Estimation of Casper Aquifer Recharge using the Soil-Water Balance Model

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1 Introduction

The Casper Aquifer is an important component of the City of Laramie's drinking water supply, especially during drought. The City obtains approximately 60 % of its total drinking water from the Casper Aquifer, with the remaining 40 % coming from the Laramie River. When flow in the Laramie River becomes too low, Laramie residents receive 100 % of their water from the Casper Aquifer. Additionally, county residents whose homes lie above the Casper Aquifer withdraw 100 % of their water from the aquifer.

Recharge is the process by which water is added to the zone of saturation to replenish an aquifer. The Casper Aquifer is recharged through drainage and fractures that are expressed at the surface, porous sandstones, and percolation of runoff through soils. Recharge to the Casper Aquifer occurs primarily in late winter and early spring during snowmelt. The amount of snowpack and the timing of snowmelt are crucial to the amount of recharge occurring.

Without sufficient recharge, significant withdrawals from the Casper Aquifer are unsustainable. Already the City Utility has seen year to year water levels dropping in municipal wells as the amount of water withdrawn exceeds annual recharge. However, in 1983 water levels in the Casper Aquifer rose significantly following a winter of higher than average snowfall. It is clear that understanding of recharge to the Casper Aquifer will be an important part of long-term water supply planning in Laramie.

The purpose of this study is to understand how changes in climate and land use may affect recharge in the Casper Aquifer. Climate change may cause changes in the amount and seasonal patterns of precipitation. An overall trend of increasing temperature will change the relative amount of snowfall. Since recharge is closely related to snowpack, the effects of temperature on recharge may be large. Furthermore, land use changes may impact recharge through changes in vegetation and therefore evapotranspiration or changes in the pervious areas which allow water to infiltrate into the Aquifer.

We used the soil-water balance (SWB) computer code developed by the US Geological Survey (USGS) to estimate recharge into the Casper Aquifer and the effects of change in climate and land use on recharge. The original code was modified to account for fracture recharge and changes of temperature with elevation. After historical climate data were used to model recharge in the study area, scenarios of climate change and land use change were modeled. Modeled climate change consist of an increase of $2^{\circ}F$ and a decrease of 25 % of precipitation over the next 50 years. Modeled land use change consists of increased urbanization levels along the west-central boundary of the model area.

1.1 Regional and local geology

The City of Laramie sits within the Laramie basin, a north-plunging asymmetrical syncline bounded by the Medicine Bow Mountains in the west, the Laramie Range on the east, the Front Range on the south, and a series of anticlines to the north. The Laramie Range lies immediately east of the City of Laramie following a north-south direction and a dip to the west of 3 to 5 degrees. The uplifting of the Laramie Range happened during the Laramide Orogeny, between 75 and 50 million years ago. The orogenic stresses that formed the range also created a network of faults and folds, many visible at the surface. In general, faults and folds observed at the surface do not propagate vertically though the entire thickness of the Satanka Shale but there are exceptions like the Sherman Hill and the Laramie Faults. Folds and faults existent near the City of Laramie have been mapped (Figure 1). The major normal faults trend northeast to east-west [WHPA, 2008].

Three important geologic formations that bound and support the Casper Aquifer are the Sherman Granite, the Casper Formation, and the Satanka Shale. The Precambrian Sherman Granite is a coarsely-crystalline igneous rock that is exposed east of the crest of the Laramie Range [WHPA, 2008]. The Pennsylvanian-Permian Casper Formation unconformably overlies the Precambrian rocks and consists of approximately $700\,ft$ of marine and aeolian sandstones (85 $\%$ of total thickness) interbedded with limestone and minor amounts of shale [WHPA, 2008]. The Casper Formation is exposed on the west flank of the Laramie Range. The Permian Satanka Shale unconformably overlies the Casper Formation and consists of approximately 250 to $320\,ft$ of red shale with interbedded siltstone and sandstone layers [WHPA, 2008]. The Satanka Shale is exposed along the western foothills of the Laramie Range and near the eastern corporate limits of the City of Laramie. Due to the uplift of the Laramie Range, the units that were originally deposited horizontally over the Precambrian basement rocks dip to the west as shown on the generalized cross section on the bottom of Figure 1 [WHPA, 2008].

1.2 Hydrology of the Casper Aquifer

The three geological formations described above are intrinsic parts of the Casper Aquifer. The Sherman granite has virtually no primary permeability and groundwater movement found in this unit is typified as conduit flow in faults and fractures, wherever present. Because of the low storing capacity and permeability of the Sherman Granite it is considered the lower boundary of the Casper Aquifer [WHPA, 2008].

The Casper Aquifer Protection Area (CAPA) was designed as part of the Casper Aquifer Protection Plan (CAPP) and was updated in 2008 by Wittman Hydro Planning Associates. The CAPA covers approximately $72\,mi^2$, extending from eastern Laramie to the crest of the Laramie Range. The northern and southern boundaries of the CAPA extend approximately 5 and $6\,mi$ from the City of Laramie, respectively. Recharge to the Casper Aquifer happens mostly in late winter and early spring as the snow melts and runoff occurs, and water either percolates though the soils, infiltrating the porous sandstones of the aquifer, or recharges through the extensive network of faults and fractures existent in the Laramie area. The CAPA covers the area where significant recharge to the Casper Aquifer takes place, and is also the area where most of the fractures and faults exist.

1.3 Study area

The purpose of the study is to estimate recharge to the Casper Aquifer using the SWB model. The modeled area was delineated to match the outer boundaries of the CAPA, since this area was determined to be the recharge area to the aquifer. The modeled area covers approximately $85\,mi^2$ east of Laramie (Figure 2) and is rectangular in shape due to model requirements. Within the study area, elevations range from aproximately 7,220 on the west to around $8,792\,ft AMSL$ on the east.

Typical vegetation within the study area includes sagebrush, grassland, and mixed-grass prairie in the intermontane valley on the west side; juniper and mountain mahogany on the foothills; and forest and alpine

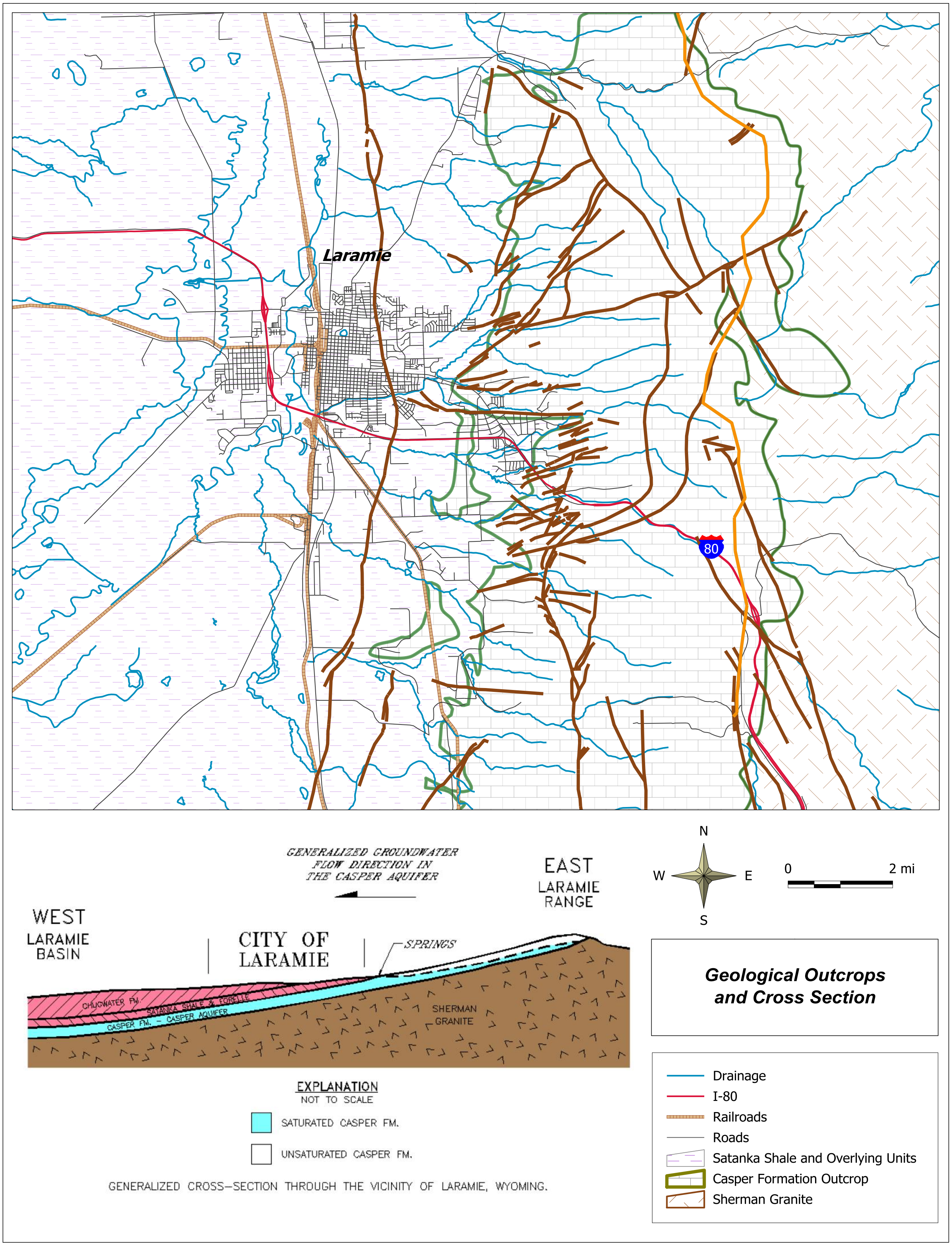


Figure 1: Geology and mapped faults near the City of Laramie.

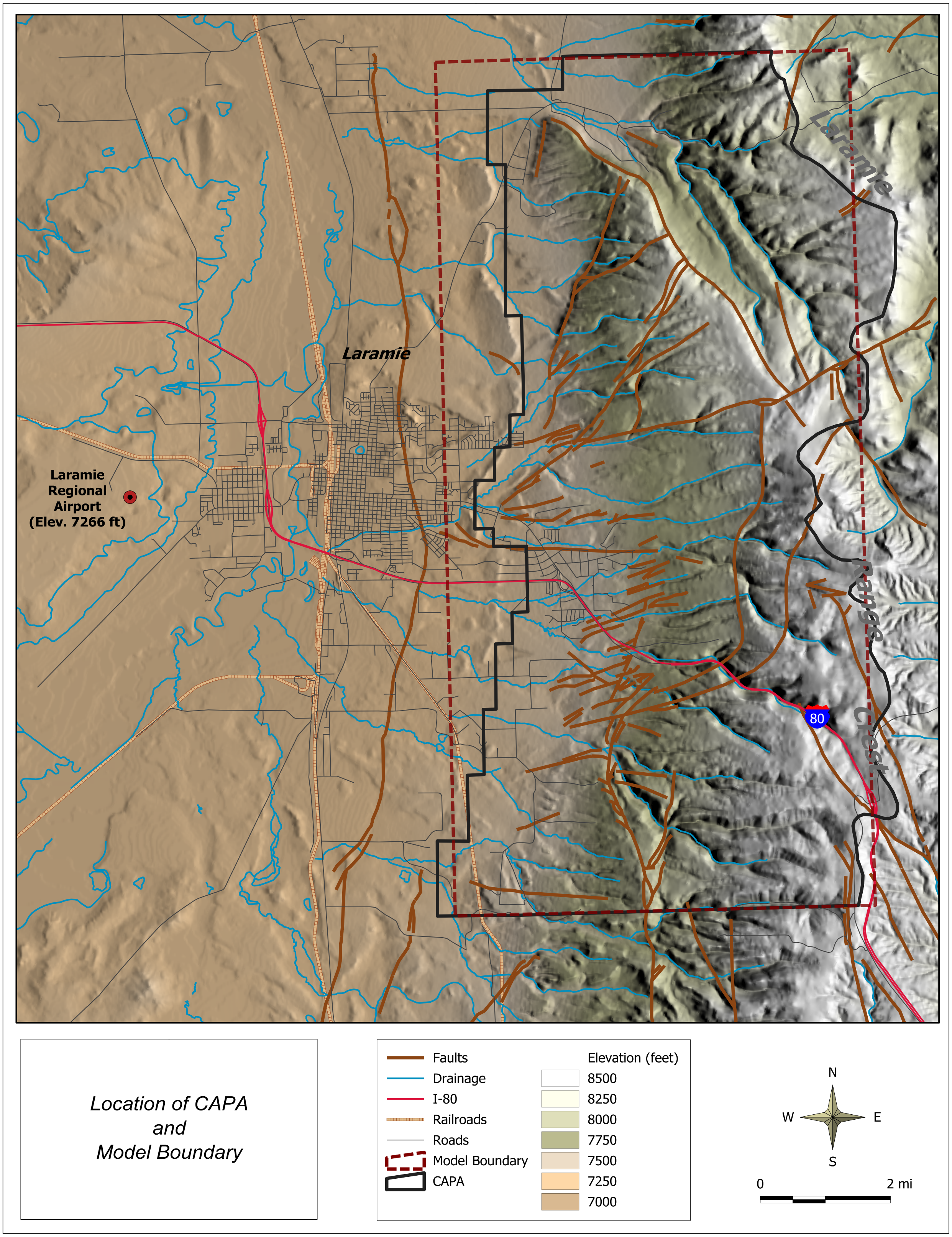


Figure 2: Location of Casper Aquifer Protection Area and modeled area.

meadows in the higher elevations of the Laramie Range on the east side [USEPA, 1998]. Land use within the study area consists of approximately $1.1\,mi^2$of urban use, $1.9\,mi^2$of open spaces, $0.5\,mi^2 of$ barren land, and the remaining land consisting of grasses ($18.4\,mi^2$), shrubs ($57.0\,mi^2$), forest ($6.1\,mi^2$), cultivated crops and pastures ($0.04\,mi^2$), and wetlands ($0.08\,mi^2$).

2 Methodology

As stated previously, recharge is the process by which water is added to the zone of saturation to replenish an aquifer. Figure 3 shows the different elements of the hydrologic cycle. As precipitation, both as snow and rain, falls to the earth, several processes may occur. Some of the precipitation will be intercepted by vegetation and eventually evaporate. The rest of the precipitation will reach the ground where it will either become runoff or infiltrate. Water that runs off may enter surface water bodies or infiltrate at a down-gradient location. The runoff which reaches a surface water body will either move downstream out of the aquifer area or be evaporated and therefore lost to the groundwater system. Water that infiltrates either through soils or through fractures, may be transpirated, evaporated, or become recharge to the aquifer.

