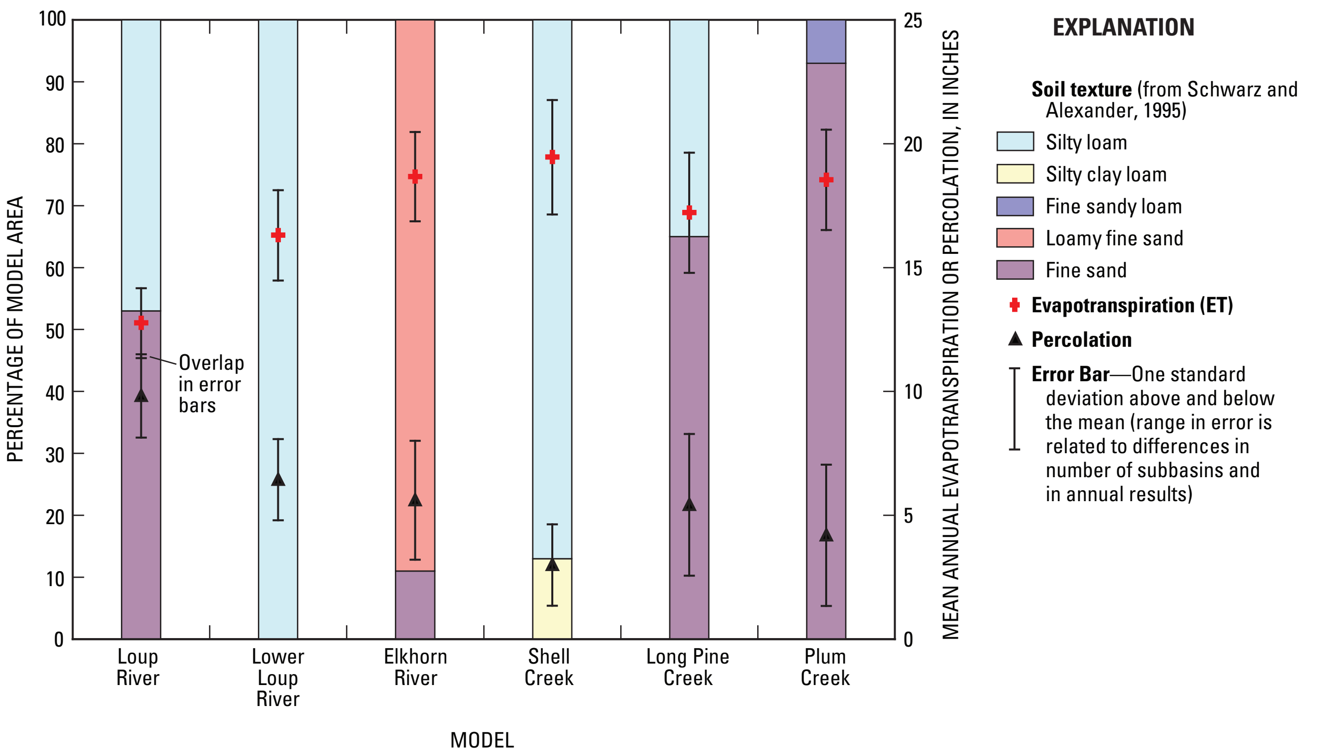

Figure 8. Relation between soil texture, simulated evapotranspiration, and simulated percolation for 1940–2005.

