5. Watershed Model

This section of the report describes the role of the watershed model in COHYST 2010. The section focuses on the processes and application of the current version of the model. It discusses the development, general methodologies, and how this model was applied across the project domain. Select summaries of the water balance, including pumping from groundwater, recharge depths, and runoff contributions to streamflow are included in the results section. Three appendixes have also been developed:

1. **Appendix 5-A** provides more detailed information on the construction of the Regional Soil Water Balance Model which is a major component of the watershed model;
2. **Appendix 5-B** provides more detailed information on the specific files and directory structure needed to make a model run; and
3. **Appendix 5-C** provides more detailed information on how to execute the watershed model independently of the other models comprising COHSYT 2010.

The primary purpose of the watershed model is to calculate a monthly water budget for every 160 acre model cell and monthly time period. The water budget is represented by two inputs - precipitation (P) and (where appropriate) applied irrigation (I) – which are then partitioned into four outputs - evapotranspiration (ET), deep percolation (DP), runoff (RO) and soil refill (soil water content or ΔSWC). DP is an input to the groundwater model and RO is an input to the surface water model. The model also is used to compile data on municipal, industrial and other non-irrigation pumping and returns.

For any given monthly precipitation, the model results are a function of soils and land use, and reflect changes over time in land use, irrigation method, and source of irrigation supply. The model is considered appropriate because its outputs have led to a reasonably well calibrated integrated model, and are consistent with the limited metering data for irrigation wells.

5.1 Model components

The watershed model has four components: a climate model; a soil water balance model; spatial and temporal distribution routines; and a regionalized soil water balance model. The components are executed sequentially to produce the files used by the surface water operations and groundwater models. Existing estimates of municipal, industrial, and other non-irrigation pumping and returns are also formatted within these components for use in the other integrated models (primarily for the groundwater model). The following sections provide additional details about each component.

5.1.1 Climate model

Weather data are the primary input into the watershed model, while the remaining parts of the model reflect how the system reacts to the weather conditions. Precipitation, temperature, and reference ET are the necessary weather data inputs to the soil water balance model (discussed below). Precipitation and temperature are readily available from weather stations; however, reference ET must be calculated. There are multiple ways to calculate reference ET depending upon the breadth of information available. The watershed model uses two approaches: the ASCE standardized Penman-Montieth method, and a modified Hargreaves Samani method. The Penman-Montieth approach is considered to be more accurate, however, the method requires several meteorological readings (temperature, wind speed, relative humidity, and net radiation) to calculate reference ET. The Hargreaves-Samani approach, on the other hand, requires only the temperature measurements to estimate reference ET; however, the simplicity of this approach is evident in its results.

Up until the last couple of decades, the expanded weather data needed for the Penman-Montieth method were not readily collected. The dataset is limited both by the timeframe and the number of stations collecting the expanded information. Within Nebraska, climate stations which collect the needed information for a Penman-Montieth based reference ET calculation are part of the Automated Weather Data Network (AWDN) and are maintained by the High Plains Regional Climate Center (HPRCC). With the temporal domain of the COHYST model extending more than half a century in the past, using the Penman-Montieth approach alone was unfeasible. Rather a calibrated Hargreaves-Samani approach was employed. Using available AWDN records, reference ET values using the Penman-Monteith method were computed and compared to the reference ET values computed using the Hargreaves-Samani methodology. A relationship was developed between the two estimates and the geographical location of the weather station. The relationship developed geographically linked coefficients for the Hargreaves-Samani method, which could be applied for the entire period of record. This allows the use of the National Weather Service and Cooperative (NWS/Coop) network of weather stations. The NWS/Coop stations usually collect less data but have been collecting the data for a longer period and a more diverse geographic range. Thus the network of stations is relatively more dense, refining the scale of influence any individual station exhibits.

5.1.2 Soil water balance model

Soils in the study area include eolian sands, alluvium, loess, and glacial till. The study area is dominated by rolling hills with major valleys along rivers and creeks with the northern edge of the model merging into the Nebraska Sandhills. Land use is often directly tied to soil type. Both the sandhills and steeper upland areas are well suited to be used as rangeland. The more gently sloping areas and deeper loamy soils are well suited for crop production. To account for this variability, the watershed model used an approach sensitive to key soil properties (water holding capacity, hydrologic soil group) and made use of annually updated land use files which reflect the area's development.

As land use has changed over the course of time in this area, so too have the related production practices. As technology has advanced through time, both the types of crops and the methods by which given crops are produced have evolved. Of particular importance to this study are changes which have occurred related to irrigation. The use of groundwater as compared to surface water as a source for irrigation has increased. The methods by which irrigation water is applied to crops have changed and become generally more efficient in terms of the amount of water applied compared to the amount of water consumed by crops. The methods employed by the watershed model attempted to capture the major effects of these changes by trending the results of a soil water balance model developed using different production practice inputs and trending application efficiencies over time.

The soil water balance model used by the watershed model is called CropSim. CropSim is a water driven point source model which encompasses weather data in combination with representative system characteristics of the area (crop phenology, soils, management, and irrigation) to estimate the daily soil water balance. It was developed by Dr. Derrel Martin with the University of Nebraska-Lincoln's Department of Biological Systems Engineering to aid in the estimation of ET, DP, and RO which occurs on a range of cropped and naturally vegetated systems in primarily agricultural regions. This report provides a short overview of the mechanics of the CropSim model.

CropSim begins with a known amount of water in the soil profile (SWC_{i-1}). Precipitation from the weather data is applied. The portion of the precipitation which infiltrates into the soil is determined with the remainder going to RO. This is accomplished using a modified curve number approach with considerations for soil moisture content and crop residue on the soil surface. The infiltrated precipitation is used to fill the top soil layer, and then continues to fill each subsequent layer until the infiltrated precipitation is assigned to a layer.

Next, the amount of water in the soil is calculated. For irrigated simulations, if the soil water content drops below a management specified level of depletion this triggers an irrigation event. A gross amount of water is applied with a net amount of irrigation infiltrating into the soil profile. The net irrigation fills the top layers and continues to fill subsequent layers until the entire depth of net irrigation is assigned.

Vegetative growth is simulated from a specified planting date, progressing through the phenologic development tracked by growing degree days. The development of the plant extends the root system deeper into the soils allowing for greater access to soil moisture. At the same time, the development of the canopy expands the transpiration potential of the crop. Transpiration demands are determined using Basal Crop Coefficients. Next, the amount of water in the root zone is determined. If sufficient water is available in the root zone to meet the transpiration demands, the water is transpired; otherwise, the crop is stressed and a reduced rate of transpiration is determined. Evaporation from the soil surface is also determined. The combination of the transpired and evaporated water is removed from the root zone as ET.

Finally, the amount and distribution of water in the soil profile is determined. If water in a soil layer exceeds field capacity, the water is moved to the ensuing layers. If no room exists in the profile below, the water will drain as DP. These steps are used to calculate the ending soil water content (SWC_i) as shown by Equation 1. The daily calculations are compiled and written to monthly summaries.

$$SWC_i = SWC_{i-1} + P + I_{net} - ET - DP - RO \tag{1}$$

SWC_i	Ending soil water content (in) {at time step *i*}
SWCi-1	Beginning soil water content (in) {at time step *i-1*}
P	Precipitation (in)
Inet	Net applied irrigation (in)}
ET	Evapotranspiration (in)
DP	Deep percolation (in)
RO	Runoff (in)

Long term simulations were made subjecting a variety of vegetation types to the climate conditions measured at selected weather stations. This process is repeated for a selection of crops (7), soil classes (20), and irrigation methods (irrigated and non-irrigated) at each weather station. Furthermore, to capture the changing effect of improved technology and farming practices, three sets of runs were created. The set of runs represent tillage practices common in 1949, 1973, and 1998 respectively.

5.1.3 Spatial and temporal distribution

The next portion of the watershed model is to interpolate between the points simulated by the soil water balance model; both spatially and temporally. First, the results from CropSim were time trended between each of the three tillage scenarios using linear interpolation.

The second step was to spatially interpolate the time trended results to the geographic extents of the watershed model domain. The watershed model uses the groundwater model grid and selection of weathers stations dispersed throughout and surrounding the grid. First, for each cell the three nearest weather stations and their distance to the cell centroid was established. Next, each cell within the grid was assigned a soil class conforming to the soil classes from the CropSim model based upon the local dominant soil type. Finally, the water balance parameters are interpolated between the three nearest weather stations using an inverse weighted distance technique and the assigned soil class. The results are a set of files depicting the water balance parameters (P, DP, RO, ET, and Net Irrigation Requirement (NIR)) for each combination of crop and irrigated condition (non-irrigated (dryland) or irrigated).

5.1.4 Regional soil water balance model

The primary purpose of the Regional Soil Water Balance (RSWB) model is to develop estimates of pumping and recharge, then create the appropriate '.WEL' and '.RCH' files for inclusion in the groundwater model. To accomplish this, the RSWB reads in precipitation values, estimates irrigation demand, applies irrigation, and partitions the total applied water (precipitation plus irrigation) while adjusting for non-idealized conditions. The partitioning includes apportioning field runoff between stream flow contributions, recharge, and ET. In addition, the RSWB model is capable of incorporating into the '.WEL' and '.RCH' files externally developed estimates (i.e. estimates developed outside of the RSWB model) of pumping and recharge.

5.2 Key model inputs

Model grid. For the RSWB model, the COHYST groundwater flow model grid was adopted. The grid consists of 138,600 cells of 160 acres organized in 275 rows and 504 columns. Within this grid there are 77,339 active cells. Of these cells, there are 239 cells in the vicinity of Lake McConaughy in which the process to estimate the recharge rate has been transferred to the groundwater model.

Soils. Soil characteristics influence how crops respond to climatic and management conditions. Soils can be thought of acting as miniature reservoirs that store and release water for vegetative growth (ET), allow the water to drain as recharge, or restrict the water from infiltrating thus resulting in runoff.

Within the RSWB model, a cell's assigned soil type served as a link to the results from the soil water balance model. To build this link, each cell was assigned a CropSim soil class. Assigned soil classes were accomplished in a three-step process. The first step was to identify the soils present in the model domain. STATSGO2, from the Natural Resources Conservation Service (NRCS), is a database which contains the spatial distribution of soil (**Figure 5.2-1**).

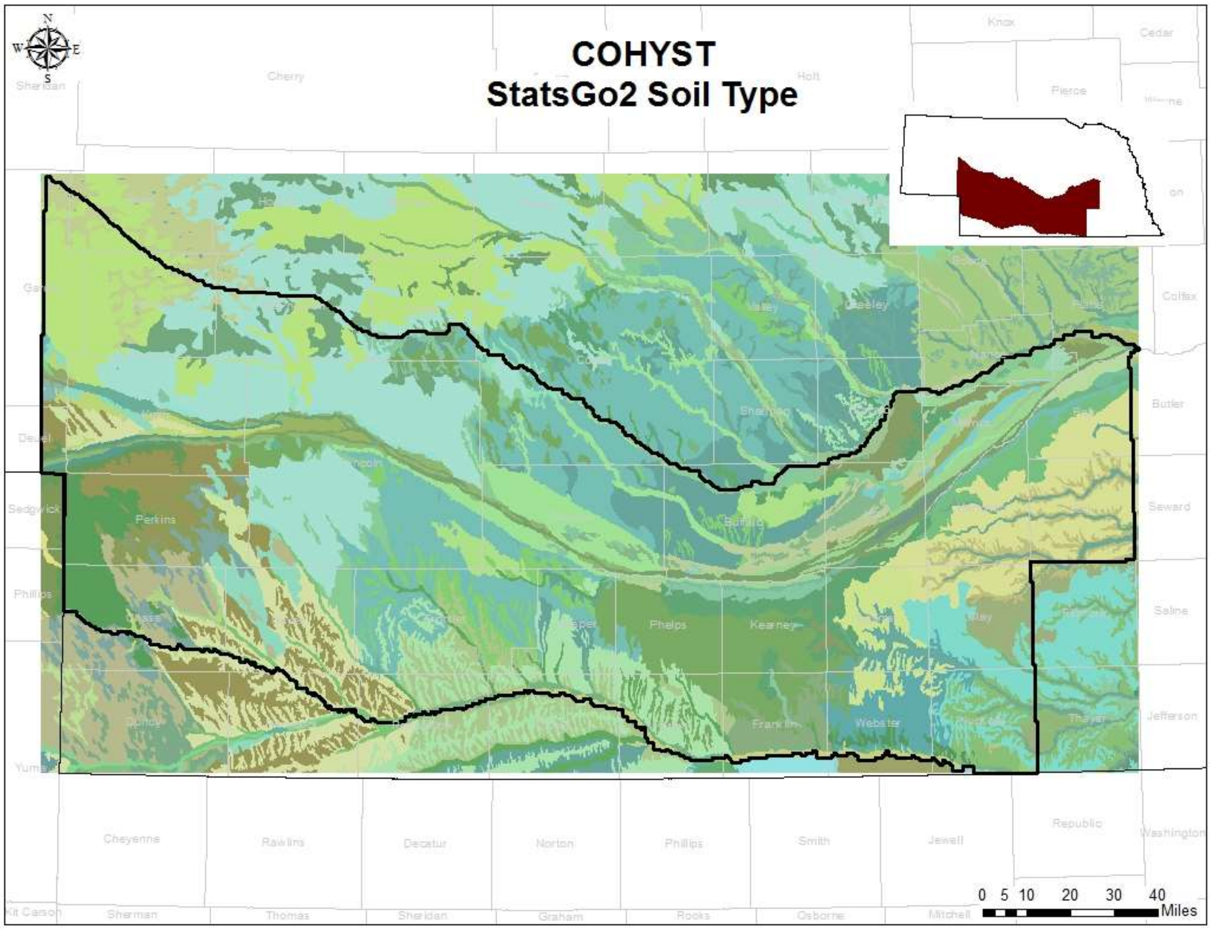

Figure 5.2-1. STATSGO2 soil coverage within the model area.

The STATSGO2 soils classification includes numerous designations within the modeled area. To simplify the modeling process, the soils were grouped together with soils which exhibit similar properties. To maintain consistency with the modeling practices used within CropSim, three soil characteristics were used to develop a three-digit soil code naming convention: water holding capacity, hydrologic soil group, and distance to groundwater. The first digit in the soil code represents water holding capacity in terms of quarter inches of holding capacity per foot of soil (e.g. a 400 series soil is considered to have a holding capacity of 1 inch of water per foot of soil). The second digit represents the hydrologic soil group (e.g. the number 1 equates to hydrologic soil group 'A'; 2 equates to hydrological soil group 'B'; 3 equates to hydrologic soil group ‘C’; and 4 equates to hydrologic soil group ‘D’). The final digit represents expected depth to groundwater (the number 1 equates to expected depths to six feet; 2 equates to expected depths greater than six feet). This naming convention results in 20 CropSim soil types within the COHYST 2010 modeling domain (**Figure 5.2-2**). Note that code 999 is used to represent open water.