2.1 SWB model

The SWB model [Westenbroek et al., 1998] calculates spatial and temporal variations in groundwater recharge using publicly available geographical information system (GIS) data layers and daily climatological data, in a tabular format. Components of the soil-moisture balance are calculated over a rectangular grid. The model provides an annual recharge estimate for the modeled area, including the distribution of recharge over the model domain.

The SWB code uses a modified Thornthwaite-Mather soil moisture accounting method to calculate recharge; recharge is calculated separately for each grid cell in the model domain. Sources and sinks of water within each grid cell are determined based on the input climate data and landscape characteristics; recharge is calculated as the difference between the change in soil moisture and moisture sources (precipitation, snowmelt, and inflow) and sinks (interception, outflow, and evapotranspiration) (equation 1).

$$R = (P + S + IN) - (I + OUT + ET) - \triangle SM \tag{1}$$

where :

R= recharge,

P= precipitation,

S =snowmelt,

IN= inflow,

I= interception,

OUT= outflow,

ET= evapotranspiration,

$\triangle SM$= change in soil moisture.

Specific water-balance components are discussed briefly below.

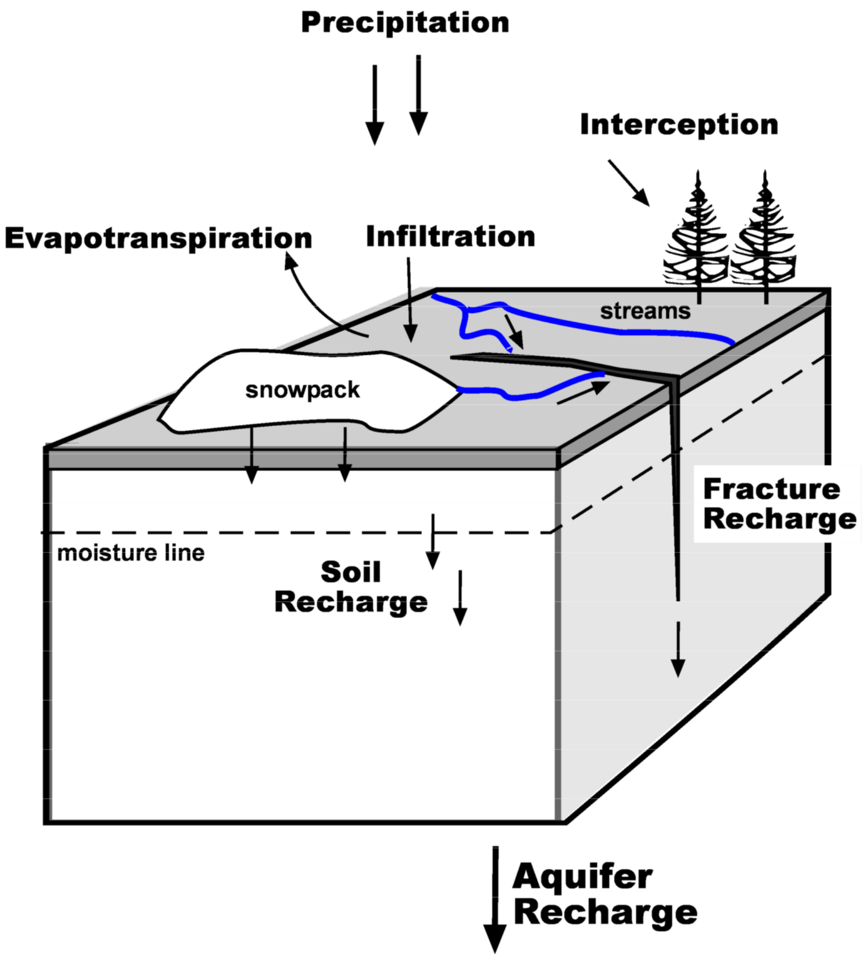


Figure 3: Aquifer recharge conceptual model.

precip Precipitation data are input on a daily basis, in inches.

snowmelt Snow is allowed to accumulate and/or melt on a daily basis. The daily mean, maximum and minimum air temperatures are used to determine whether precipitation takes the form of rain or snow. Precipitation that falls on a day when the mean temperature minus one-third the difference between the daily high and low temperatures is less than or equal to $32F$ is considered to fall as snow. Snowmelt takes place based on a temperature-index method. In the SWB code it is assumed that $1.5\,mm$ ($0.059\,in$) of water-equivalent snow melts per day per average degree Celsius that the daily maximum temperature is above the freezing point.

inflow Inflow is calculated using a flow direction grid derived from a digital elevation model to route outflow (surface runoff, see below) to adjacent downslope grid cells. Inflow is considered to be zero if flow routing is turned off.

interception Interception is treated simply using a “bucket” model approach—a specific amount of rainfall (user specified) is assumed to be trapped and used by vegetation and evaporated or transpired from plant surfaces. Daily precipitation values must exceed the specified interception amount before any water is assumed to reach the soil surface. Interception values are specified for each land use type and season (growing and non-growing).

outflow Outflow (or surface runoff) from a cell is calculated using a Soil Conservation Service curve-number rainfall-runoff relationship (Table 2). Values were adapted for fracture soils group differing from model runs for other areas. This rainfall-runoff relationship relates rainfall to runoff based on four basin properties: soil type, land use, surface condition, and antecedent runoff condition. The curve number method defines runoff in relationship to the difference between precipitation and an “initial abstraction” term. Conceptually, this initial abstraction term represents the summation of all processes that might act to reduce runoff, including interception by plants and fallen leaves, depression storage, and infiltration. The equation used to calculate runoff volumes is given in equation 2.

$$R = \frac{(P - I_a)^2}{(P + [S_{max} - I_a])} \quad P > I_a \tag{2}$$

where:
R is the runoff,
P is the daily precipitation,
S_{max} is defined as a the maximum soil moisture holding capacity,
I_a is the initial abstraction, the amount of precipitation that must fall before any runoff is generated.
The initial abstraction (I_a) term is related to a maximum storage term (S_{max}) (equation 3):

$$I_a = 0.2 S_{max} \tag{3}$$

The maximum storage term is defined by the curve number for the land cover type under consideration (equation 4):

$$S_{max} = \left(\frac{1000}{CN}\right) - 10 \tag{4}$$

Curve numbers are adjusted upward or downward depending on how much precipitation has occurred in the previous 5-day period. The amount of precipitation that has fallen in the previous 5-day period is used to describe soil moisture conditions; three classes of moisture conditions are defined, and are called antecedent runoff condition depending on the soil wetness.

When soils are “nearly saturated”, the curve number for a grid cell is adjusted upward to account for generally higher observed runoff amounts experienced when precipitation falls on saturated soil. Conversely, when soils are “dry”, curve numbers are adjusted downward in an attempt to reflect the increased infiltration rates of dry soils. Between “dry” and “nearly saturated” represents an average rainfall-runoff relationship for “moderate” soil moisture conditions.

Curve numbers have been defined as ranging from 0 to 100. If we define a useful range of curve numbers with minimum of 30 and maximum of 98, the maximum storage term (S_{max}) varies from a low of about $0.2\,in$ to a high of about $23\,in$. Using an initial abstraction term of $0.2\,S_{max}$ implies that between $0.04\,in$ and $4.6\,in$ of precipitation must fall before initiation of runoff processes; using an initial abstraction term of $0.05\,S_{max}$ implies that between 0.01 and $1.15\,in$ of precipitation must fall prior to initiation of runoff.

Frozen ground conditions are tracked by use of a simple continuous frozen-ground index (equation 5).

$$CFGI_i = A.CFGI_{i-1} - T.e^{(-0.4.K.D)} \geq 0 \tag{5}$$

where:

$CFGI_i$ = continuous frozen ground index on day i ,

$CFGI_{i-1}$= continuous frozen ground index on day $i-1$,

T= mean daily air temperature (°C),

A= daily decay coefficient,

K= snow reduction coefficient,

D= depth of snow on ground (centimeters).

The value for the coefficients A and K are: $K = 0.5\,cm$ for above freezing periods; $K = 0.08\,cm$ for below freezing periods, and A = 0.97.

The continuous frozen ground index is applied by allowing for a transition range to be applied through which runoff enhancement would go from “negligible to strong”. A probability of runoff enhancement factor, P_f, is defined as

$$P_f = \frac{CFGI - LL}{UL - LL} \tag{6}$$

where:

P_f= probability that runoff will be enhanced due to frozen ground conditions,

$CFGI$= continuous frozen ground index,

UL= upper limit of the $CFGI$, above which frozen ground conditions presumably exist,

LL= lower limit of the $CFGI$, below which frozen ground conditions presumably do not exist.

If no values are assigned, the $CFGI$ routine will be ignored. If the $CFGI$ option is used it is recommend to start with a value of $83C$-days for the upper limit (UL) and a value of $56C$-days for the lower limit (LL).

Outflow from a cell becomes inflow to the downslope cell as determined from the flow direction grid.

evapotranspiration (ET) Thornthwaite-Mather method was used to estimate potential evapotranspiration from portions of the soil zone that are not included in the interception calculation.

$\triangle$**soil moisture** In order to track changes in soil moisture, a number of intermediary values are calculated, including precipitation minus potential evapotranspiration ($P-PE$), accumulated potential water loss (APWL), actual evapotranspiration, soil moisture surplus, and soil moisture deficit. These terms are described below. The first step in calculating a new soil moisture value for any given grid cell is to subtract potential evapotranspiration from the daily precipitation ($P\breve{}PE$). Negative values of $P-PE$ represent a potential deficiency of water, while positive $P-PE$ values represent a potential surplus of water.

accumulated potential water loss (APWL) The accumulated potential water loss is calculated as a running total of the daily $P-PE$ values during periods when the $P-PE$ values are negative. This running total represents the total amount of unsatisfied potential evapotranspiration to which the soil has been subjected. Soils typically yield water more easily during the first days in which $P-PE$ is negative. On subsequent days as the APWL grows, soil moisture is less readily given up. The nonlinear relationship between soil moisture and the accumulated potential water loss was described by Thornthwaite and Mather in a series of tables. These tables are incorporated into the SWB code.

soil moisture, $\triangle$**soil moisture** When $P-PE$ is positive, the new soil moisture value is found by adding this $P-PE$ term directly to the old soil moisture value. If the new soil moisture value is still below the maximum water-holding capacity, the Thornthwaite-Mather soil-moisture tables are consulted to calculate a new, reduced accumulated potential water loss value. If the new soil moisture value exceeds the maximum water-holding capacity, the soil moisture value is capped at the value of the maximum water-holding capacity, the excess moisture is converted to recharge, and the accumulated potential water loss term is reset to zero. When $P-PE$ is negative, the new soil moisture term is calculated using the new accumulated potential water loss value, looking up the resultant soil moisture in the Thornthwaite-Mather tables.

actual ET When $P-PE$ is positive, the actual evapotranspiration equals the potential evapotranspiration. When $P-PE$ is negative, the actual evapotranspiration is equal only to the amount of water that can be extracted from the soil ($\triangle$ soil moisture).

soil moisture SURPLUS If the soil moisture reaches the maximum soil moisture capacity, any excess precipitation is added to the daily soil moisture surplus value. Under most conditions, the soil moisture surplus value is considered as equivalent to the daily groundwater recharge value.

soil moisture DEFICIT The daily soil moisture deficit is the amount by which the actual evapotranspiration differs from the potential evapotranspiration.

2.2 Model assumptions

Runoff routing The inclusion of overland flow routing in the code ensures that runoff from an upslope grid cell has one or more opportunities to contribute to infiltration in the cells that are downslope from it. However, all runoff from a cell is assumed to infiltrate in downslope cells or be routed out of the model domain on the same day in which it originated as rainfall or snowmelt.

In addition, once water is routed to a closed surface depression, and evapotranspiration and soil moisture demands are met, the only loss mechanism is recharge. This results in cases where maximum recharge values of hundreds or thousands of inches per year are calculated. These extremely high values are unrealistic and are likely due to the fact that surface storage of water is not accounted for. The SWB code described here allows the user to enter a maximum recharge rate for each land cover and soil group combination. This offers a way to restrict the estimated recharge values to a more reasonable range, however, the “rejected recharge” is nonetheless removed from the model domain on the same day in which it originated as precipitation or snowmelt.

Groundwater / surface water interaction Interactions between surface water and groundwater features are not simulated in the SWB code, and could not be without significantly increasing the complexity of the model. In locations where the groundwater table is beneath the bottom of the root zone, the SWB code should be capable of producing reasonable results on an annual basis. The depth from the bottom of the root zone to the top of the water table is not considered in the estimation of recharge; there may be a significant travel time through the unsaturated zone. Coupling the SWB code with an unsaturated zone code that could route water to the water table, such as the MODFLOW UZF Package, would be one way to address this limitation.

In areas with wetlands, springs, lakes, or other landscape features where groundwater is near the surface, the SWB code can be expected to perform poorly; there is currently no provision for recharge rejection via saturation excess, other than by specifying a maximum recharge rate for a particular land use and soil type combination. Since groundwater is generally not near the surface in Laramie, this model is appropriate.

Curve number method The current version of the SWB assumes that infiltration is sum of precipitation, snowmelt, and inflow, minus the runoff calculated by means of the USDA-NRCS curve number method. Runoff calculation at a plot or field scale in a continuous simulation by means of the curve number method may be beyond the limits of the method. The list of perceived flaws associated with the curve number method include:

- the inability to identify runoff processes, source areas, or flow paths;
- method is a watershed scale method that should not be applied at a plot or field (or grid cell) scale; and

- method was developed to evaluate flood events and was not designed to simulate daily flows of ordinary magnitude.

In addition, it has been suggested that the curve number is not constant, but varies from event to event, and that the antecedent runoff condition only explains a portion of this variability. Given variability in the curve numbers themselves as well as the other limitations of the curve number method, it would seem reasonable to assume that the standard curve number table values merely represent starting points; ideally the curve numbers should be verified using observed paired precipitation-runoff data. SWB adjusts curve numbers for the antecedent soil moisture conditions.

The SWB code contains an alternative method for calculating runoff that incorporates a much smaller initial abstraction term. Use of this alternative method for calculating the initial abstraction may be more appropriate for continuous simulation. Users of the SWB code have the option of defining the initial abstraction term as $I_a = 0.05 \times S_{max}$, compared to $I_a = 0.2 \times S_{max}$. The use of this smaller initial abstraction term results in more runoff generation for areas with low curve numbers and for storms of smaller magnitude. If the smaller initial abstraction term is used, curve numbers are automatically scaled by the SWB code to maintain an appropriately shaped rainfall-runoff curve. We used the smaller initial abstraction of $I_a = 0.05 \times S_{max}$.