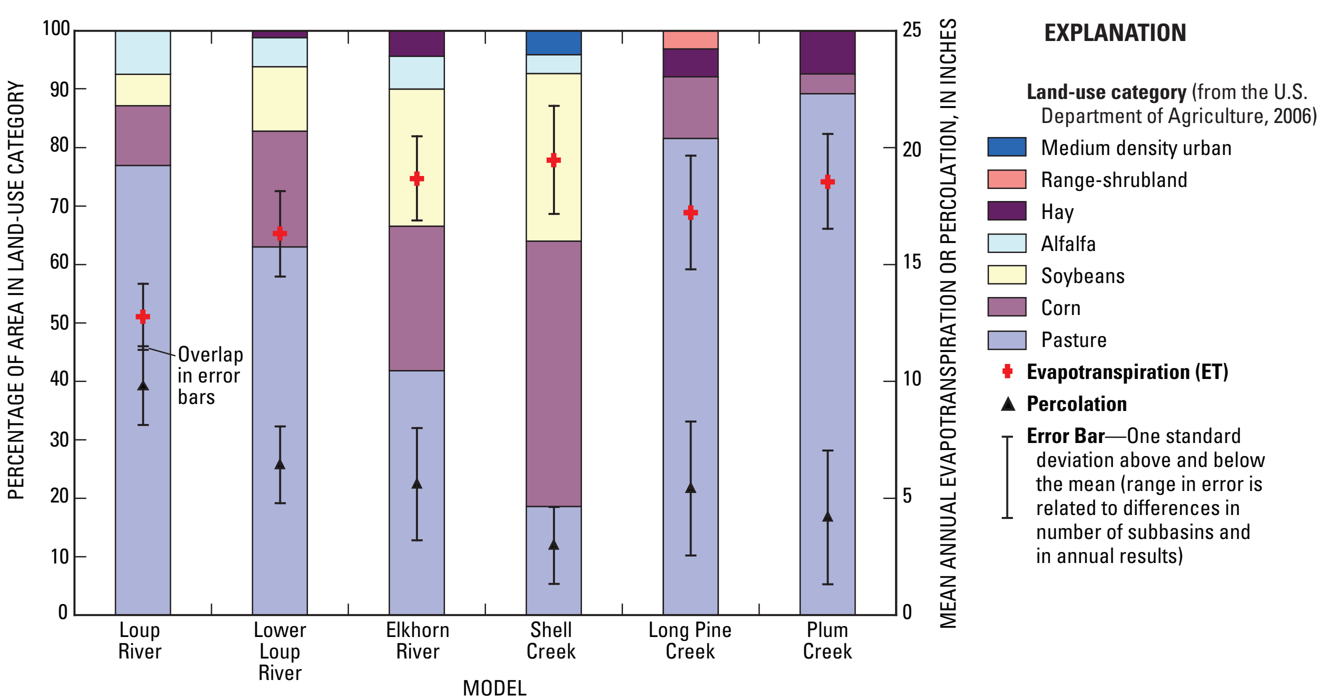

Figure 9. Relation between land use, simulated evapotranspiration, and simulated percolation for 1940–2005.

the calibration period, a model was deemed satisfactory. The resulting simulated percolation values can be used as quality assurance for, or input to, developed groundwater models.

The models failed to meet objective satisfactory performance criteria for effective simulation of streamflow; however, the failure derived primarily from the inability of the model to adequately simulate the response of the hydrologic system in the Sand Hills to precipitation. Most of the precipitation falling on the predominantly sandy study area infiltrates to the groundwater system. With this in mind, it is reasonable to assume that, even though the streamflow simulated by the model did not correspond well to recorded streamflow, the percolation of all non-transpired soil water from the root zone to the shallow aquifer is more representative of actual conditions assuming that the simulated water balance components represented the recorded and reported values for each watershed model and study area.

Simulated percolation from the watershed models was compared to published values in the ELM study area. The simulated percolation compared favorable to published values in all of the basins except for the Loup River and Long Pine Creek Basins, where it was greatly overpredicted when comparing mean annual values from 1940–2005. Percolation was also analyzed for how it responded to precipitation. Moving 10-year annual average values of percolation and precipitation were compared for 1940–2005 to examine how percolation in the basin responded to precipitation. The watershed models that were located mainly in the Sand Hills (Long Pine Creek, Plum Creek, Loup River) had more pronounced and greater responses to precipitation, whereas watershed models that were not located in the Sand Hills (Elkhorn River, Shell Creek, Lower Loup River) showed a less distinct response to precipitation. Soil texture, land use, and ET where examined to see the combined effects on percolation. If the simulated water balance components of the watershed matched recorded/published values, the percolation in the basins tended to be higher in the basin in which the soil texture contained larger percentages of fine and loamy fine sand. Percolation was also higher in basins that have a larger percentage of pasture/rangelands, but this is due largely in part because most of pasture/rangelands are located on sandy soil textures.

Future model changes that may achieve statistically valid streamflow are to calibrate and validate at a daily time step, and allow the model a longer period of time to develop and equilibrate its groundwater system. With a longer period of development, theoretically it might be easier to produce a responsive groundwater system while maintaining base flows. Another method that could provide more accurate and valid percolation results is to use a model specifically designed to estimate percolation, such as the USGS Modular Modeling System Deep Percolation Model.

References Cited

Bleed, A. S., and Flowerday, C. A., 1998, An Atlas of the Sand Hills: Lincoln, University of Nebraska-Lincoln, Conservation and Survey Division, Institutue of Agriculture and Natural Resources, Resource Atlas RA-5b, 260 p.