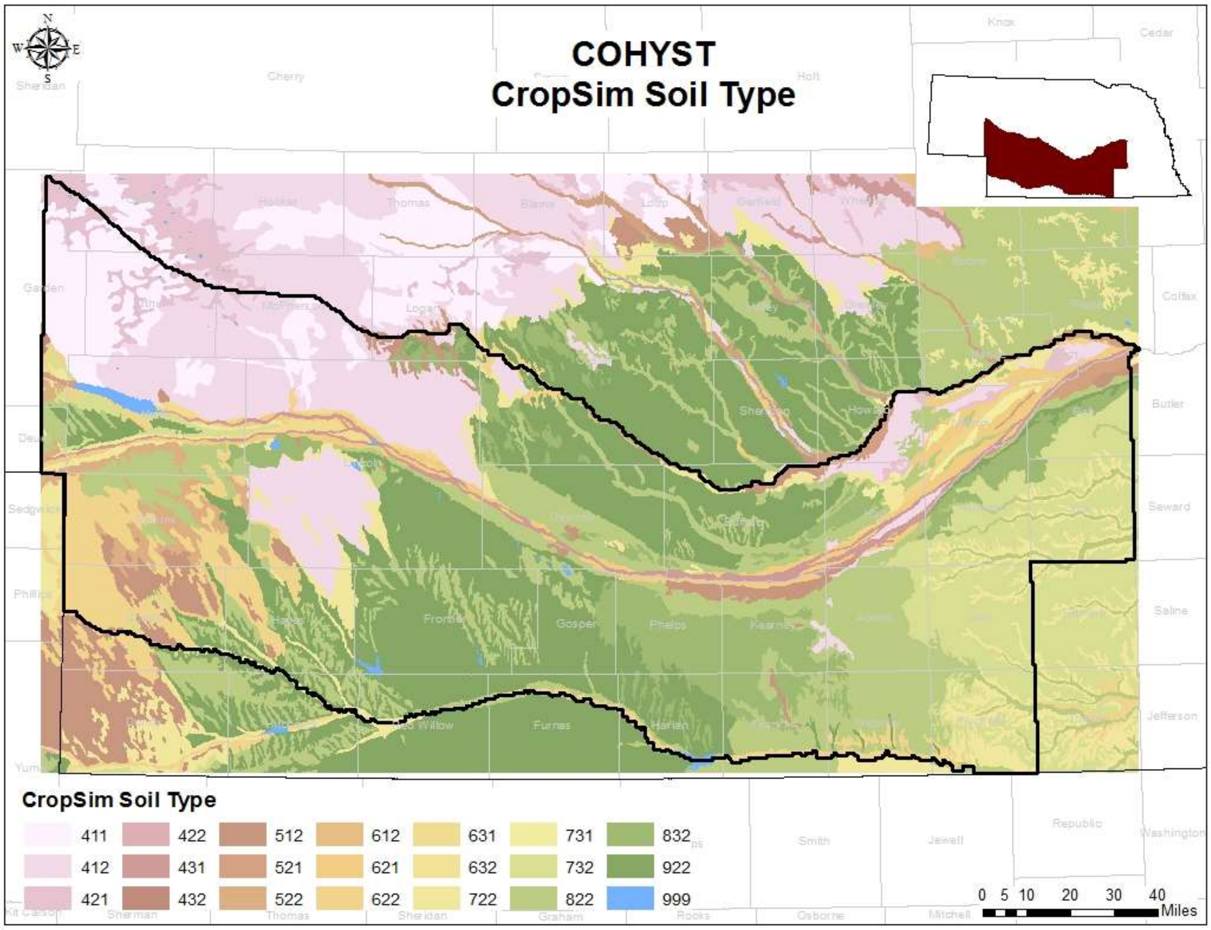

Figure 5.2-2. CropSim soil type coverage within the model area derived from soil properties recorded in the STATSGO2 soils database.

Next the predominant soil type within each cell was determined. The CropSim soils map was overlaid with the model grid and the area of each soil type within a given cell was calculated. The soil type covering the largest area within that cell was identified and assigned to that cell.

As **Figure 5.2-3** shows, this did result in a slightly more pixelated map; however, all 20 of the CropSim soil types derived from the STATSGO2 soils in the model area remain.

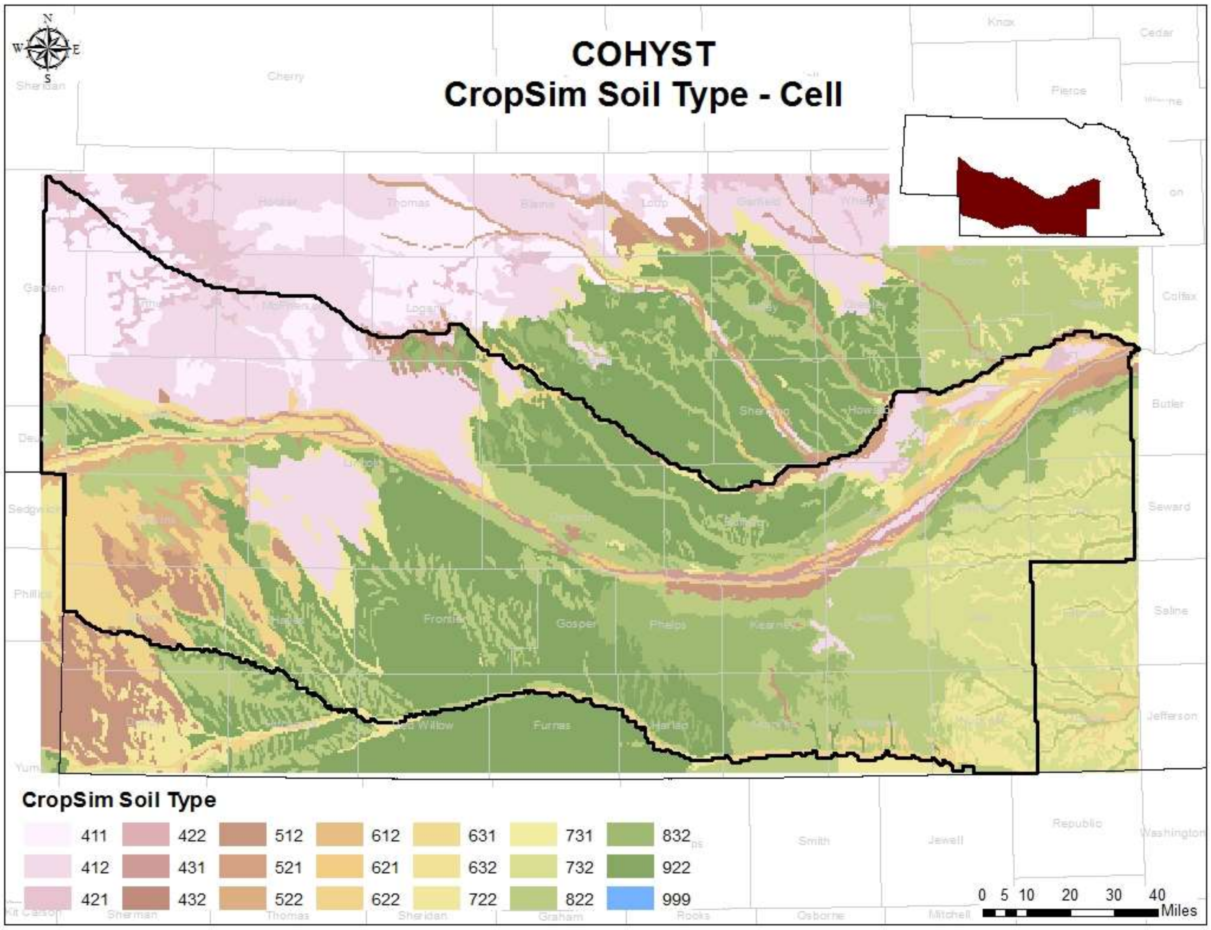

Figure 5.2-3. CropSim soil type assigned to each 160 acre model grid cell.

Climate. Climatic conditions also exhibit a strong influence on vegetative growth; and thus, are a significant input into the CropSim model. Weather data was collected from 77 weather stations in and around the model domain (**Figure 5.2-4**). Within the model domain the average precipitation ranges from 16” in the west to roughly 26” in the east. The weather stations are listed in **Table 5.2-1**.

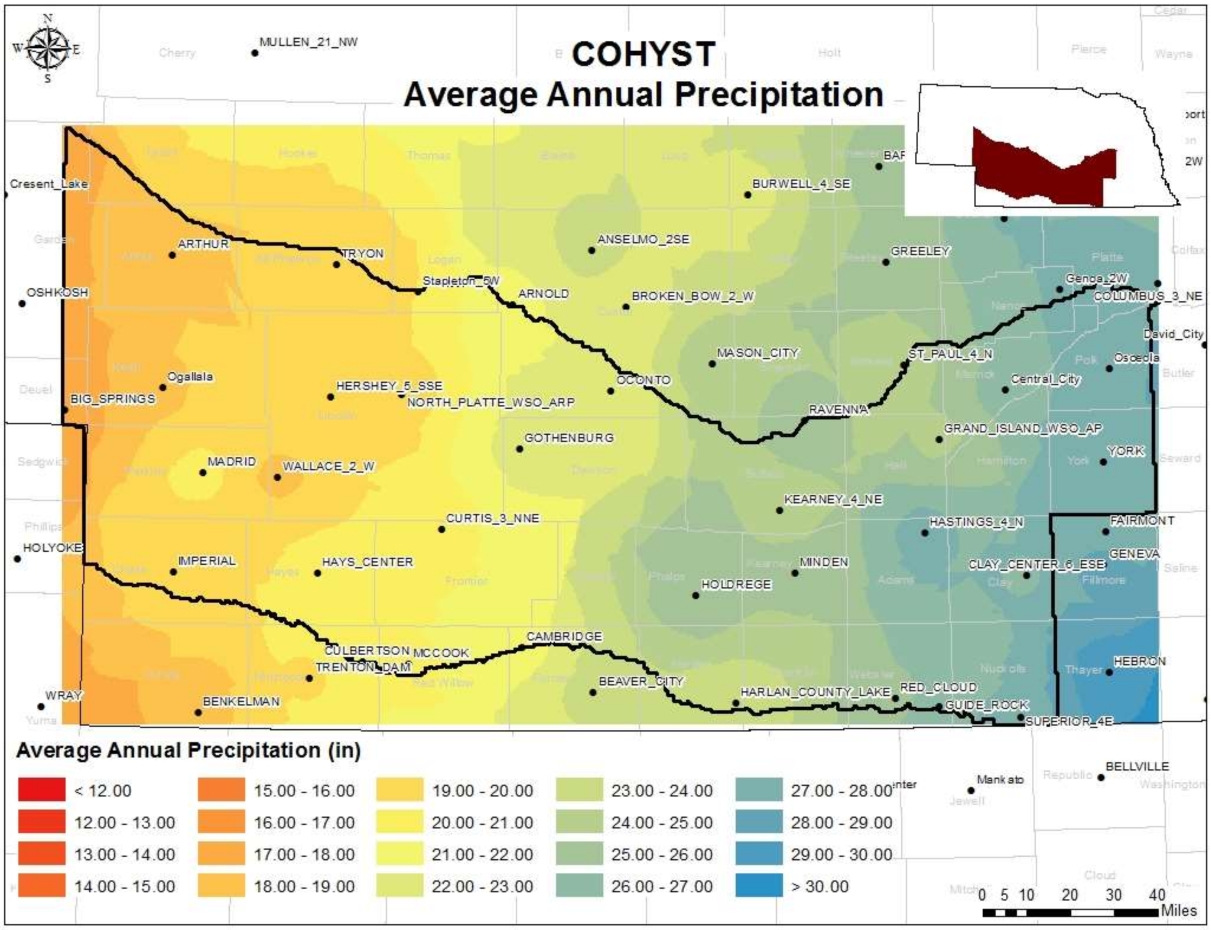

Figure 5.2-4. Location of the weather stations and average annual precipitation for the COHYST model domain.

Table 5.2-1. NWS weather stations used in the COHYST model.

Index	Station	State	Station Code	NWS Code	Latitude	Longitude	Elevation
1	Ainsworth	NE	AINS	c250050	42.55	-99.86	2,510
2	Albion	NE	ALBI	c250070	41.69	-98.00	1,790
3	Alliance 1 WNW	NE	ALI1	c250130	42.11	-102.90	3,994
4	Anselmo 2 SE	NE	ANSE	c250245	41.60	-99.83	2,604
5	Arnold	NE	ARNO	c250355	41.42	-100.18	2,718
6	Arthur	NE	ARTH	c250365	41.57	-101.69	3,500
7	Atkinson	NE	ATKI	c250420	42.51	-99.03	2,090
8	Atwood 2 SW	KS	ATW2	c140439	39.80	-101.04	2,934
9	Bartlett 4 S	NE	BART	c250525	41.87	-98.55	2,219
10	Beaver City	NE	BEAV	c250640	40.13	-99.83	2,160
11	Benkelman	NE	BENK	c250760	40.05	-101.54	3,025
12	Big Springs	NE	BIGS	c250865	41.05	-102.15	3,678
13	Bellville	KS	BLVK	c140682	39.82	-97.64	1,535

Table 5.2-1. NWS weather stations used in the COHYST model.

Index	Station	State	Station Code	NWS Code	Latitude	Longitude	Elevation
14	Broken Bow 2 W	NE	BROK	c251200	41.41	-99.68	2,500
15	Burwell 4 SE	NE	BURW	c251345	41.78	-99.14	2,176
16	Cambridge	NE	CAMB	c251415	40.28	-100.14	2,239
17	Clay Center 6 ESE	NE	CLY6	c251680	40.50	-97.94	1,734
18	Central City	NE	CNTC	c251560	41.12	-98.01	1,695
19	Columbus 3 NE	NE	COLU	c251825	41.46	-97.33	1,450
20	Crete	NE	CRET	c252020	40.62	-96.95	1,435
21	Cresent Lake	NE	CRSC	c252000	41.76	-102.44	3,820
22	Culbertson	NE	CULB	c252065	40.23	-100.83	2,614
23	Curtis 3 NNE	NE	CURT	c252100	40.67	-100.49	2,721
24	David City	NE	DAVI	c252205	41.25	-97.13	1,610
25	Fairbury	NE	FAIB	c252820	40.07	-97.17	1,350
26	Fairmont	NE	FAIM	c252840	40.64	-97.59	1,640
27	Geneva	NE	GENE	c253175	40.53	-97.60	1,630
28	Genoa 2 W	NE	GNO2	c253185	41.45	-97.76	1,590
29	Gothenburg	NE	GOTH	c253365	40.94	-100.15	2,585
30	Grand Island WSO Airport	NE	GRAN	c253395	40.96	-98.31	1,840
31	Greeley	NE	GREE	c253425	41.55	-98.53	2,020
32	Guide Rock	NE	GUID	c253485	40.07	-98.33	1,635
33	Harlan County Lake	NE	HARL	c253595	40.09	-99.21	2,000
34	Hastings 4 N	NE	HAST	c253660	40.65	-98.38	1,938
35	Hays Center	NE	HAYC	c253690	40.52	-101.03	3,045
36	Hebron	NE	HEBR	c253735	40.17	-97.59	1,480
37	Hershey 5 SSE	NE	HERS	c253810	41.11	-100.98	2,952
38	Holdrege	NE	HOLD	c253910	40.45	-99.38	2,320
39	Holyoke	CO	HOLY	c054082	40.55	-102.34	3,780
40	Idalia 4 NNE	CO	IDAL	c054242	39.70	-102.29	3,965
41	Imperial	NE	IMPE	c254110	40.52	-101.66	3,280
42	Kearney 4 NE	NE	KEAR	c254335	40.73	-99.01	2,130
43	Madison 2 W	NE	MADI	c255080	41.83	-97.45	1,580
44	Madrid	NE	MADR	c255090	40.85	-101.54	3,200
45	Mankato	KS	MANK	c144982	39.79	-98.20	1,755
46	Mason City	NE	MASO	c255250	41.22	-99.30	2,260
47	McCook	NE	MCCO	c255310	40.22	-100.63	2,565
48	Minden	NE	MIND	c255565	40.52	-98.95	2,160
49	Mullen 21 NW	NE	MULL	c255702	42.25	-101.34	3,460

Table 5.2-1. NWS weather stations used in the COHYST model.