Snowmelt and infiltration For temperate areas that experience snowfall and snowmelt, the SWB model is sensitive to snowmelt, and in particular, to how snowmelt translates into surface runoff. The addition of a continuous frozen ground index to the SWB code offers a simple way to approximate the effects of frozen ground. Spring runoff may be increased by altering the set-point at which the ground is considered to be frozen; above this set-point the curve numbers are forced to antecedent runoff condition. Other modelers have altered the curve number in an attempt to simulate runoff from frozen ground. Despite this, there is no theoretical basis supporting the derivation of a “frozen ground curve number” thus its use in the SWB code is primarily for expediency and consistency with other model input considerations.

Climate variability The year-to-year climate variability causes corresponding variability in the recharge values. Use of multiple years of climate data should help to ensure representative variability in estimated recharge values. We used 27 years of climate data (1980 - 2007) and ignored the first year of results, which was considered a start up period. The model uses antecedent conditions to calculate values, thus the first year run does not provide reliable results.

2.3 SWB application in the mountain West

The standard SWB code was developed for applications in humid areas with only moderate changes in elevation. In the mountain West, the standard code had some important limitations and are listed below.

Recharge into fractured rock The standard SWB code does not have the ability to specifically manage recharge directly into fractured bedrock, particularly in a region where major fractures have been mapped. We developed methodologies and code enhancements to improve this capability.

Temperature variations In the mountain West, it is common for the ground elevation to vary by thousands of feet over fairly small regions. Furthermore, water availability is closely related to the presence or absence of winter snowpack. The standard SWB can make use of gridded daily meteorological data, but at the cost of increased disk space usage for the grids and increased run times. Furthermore, it is uncommon to find mountain weather stations in a typical catchment that is to be simulated with SWB. We developed code enhancements that allow the modeler to adjust temperature as a function of elevation within SWB.

2.3.1 Modeling recharge into fractured rock aquifers

With SWB, the simulation of recharge into densely fractured bedrock aquifers can typically be handled by assuming that at the scale of the model, and for the purpose of estimating recharge, the aquifer may be treated as if it were a porous media (the "representative elementary volume" assumption). However, in regions where major bedrock fracture lineaments may be identified, there will be two different recharge regimes: (1) recharge into more dense, smaller fractures, which will typically yield small recharge rates; and (2) more rapid recharge into the fracture zones along major fracture lineaments. Additionally, a third recharge mechanism may be present: during major storm runoff events, some runoff can enter fractures that intersect with ephemeral streams, providing direct recharge into the fracture network.

We developed approaches for simulating recharge into the fractured bedrock aquifer in the project region. For the problem of recharge into fractured rock that underlie the surface soils, this was accomplished by modifying the input data for the standard SWB code. For direct recharge during storm runoff events, we modified the SWB code.

Recharge into fractures beneath soils As discussed above, we have developed a methodology for managing the inflow of recharge through surface soils (where present) into the fractured bedrock aquifer in the project region. Over most of the landscape, between the major identified fracture lineaments, we use the "standard" SWB approach, which provides recharge to the aquifer when water that exceeds the soil moisture capacity infiltrates into the soil.

Much of the model domain, however, has very little soil present. Therefore, in cells that overlie major fractures, we accounted for the additional potential for localized infiltration by reducing the soil moisture capacity to about $0.5\,in$. This results in recharge patterns that make good conceptual sense; recharge is concentrated in the areas where major fractures are present.

Recharge from streams into fractures In Laramie, there are many drainage features that carry water only during and shortly after major precipitation events. Some of those ephemeral stream channels intersect with the major fractures that were identified above. We modified SWB to allow the user to provide an input grid that identifies cells where this can occur. It is then assumed that a fraction of the water that flows into the cell will directly recharge the aquifer. For the cell in row j and column i the user provides $\overset{ji}{R}_{max}$, the maximum allowable daily value for this "fracture recharge" and $\overset{ji}{Q}_{max}$ the daily overland inflow to cell (j,i) that corresponds to the fracture recharge rate $\overset{ji}{R}_{max}$. For the date d, SWB computes the daily fracture recharge from the daily inflow rate according to:

$$\overset{ji}{Q}_d=\overset{ji}{Q}_{max}\times\frac{\overset{ji}{R}_d}{\overset{ji}{R}_{max}} \tag{7}$$

where $\overset{ji}{R}_d$ is the total inflow into cell (j,i). It is left to the modeler to adjust the parameters $\overset{ji}{R}_{max}$ and $\overset{ji}{Q}_{max}$ during model calibration.

2.3.2 Adjusting temperature with elevation

In the mountain West, much of the water supply is associated with the magnitude of the winter snowpack and the timing and intensity of spring melting events. SWB determines the amount of daily precipitation that arrives as snow based upon the air temperature. As a result, it is very important that accurate temperature data are used over the entire model domain. There are large mountain ranges present within the model domain for the project region, but no weather stations are present to allow for interpolated grids of daily temperature.

It has been reported elsewhere that the air temperature varies according to elevation, according to:

$$T_z = T_0 - A(z - z_0) \tag{8}$$

where T_z is the temperature at the elevation z, z_0 is the elevation of the weather station, and T_0 is the measured temperature at the weather station. The parameter A has units of the change in temperature (in $^{\circ}F/1000\,ft$ of elevation difference). According to the Wyoming Climate Atlas, 2005, the coefficient A has values of $5.5^{\circ}F/1000\,ft$ per in dry air and $3.5^{\circ}F/1000\,ft$ in saturated air.

We modified SWB to allow the user to read a digital elevation model of the land surface elevation and to provide “dry” and “humid” values for the parameter A. In addition, a threshold relative humidity is provided that determines whether the model should adjust the cell-by-cell temperature according to the “dry” or the “humid” parameter. It should be noted that at Laramie, there were no available humidity data, and the “dry” value was used throughout. The airport sits at $7266\,ftAMSL$, and the highest elevation on the model grid is $8792\,ft$. The lowest elevation in the model is $7221\,ft$. Thus, on any given day, the temperature in the model grid varies over range $T_d + 0.1575 \leq T_d \leq T_d - 5.341\,^{\circ}F$, where T_d is the daily temperature value from the weather station. This is a substantial amount of variation in temperature over the model domain, and this code enhancement has an important effect on the distribution and magnitude of snowpack and the timing of the spring melt.

Changes in total precipitation due to elevation changes were modeled with PRISM [PRISM Group, 2008]. For the study area, increase in precipitation is, on average, 50 % higher on the mountain side than on the basin side of the study area. PRISM is a complex model that accounts for many parameters not included in the soil-water balance model. Therefore, our model does not account for changes in precipitation with elevation except to change rainfall to snow when temperatures are right.

2.4 Data input

The SWB model requires tabular data sets for weather and gridded land surface data (land use, hydrologic soil group, and elevation). These data sets are readily available online in many formats which needed to be manipulated in order to fit the model format requirements.

2.4.1 Meteorological data

Meteorological data is registered by weather stations in a daily basis. For this project data was derived from the weather station 485415 at KLAR Laramie Regional Airport. Data for the model include daily average, minimum, and maximum air temperature (in$^\circ F$), and daily precipitation (in inches). Because of the considerable differences of elevation between the weather station and the Laramie Range areas within the study area (approximately $1,570\,ft$), we implemented the temperature correction described in section 2.3.2. This accounts for the decrease in temperature and consequent increase of snowfall at higher elevations.

2.4.2 Land use/land cover

The model requires land use/land cover information, together with the soil available water capacity information, to calculate surface runoff and assign a maximum soil moisture holding capacity for each grid cell. Land use/land cover data is classified according to Anderson Level II Land Cover Classification method (Table 1) and accompanies a land use look-up table containing the curve number, maximum recharge, and rooting depth data for each land use type contained in the grid (Tables 2 and 3). Figure 4 shows the land use/land cover classification within the study area.

2.4.3 Hydrologic soils group

The Soil Conservation Service (SCS) has categorized over 14,000 soil series within the United States into 1 of 4 hydrologic soil groups based on its infiltration capacity (A - D). Soil group information may be input to the model as an ARC ASCII or Surfer ASCII grid with integer values ranging from 1 (soil group A) to 4 (soil group D). The SCS soil hydrologic group "A" soils have a high minimum infiltration capacity and subsequently, a low overland flow potential while, "D" soils have a very low infiltration capacity and subsequently, a high overland flow potential. Available water capacity values were given to each hydrologic soil group as shown in Table 4. Figure 5 shows the soils groups within the study area. Note that the faults were given a separate soil group value of 5 because of their distinctive hydrologic nature when compared to soils.

2.4.4 Flow direction

Flow direction is calculated from an Digital Elevation Model (DEM), available at the USGS website [USGS, 2001]. Elevation values are analyzed for eight neighboring cells for each cell, the neighboring cell with the lowest elevation will be the direction to which surface runoff is routed from that cell. Table 5 shows

Table 1: Land use classification within the study area, based on Anderson Level II land use classification.

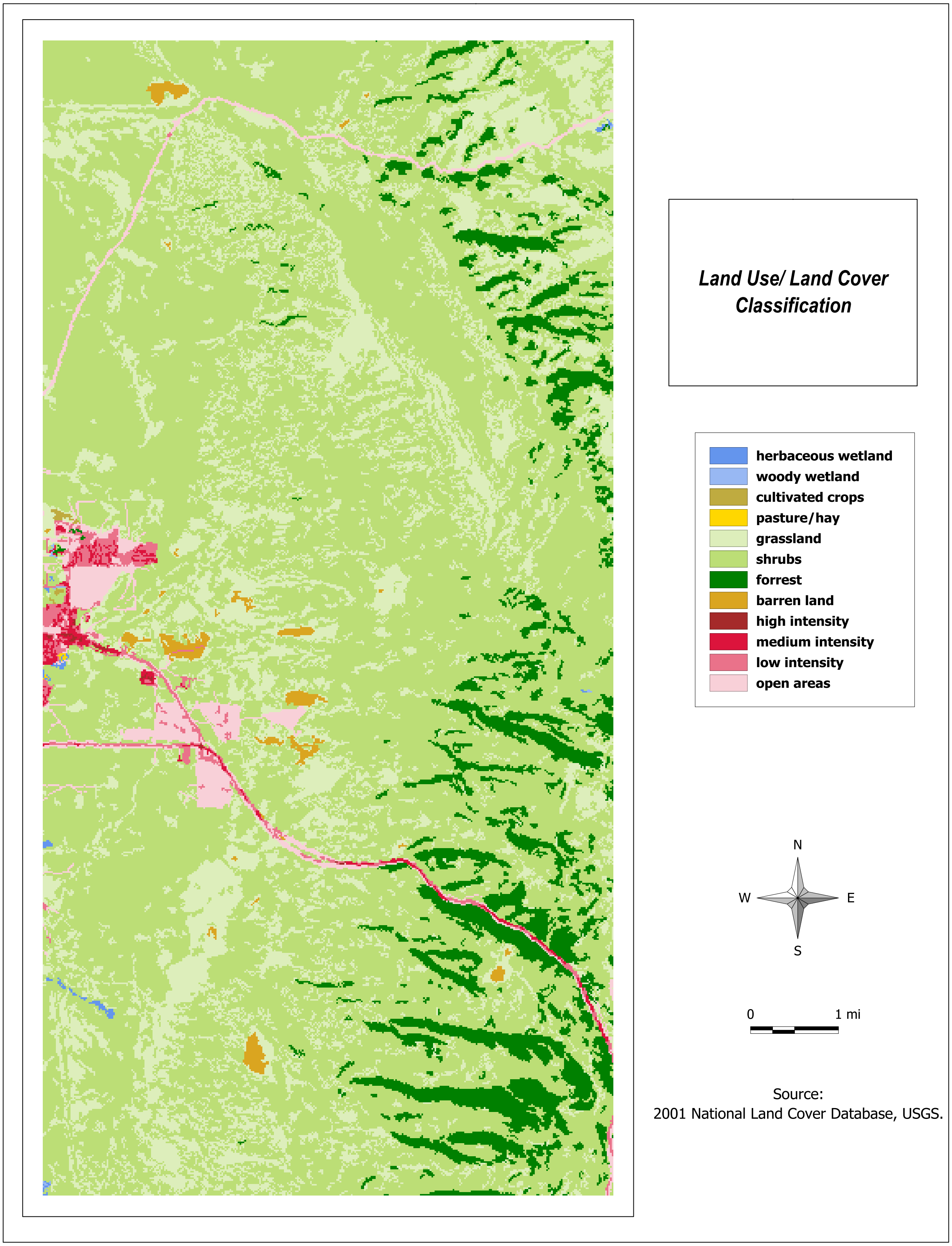
Class name	Class value	Class name	Class value
Water		**Herbaceous upland natural/semi-natural vegetation**	
Open water	11	Grassland/herbaceous	71
Perennial ice/snow	12	Sedge/Herbaceous	72
Developed		Lichens	73
Open spaces	21	Moss	74
Low intensity	22	**Herbaceous planted/cultivated**	
Medium intensity	23	Pasture/hay	81
High intensity	24	Cultivated crops	82
Barren		**Wetlands**	
Barren land (rock/sand/clay)	31	Woody wetlands	90
Unconsolidated shore	32	Palustrine forested wetland	91
Vegetated: natural forested upland		Palustrine scrub/shrub wetland	92
Deciduous forest	41	Estuarine forested wetland	93
Evergreen forest	42	Estuarine scrub/shrub wetland	94
Vegetated: natural shrubland		Emergent Herbaceous wetlands	95
Dwarf scrub	51	Palustrine emergent wetland (persistent)	96
Shrub/scrub	52	Estuarine emergent wetland	97
		Palustrine aquatic bed	98
		Estuarine aquatic bed	99

Table 2: Look-up table for land use curve numbers and maximum recharge used in the model.