DiLuzio, M., Srinivasan, R., Arnold, J.G., and Neitsch, S.L., 2002, ArcView interface for SWAT2000—User's guide: College Station, Tex., Texas Water Resources Institute, TWRI Report TR-193, 345 p. accessed August 17, 2007, at *http://www.brc.tamus.edu/swat/avswat.html*

Dugan, J.T., and Zelt, R.B., 2000, Simulation and analysis of soil-water conditions in the Great Plains and adjacent areas, central United States, 1951–80: U.S. Geological Survey Water-Supply Paper 2427, 81 p.

Dugan, J.T., Hobbs, R.D., and Ihm, L.A., 1990, Hydrologic characteristics of soils in the High Plains, northern Great Plains, and Central Texas Carbonates Regional Aquifer Systems: U.S. Geological Survey Hydrologic Atlas 714, 1 Map.

Fitzhugh, T.W., and Mackay, D.S., 2000, Impacts of input parameter spatial aggregation on an agricultural nonpoint source pollution model: Journal of Hydrology, v. 236 p. 35–53.

Gutentag, E. D., Heimes, F. J., Krothe, N. C., Luckey, R. R., and Weeks, J. B., 1984, Geohydrology of the High Plains Aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400-B, p. 33

Helsel, D.R., and Hirsch, R.M., 2002, Statistical Methods in Water Resources: U.S. Geological Survey Techniques of Water Resources Investigations, book 4, chap. A3, 522 p.

Klocke, N.L., Hubbard K.G., Kranz W.L., and Watts, D.G., 1990, Evapotranspiration (ET) or crop water use: Lincoln, University of Nebraska-Lincoln NebGuide G90-992, 8 p.

Monteith, J.L., 1965, Evaporation and the environment, *in* The state and movement of water in living organisms, 19th Symposia of the Society for Experimental Biology: London, Cambridge University Press, p. 205–234.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., and Veith, T.L., 2007, Model evaluation guidelines for systematic quantification of accuracy in watershed simulations: Transactions of the American Society of Agricultural and Biological Engineers, v. 50, no. 3, p. 885–900.

National Oceanic and Atmospheric Administration, 2006, National Climatic Data Center, daily data, United States, June 2007: National Oceanic and Atmospheric Administration, information available on Web, accessed June 2007, at *http://gis.ncdc.noaa.gov/aimstools/gis.jsp*

Nebraska Department of Natural Resources, 2007a, LB962 enacted into law: Lincoln, NDNR, accessed November 4, 2007, at URL *http://www.dnr.ne.gov/watertaskforce/LB962/LB962SCREEN.pdf*

Nebraska Department of Natural Resources, 2007b, Nebraska Department of Natural Resources Stream Gaging Data Bank, accessed May 2007, at *http://dnrdata.dnr.ne.gov/shifts/stream.asp*

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., and Williams, J.R., 2005, Soil and Water Assessment Tool theoretical documentation—Version 2005: Temple, Tex., Texas Agricultural Experimentation Station, 476 p., accessed August 2007, at *http://www.brc.tamus.edu/swat/doc.html*

Schwarz, G.E., and Alexander, R.B., 1995, State soil geographic (STATSGO) data base for the conterminous United States: U.S. Geological Survey Open-File Report 95-449, Arc 7.0 coverage.

Soil Conservation Service, 1986, Urban hydrology for small watersheds: U.S. Department of Agriculture, Natural Resources Conservation Service Technical Release 55, 164 p.

U.S. Department of Agriculture, National Agricultural Statistics Service, Research and Development Division, Geospatial Information Branch, Spatial Analysis Research Section, 2006, USDA—National Agricultural Statistics Service's 1:100,000-scale 2005 cropland data layer, a crop-specific digital data layer for Nebraska, 2006 March 14: Washington, D.C., United States Department of Agriculture, National Agriculture Statistics Service, raster digital data.

U.S. Geological Survey, 2007, National Water Information System: U.S. Geological Survey, accessed May 2007, at *http://waterdata.usgs.gov/nwis*

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.

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Nebraska Water Science Center
5231 South 19 Street
Lincoln, NE 68512
(402) 328–4100

Or visit the Nebraska Water Science Center Web site at:
http://ne.water.usgs.gov

USGS

Strauch and Linard—**Streamflow Simulations and Percolation Estimates Using the Soil and Water Assessment Tool for Selected Basins**—Scientific Investigations Report 2009–5075