Index	Station	State	Station Code	NWS Code	Latitude	Longitude	Elevation
50	Norton 9 SSE	KS	NORT	c145856	39.74	-99.84	2,360
51	North Platte WSO Airport	NE	NPLA	c256065	41.12	-100.67	2,778
52	Norfork Karl Stefan Airport	NE	NRFA	c255995	41.99	-97.44	1,551
53	Oakdale	NE	OAKD	c256135	42.07	-97.97	1,710
54	Oberlin 1 E	KS	OBER	c145906	39.82	-100.53	2,610
55	Oconto	NE	OCON	c256167	41.13	-99.75	2,578
56	Ogallala	NE	OGAL	c256200	41.13	-101.72	3,230
57	O'Neill	NE	ONEI	c256290	42.46	-98.66	1,990
58	Osceola	NE	OSCE	c256375	41.18	-97.55	1,640
59	Oshkosh	NE	OSHK	c256385	41.40	-102.35	3,390
60	Purdum	NE	PURD	c256970	42.07	-100.25	2,690
61	Ravenna	NE	RAVE	c257040	41.03	-98.90	2,050
62	Red Cloud	NE	REDC	c257070	40.10	-98.52	1,720
63	Sedgwick 5 S	CO	SDG2	c057515	40.86	-102.52	3,990
64	Seward	NE	SEWA	c257715	40.90	-97.09	1,445
65	Smith Center	KS	SMIT	c147542	39.78	-98.78	1,780
66	Stapleton 5 W	NE	STAP	c258133	41.46	-100.60	2,990
67	Saint Francis	KS	STFR	c147093	39.77	-101.81	3,362
68	St Paul 4 N	NE	STPA	c257515	41.21	-98.46	1,796
69	Superior 4 E	NE	SUPE	c258320	40.03	-97.98	1,620
70	Trenton Dam	NE	TRED	c258628	40.17	-101.06	2,810
71	Tryon	NE	TRYO	c258650	41.55	-100.96	3,247
72	Valentine National Wildlife Refuge	NE	VALG	c258755	42.57	-100.69	2,930
73	Wallace 2 W	NE	WALL	c258920	40.84	-101.21	3,100
74	Wayne	NE	WAYN	c259045	42.24	-97.01	1,465
75	Wray	CO	WRAY	c059243	40.06	-102.22	3,680
76	York	NE	YORK	c259510	40.87	-97.59	1,610
77	Yuma	CO	YUMA	c059295	40.12	-102.72	4,140

Daily records of precipitation, maximum temperature, and minimum temperature were downloaded from the HPRCC for the historic period of record. The weather data was reviewed for completeness and reliability. Following the quality control efforts, the information was run through the climate model and prepared into ‘.WEA’ files for use in the CropSim model.

Water balance parameters. The weather data from each station was run through the CropSim Model to simulate the water balance for each crop, soil and irrigation practice as described in Section 5.1.2. The spatial and temporal distribution model, in conjunction with the soil distribution, was used to distribute the water balance results of the CropSim model to each cell in the model grid. The process created annual files for each water balance parameter (P, NIR, ET, DP, and RO) for each combination of crop and irrigation method. **Figure 5.2-5** represents this process by showing the average annual NIR for corn. The image depicts the influence of both weather data and soil class by mimicking the patterns in **Figure 5.2-4** and **Figure 5.2-3** respectively.

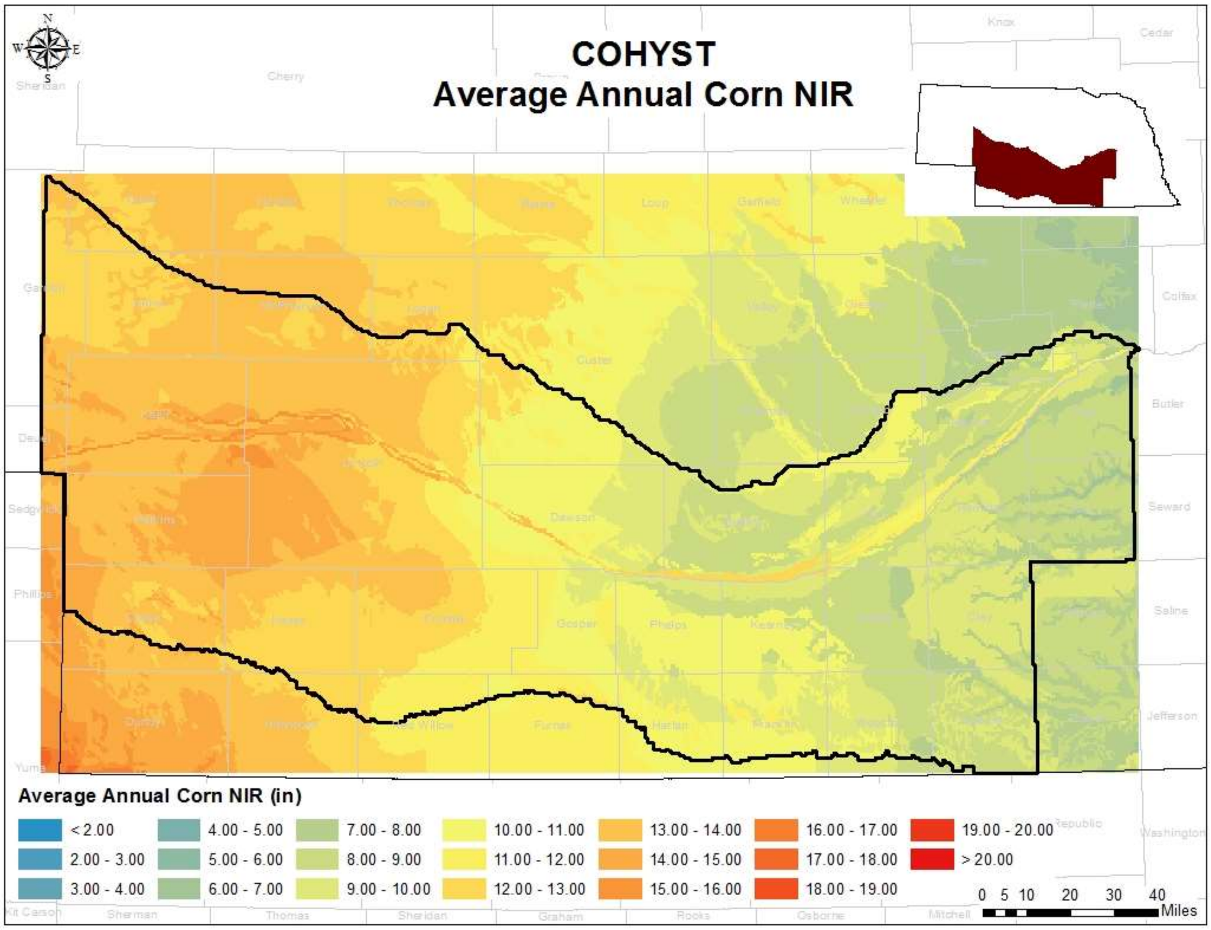

Figure 5.2-5. Average annual net irrigation requirement for corn within the COHYST model domain.

Land use. Land use inputs specify the types of crops being grown in the watershed; as well as if they are being irrigated and from which source (dryland, groundwater only, surface water only, or comingled). This definition is used to determine the initial water balance parameters and scale the point results to the field level. Land use was developed by the Nebraska DNR on a cell basis. The area within each cell was summed based upon the combination of crop coverage and irrigation source. The balance of land was assigned as dryland pasture. **Figure 5.2-6** shows the development of irrigation over the modeled period.

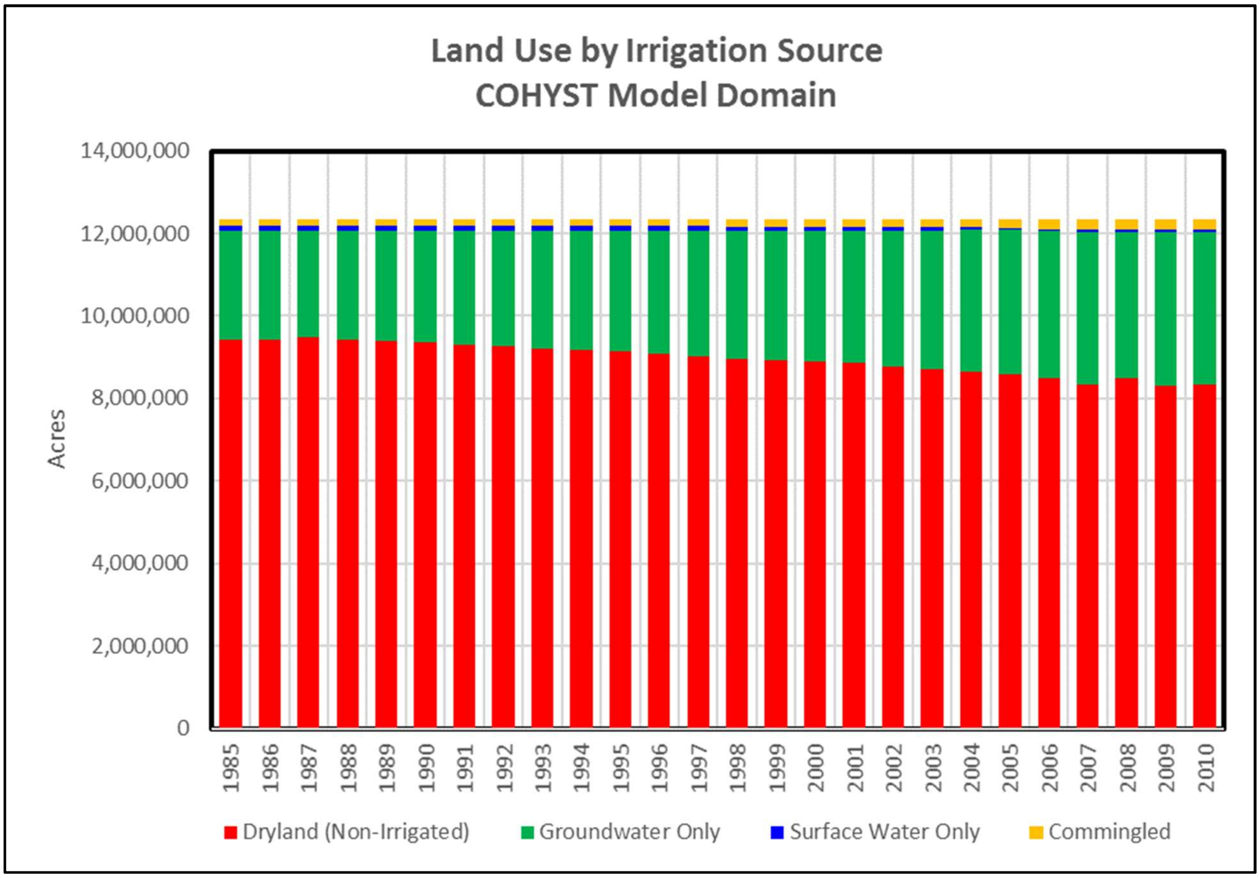

Figure 5.2-6. Development of irrigated acres within the COHYST model domain.

Model regions. The RSWB model employs input regions to aid in the spatial calibration of the model. The input regions allow for adjustment to sub-areas, independent of the rest of the model domain, to reflect significant localized conditions. The RSWB model uses three types of input regions: surface water irrigation districts; runoff zones; and coefficient zones.

Surface Water Irrigation Districts. Surface water irrigation districts represent collections of irrigated lands which have defined water rights and collectively extract water from one or more points on the river. The RSWB uses the collection definitions to amass estimates of demands for surface water irrigation and to distribute surface water deliveries from the headgate to the fields.

There are currently 26 surface water irrigation districts in the Platte and Republican River basins within the active model domain (**Figure 5.2-7**). Fifteen of these irrigation districts, which take water from the Platte River or its tributaries downstream from Lake MCConaughy, are represented in the surface water operations model. The remaining 11 districts, located either in the Republican River basins or upstream of Lake McConaughy, are not represented in the surface water operations model. A complete list of the irrigation districts in the model is shown in **Table 5.2-2**.

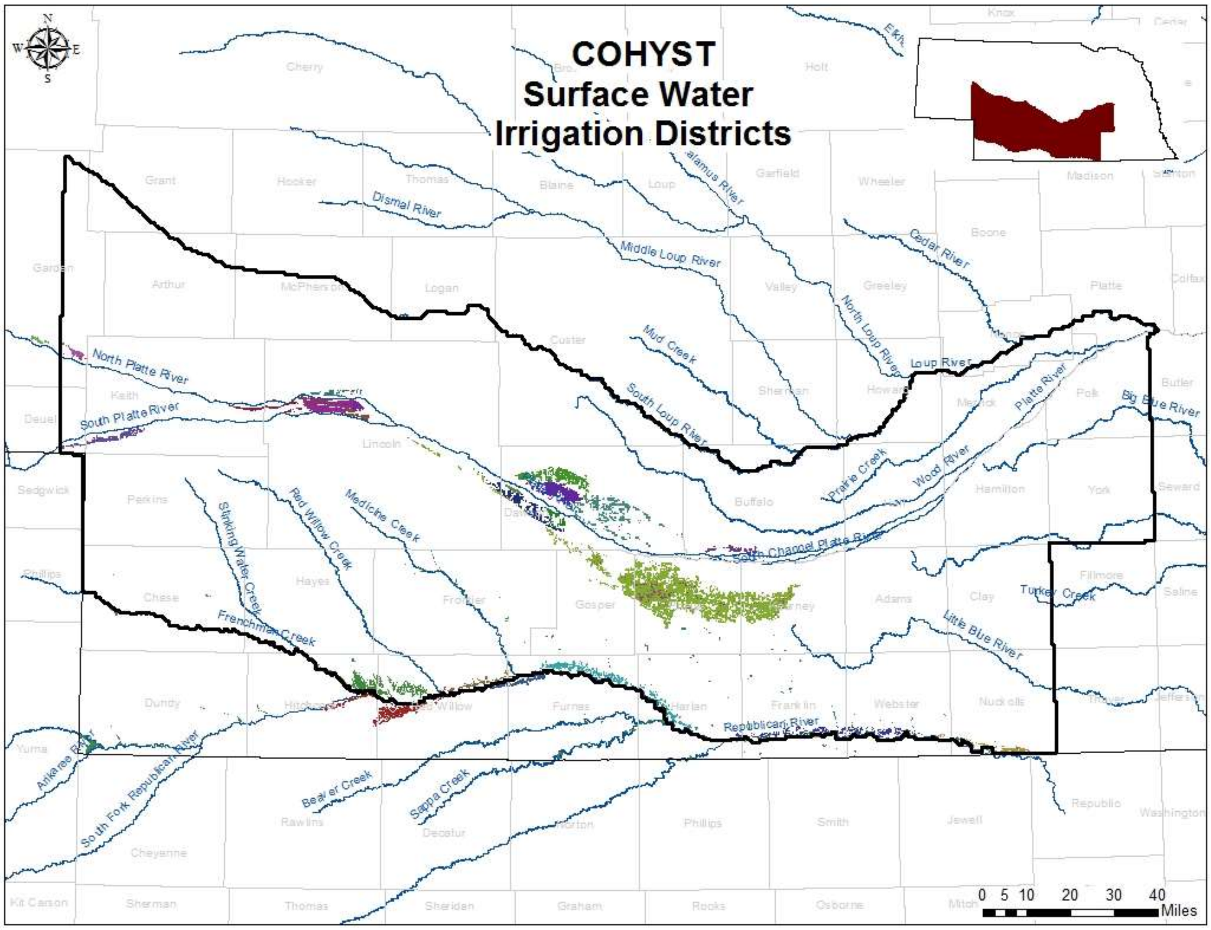

Figure 5.2-7. Surface water irrigation districts in the COHYST model area.