	Curve numbers					Max Recharge (in/day)				
	Soil 1 (A)	Soil 2 (B)	Soil 3 (C)	Soil 4 (D)	Soil 5	Soil 1 (A)	Soil 2 (B)	Soil 3 (C)	Soil 4 (D)	Soil 5
LU code	Medium	Fine	Loamy Till	Clay Till	Fractures	Medium	Fine	Loamy Till	Clay Till	Fractures
11	100	100	100	100	100	2	0.6	0.24	0.12	5
12	5	5	5	5	100	2	0.6	0.24	0.12	5
21	89	94.5	94	95	100	2	0.6	0.24	0.12	5
22	54	82.5	80	85	100	2	0.6	0.24	0.12	5
23	61	85	83	87	100	2	0.6	0.24	0.12	5
24	77	91	90	92	100	2	0.6	0.24	0.12	5
31	5	5	5	5	100	2	0.6	0.24	0.12	5
32	5	5	5	5	100	2	0.6	0.24	0.12	5
41	42	82	79	85	100	2	0.6	0.24	0.12	5
42	34	76	73	79	100	2	0.6	0.24	0.12	5
51	39	77	74	80	100	2	0.6	0.24	0.12	5
52	39	77	74	80	100	2	0.6	0.24	0.12	5
71	39	77	74	80	100	2	0.6	0.24	0.12	5
72	39	77	74	80	100	2	0.6	0.24	0.12	5
73	39	77	74	80	100	2	0.6	0.24	0.12	5
74	39	77	74	80	100	2	0.6	0.24	0.12	5
81	39	77	74	80	100	2	0.6	0.24	0.12	5
82	67	87	85	89	100	2	0.6	0.24	0.12	5
90	34	76	73	79	100	2	0.6	0.24	0.12	5
91	34	76	73	79	100	2	0.6	0.24	0.12	5
92	100	100	100	100	100	2	0.6	0.24	0.12	5
93	100	100	100	100	100	2	0.6	0.24	0.12	5
94	100	100	100	100	100	2	0.6	0.24	0.12	5
95	100	100	100	100	100	2	0.6	0.24	0.12	5
96	100	100	100	100	100	2	0.6	0.24	0.12	5
97	100	100	100	100	100	2	0.6	0.24	0.12	5
98	100	100	100	100	100	2	0.6	0.24	0.12	5
99	100	100	100	100	100	2	0.6	0.24	0.12	5

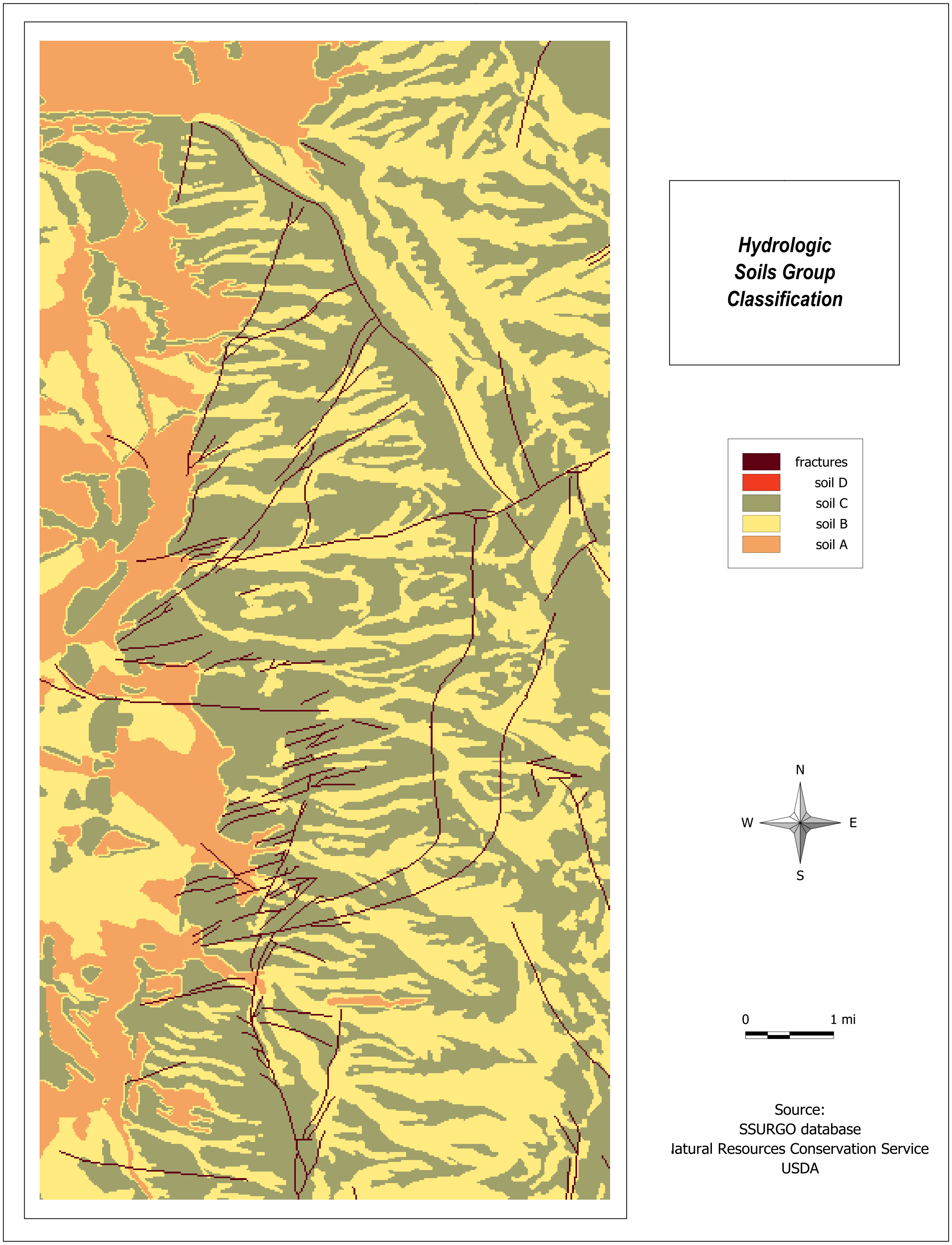
Table 3: Look-up table for land use and root zone depth used in the model.

	Root zone depth (ft)				
	Soil 1 (A)	Soil 2 (B)	Soil 3 (C)	Soil 4 (D)	Soil 5
LU code	Medium	Fine	Loamy Till	Clay Till	Fractures
11	0	0	0	0	0
12	0	0	0	0	0
21	1	1	1	1	0.5
22	1	1	1	1	0.5
23	1	1	1	1	0.5
24	1	1	1	1	0.5
31	0.5	0.5	0.5	0.5	0.5
32	0.5	0.5	0.5	0.5	0.5
41	1	0.9	1	0.9	0.5
42	1	0.9	1	0.9	0.5
51	1.7	1.7	1.8	1.3	0.5
52	1.7	1.7	1.8	1.3	0.5
71	1.7	1.7	1.8	1.1	0.5
72	1.7	1.7	1.8	1.1	0.5
73	1.7	1.7	1.8	1.1	0.5
74	1.7	1.7	1.8	1.1	0.5
81	1.7	1.7	1.8	1.1	0.5
82	0.8	0.8	1	0.3	0.5
90	2.3	2.3	2.3	2.3	0.5
91	2.3	2.3	2.3	2.3	0.5
92	2.3	2.3	2.3	2.3	0.5
93	2.3	2.3	2.3	2.3	0.5
94	2.3	2.3	2.3	2.3	0.5
95	2.3	2.3	2.3	2.3	0.5
96	2.3	2.3	2.3	2.3	0.5
97	2.3	2.3	2.3	2.3	0.5
98	2.3	2.3	2.3	2.3	0.5
99	2.3	2.3	2.3	2.3	0.5



Source:
2001 National Land Cover Database, USGS.

Figure 4: Land use/land cover classification of the study area.



Hydrologic Soils Group Classification

Source:
SSURGO database
atural Resources Conservation Service
USDA

Figure 5: Hydrologic soils group classification within the study area.

Table 4: Available water capacity values for each hydrologic soil group.

Hydrologic soil group	available water capacity (in/ft)
A	1.2
B	2.0
C	2.8
D	3.6
fracture	0.5

Table 5: Flow direction values depending on direction of runoff flow.

32	64	128
16	center	1
8	4	2

the flow direction values used in the model and respective flow directions. Figure 6 shows the flow direction grid used in the model.

2.4.5 Faults and fractures

A shapefile of mapped faults and fractures were provided by the City of Laramie. The shapefile was converted to a raster data set in order to be used in the model. After the raster coverage was created, "fracture zones" in the model were generated by widening the mapped raster fractures.

2.4.6 Implementing the climate change scenario

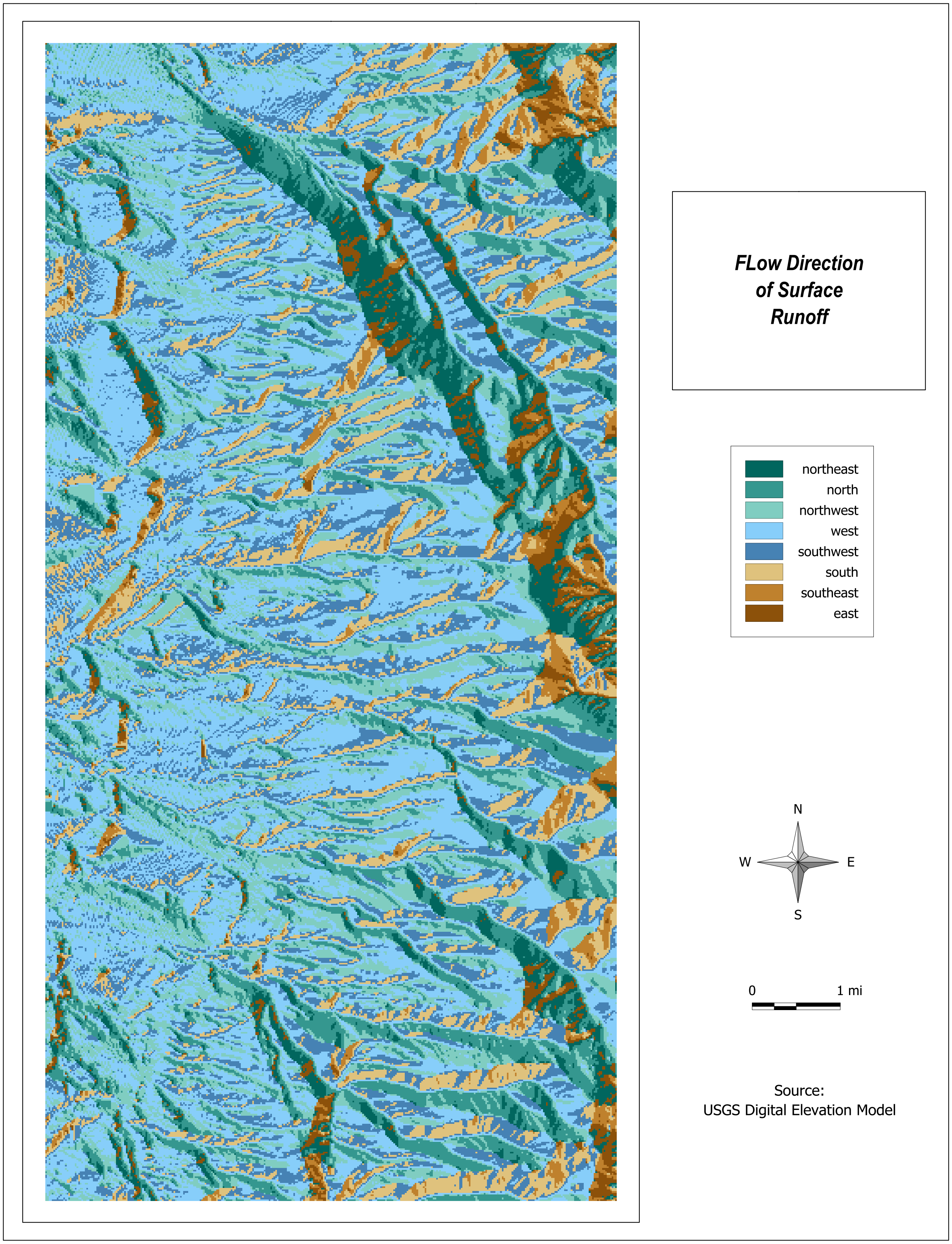
We developed a climate change scenario for the "future" model runs using a method based on recent literature reports of the changes in temperature and precipitation. Temperature and precipitation changes are expected to vary over the course of a decade as shown in Figure 7.

We developed a preprocessing computer script that reads a table of month-by-month adjustments in temperature and precipitation, then applies that month-by-month schedule to the time series of actual meteorological data used in the calibrated model. The model results that are based on "climate-adjusted" meteorological data may be readily compared to the calibrated model in order to identify how recharge rates will be affected.

The preprocessor script adjusts the daily temperature according to

$$T_d^* = T_d + \Delta T_m \tag{9}$$

where T_d^* is the adjusted temperature on date d, T_d is the measured temperature, and ΔT_m is the magnitude of the temperature adjustment provided for the month m which contains the date d (e.g. $\Delta T_2 = 1.5$ if February



FLow Direction of Surface Runoff

Source:
USGS Digital Elevation Model

Figure 6: Flow direction grid showing direction of runoff flow.

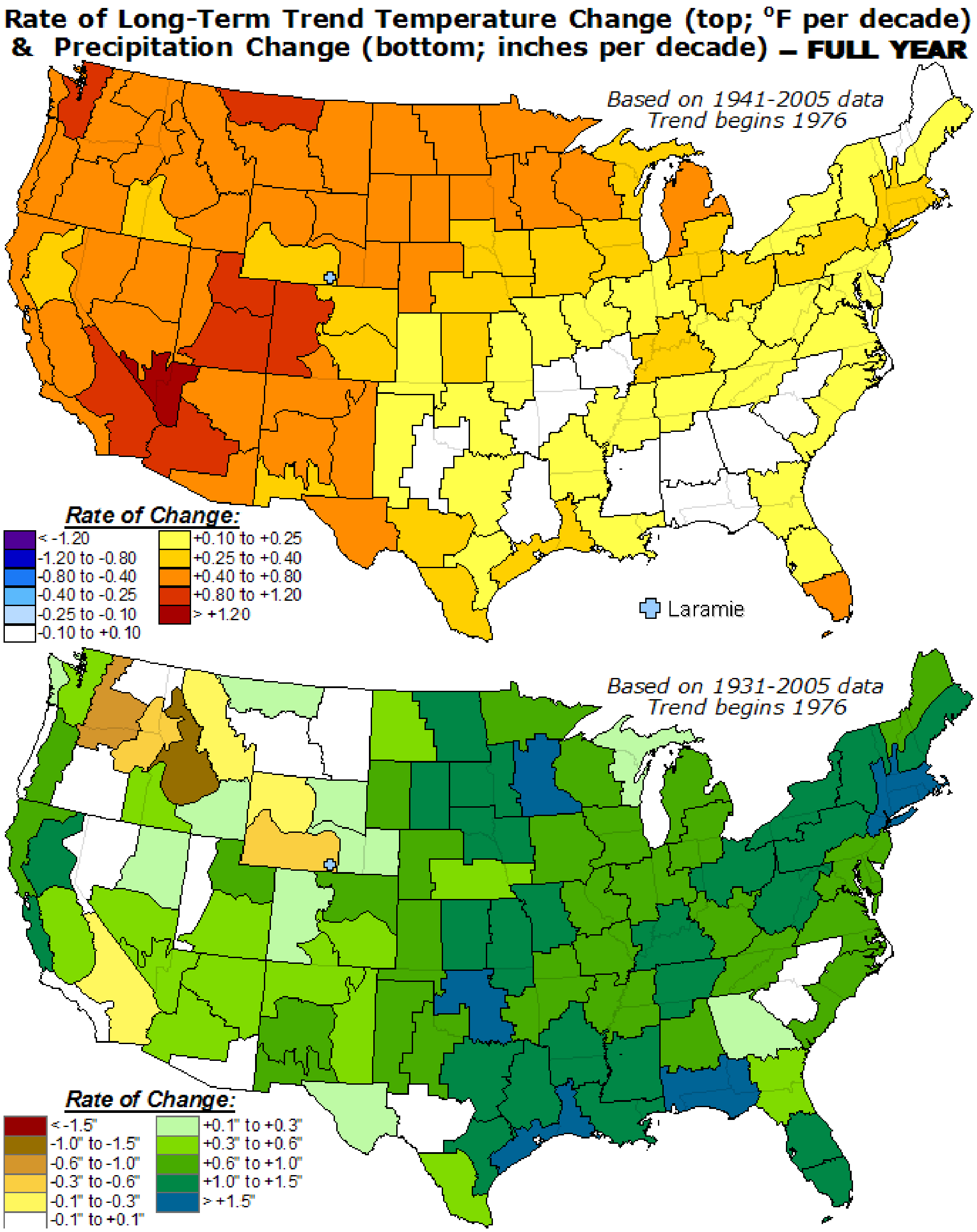


Figure 7: Long term trend of temperature and precipitation change. Source: National Weather Service.

Table 6: Average snowfall differences between the uncorrected single station and the corrected elevation-dependent weather data.

Mean annual precipitation (in/year)	9.7
Uncorrected snowfall (in/year)	2.3
Uncorrected snowfall as percent of precipitation (%)	24.9
Elevation corrected snowfall (in/year)	3.2
Elevation corrected snowfall as percent of precipitation (%)	33.5
Average change in total snowfall (in/year)	0.9

temperatures are expected to increase by $1.5°F$).

Similarly, the script adjusts the daily precipitation for date d in the month m according to

$$R_d^* = R_d \times \alpha_m \tag{10}$$

where R_d^* is the adjusted temperature on date d, R_d is the measured temperature, and α_m is a factor (e.g. $\alpha_5 = 0.8$ if a 20% reduction in precipitation is expected in May).

2.5 Model calibration

Weather data used for recharge modeling consists of a set of 27 years, from 1980 through 2007. The first year of the model run (1980) is used by the model to set antecedent conditions for the other years. Results for 1980 were ignored because they are not reliable. Normal climate data (1971-2000) indicates a mean total annual precipitation of approximately $11\,in$ at the Laramie Regional Airport.

2.5.1 Current conditions - climate

Daily temperature was corrected for change in elevation as described in the methodology section; each cell in the model has a daily temperature value adjusted for elevation. As the elevation increases, the temperature decreases and consequently the potential precipitation that falls as snow increases with elevation, even though the precipitation value is constant over the grid. Table 6 shows an example of model results of snowfall amounts (as water equivalent, in inches) between the uncorrected single station input and the corrected elevation-dependent temperature.

2.5.2 Current conditions - land use

Most of the study area covers the western flank of the Laramie Range where the elevation gradient is steep and consequently, the most common land cover is shrubs and grassland, and towards the top of the range, evergreen forests. Urban areas are found towards the west-central side of the study area, representing the eastern side of the City of Laramie. Table 7 shows the percent of each land cover within the model boundaries based on 2001 National Land Cover Database (add citation).

Table 7: Land use/land cover characteristics of the modeled area.

2001 land use code	Land use name	Number of cells	Square miles (mi^2)
21	Open spaces	5,402	1.88
22	low intensity	2,120	0.74
23	medium intensity	995	0.35
24	high intensity	71	0.02
31	barren land	1,500	0.52
41	deciduous forest	58	0.02
42	evergreen forest	17,549	6.10
52	shrub	164,249	57.08
71	grassland/herbaceous	53,040	18.43
81	pasture/hay	21	0.01
82	cultivated crops	86	0.03
90	woody wetlands	41	0.01
95	herbaceous wetlands	208	0.07
	Total	245,340	85.25

3 Recharge scenarios

Two scenarios were modeled in order to analyze the impact of climate change and increase in urbanization on the total recharge to the Casper Aquifer. The "climate change" scenario includes changes in temperature and precipitation as indicated by long-term trends. The "urbanization" scenario was designed to see how much increase in urbanization in the eastern Laramie area would affect total recharge.

3.1 Climate change scenario

Changes in climate patterns observed during recent decades has sparked public awareness and scientific inquiry about the effects of climate change. Complex climatological models have been developed to predict the increase of the atmosphere's heat-trapping ability and resulting impact on climate. Although results of models vary, generally accepted trends are temperature increase and changes in precipitation. In Climate Change and Wyoming, the EPA reports that global surface average temperatures increases between 1.6 to $6.3\,^{\circ}F$ could be seen by 2100 with significant regional variation. In Laramie, an increase in temperature of $1.5\,^{\circ}F$, and decrease in precipitation of up to 20 % has been observed for in Wyoming over the last century.

According to the National Weather Service (NWS), rates of long-term trend temperature and precipitation changes for the area surrounding the City of Laramie range from +0.25 to $+0.4\,^{\circ}F$ and -0.3 to $-0.6\,in$ respectively, per decade, based on 1941-2005 data [National Weather Service, 2005]. The NWS data is also available with seasonal variations, aggregated in three month running averages for temperature and three months totals for precipitation. We used the NWS data with seasonal variations for the Laramie region to

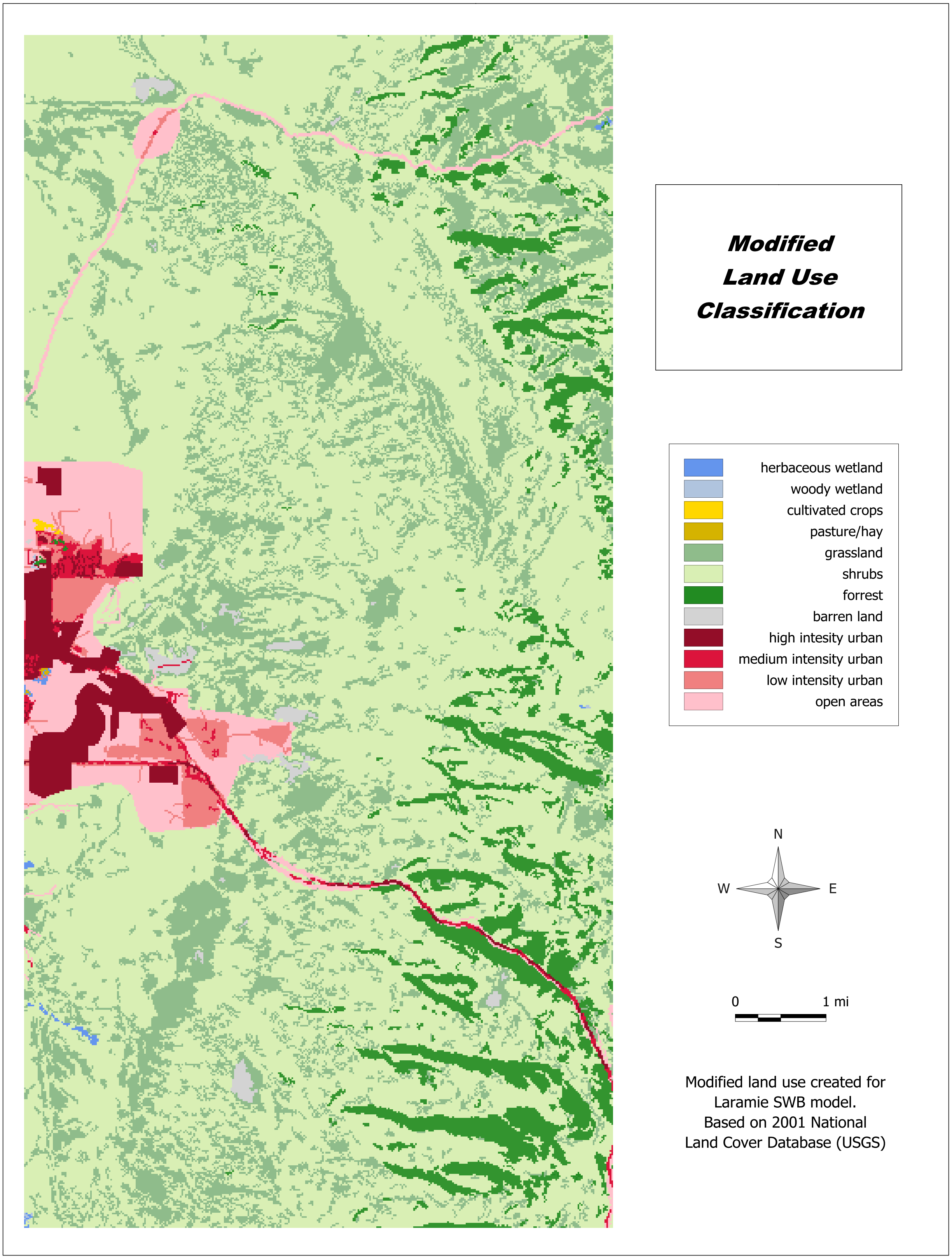
Table 8: Values used to represent seasonal effects on climate change parameters.

Months	Trend temperature increase ($^\circ F$)	Trend precipitation decrease (*in*)
DJF	0.87	-0.40
JFM	5.00	-0.40
FMA	5.00	-0.40
MAM	5.00	-0.14
AMJ	3.00	-0.14
MJJ	1.62	-0.14
JJA	1.62	-0.14
JAS	1.62	-0.14
ASO	0.87	-0.14
SON	0.00	-0.14
OND	-0.87	-0.40
NDJ	0.87	-0.40
Average/Total	2.00	-3.00

estimate an increase of $2^\circ F$ and a decrease of 25 % of precipitation over the next 50 years. These values represent a worse-case scenario, given the two estimations of climate change described above. The precipitation reduction of 25 % derived from the higher end of the precipitation ($-0.6\,in$ per decade) multiplied by the five decades modeled. The resulting $3\,in$ increase was than compared to the normal annual precipitation of $11.4\,in$ which resulted on a decrease of approximately 25 % in precipitation. Seasonal variations of temperature and precipitation used in the model are shown in Table 8.

3.2 Urbanization scenario

Future land use/land cover changes were created based on the original 2001 land use/land cover grid. Changes were made by expanding urbanization found on the eastern side of Laramie, or on the western portion of the study area. Existing urbanization levels were increased a level (i.e., from medium to intensive urbanization) and surrounding areas that had a land use other than urban received a low intensity urbanization status. Figure 8 shows the modified land use/land cover used for the land use change scenario. Land use was not changed on the higher elevations areas towards the creast of the Laramie Range because of highly unlikly possibility that urbanization will occur in this area. Urbanization can be expected to expand from the city towards the east.



Modified land use created for
Laramie SWB model.
Based on 2001 National
Land Cover Database (USGS)

Figure 8: Modified land use representing possible future urbanization (more intense urbanization).

Table 9: Results of model using historical climate data (1981-2007).

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
average	10.97	4.20	38.63	1.02	0.07	1.09	9.48
maximum	16.60	10.40	65.79	4.98	0.20	5.07	24.55
minimum	5.40	1.88	20.42	0.08	0.03	0.11	1.76

4 Results and implications

This section describes results obtained from running the SWB model under current conditions (historical weather data: 1981 - 2007 and the 2001 land use/land cover classification) and the climate change and land use change scenarios.. The current conditions combination of land use and weather data gives us a base to compare model runs with changes in land use and climate.

4.1 Current conditions

Model results show an overall decrease in recharge over the last 26 years, while the temperature (plotted as 2-year moving average) shows an increasing trend (Figure 9). The highest rate of recharge, over 5.07 *in*, occurred in 1983 when the recorded total annual precipitation was 15.80 *in* and snowfall was 10.40 *in*. The lowest recharge of 0.11 *in* occurred in 2002 when the total precipitation was only 5.40 *in* and snowfall was 2.16 *in*, this was following a year of similarly low precipitation and snowfall of 6.05 and 2.15 *in*, respectively (Table 9). Also in 2002 approximately 25 % of total recharge was fracture recharge, while in 1983, fracture recharge was 1.2 % of total recharge. The average recharge rate for the 26-year period was 1.09 *in* with an average precipitation of 10.97 *in* and average snow fall of 4.20 *in* per year. On average, 10 % of precipitation is recharged into the aquifer, 38 % of precipitation occurs as snowfall, and 9.4 % of recharge occurs as fracture recharge. Figure 10 illustrates the concept that for years of low precipitation, the amount of the recharge that occurs though the fractures is higher than those years of higher precipitation rates. In relatively dry years, up to 25 % of the recharge can occur from fractures, like in 2002, and in wet years fracture recharge can drop to as low as 2 %, like in 1983. For annual results of modeled recharge see Appendix A, Table 12. Appendix B shows a sample log file for the base model run.

4.2 Future conditions

Future modeled conditions include climate change as well as increased urbanization. This section describes the results from the two different scenarios.