The canals fed by the Tri-County Canal (Phelps, Loomis, E65, E67, and the Supply Canal) are all grouped in The Central Nebraska Public Power and Irrigation District. To simplify viewing results and evaluating modeling scenarios by canal as part of the COHYST 2010 effort, the irrigated lands of The Central Nebraska Public Power and Irrigation District are further broken down into a series of sub-districts (**Figure 5.2-8**).

Of the 15 districts in the surface water operation model, the demands and supplies are passed between the RSWB and the surface water operations model for 14. For the Kearney canal, the water demand for power production dwarfs the irrigation demand for agriculture. Therefore, during the modeling process it is assumed that the supply to agricultural lands fed by the Kearney canal is sufficient to meet demands.

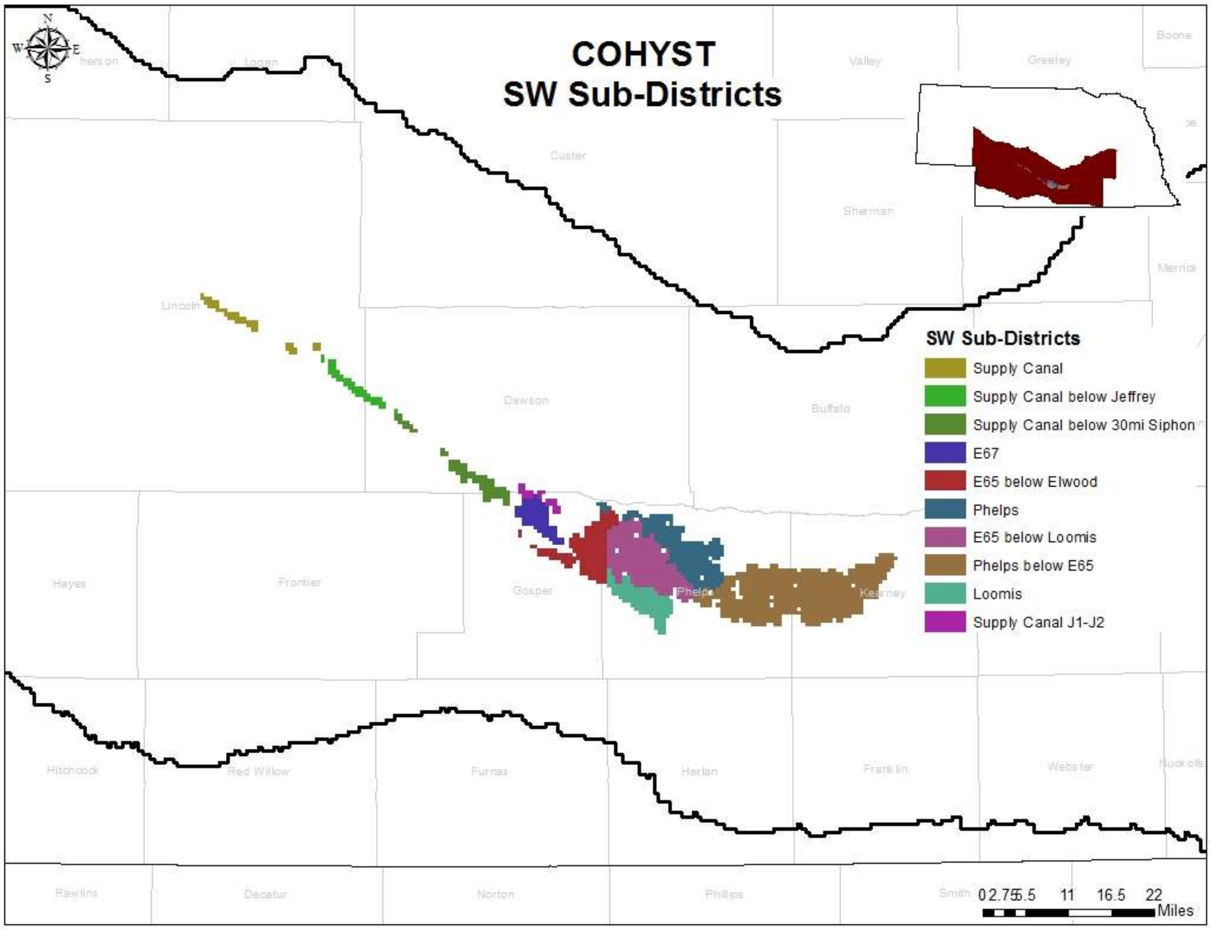

Figure 5.2-8. Surface water irrigation sub-districts within The Central Nebraska Public Power and Irrigation District

Table 5.2-2. Surface water irrigation districts

Index	Surface Water District Identifier	Canal Name
1	5	Birdwood Canal†
2	6	Blue Creek Canal
3	8	Cambridge Canal
4	12	Central Nebraska Public Power and Irrigation District†
5	13	Cody-Dillon Canal†
6	16	Cozad Canal†
7	17	Culbertson Canal
8	18	Dawson County Canal†
9	22	Franklin Canal
10	23	Franklin Pump
11	26	Gothenburg Canal†
12	27	Graf Canal
13	28	Hooper Canal
14	29	Kearney Canal

Table 5.2-2. Surface water irrigation districts

Index	Surface Water District Identifier	Canal Name
15	30	Keith-Lincoln Canal†
16	38	Naponee Canal
17	40	North Platte Canal†
18	42	Orchard-Alfalfa Canal†
19	45	Paxton-Hershey Canal†
20	46	Private Pumpers
21	48	Red Willow Canal
22	50	Six-Mile Canal†
23	51	Suburban Canal†
24	52	Superior Canal
25	53	Thirty-Mile Canal†
26	55	Western Canal†

†Canals included in the irrigation volume exchange with the surface water operations model.

Runoff Zones. Runoff zones represent a delineation of the model domain by selected drainage basins. These areas consist of the land area which drains to a specific point designated by a stream gauge. The RSWB model consists of 37 runoff zones in the Platte River Basin (**Figure 5.2-9**) with the balance of the model domain assigned to a generic zone.

The runoff zones are used to calibrate the portion of the field runoff which contributes to stream flow. The runoff zones use the loss per mile parameters to regulate the rate at which runoff is lost during transit from the field to the stream gauge. The runoff totals for each zone are compiled for each stress period and provided for use in the surface water operations model and the groundwater model. It represents a slight contributing factor which is combined with the simulated baseflow for total flow analysis in the river. The definition of the runoff zones can be found in **Table 5.2-3**; while the runoff zone parameter values are listed in the file ROZCOEF.txt which is discussed in Appendix 5-B.

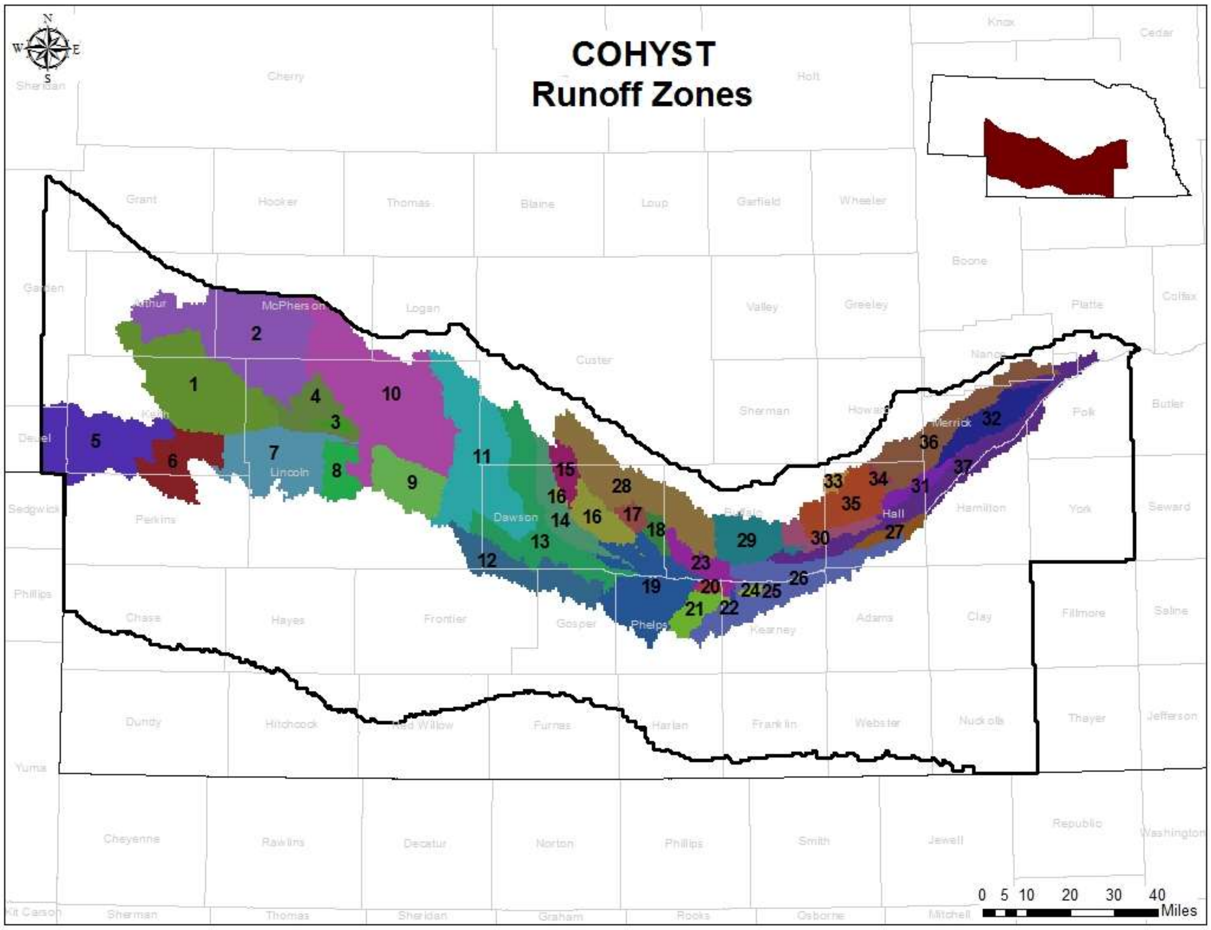

Figure 5.2-9. COHYST runoff zones

Table 5.2-3. COHYST runoff zones

Zone	Gauge Location	Gauge Number	Reach	Drainage Area (Acres)
1	N. Platte River @ Sutherland	66910.00	Key-Suth	330,357
2	Birdwood Creek	66920.00	Suth-NP	468,799
3	Lincoln Co. Drain 1	66925.00	Suth-NP	8,508
4	N. Platte River @ N. Platte	66930.00	Suth-NP	94,162
5	S. Platte River @ Roscoe	67648.80	Jules-Ros	432,007
6	S. Platte River @ Paxton	67650.00	Ros-NP	126,576
7	S. Platte River @ N. Platte	67655.00	Ros-NP	206,333
8	Fremont Slough	67657.10	NP-Brady	62,431
9	Platte River @ Brady (S Channel)	67659.90	NP-Brady	113,200
10	Platte River @ Brady (Total Flow)	67660.00	NP-Brady	515,513
11	Platte River @ Cozad	67665.00	Brady-Coz	329,641
12	Plum Creek	67675.00	Coz-Over	145,779
13	Platte River @ Overton	67680.00	Coz-Over	219,807

Table 5.2-3. COHYST runoff zones

Zone	Gauge Location	Gauge Number	Reach	Drainage Area (Acres)
14	Spring Creek	67680.20	Over-Odes	87,695
15	Buffalo Creek @ Darr	67685.00	Over-Odes	40,787
16	Buffalo Creek @ Overton	67690.00	Over-Odes	77,593
17	Elm Creek @ Overton	67695.00	Over-Odes	21,051
18	Elm Creek @ Elm Creek	67695.25	Over-Odes	23,891
19	Platte River @ Odessa	67700.00	Over-Odes	213,938
20	Whiskey Slough East of Phelps-Kearney County Line	67701.75	Odes-GI	9,150
21	N. Dry Creek @ Kearney	67701.90	Odes-GI	48,766
22	N. Dry Creek 2 miles SW Kearney	67701.95	Odes-GI	1,618
23	Platte River @ Kearney	67702.00	Odes-GI	57,650
24	Ft. Kearney Slough	67702.40	Odes-GI	5,967
25	Downstream Drain	67702.55	Odes-GI	1,732
26	Platte River @ Grand Island (S Channel)	67704.78	Odes-GI	210,764
27	Platte River @ Grand Island	67705.00	Odes-GI	29,048
28	Wood River @ Riverdale	67710.00	GI-Dun	234,847
29	Wood River @ Gibbon	67715.00	GI-Dun	101,322
30	Wood River @ Alda	67720.00	GI-Dun	48,764
31	Warm Slough	67727.75	GI-Dun	35,818
32	Silver Creek @ Silver Creek	67728.98	GI-Dun	93,324
33	Dry Creek	67730.00	GI-Dun	12,767
34	Prairie Creek @ Ovina	67730.50	GI-Dun	7,337
35	Silver Creek @ Ovina	67731.50	GI-Dun	112,149
36	Prairie Creek @ Silver Creek	67735.00	GI-Dun	177,756
37	Platte River @ Duncan	67740.00	GI-Dun	219,451

Coefficient Zones. Coefficient Zones represent a geographical group of cells which exhibit similar water balance responses. The COHYST RSWB model includes 18 coefficient zones (**Figure 5.2-10**). These zones were created to capture the unique conditions present in several locations within the model domain. Specific zones were created for each of the Platte River surface water irrigation districts and the Upper Republican NRD. The remainder of the model area was divided by North of the Platte River, South of the Platte River, and a band within 2 miles of the Platte River. Each coefficient zone controls the application efficiencies, runoff partition factor, and coefficient zone parameters used within its boundaries.