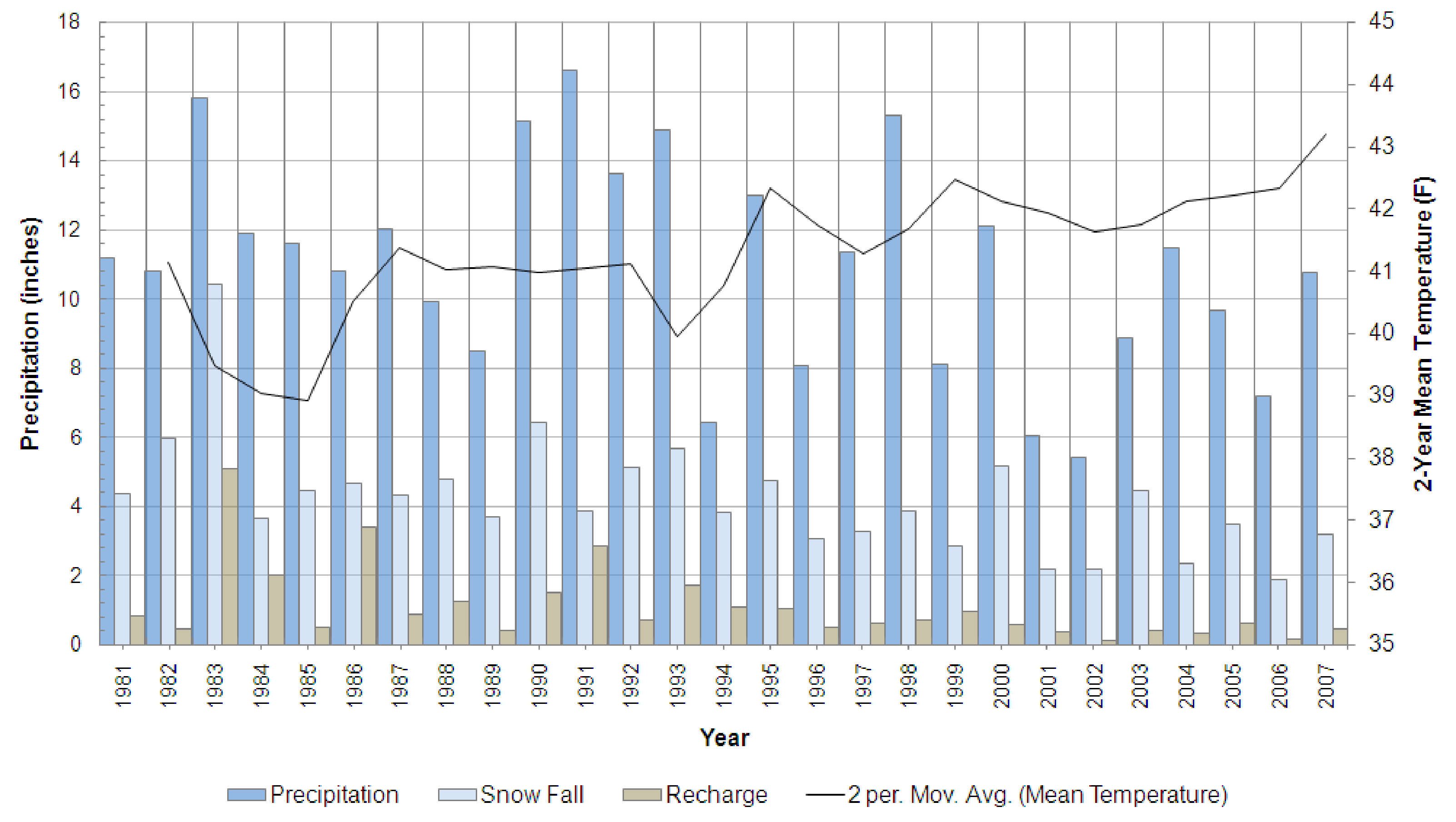


Figure 9: Relationship between total annual precipitation, snowfall and recharge (1981 - 2007 modeled years).

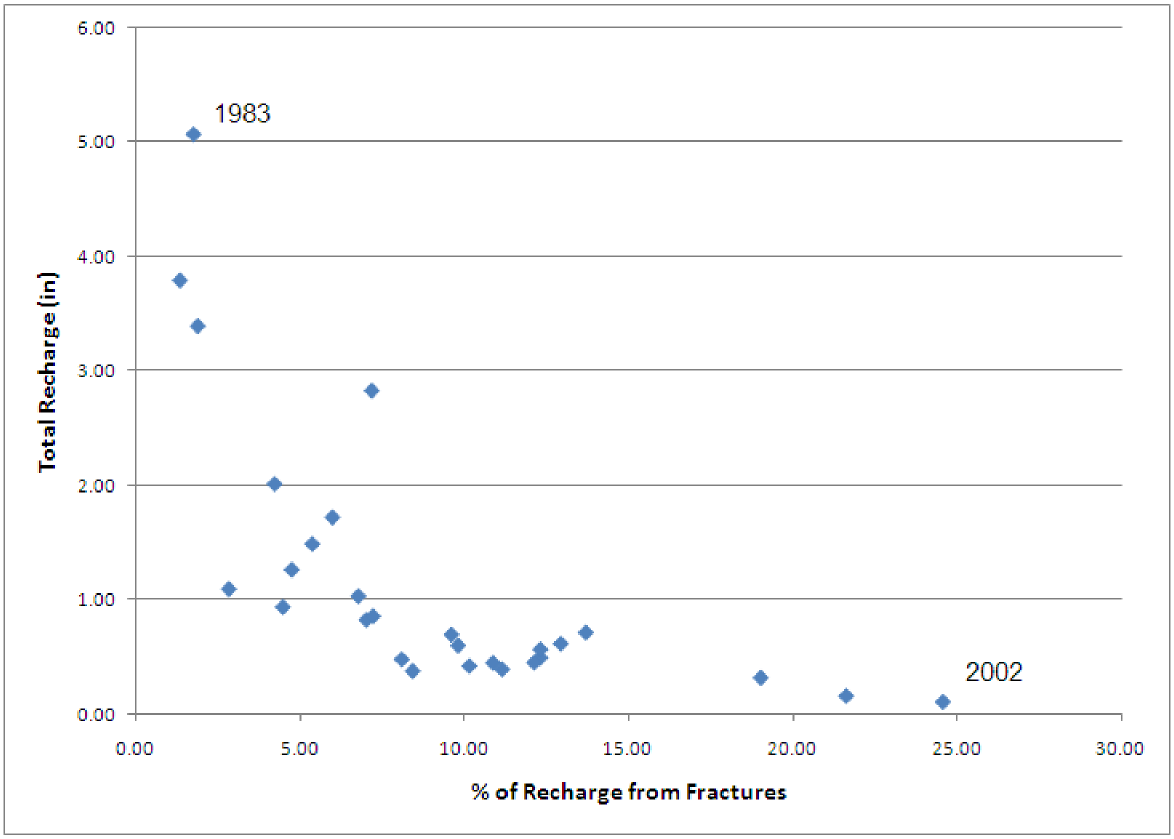


Figure 10: Recharge from fractures as a percent of the total recharge.

Table 10: Average inter-annual (1981-2007) recharge changes influenced by climate change from historical model results.

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
historical (1981-2007)	10.97	4.20	38.63	1.02	0.07	1.09	9.48
climate change scenario	10.24	3.14	31.10	0.62	0.06	0.68	14.53
change %	-6.65	-25.24	-19.49	-39.22	-14.29	-37.61	53.27
precipitation change only	10.25	3.83	37.81	0.84	0.06	0.90	10.39
change %	-6.64	-8.81	-2.12	-17.65	-8.21	-17.08	9.57
temperature change only	10.98	3.48	32.03	0.75	0.07	0.82	13.33
change %	0.02	-17.25	-17.10	-26.61	0.00	-25.01	40.64

4.2.1 Climate change scenario

In addition to the climate change scenario, which include estimated climate changes of increase temperature of $2.0\,^{\circ}F$ and decrease in precipitation of 25 %, temperature and precipitation factors were modeled individually in order to verify the impact of each factor on total recharge. Figure 11 shows the results of historical and modeled recharge. As expected, the compounded effect of changes in precipitation and temperature, together, cause a larger decrease in recharge than temperature or precipitation alone.

Recharge estimates decrease by 37 % from the historical climate data results (from 1.09 to $0.68\,in$ per year) (Table 10). Comparing the effects of the individual factors, the decrease in precipitation is less of a factor in recharge than the temperature increase. Decrease of annual recharge from historical average due to the influence of precipitation alone was 17 %, or from 1.09 to $0.90\,in$, and the influence of temperature alone was 25 % or from 1.1 to $0.8\,in$ (Table 10). For annual recharge results of the effect of climate change, see Appendix A, Table 13. For annual recharge results of individual climate change parameters see Appendix A Tables 14 and 15.

4.2.2 More intense urbanization scenario

The increase in urbanization levels, exaggerated for purposes of analyzing the influence of urbanization on recharge, showed little impact on aquifer recharge. Average increase in recharge was approximately 3 % (Table 11). The differences in recharge are due to increase in soil recharge. Fracture recharge remains the same because the location of the faults and fractures are located at higher elevations to the east of the urbanization area. For annual recharge results see Appendix A, Table 16.

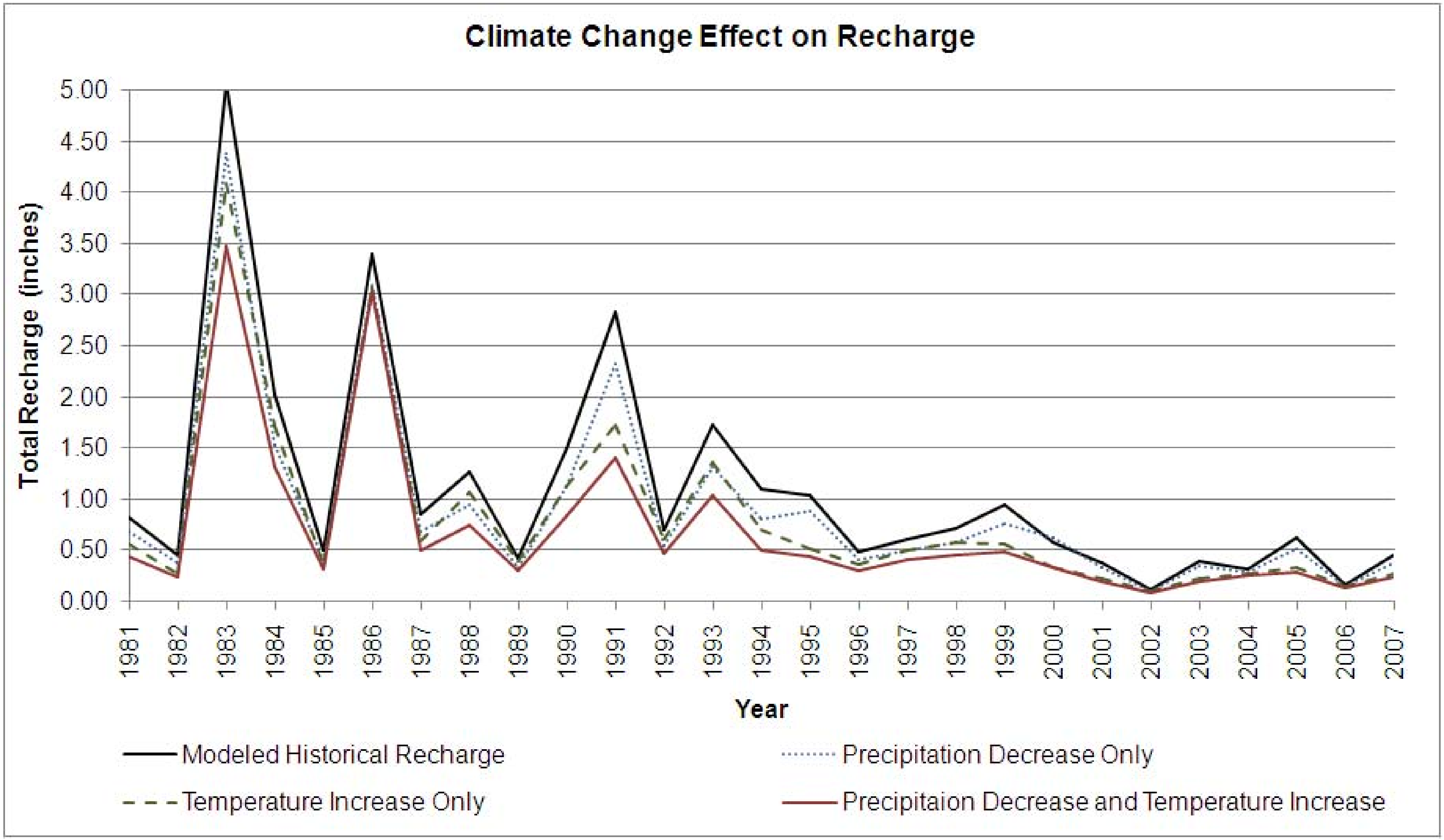


Figure 11: Total recharge under current conditions and the climate change scenario.

Table 11: Changes in recharge due to increase in urbanization.

Year	Total precipitation (in)	Total snowfall (in)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
original land use	10.97	4.20	1.02	0.07	1.09	9.48
modified land use	10.97	4.20	1.05	0.07	1.12	9.57
change %	0	0	2.59	0	2.64	0.92

5 Conclusions

The SWB model results indicate an average annual recharge of approximately $1\,in$ for the last 26 years. The large precipitation events of 1983 are reflected in the model as record recharge of over $5\,in$. The results also indicate a long-term trend of decreasing recharge and consequently, water levels. This decline in water level has been observed by the City of Laramie Utility.

Recharge to the aquifer occurs mostly during spring snowmelt events when the amount of water generated is enough to saturate soils and allow the surplus of water to recharge the aquifer. Snowmelt events also feed ephemeral streams that run into lower lying areas near Laramie. Recharge through faults accounts in average for nearly 10 % of total aquifer recharge. Fault recharge increases in relation to annual average precipitation, as the precipitation decreases. With more precipitation, recharge through soil infiltration increases because surplus water can then percolate through the wet soil, recharging the aquifer rather than being lost to evapotranspiration. With less precipitation, water that does runoff into streams feed fracture recharge where faults and fractures intersect these streams.

As the climate changes, the effects of temperature increase are expected to be larger than those of reduced precipitation, although, both trends reduce recharge. Modeled results show that with the increase of $2\,°F$ in temperature and decrease of 25 % of precipitation in 50 years, recharge rates could drop by 37 %. This would be significant for an aquifer that gets an estimated annual average recharge of $1\,in$ and average precipitation of $11\,in$.

Significant decreases in water levels have been observed in the Casper Aquifer recently but little or no growth in population or water demand. With the increasing temperature trends shown by historical weather data over the last few decades, it can be expected that water levels will keep falling, since temperature increase has a strong influence on recharge.