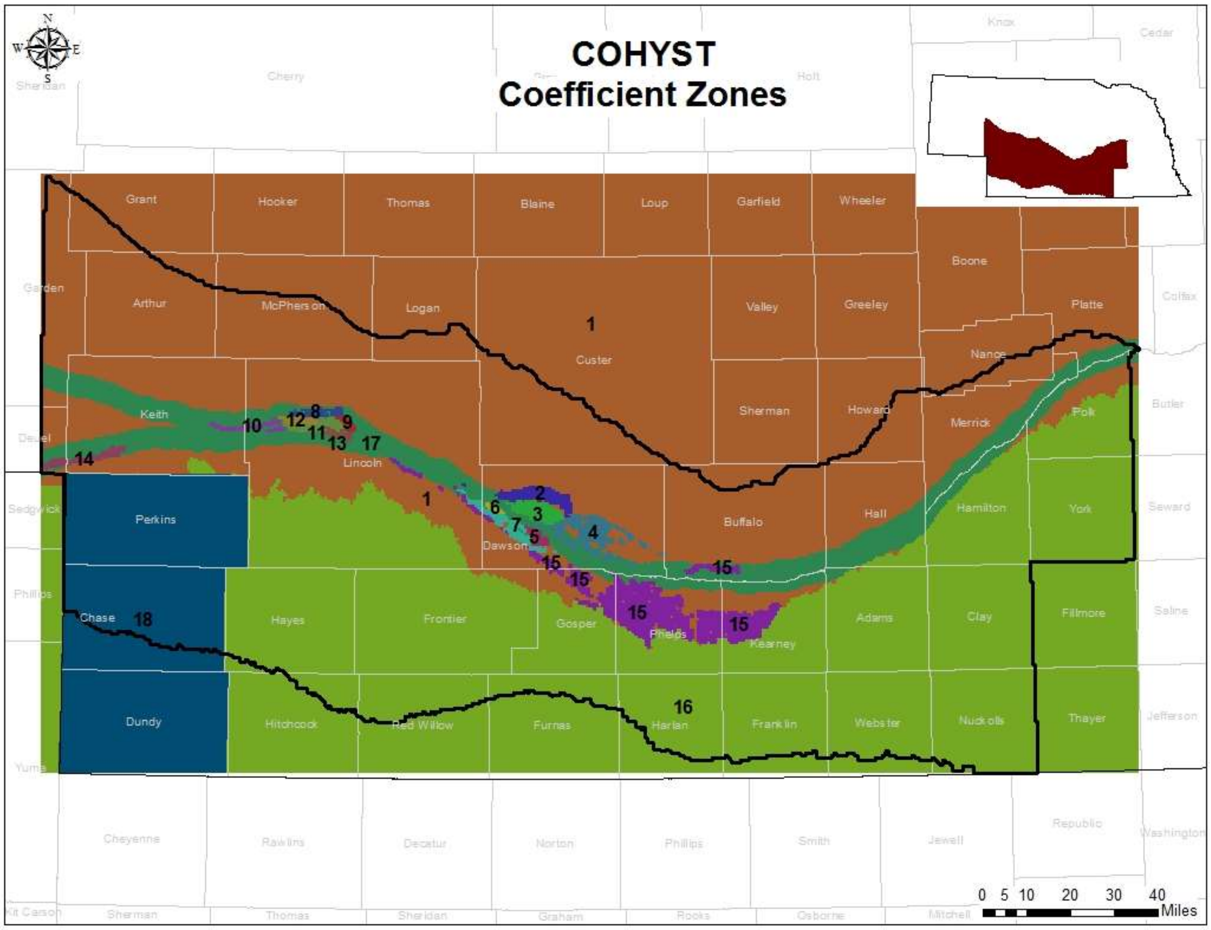

Figure 5.2-10. COHYST coefficient zones

The application efficiency is the ratio of net irrigation to gross irrigation. It is dependent upon the techniques used to physically apply water to the field. Within the watershed model the method for applying irrigation to individual fields was not defined, therefore application efficiency was assigned based upon irrigation source (groundwater or surface water).

The RSWB model allows the application efficiency (AE) to trend over time within each coefficient zone (Equation 2). This allows the model to capture the influence of improved technology and better irrigation management practices. The trending process uses two flat values book ending a trended period between two defined years. The application efficiencies for each coefficient zone can be found in the file AE.txt described in more detail in Appendix 5-B.

$$AE = \begin{cases} AE_{ini} & year \leq YR_{AE,ini} \\ AE_{ini} + \left(AE_{fin} - AE_{ini}\right)\left(\frac{year- \quad {}_{AE,ini}}{YR_{AE,fin}-YR_{AE,ini}}\right) & YR_{AE,ini} < year < YR_{AE,fin} \\ AE_{fin} & year \geq YR_{AE,fin} \end{cases} \qquad (2)$$

AE	Application efficiency
AE_{ini}	The initial application efficiency
AE_{fin}	The final application efficiency
Year	The relevant year
$YR_{AE,\ ini}$	The year the trending process begins
$YR_{AE,\ fin}$	The year the trending process ends

The RSWB model also controls the partitioning of runoff transmission losses between ET and recharge through the use of a runoff partitioning factor. This partitioning factor is controlled separately for each coefficient zone. The values of the partitioning factor can be found in the file PCTRCH.txt described in more detail in Appendix 5-B.

Each coefficient zone is further sub-divided by soil type and crop. Each coefficient zone sub group contains a set of RSWB adjustment coefficients used during the calibration of the watershed model. There are thirteen different adjustment coefficients described below. The values for the adjustment coefficients are contained in the file COEFFILE.csv described in more detail in Appendix 5-B.

1. Irrigation Target ($Target_{NIR}$): Specifies the portion of the net irrigation requirement to be met by irrigation when volumes are simulated.
2. Dryland ET Adjustment Factor ($ADJ_{ET,\ dry}$): Adjusts ET for the difference between the results from the soil water balance model and realized field conditions for dryland crops
3. Irrigated ET Adjustment Factor ($ADJ_{ET,\ irr}$): Adjusts ET for the difference between the results from the soil water balance model and realized field conditions for irrigated crops
4. Surface Loss Fraction – Groundwater (FSL_{GW}): Specifies a percentage of applied groundwater irrigation that is lost to non-beneficial consumptive use
5. Surface Loss Fraction – Surface water (FSL_{SW}): Specifies a percentage of applied surface water irrigation that is lost to non-beneficial consumptive use
6. Dryland ET to Runoff ($DryET_2RO$): Specifies the portion of the dryland ET adjustment that is converted to runoff with the remainder becoming deep percolation
7. Deep Percolation Adjustment (ADJ_{DP}): Adjusts the deep percolation results from the soil water balance model with the change being converted to non-beneficial consumptive use
8. Runoff Adjustment (ADJ_{RO}): Adjusts the runoff results from the soil water balance model with the change being converted to non-beneficial consumptive use
9. Maximum Partitioning Factor (RO_{max}): Maximum value of the irrigated partitioning factor ($RODP_{wt}$) used to divide unassigned water between runoff and deep percolation
10. Minimum Partitioning Factor (RO_{min}): Minimum value of the irrigated partitioning factor ($RODP_{wt}$) used to divide unassigned water between runoff and deep percolation

11. Deep Percolation Lower Threshold (DP_{ll}): Sets the lower limit at which the RSWB model begins to taper off annual deep percolation rates
12. Deep Percolation (DP_{cap}): Sets the maximum rate of deep percolation the program will allow
13. Runoff Weighting Factor (RO_fDP): Weighting factor used to influence the effect of runoff on the irrigation partition factor ($RODP_{wt}$)

Canal recharge. Canal recharge represents the transmission losses accrued through the delivery of surface water through canal systems. The RSWB model defines canal seepage rates and locations and combines this data with the agricultural recharge in the '.RCH' file. There are two sets of canal recharge incorporated into the COHYST model. In the Platte River, seepage estimates are developed by the surface water operations model and passed to the groundwater model to be added to the recharge inputs in the '.RCH' file developed by the RSWB[1]. For the Republican River canals, seepage estimates from the inputs approved for the Republican River Compact Administration were used for the years 1985 - 1998.

Given limited public availability of post 1998 values related to litigation activities in the Republican River Basin, the seepage volume from 1998 was carried forward through 2010. **Figure 5.2-11** shows the canal recharge from the Republican River Canals. This recharge is combined by the RSWB into the '.RCH' file provided to the groundwater model.

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[1] The RSWB is capable of adding the Platte River canal seepage by adding the data set to the Canal Master file.

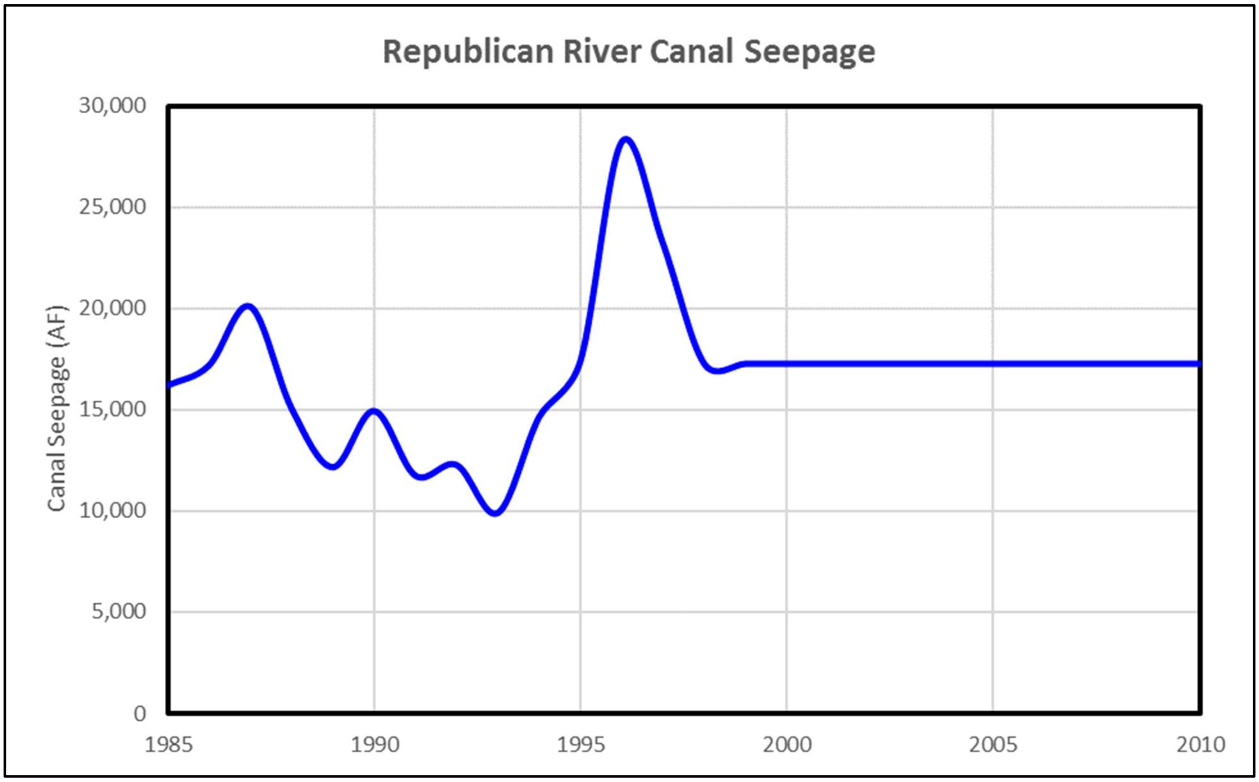

Figure 5.2-11. Canal seepage from the irrigation district canals in the Republican River area.

<u>Municipal and industrial pumping</u>. Municipal and industrial (M&I) pumping in the COHYST model was extracted from the statewide M&I database. Municipal pumping estimates were developed on a per capita basis for each city and town. The pumping was then divided among the identified active public wells feeding the relevant municipality. Industrial pumping estimates were developed based upon the industry category and total active well capacity. The extent of the municipal and industrial pumping in the COHYST model domain can be seen in **Figures 5.2-12.** - **5.2-13.** Further information on the development of the M&I data base can be found in the Statewide M&I documentation.

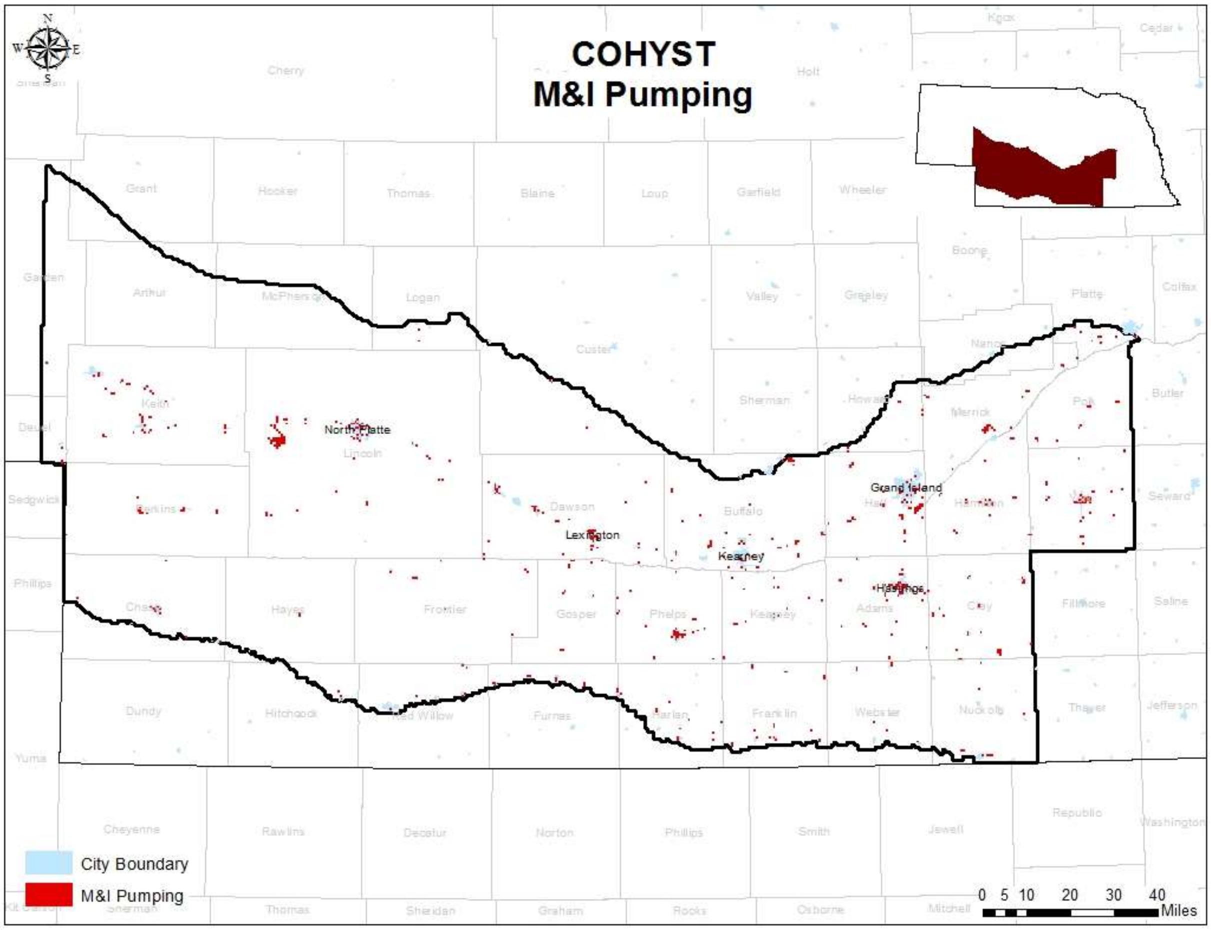

Figure 5.2-12. Distribution of municipal and industrial pumping within the COHYST domain.

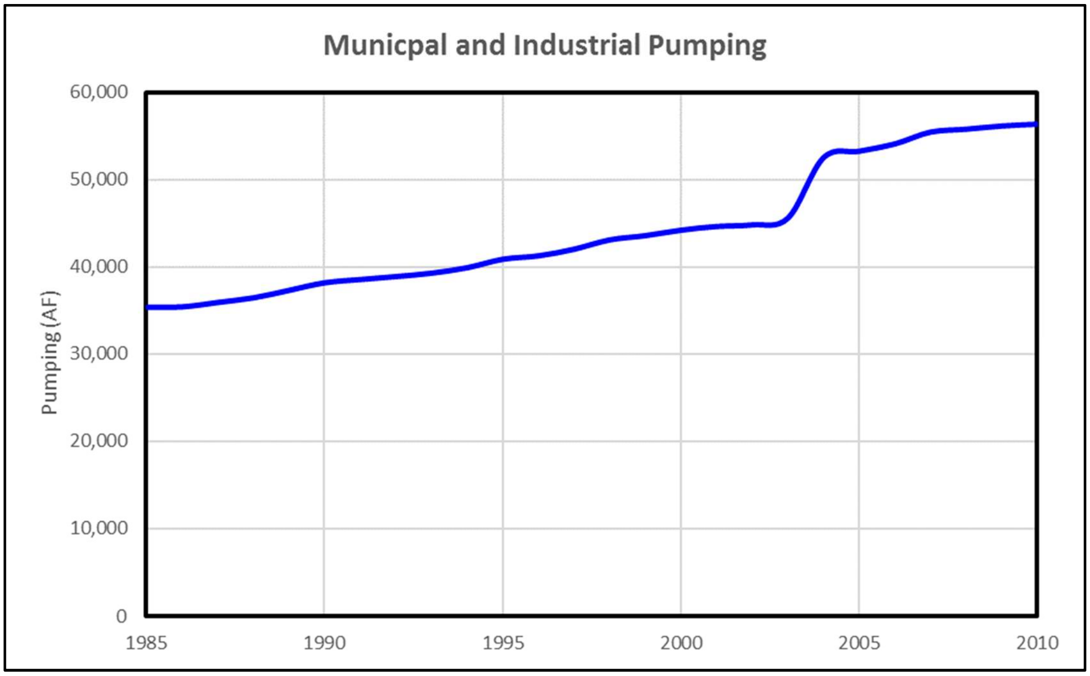

Figure 5.2-13. Development of municipal and industrial pumping within the COHYST model domain.