While large precipitation events can provide significant recharge to the Casper Aquifer as shown by events in 1983, long-term trends of increasing temperatures may reduce recharge. As temperature increase due to climate changes, it is important for Laramie to understand and prepare for declining water levels. A conservation plan that will address long-term water demand would help direct the City in conserving groundwater for a sustainable water supply.

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Appendix A - Model results

Table 12: Results of model using historical climate data (1981-2007).

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
1981	11.19	4.36	38.99	0.77	0.06	0.83	7.01
1982	10.80	5.95	55.08	0.40	0.05	0.45	10.86
1983	15.80	10.40	65.79	4.98	0.09	5.07	1.76
1984	11.87	3.63	30.57	1.93	0.09	2.01	4.22
1985	11.58	4.43	38.25	0.44	0.06	0.50	12.30
1986	10.80	4.65	43.08	3.33	0.06	3.39	1.89
1987	12.00	4.33	36.07	0.80	0.06	0.86	7.22
1988	9.93	4.77	47.99	1.21	0.06	1.27	4.74
1989	8.49	3.68	43.29	0.38	0.04	0.42	10.14
1990	15.11	6.41	42.42	1.41	0.08	1.49	5.37
1991	16.60	3.86	23.27	2.63	0.20	2.83	7.18
1992	13.61	5.11	37.57	0.63	0.07	0.70	9.60
1993	14.87	5.65	38.00	1.62	0.10	1.72	5.98
1994	6.42	3.80	59.13	1.07	0.03	1.10	2.83
1995	12.97	4.75	36.60	0.96	0.07	1.03	6.77
1996	8.05	3.07	38.11	0.44	0.04	0.48	8.09
1997	11.35	3.24	28.58	0.54	0.06	0.60	9.80
1998	15.28	3.83	25.09	0.62	0.10	0.72	13.69
1999	8.09	2.83	35.01	0.90	0.04	0.94	4.47
2000	12.09	5.17	42.72	0.50	0.07	0.57	12.30
2001	6.05	2.15	35.55	0.35	0.03	0.38	8.42
2002	5.40	2.16	39.96	0.08	0.03	0.11	24.55
2003	8.87	4.45	50.20	0.35	0.04	0.40	11.14
2004	11.47	2.34	20.42	0.26	0.06	0.32	19.00
2005	9.65	3.46	35.87	0.54	0.08	0.62	12.92
2006	7.19	1.88	26.11	0.13	0.04	0.16	21.60
2007	10.75	3.16	29.40	0.40	0.06	0.45	12.11
average	10.97	4.20	38.63	1.02	0.07	1.09	9.48
maximum	16.60	10.40	65.79	4.98	0.20	5.07	24.55
minimum	5.40	1.88	20.42	0.08	0.03	0.11	1.76

Table 13: Recharge changes influenced by the decrease of 25% of precipitation and increase of $2^{\circ}F$ in temperature(1981-2007).

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
1981	10.48	2.95	28.20	0.39	0.05	0.44	12.10
1982	9.97	4.27	42.80	0.19	0.05	0.23	19.83
1983	14.53	7.32	50.40	3.40	0.08	3.48	2.30
1984	11.11	3.02	27.20	1.23	0.08	1.31	5.73
1985	10.85	3.48	32.10	0.25	0.06	0.31	18.51
1986	10.13	3.75	37.00	2.98	0.06	3.04	1.91
1987	11.10	3.62	32.60	0.44	0.06	0.50	11.20
1988	9.17	3.74	40.80	0.69	0.05	0.75	6.97
1989	7.84	2.98	38.00	0.26	0.04	0.30	13.29
1990	13.98	4.88	34.90	0.76	0.07	0.83	8.65
1991	15.58	3.18	20.40	1.23	0.18	1.41	13.03
1992	12.55	3.86	30.80	0.41	0.06	0.47	13.38
1993	13.80	4.43	32.10	0.96	0.08	1.04	7.50
1994	5.91	2.96	50.00	0.47	0.03	0.50	5.43
1995	12.24	3.05	25.00	0.38	0.07	0.44	14.74
1996	7.53	2.34	31.10	0.26	0.04	0.29	12.59
1997	10.62	2.64	24.90	0.36	0.06	0.41	13.29
1998	14.36	2.91	20.30	0.37	0.09	0.46	19.69
1999	7.59	2.11	27.80	0.44	0.04	0.48	8.68
2000	11.41	3.53	30.92	0.27	0.06	0.33	19.03
2001	5.68	1.72	30.34	0.16	0.03	0.19	15.43
2002	5.06	1.64	32.41	0.06	0.03	0.09	28.74
2003	8.26	3.04	36.77	0.15	0.04	0.20	21.03
2004	10.87	1.56	14.33	0.19	0.06	0.25	22.98
2005	9.05	2.62	28.89	0.20	0.08	0.28	29.08
2006	6.79	1.47	21.58	0.10	0.03	0.13	25.38
2007	10.12	1.83	18.13	0.18	0.05	0.24	21.70
average	10.24	3.14	31.10	0.62	0.06	0.68	14.53
maximum	15.58	7.32	50.40	3.40	0.18	3.48	29.08
minimum	5.06	1.47	14.33	0.06	0.03	0.09	1.91
historical average	10.97	4.20	38.63	1.02	0.07	1.09	9.48
change %	-6.65	-25.21	-19.49	-39.34	-8.83	-37.51	53.21

Table 14: Recharge changes influenced by the decrease of 25% of precipitation (1981-2007).

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
1981	10.48	4.20	40.10	0.63	0.05	0.69	7.87
1982	9.97	5.42	54.32	0.34	0.05	0.38	11.72
1983	14.53	9.43	64.90	4.30	0.08	4.38	1.85
1984	11.11	3.31	29.79	1.45	0.08	1.52	5.06
1985	10.85	4.08	37.61	0.36	0.06	0.41	13.77
1986	10.13	4.34	42.89	3.04	0.06	3.10	1.94
1987	11.10	3.92	35.28	0.63	0.06	0.69	8.28
1988	9.17	4.27	46.53	0.89	0.05	0.94	5.72
1989	7.84	3.26	41.64	0.29	0.04	0.33	11.75
1990	13.98	5.72	40.91	1.06	0.07	1.13	6.47
1991	15.58	3.49	22.39	2.14	0.18	2.33	7.90
1992	12.55	4.48	35.68	0.48	0.06	0.54	11.52
1993	13.80	5.04	36.54	1.23	0.09	1.31	6.70
1994	5.91	3.43	57.92	0.79	0.03	0.81	3.44
1995	12.24	4.43	36.17	0.82	0.07	0.89	7.34
1996	7.53	2.80	37.19	0.37	0.04	0.40	9.20
1997	10.62	2.92	27.46	0.44	0.05	0.49	10.98
1998	14.36	3.49	24.29	0.49	0.09	0.58	15.65
1999	7.59	2.60	34.20	0.72	0.04	0.76	5.53
2000	11.41	4.83	42.33	0.55	0.06	0.62	10.41
2001	5.72	1.97	34.40	0.31	0.03	0.34	8.90
2002	5.06	1.98	39.09	0.07	0.03	0.10	25.51
2003	8.26	4.07	49.25	0.30	0.04	0.34	12.02
2004	10.87	2.20	20.22	0.23	0.06	0.28	20.14
2005	9.05	3.19	35.18	0.44	0.07	0.51	14.48
2006	6.79	1.75	25.74	0.11	0.03	0.14	22.92
2007	10.12	2.93	28.91	0.33	0.05	0.38	13.39
average	10.25	3.83	37.81	0.84	0.06	0.90	10.39
maximum	15.58	9.43	64.90	4.30	0.18	4.38	25.51
minimum	5.06	1.75	20.22	0.07	0.03	0.10	1.85
historical average	10.97	4.20	38.63	1.02	0.07	1.09	9.48
change %	-6.64	-8.81	-2.12	-17.65	-8.21	-17.08	9.57

Table 15: Recharge changes influenced by $2^{\circ}F$ increase in temperature (1981-2007).

Year	Total precipitation (in)	Total snowfall (in)	Percent snowfall (%)	Soil recharge (in)	Fracture recharge (in)	Total recharge (in)	Fracture recharge (%)
1981	11.19	3.26	29.12	0.50	0.06	0.55	10.31
1982	10.80	4.82	44.60	0.23	0.05	0.28	17.75
1983	15.80	8.19	51.80	3.99	0.10	4.09	2.32
1984	11.87	3.34	28.17	1.63	0.08	1.72	4.90
1985	11.58	3.83	33.07	0.31	0.06	0.37	16.58
1986	10.80	4.08	37.77	3.01	0.06	3.07	1.99
1987	12.00	4.06	33.85	0.53	0.06	0.59	10.46
1988	9.93	4.22	42.54	1.01	0.06	1.07	5.45
1989	8.49	3.37	39.74	0.36	0.04	0.40	11.03
1990	15.11	5.49	36.36	1.05	0.08	1.13	6.98
1991	16.60	3.53	21.25	1.53	0.20	1.73	11.77
1992	13.61	4.44	32.65	0.53	0.07	0.60	11.30
1993	14.87	4.98	33.48	1.27	0.09	1.36	6.42
1994	6.42	3.30	51.42	0.67	0.03	0.70	4.32
1995	12.97	3.27	25.22	0.44	0.07	0.51	13.81
1996	8.05	2.58	32.07	0.32	0.04	0.36	11.02
1997	11.35	2.96	26.05	0.45	0.06	0.51	11.68
1998	15.28	3.11	20.37	0.48	0.10	0.57	17.07
1999	8.09	2.30	28.39	0.53	0.04	0.57	7.23
2000	12.09	3.78	31.29	0.27	0.07	0.34	20.12
2001	6.10	1.90	31.08	0.20	0.03	0.23	14.04
2002	5.40	1.80	33.35	0.07	0.03	0.10	27.27
2003	8.87	3.35	37.71	0.19	0.04	0.23	19.21
2004	11.47	1.68	14.64	0.21	0.06	0.27	22.76
2005	9.65	2.73	28.24	0.24	0.10	0.33	28.83
2006	7.19	1.58	22.03	0.11	0.04	0.14	24.65
2007	10.75	1.98	18.45	0.21	0.06	0.27	20.75
average	10.98	3.48	32.03	0.75	0.07	0.82	13.33
maximum	16.60	8.19	51.80	3.99	0.20	4.09	28.83
minimum	5.40	1.58	14.64	0.07	0.03	0.10	1.99
historical average	10.97	4.20	38.63	1.02	0.07	1.09	9.48
change %	0.02	-17.25	-17.10	-26.61	-0.00	-25.01	40.64

Table 16: Annual results of changes in recharge due to increase in urbanization.

Year	Precipitation (in)	Snowfall (in)	Recharge - original land use (in)	Recharge - modified land use (in)	Change (%)
1981	11.19	4.36	0.83	0.86	3.5
1982	10.80	5.95	0.45	0.46	1.1
1983	15.80	10.40	5.07	5.13	1.2
1984	11.87	3.63	2.01	2.09	3.5
1985	11.58	4.43	0.50	0.51	2.2
1986	10.80	4.65	3.39	3.45	1.6
1987	12.00	4.33	0.86	0.90	4.9
1988	9.93	4.77	1.27	1.33	4.7
1989	8.49	3.68	0.42	0.45	6.6
1990	15.11	6.41	1.49	1.55	4.0
1991	16.60	3.86	2.83	2.86	1.1
1992	13.61	5.11	0.70	0.74	5.6
1993	14.87	5.65	1.72	1.80	4.4
1994	6.42	3.80	1.10	1.14	3.9
1995	12.97	4.75	1.03	1.05	1.5
1996	8.05	3.07	0.48	0.49	2.1
1997	11.35	3.24	0.60	0.63	5.1
1998	15.28	3.83	0.72	0.75	4.3
1999	8.09	2.83	0.94	0.97	2.9
2000	12.09	5.17	0.57	0.59	3.5
2001	6.05	2.15	0.38	0.39	3.7
2002	5.40	2.16	0.11	0.11	0.9
2003	8.87	4.45	0.40	0.40	1.5
2004	11.47	2.34	0.32	0.33	1.9
2005	9.65	3.46	0.62	0.62	0.2
2006	7.19	1.88	0.16	0.16	0.6
2007	10.75	3.16	0.45	0.46	0.9
average	11.0	4.2	1.1	1.1	2.9

Appendix B - Run log for SWB calibration run

```
Soil Water Balance Code compiled on: 02 May 2008
Model execution started: 20080522_213138
Running fracture-recharge.ctl
A downhill routing table exists from a previous run...
>> GRID 348 705 452887.8679 4562937.0619 463327.8654 4584087.0554
30.0
Reading in grid dimensions
>> GRID_LENGTH_UNITS METERS
Setting grid length units
>> SUPPRESS_DAILY_FILES
>> GROWING_SEASON 156 250 TRUE
Reading growing season
Northern Hemisphere = T
>> ANSI_COLORS FALSE
Setting ANSI color screen output option
>> RLE_MULTIPLIER 10000
Setting the value for the RLE multiplier
>> PRECIPITATION SINGLE_STATION
Configuring precipitation data input
Precip data will be read for a single station
>> TEMPERATURE SINGLE_STATION
Configuring temperature data input
Temperature data will be read for a single station
>> OUTPUT_GRID_SUFFIX grd
Setting output grid file suffix
>> INITIAL_ABSTRACTION_METHOD TR55
Setting initial abstraction method
>> INITIAL_FROZEN_GROUND_INDEX CONSTANT 0
Initializing continuous frozen ground index
>> UPPER_LIMIT_CFGI 9999
Initializing upper boundary for continuous frozen ground
index threshold
Ground will be considered frozen at a CFGI value of:
9999.0000000000000
>> LOWER_LIMIT_CFGI 9999
Initializing lower boundary for continuous frozen ground
index threshold
Ground will be considered unfrozen at a CFGI value of:
9999.0000000000000
>> DRIPPS_COMPATIBILITY FALSE
Setting compatibility option regarding recharge calculation
>> FLOW_DIRECTION ARC_GRID input\Flow_dir.grd
Populating flow direction grid
```

```
Summary of integer grid data values
7221 grid cells have value: 1
7619 grid cells have value: 2
24879 grid cells have value: 4
39902 grid cells have value: 8
75330 grid cells have value: 16
44654 grid cells have value: 32
30870 grid cells have value: 64
14865 grid cells have value: 128
Total number of grid cells: 245340
Total number of grid cells with value [0-256]: 245340
>> SOIL_GROUP ARC_GRID input\Soils_5_Types_widen_1.grd
Populating soil group grid
Summary of integer grid data values
36993 grid cells have value: 1
89875 grid cells have value: 2
99570 grid cells have value: 3
18902 grid cells have value: 5
Total number of grid cells: 245340
Total number of grid cells with value [0-256]: 245340
>> LAND_USE ARC_GRID input\land_use.grd
Populating land use grid
Summary of integer grid data values
5402 grid cells have value: 21
2120 grid cells have value: 22
995 grid cells have value: 23
71 grid cells have value: 24
1500 grid cells have value: 31
58 grid cells have value: 41
17549 grid cells have value: 42
164249 grid cells have value: 52
53040 grid cells have value: 71
21 grid cells have value: 81
86 grid cells have value: 82
41 grid cells have value: 90
208 grid cells have value: 95
Total number of grid cells: 245340
Total number of grid cells with value [0-256]: 245340
>> LAND_USE_LOOKUP_TABLE std_input\lulookup5SoilsLowIntercept.txt
Reading land-use lookup table
==> allocating memory for 28 landuse types within lookup table
==> allocating memory for 5 soil types within lookup table
-----------------------------------------------------------
Reading landuse record number 1 of 28
```

```
landuse type = 11
landuse description = Open water
assumed % imperviousness = not applicable
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 0.0000000000000000
ROOTING DEPTH for soil group 2 : 0.0000000000000000
ROOTING DEPTH for soil group 3 : 0.0000000000000000
ROOTING DEPTH for soil group 4 : 0.0000000000000000
ROOTING DEPTH for soil group 5 : 0.0000000000000000
------------------------------------------------------------
Reading landuse record number 2 of 28
landuse type = 12
landuse description = Perennial Ice/Snow
assumed % imperviousness = not applicable
curve number for soil group 1 : 5.0000000000000000
curve number for soil group 2 : 5.0000000000000000
curve number for soil group 3 : 5.0000000000000000
curve number for soil group 4 : 5.0000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 0.0000000000000000
ROOTING DEPTH for soil group 2 : 0.0000000000000000
ROOTING DEPTH for soil group 3 : 0.0000000000000000
ROOTING DEPTH for soil group 4 : 0.0000000000000000
ROOTING DEPTH for soil group 5 : 0.0000000000000000
------------------------------------------------------------
Reading landuse record number 3 of 28
```

```
landuse type = 21
landuse description = Commercial/Industrial/Transportation
assumed % imperviousness = 85
curve number for soil group 1 : 89.000000000000000
curve number for soil group 2 : 94.500000000000000
curve number for soil group 3 : 94.000000000000000
curve number for soil group 4 : 95.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 1.00000000000000000
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 1.00000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 4 of 28
landuse type = 22
landuse description = Low density Residential
assumed % imperviousness = 12
curve number for soil group 1 : 54.000000000000000
curve number for soil group 2 : 82.500000000000000
curve number for soil group 3 : 80.000000000000000
curve number for soil group 4 : 85.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 1.00000000000000000
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 1.00000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 5 of 28
```

```
landuse type = 23
landuse description = Medium density Residential
assumed % imperviousness = 38
curve number for soil group 1 : 61.000000000000000
curve number for soil group 2 : 85.000000000000000
curve number for soil group 3 : 83.000000000000000
curve number for soil group 4 : 87.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 1.00000000000000000
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 1.00000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
------------------------------------------------------------
Reading landuse record number 6 of 28
landuse type = 24
landuse description = High density Residential
assumed % imperviousness = 65
curve number for soil group 1 : 77.000000000000000
curve number for soil group 2 : 91.000000000000000
curve number for soil group 3 : 90.000000000000000
curve number for soil group 4 : 92.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 1.00000000000000000
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 1.00000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
------------------------------------------------------------
Reading landuse record number 7 of 28
```

```
landuse type = 31
landuse description = Bare Exposed Rock / Sand / Clay (assume
similar to dirt road)
assumed % imperviousness = not applicable
curve number for soil group 1 : 5.0000000000000000
curve number for soil group 2 : 5.0000000000000000
curve number for soil group 3 : 5.0000000000000000
curve number for soil group 4 : 5.0000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 0.50000000000000000
ROOTING DEPTH for soil group 2 : 0.50000000000000000
ROOTING DEPTH for soil group 3 : 0.50000000000000000
ROOTING DEPTH for soil group 4 : 0.50000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
------------------------------------------------------------
Reading landuse record number 8 of 28
landuse type = 32
landuse description = Quarries/Gravel Pits (assume similar to
commercial)
assumed % imperviousness = 0
curve number for soil group 1 : 5.0000000000000000
curve number for soil group 2 : 5.0000000000000000
curve number for soil group 3 : 5.0000000000000000
curve number for soil group 4 : 5.0000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 0.50000000000000000
ROOTING DEPTH for soil group 2 : 0.50000000000000000
ROOTING DEPTH for soil group 3 : 0.50000000000000000
ROOTING DEPTH for soil group 4 : 0.50000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
```

```
-----------------------------------------------------------
Reading landuse record number 9 of 28
landuse type = 41
landuse description = Deciduous Forest
assumed % imperviousness = 0
curve number for soil group 1 : 42.000000000000000
curve number for soil group 2 : 82.000000000000000
curve number for soil group 3 : 79.000000000000000
curve number for soil group 4 : 85.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 0.90000000000000002
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 0.90000000000000002
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 10 of 28
landuse type = 42
landuse description = Evergreen Forest
assumed % imperviousness = 0
curve number for soil group 1 : 34.000000000000000
curve number for soil group 2 : 76.000000000000000
curve number for soil group 3 : 73.000000000000000
curve number for soil group 4 : 79.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.00000000000000000
ROOTING DEPTH for soil group 2 : 0.90000000000000002
ROOTING DEPTH for soil group 3 : 1.00000000000000000
ROOTING DEPTH for soil group 4 : 0.90000000000000002
ROOTING DEPTH for soil group 5 : 0.50000000000000000
```

```
-----------------------------------------------------------
Reading landuse record number 11 of 28
landuse type = 51
landuse description = Shrubland (assumed same as parkland)
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.3000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 12 of 28
landuse type = 52
landuse description = Shrubland/scrub
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.3000000000000000
ROOTING DEPTH for soil group 5 : 0.50000000000000000
```

```
-----------------------------------------------------------
Reading landuse record number 13 of 28
landuse type = 71
landuse description = Grasslands / Herbaceous (Deep-rooted ag)
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.1000000000000001
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 14 of 28
landuse type = 72
landuse description = Grasslands / Herbaceous (Deep-rooted ag)
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.1000000000000001
ROOTING DEPTH for soil group 5 : 0.50000000000000000
```

```
-----------------------------------------------------------
Reading landuse record number 15 of 28
landuse type = 73
landuse description = Grasslands / Herbaceous (Deep-rooted ag)
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.00000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.1000000000000001
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 16 of 28
landuse type = 74
landuse description = Grasslands / Herbaceous (Deep-rooted ag)
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.00000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.1000000000000001
ROOTING DEPTH for soil group 5 : 0.50000000000000000
```

```
-----------------------------------------------------------
Reading landuse record number 17 of 28
landuse type = 81
landuse description = "Pasture (assumed type pasture,
good condition)"
assumed % imperviousness = 0
curve number for soil group 1 : 39.000000000000000
curve number for soil group 2 : 77.000000000000000
curve number for soil group 3 : 74.000000000000000
curve number for soil group 4 : 80.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 1.7000000000000000
ROOTING DEPTH for soil group 2 : 1.7000000000000000
ROOTING DEPTH for soil group 3 : 1.8000000000000000
ROOTING DEPTH for soil group 4 : 1.1000000000000001
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 18 of 28
landuse type = 82
landuse description = Row Crops (Shallow-Rooted Agriculture)
assumed % imperviousness = 0
curve number for soil group 1 : 67.000000000000000
curve number for soil group 2 : 87.000000000000000
curve number for soil group 3 : 85.000000000000000
curve number for soil group 4 : 89.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 0.80000000000000004
ROOTING DEPTH for soil group 2 : 0.80000000000000004
ROOTING DEPTH for soil group 3 : 1.0000000000000000
ROOTING DEPTH for soil group 4 : 0.29999999999999999
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 19 of 28
landuse type = 90
landuse description = Woody wetlands
assumed % imperviousness = 0
curve number for soil group 1 : 34.000000000000000
curve number for soil group 2 : 76.000000000000000
curve number for soil group 3 : 73.000000000000000
curve number for soil group 4 : 79.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 20 of 28
landuse type = 91
landuse description = Forested Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 34.000000000000000
curve number for soil group 2 : 76.000000000000000
curve number for soil group 3 : 73.000000000000000
curve number for soil group 4 : 79.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 21 of 28
landuse type = 92
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 22 of 28
landuse type = 93
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 23 of 28
landuse type = 94
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 24 of 28
landuse type = 95
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 25 of 28
landuse type = 96
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 26 of 28
landuse type = 97
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 27 of 28
landuse type = 98
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
ROOTING DEPTH for soil group 5 : 0.50000000000000000
-----------------------------------------------------------
Reading landuse record number 28 of 28
landuse type = 99
landuse description = Wetland
assumed % imperviousness = 0
curve number for soil group 1 : 100.000000000000000
curve number for soil group 2 : 100.000000000000000
curve number for soil group 3 : 100.000000000000000
curve number for soil group 4 : 100.000000000000000
curve number for soil group 5 : 100.000000000000000
MAXIMUM RECHARGE for soil group 1 : 2.0000000000000000
MAXIMUM RECHARGE for soil group 2 : 0.59999999999999998
MAXIMUM RECHARGE for soil group 3 : 0.23999999999999999
MAXIMUM RECHARGE for soil group 4 : 0.12000000000000000
MAXIMUM RECHARGE for soil group 5 : 5.0000000000000000
Interception value for growing season = 0.0000000000000000
Interception value for non-growing season = 0.0000000000000000
ROOTING DEPTH for soil group 1 : 2.2999999999999998
ROOTING DEPTH for soil group 2 : 2.2999999999999998
ROOTING DEPTH for soil group 3 : 2.2999999999999998
ROOTING DEPTH for soil group 4 : 2.2999999999999998
```

```
ROOTING DEPTH for soil group 5 : 0.50000000000000000
>> WATER_CAPACITY ARC_GRID input\water_cap.grd
Populating water capacity grid
Water capacity grid MINUMUM VALUE: 1.1999679999999999
Water capacity grid MAXIMUM VALUE: 3.5999550000000000
>> SM T-M std_input\soil-moisture-retention-extended.grd
Configuring soil-moisture options
Reading std_input\soil-moisture-retention-extended.grd for
soil-moisture retention information
Read in the soil-moisture retention file with the following
dimensions:
iNX = 35
iNY = 408
iDataType = 1
rX0, rX1 = 0.50000000000000000 17.500000000000000
rY0, rY1 = -40.700000000000003 0.0000000000000000
>> INITIAL_SOIL_MOISTURE CONSTANT 100
Populating initial moisture grid
>> INITIAL_SNOW_COVER CONSTANT 0
Reading initial snow cover
>> RUNOFF C-N DOWNHILL
Configuring runoff options
Configuring the curve number runoff model
Configuring the downhill runoff procedure
>> ET HARGREAVES 41.13 41.24
Configuring ET options
Configuring Hargreaves PET model
>> FRACTURE_INDEX ARC_GRID input\NewDEMIntersection.grd
Populating fracture index grid
Summary of integer grid data values
245094 grid cells have value: 0
246 grid cells have value: 1
Total number of grid cells: 245340
Total number of grid cells with value [0-256]: 245340
>> STREAM_INTERACTIONS 1 1.0 0.5
>> ELEVATION ARC_GRID input\DEM_Feet.grd
Reading elevation grid
>> ELEVATION_ADJUSTMENT 7266.0 0.005 0.0035 9999
>> OUTPUT_OPTIONS RECHARGE NONE BOTH BOTH
Setting the output options (daily, monthly, annual)
Options have been set for: RECHARGE
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
```

```
>> OUTPUT_OPTIONS SM_APWL NONE NONE NONE
Setting the output options (daily, monthly, annual)
Options have been set for: SM_APWL
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
>> OUTPUT_OPTIONS SNOWCOVER NONE BOTH NONE
Setting the output options (daily, monthly, annual)
Options have been set for: SNOWCOVER
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
>> OUTPUT_OPTIONS RUNOFF_OUTSIDE NONE NONE GRAPH
Setting the output options (daily, monthly, annual)
Options have been set for: RUNOFF_OUTSIDE
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
>> OUTPUT_OPTIONS ACT_ET NONE NONE NONE
Setting the output options (daily, monthly, annual)
Options have been set for: ACT_ET
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
>> OUTPUT_OPTIONS POT_ET NONE NONE NONE
Setting the output options (daily, monthly, annual)
Options have been set for: POT_ET
STAT_INFO(iVarNum)%iAnnualOutput: 0
STAT_INFO(iVarNum)%iMonthlyOutput: 0
STAT_INFO(iVarNum)%iDailyOutput: 0
>> OUTPUT_FORMAT ARC_GRID
Selecting ARC output format
>> SOLVE Bmet_data_1980.txt
Solving the model
model.f95: calling model_InitializeSM
model.f95: runoff_InitializeCurveNumber
Initializing the base curve numbers
CN minimum: 5.0000000000000000
CN maximum: 100.000000000000000
returning from base curve number initialization...
model.f95: model_InitializeET
model_InitializeET :
filename = Bmet_data_1980.txt
Initializing Hargreaves PET model
```

```
model.f95: model_InitialMaxInfil
*******************************************************
NOTE: Read in downhill routing information from existing
swb_routing.bin file
*******************************************************
Opening time series file: Bmet_data_1980.txt
Skipping: MONTH DAY YEAR MNTP PRCP RH TMAX TMIN WIND MIN-RH PSS
finished calcs for: 1/1980
finished calcs for: 2/1980
finished calcs for: 3/1980
finished calcs for: 4/1980
finished calcs for: 5/1980
finished calcs for: 6/1980
finished calcs for: 7/1980
finished calcs for: 8/1980
finished calcs for: 9/1980
finished calcs for: 10/1980
finished calcs for: 11/1980
finished calcs for: 12/1980
CALCULATING ANNUAL SUMS for FRACTURE_RECHARGE
FRACTURE_RECHARGE 0.0000 0.0514 900.0225
CALCULATING ANNUAL SUMS for STREAM_INFLOW
STREAM_INFLOW 0.0000 0.0000 0.0000
```