5.3 Model construction

The RSWB consists of 9 programs (listed below) which incorporate distributed CropSim results, develop irrigation estimates, make adjustments to the water balance parameters, organize the results into properly formatted groundwater model input files, and generate water balance summary reports. Within the COHYST 2010 model, the RSWB can make two types of runs as part of the integrated model: demand run and supply run. The 9 programs comprising the RSWB model are:

1. Irrigation Application and Demand (IAD)
2. District Demand
3. Irrigation Application and Supply (IAS)
4. Water Supply Partitioning Program (WSPP)
5. Make Well
6. Make Recharge
7. Compile Well
8. Compile Recharge
9. Summary Reports

Appendix 5-A provides a description of each program comprising the RSWB model. Generalized schematics showing major conceptual components of the major programs are provided to assist a user interested in reviewing source code. The descriptions discuss in general terms the inputs required for each program. Refer to Appendix 5-B for a more complete discussion of the input parameters and their development.

5.4 Model results

The watershed model can produce a wide variety of outputs at varying temporal-spatial scales. The following section will describe a selection of these results to provide insight into the watershed model output on a global, regional, and local level. This section contains results depicting average conditions, snapshots of a single point in time, and time series values. The results presented are from RSWB Run028b2, which provided the calibrated pumping, recharge, and runoff contributions to stream flow to the surface water operations model and groundwater model.

5.4.1 Global water balance

This section presents selected results from the entire RSWB model domain. **Table 5.4-1** provides an overall summary of the key water balance terms represented in the RSWB model. Terms in italics were inputs to the RSWB model while the non-italicized terms were computed by the model. Parameter values are shown in terms of average annual volume, depth per acre, and percent of total applied water (TAW). Depth per acre values shown in **Table 5.4-1** represent the average volume divided by the area of the entire model domain. The applied irrigation is further broken down in **Table 5.4-4** to show the depth of applied irrigation only on irrigated acreage rather than the entire model domain area acreage as shown on **Table 5.4-1**. The annual field water balance can be found in **Table 5.4-3** for the active COHYST domain; while the runoff balance can be found in **Table 5.7**.

Table 5.4-1. Long term average water balance for the COHYST model.

Parameter	Run 028		
	AF	in	%
Acres	*12,336,000*		
Precipitation	*24,112,174*	*23.46*	*90.0%*
Groundwater Pumping	2,448,889	2.38	9.1%
Surface Water Deliveries	221,170	0.22	0.8%
Total Applied Water	26,782,233	26.05	100.0%
Field Evapotranspiration	21,994,798	21.40	82.1%
Field Deep Percolation	2,647,784	2.58	9.9%
Field Runoff	2,011,730	1.96	7.5%
Irrigation Surface Losses	129,080	0.13	0.5%
Field Water Balance	(1,158)	0.00	0.0%
Lateral Losses	15,038	0.01	0.1%
Field Runoff	2,011,730	1.96	7.5%
Runoff Contributions to Streamflow	1,138,562	1.11	4.3%
Runoff Losses to Recharge	436,584	0.42	1.6%
Runoff Losses to Evapotranspiration	436,584	0.42	1.6%
Municipal and Industrial Pumping	*44,162*	*0.04*	*0.2%*
Canal Recharge Platte River	0	0.00	0.0%
Canal Recharge Republican River	*16,838*	*0.02*	*0.1%*

Table 5.4-2. Long term average annual applied irrigation.

Parameter	(AF)	(in)
Surface Water Only Delivery	100,827	12.92
Comingled Surface Water Delivery	120,343	8.35
Groundwater Only Pumping	2,375,304	9.25
Comingled Pumping	73,585	4.85

Long term averages fell within a range of results from other projects in the modeled area. The estimated long-term average recharge of 3” (2.58” of direct on-field recharge plus 0.42” of additional recharge occurring as runoff considered to be leaving field edges travels towards a stream) is within the range of research conducted by the University of Nebraska Lincoln (Szilagyi, 2003; Szilagyi, 2005) which estimated the mean long term annual recharge in the area between 0.5” in the west to roughly 3” in the east.

Table 5.4-3. Annual Field Water Balance (AF).

Year	Precipitation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Field Evapotranspiration	Field Deep Percolation	Field Runoff	Irrigation Surface Losses	Field Water Balance	Lateral Losses
1985	24,182,988	2,219,733	258,343	26,661,064	21,849,850	1,933,947	2,285,468	118,737	473,061	17,662
1986	23,371,252	2,190,769	297,192	25,859,213	22,140,538	2,228,671	1,714,547	118,454	(342,997)	21,269
1987	26,969,016	2,212,398	225,117	29,406,531	22,991,335	3,593,306	2,621,428	117,373	83,089	15,663
1988	20,934,214	2,870,647	290,407	24,095,268	21,036,124	1,591,509	1,619,864	152,245	(304,474)	21,699
1989	19,043,586	2,030,991	217,267	21,291,843	18,218,315	1,119,792	1,659,219	108,068	186,449	13,471
1990	21,604,088	2,506,036	350,442	24,460,567	21,525,006	1,830,927	1,647,100	135,815	(678,281)	25,934
1991	22,471,130	3,297,140	369,722	26,137,991	20,966,171	1,685,930	1,739,296	175,949	1,570,645	28,055
1992	24,978,274	1,654,090	158,023	26,790,387	23,027,654	2,229,258	1,712,573	87,445	(266,543)	10,400
1993	33,449,042	654,116	48,371	34,151,529	25,037,362	4,785,880	3,673,223	34,157	620,907	1,439
1994	22,609,394	1,993,471	206,211	24,809,076	22,049,224	1,645,174	1,168,088	105,860	(159,270)	13,519
1995	22,979,202	2,777,833	300,315	26,057,350	21,908,005	3,750,977	1,764,671	147,901	(1,514,203)	21,791
1996	27,983,728	1,192,432	89,752	29,265,911	21,763,776	2,394,644	2,570,165	62,314	2,475,012	5,688
1997	22,727,524	2,372,147	273,218	25,372,889	21,345,210	1,982,185	1,600,107	126,804	318,584	20,040
1998	24,007,328	1,950,368	213,968	26,171,664	22,011,775	3,146,110	1,912,694	103,937	(1,002,851)	14,745
1999	23,844,688	1,652,743	161,925	25,659,356	22,347,230	3,266,079	2,047,813	87,495	(2,089,261)	10,971
2000	20,116,002	3,582,545	369,404	24,067,951	19,129,693	1,160,018	1,246,818	190,209	2,341,213	27,259
2001	24,453,046	2,697,386	253,220	27,403,651	22,798,220	2,685,072	2,042,685	142,466	(264,791)	18,318
2002	15,153,124	3,849,384	304,825	19,307,333	17,605,706	1,324,877	947,559	201,614	(772,424)	20,120
2003	19,614,828	3,939,842	259,502	23,814,171	20,948,452	1,909,218	1,418,627	204,777	(666,903)	18,511
2004	24,081,148	3,097,204	172,430	27,350,782	22,786,076	1,636,421	1,269,349	160,033	1,498,903	12,178

Year	Precipitation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Field Evapotranspiration	Field Deep Percolation	Field Runoff	Irrigation Surface Losses	Field Water Balance	Lateral Losses
2005	22,758,588	3,148,506	178,526	26,085,619	22,341,228	2,463,186	1,940,439	162,781	(822,015)	13,343
2006	23,052,706	2,867,872	180,061	26,100,639	20,130,395	1,501,325	1,535,822	148,795	2,784,302	10,083
2007	31,119,946	2,067,990	150,700	33,338,635	25,008,635	5,842,142	3,735,845	107,920	(1,355,907)	8,306
2008	31,023,594	2,403,543	154,036	33,581,173	24,042,755	4,443,089	3,967,946	124,798	1,002,585	8,199
2009	26,259,058	2,631,987	166,091	29,057,136	24,188,933	3,391,484	1,643,388	136,582	(303,250)	8,464
2010	28,129,032	1,809,954	101,350	30,040,336	24,667,083	5,301,172	2,820,240	93,538	(2,841,697)	3,859

Column Notes:

Precipitation – Volume of precipitation which fell on the fields

Groundwater pumping – Gross volume of water pumped for irrigation

Surface Water Deliveries – Volume of surface water considered applied at the farm headgate

Total Applied Water – Total volume of precipitation and irrigation applied to the fields

Field Evapotranspiration – The estimate of ET resulting from the applied water; this does not include ET related to transmission losses

Field Deep Percolation – The estimate of recharge resulting from the applied water; this does not include recharge from transmission losses

Field Runoff – The estimate of runoff occurring at the field boundaries

Irrigation Surface Losses – Evaporative losses related to the application of irrigation to the field

Field Water Balance – Change in soil water content

Lateral Losses – Surface water transmission losses between the main canal and the field

Table 5.4-4. Annual Runoff Water Balance (AF).

Year	Field Runoff	Runoff Contributions to Streamflow	Runoff Losses to Recharge	Runoff Losses to Evapotranspiration
1985	2,285,468	1,276,928	504,270	504,270
1986	1,714,547	959,136	377,706	377,706
1987	2,621,428	1,477,308	572,060	572,060
1988	1,619,864	937,709	341,078	341,078
1989	1,659,219	941,209	359,005	359,005
1990	1,647,100	925,787	360,656	360,656
1991	1,739,296	988,765	375,266	375,266
1992	1,712,573	961,293	375,640	375,640
1993	3,673,223	2,063,386	804,919	804,919
1994	1,168,088	660,796	253,646	253,646
1995	1,764,671	1,001,715	381,478	381,478
1996	2,570,165	1,448,210	560,978	560,978
1997	1,600,107	895,224	352,441	352,441
1998	1,912,694	1,073,799	419,447	419,447
1999	2,047,813	1,156,961	445,426	445,426
2000	1,246,818	718,688	264,065	264,065
2001	2,042,685	1,141,483	450,601	450,601
2002	947,559	546,366	200,597	200,597
2003	1,418,627	793,115	312,756	312,756
2004	1,269,349	723,771	272,789	272,789
2005	1,940,439	1,099,510	420,464	420,464
2006	1,535,822	878,249	328,787	328,787
2007	3,735,845	2,120,110	807,868	807,868
2008	3,967,946	2,260,010	853,968	853,968
2009	1,643,388	943,102	350,143	350,143
2010	2,820,240	1,609,976	605,132	605,132

Column Notes:

Field Runoff – the estimate of runoff occurring at field boundaries

Recharge as a percentage of applied water (11.5%) was within the range (1-11%) reported across the region. However, it is important to remember that the estimates out of the RSWB include considerations for irrigation and the level of irrigation development in the COHYST area. Finally, the average rate of runoff (1.9") was consistent with the runoff estimates from the USGS which ranged from 0.5" in the west and just less than 3" in the east.

The remaining terms represent the results of the further partitioning of the Field Runoff water:
Runoff Contributions to Streamflow – the volume of field runoff which results in streamflow at the gauge

Runoff Losses to Recharge – volume of transmission losses resulting in additional recharge

Runoff Losses to Evapotranspiration – volume of transmission losses resulting in additional ET

5.4.2 Groundwater pumping

Groundwater pumped for irrigation reflects the extraction of water from the aquifer for agricultural production. The pumping rate estimates are a function of the NIR, the NIR target, and the application efficiency. Furthermore, pumping rates are developed with considerations for weather, soils, crop, timing of water needs, irrigation system, and assumptions about management characteristics. **Figure 5.4-1** shows the average pumping volume per 160-acre cell in the COHYST model area during the simulation period.

In 1985 at the onset of the COHYST model simulation period, there were approximately 2.8 million acres of groundwater irrigated lands. Over the next quarter of a century, development increased this area to just under 4 million acres (**Figure 5.4-2**) with a corresponding increase in groundwater pumped for irrigation (**Figures 5.4-3**. **- 5.4-4.**).

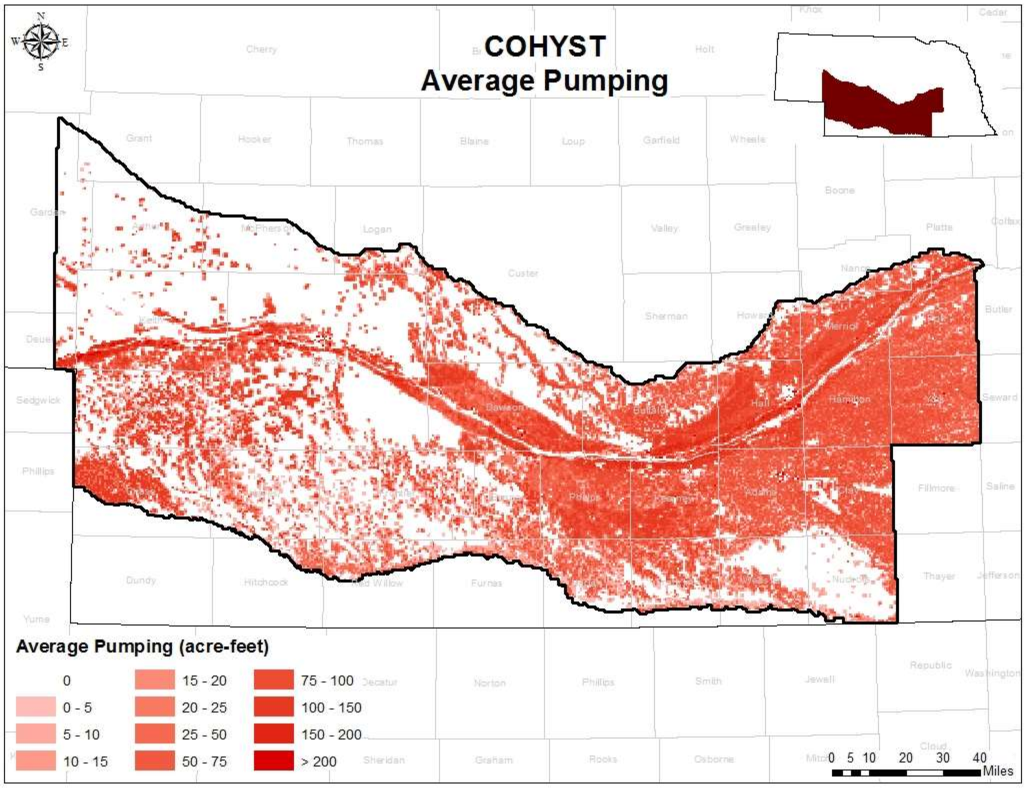

Figure 5.4-1. Average volume of pumping per 160-acre cell in the COHYST model area.

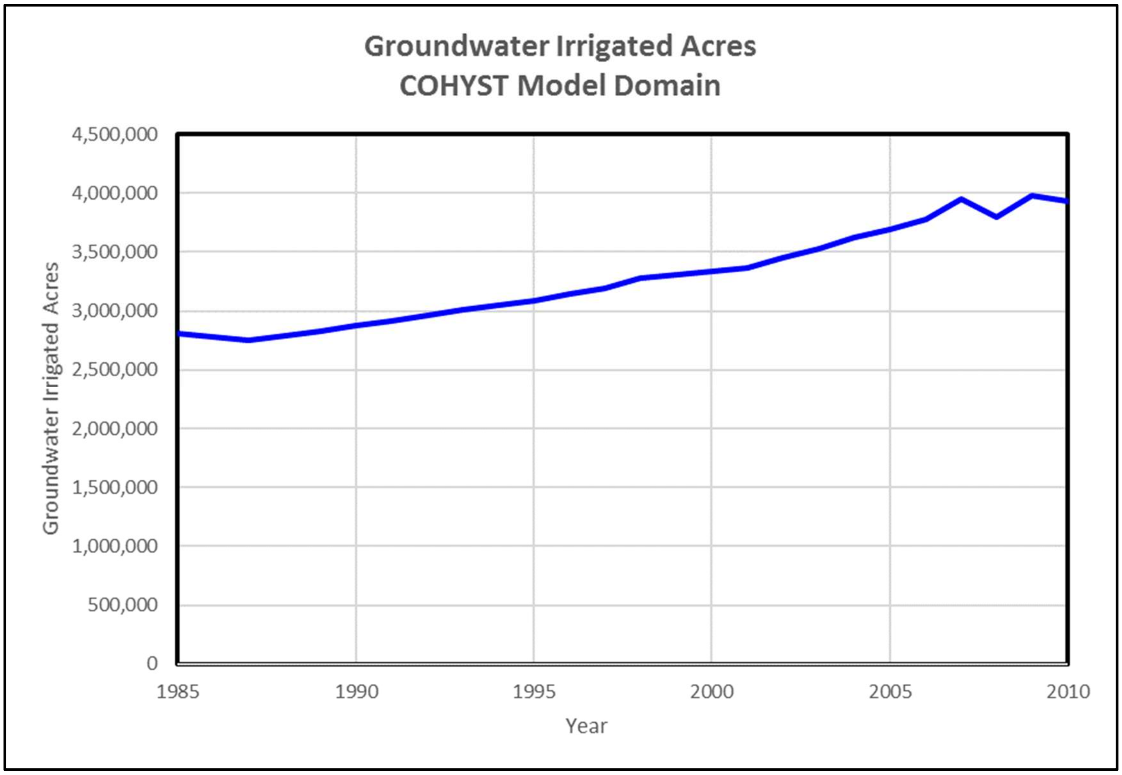

Figure 5.4-2. Development of groundwater irrigated acres in the COHYST model domain.

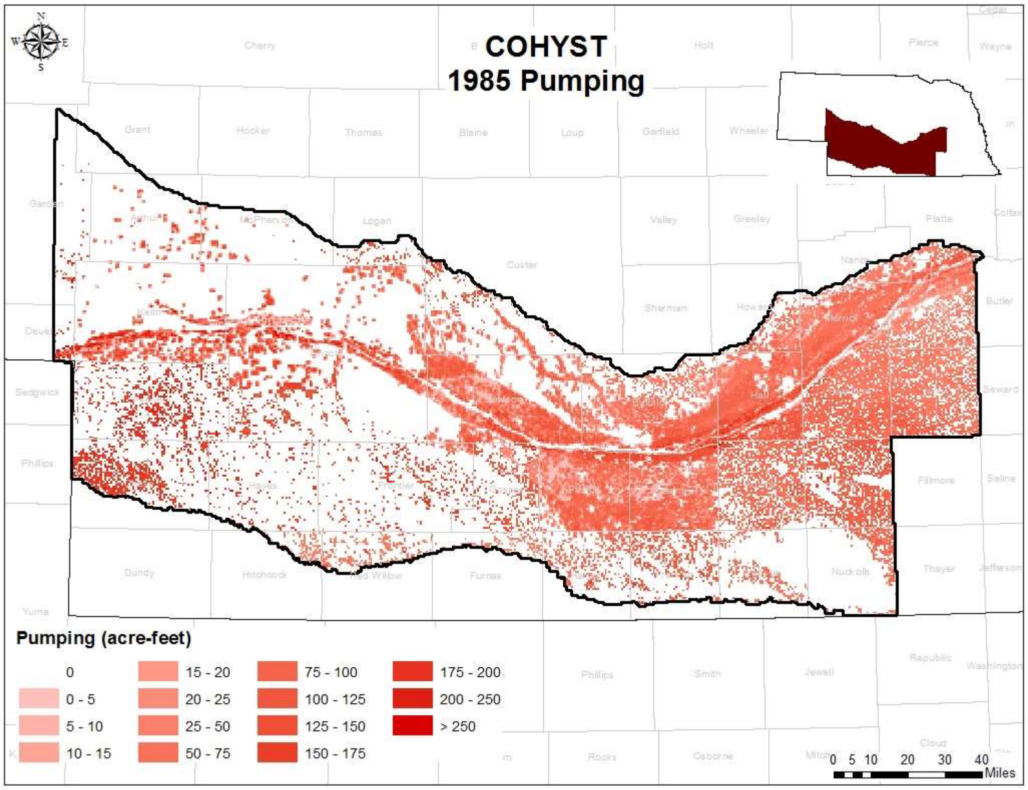

Figure 5.4-3. Extent of groundwater pumping per 160-acre cell in 1985.

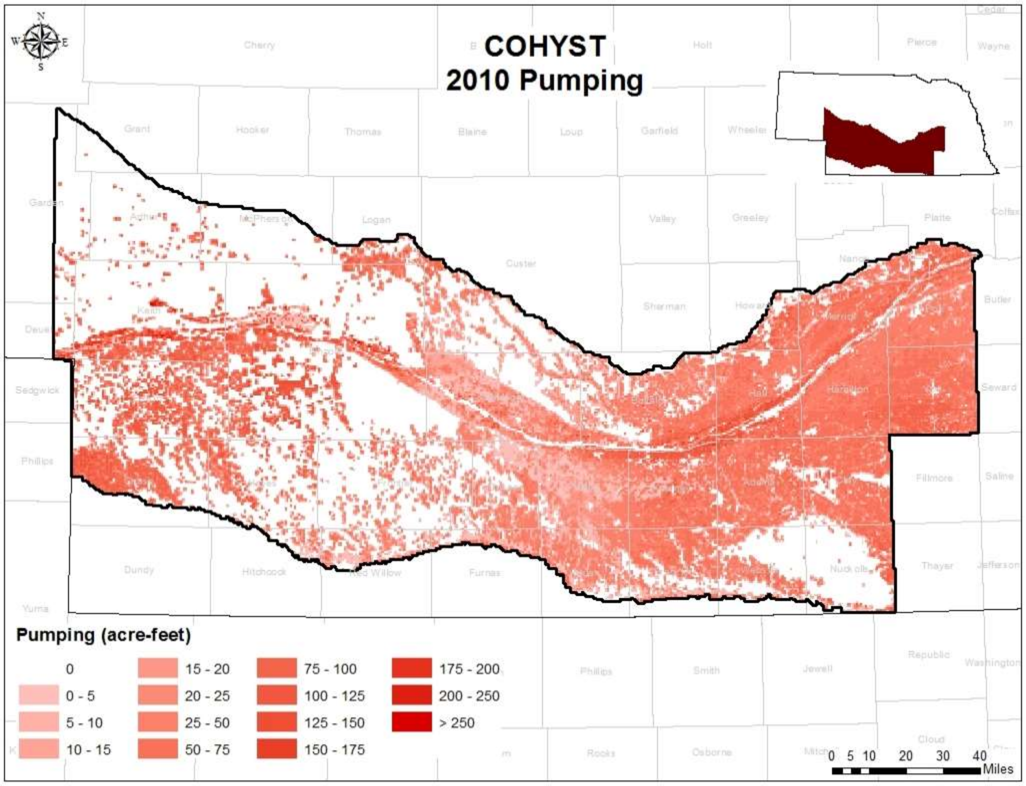

Figure 5.4-4. Extent of groundwater pumping per 160-acre cell in 2010.

During this period the average precipitation on groundwater irrigated acres is roughly 25.3 inches and ranged annually from 16.3 inches to 35.5 inches; while pumping was roughly 9.25 inches and ranged from 2.6” to 14” (**Figure 5.4-5**) with the volumes shown in **Figure 5.4-6**.

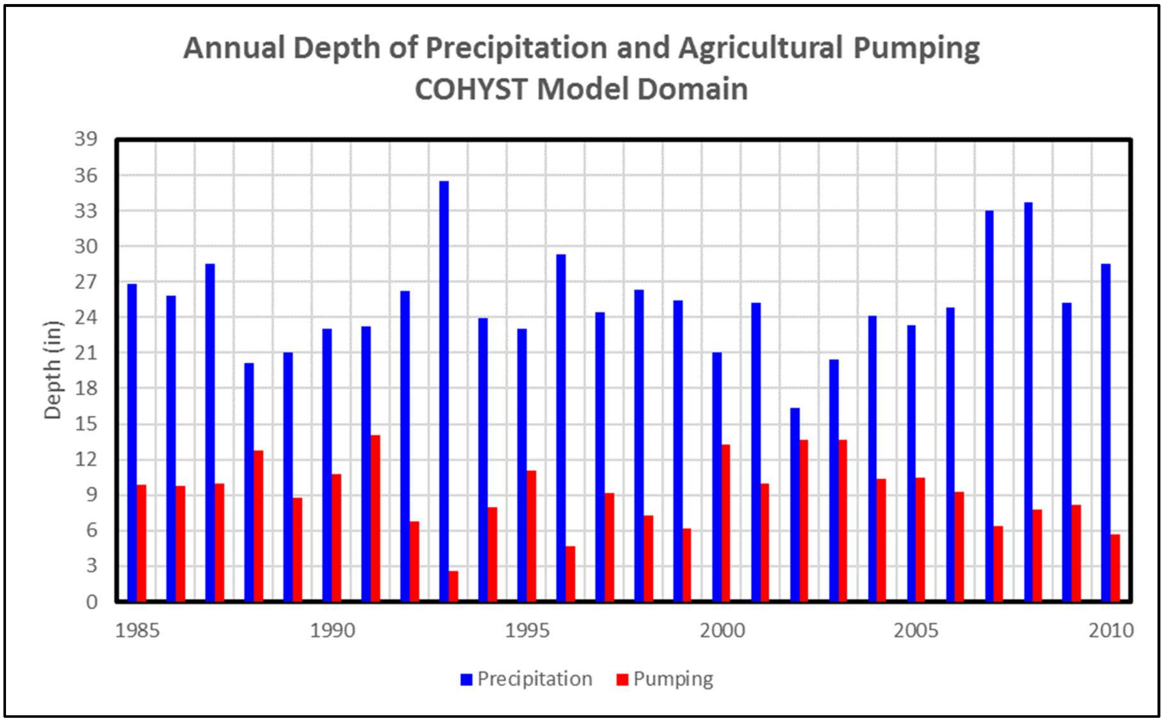

Figure 5.4-5. Annual depth of precipitation and agricultural pumping in the COHYST model domain.

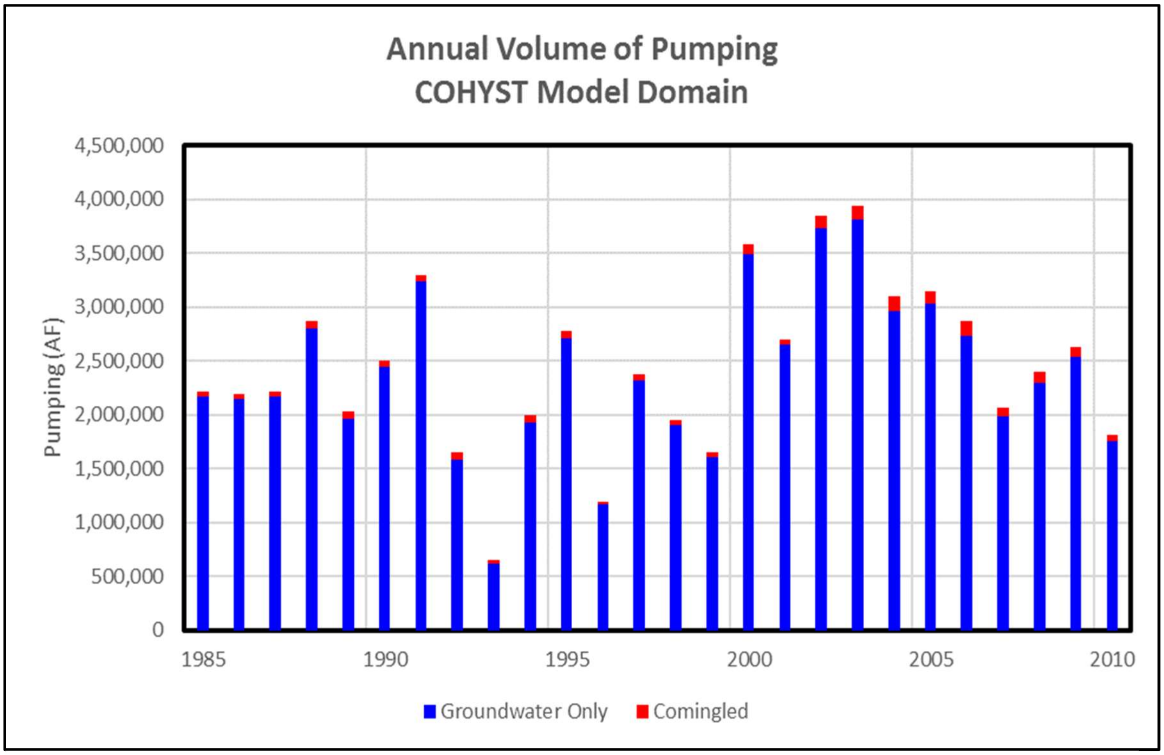

Figure 5.4-6. Annual volume of pumping in the COHYST model domain.

Perkins County. Perkins county is located in the Upper Republican NRD along the Nebraska-Colorado border. Agricultural pumping in the county has been metered since before 1985. The modeled pumping from Run028 was compared to the metered pumping (**Figure 5.4-7**). Visual inspection of the results indicate that over the course of the metered time frame the model was able to predict pumping in the county with a reasonable degree of accuracy.

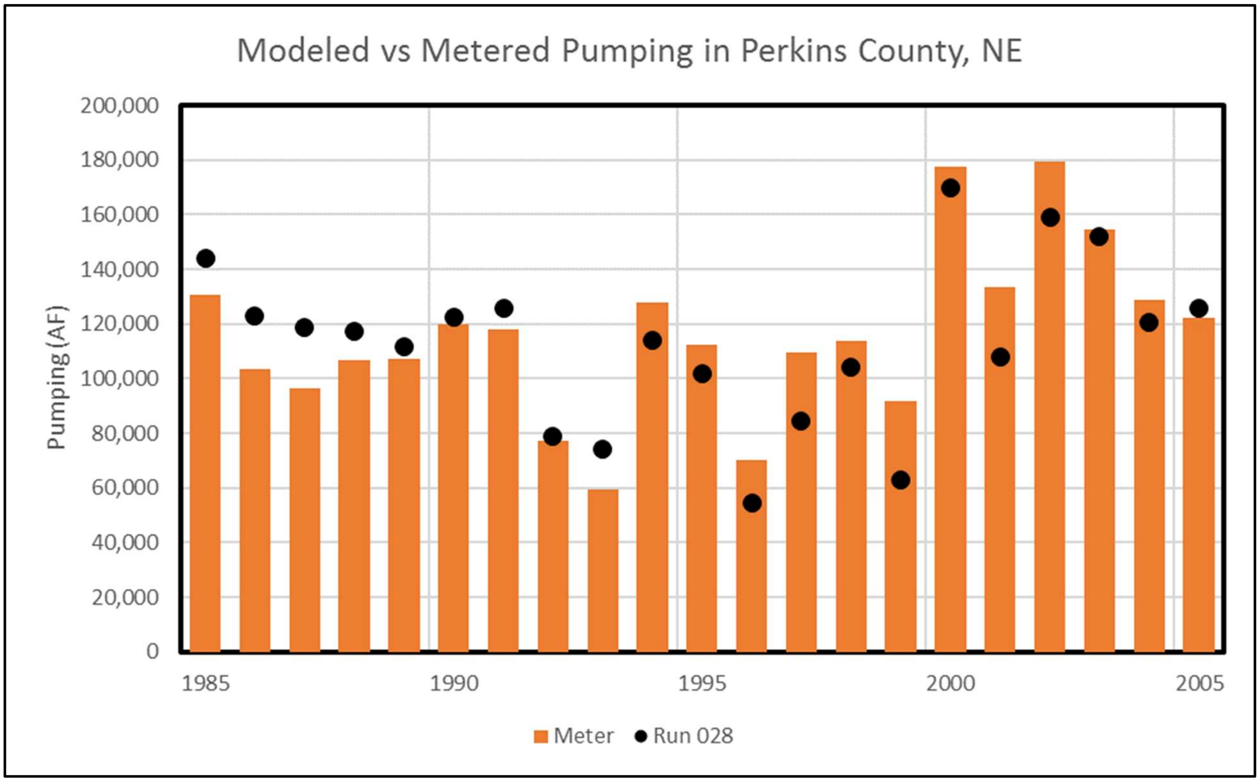

Figure 5.4-7. Comparison of the modeled pumping to metered pumping in Perkins County, NE.

Merrick County . Merrick County is located in the Northeastern portion of the COHYST model domain, and is located in the Central Platte NRD (CPNRD). In 2005, CPNRD began to meter agricultural pumping[2]. These records were compared to the simulated values from the RSWB. **Figure 5.4-8** presents the range of applied depths based on meter readings for the years 2005 through 2010 through a series of box and whisker plot lines. Vertical indicators on each line indicate the minimum, 25% exceedance, 50% exceedance, 75% exceedance, and maximum value for each year (the box highlights the 25% to 75% range of the meter based values). The blue dots shown on each line represent the average depth of pumping (in inches) predicted by the RSWB model within Merrick county. Visual inspection of the results

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[2] The metered data in Merrick County is limited to a small sample (roughly 300) of the total number of wells in the county.

indicates that over the course of the metered time frame the RSWB was able to reasonably predict groundwater pumping.

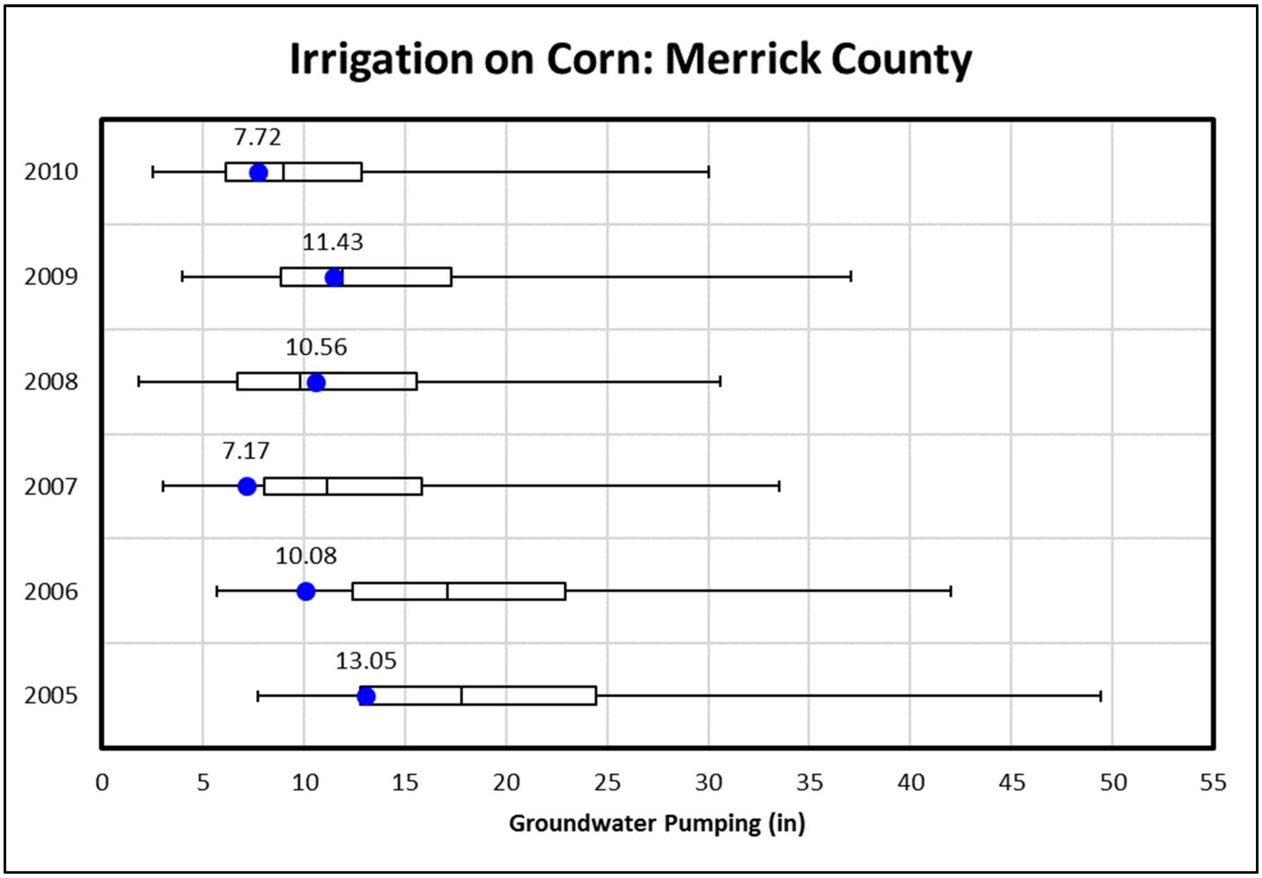

Figure 5.4-8. Comparison of simulated pumping to metered pumping on irrigated corn in Merrick County.

5.4.3 Recharge

Recharge represents the portion of the water which drains past the root zone and reaches the aquifer below. On average, there was approximately 3.0 inches of recharge in the model domain. Annual values did fluctuate with climate and there were years where, due to extremely wet conditions, recharge rates were restricted. Additional details regarding the implementation of the recharge restriction are discussed in Appendix 5-A. Within the RSWB in the COHYST area there are two main contributing sources of recharge: direct recharge (2.58”) from the field and indirect recharge (0.42”) resulting from transmission losses from runoff. **Figure 5.4-9** shows the average annual recharge for the COHYST model area; while **Figure 5.4-10** depicts the average annual model wide recharge rate for the simulation period. The images below show the spatial and temporal variability of the recharge rates and reflect the effect of soils, precipitation, irrigation, soil water content and timing.

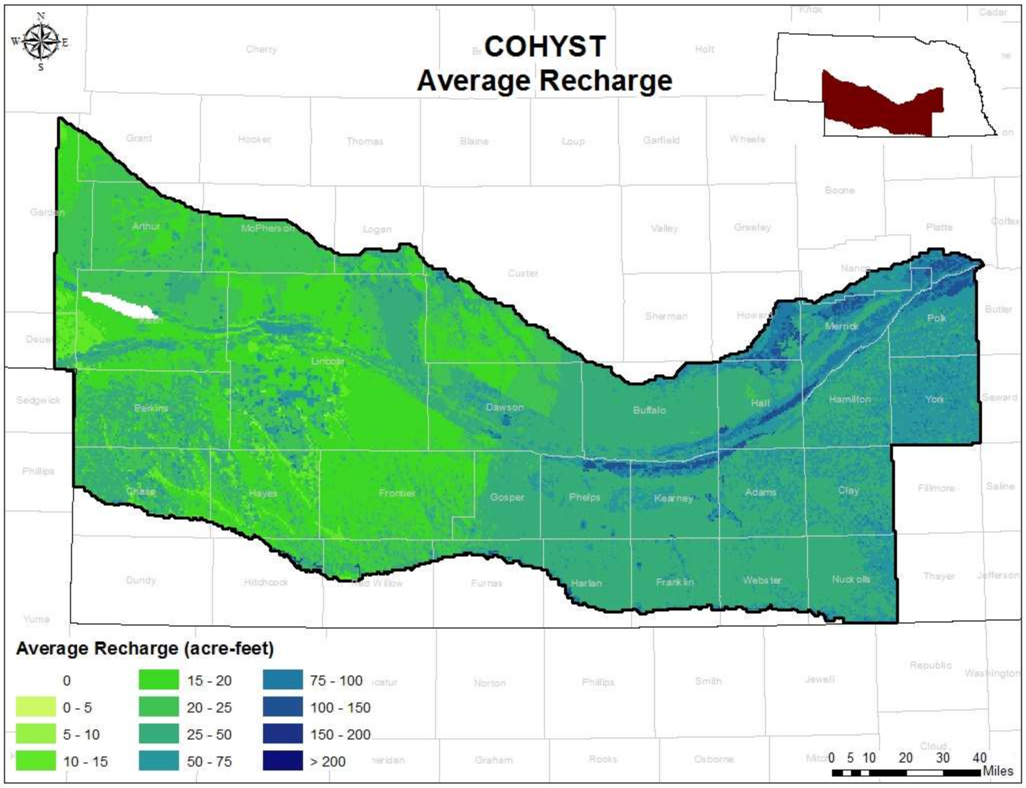

Figure 5.4-9. Average annual recharge per 160-acre cell in the COHYST model area.

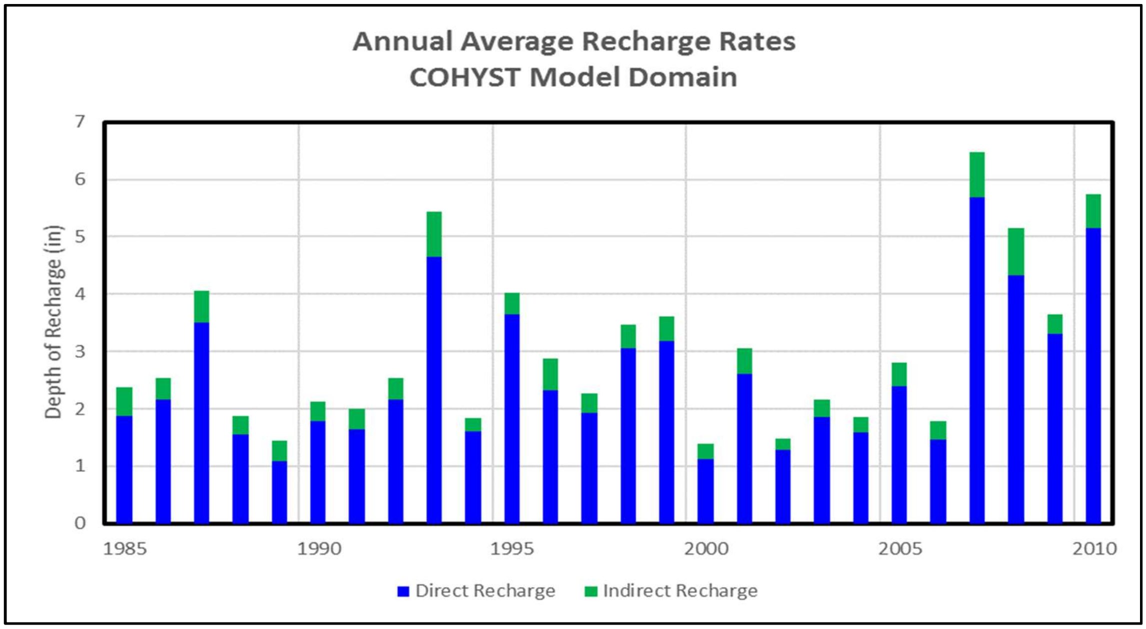

Figure 5.4-10. COHYST annual average recharge rates.

5.4.4 Net Recharge

Net recharge represents the cumulative flux into the aquifer. It considers the recharge to the aquifer (+) and the pumping being extracted (-) which is reflected in **Figure 5.4-11**. On average, there was approximately 0.62 inches of net recharge in the COHYST model domain.

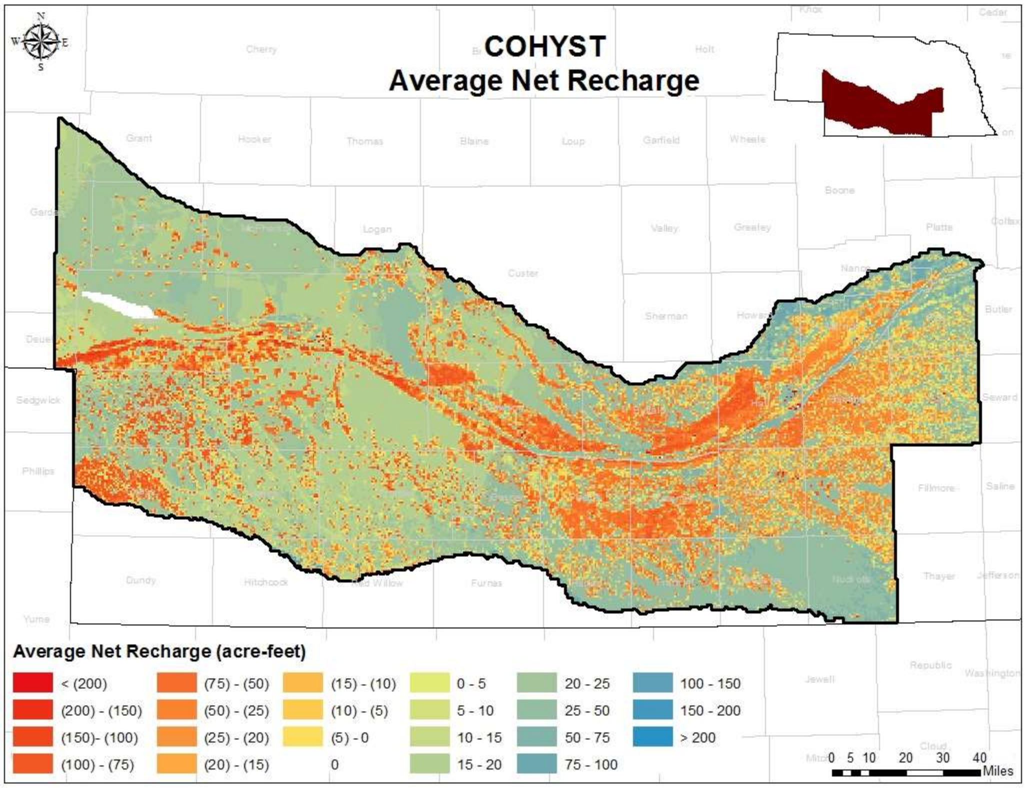

Figure 5.4-11. Average net recharge per 160-acre cell in the COHYST model domain.