4. DATA SETS

This section discusses how the COHYST 2010 team built datasets that are used either as input to one or more models, or as targets against which to compare model results. In some cases, the source data were developed outside of COHYST 2010, and simply formatted for use in a model. For other datasets, there was substantial effort in developing new information. Where appropriate, this documentation provides references and/or links to the source data and/or processed data. By far the most extensive discussion relates to the Land Use Dataset, as unlike other data that were obtained or developed from existing sources, these data were created specifically for the COHYST 2010 model.

In some cases, authors of other model sections chose to describe certain input and/or target datasets as part of their model-specific documentation, rather than in this section. Users of this documentation are assumed to be familiar with the types of data commonly used in the development of regional watershed, groundwater and surface water models; thus, foundation concepts (such as explaining the nature of a "DEM") are not presented.

4.1 Datasets Used by All Models

4.1.1 Climate

National Weather Service data used in the COHYST 2010 models come from the University of Nebraska High Plains Regional Climate Center: www.hprcc.unl.edu/index.php. **Appendix 4-A** identifies 77 weather stations for which data were obtained. These data were used as follows: to build the Phase 1 water budget (see Section 3.3); as input to the CROPSIM runs which are the foundation of the Watershed model, and then as direct input to that model (Section 5); and as direct input to Surface Water model calculations of open water (reservoir, rivers and canals) water budgets (Section 6).

4.1.2 Elevations and Drainage Network

All models require stream and surface water features to be spatially represented. In addition, the watershed model requires delineation of drainage areas and the groundwater model makes use of elevations for the land surface, monitoring wells, and stream beds. Surface elevations were taken from 10 meter DEMs at http://dnr.nebraska.gov/data/elevation-data . Selected elevations were field checked by DNR; see **Appendix 4-B**. Watershed boundaries and locations of streams, drains and reservoirs are from the National Hydrography Dataset (NHD) at http://dnr.nebraska.gov/data/surface-water-data . Selected features have been checked by DNR and HDR using air photos and expert input; see **Appendix 4-C**.

4.2 Land Use

4.2.1 Introduction

4.2.1.1 Objectives of the Land Use Dataset

The model approach set out in Section 3 requires that the water use for each 160-acre model cell be calculated by the watershed model for each month of the study period. In turn, this requires a representation of the land use over time for each cell, including whether the land is irrigated or not; and if agricultural, what crops were grown.

No record or method is known to be available by which the actual crop on each field can be determined over time. However, methods do exist by which data available at a county level can be scaled down to provide representative land use information that can be applied to each cell. Such information was developed for the previous COHYST groundwater models. A quality assurance review of the prior data base identified a significant problem, specifically a discontinuity in time (at 1997) caused using different techniques to estimate irrigated acres before and after that time.

Recognizing that developing a new or replacement dataset would be time-consuming, this discontinuity was subject to considerable discussion by the Sponsors. The Sponsors determined that it was necessary to replace the prior dataset for counties within the Platte River drainage, but that the prior dataset could continue to be used outside that drainage (to be replaced at some future time).

The Sponsors specified that the replacement land use dataset would meet the following objectives:

- Represent estimated actual irrigated and dryland acres through time;
- Use consistent historical datasets to eliminate disconnects in time;

- Use the best available data and method;
- Be validated at the county scale;
- Be simpler and more understandable than the previous method;
- Serve the additional purpose of annual tracking and accounting at a regional scale.

It was not required or expected that the resulting dataset would represent actual land use on any farm; see further discussion in Section 4.2.4.

4.2.1.2 Spatial Coverage

Figure 4.2-1 illustrates the area for which the land use dataset was developed. As shown, the new dataset was developed for the entirety of the Central Platte and Twin Platte NRDs, and for the Tri-Basin NRD except for Gosper County for which the necessary foundation data were not available. Gosper County is discussed in Section 4.2.3. The term “Redevelopment data set” refers to these data.

4.2.1.3 Time Coverage

The land use dataset was developed for years 1950 to 2007. Values as early as 1950 were needed in anticipation of extension of the models back in time. The year 1950 corresponds to a time when groundwater irrigation was becoming significant. The year 2007 corresponds to the last year when the most recent Census of Agriculture was available for this study. The Census of Agriculture is the only data source that includes crop types and is consistent through the entire timeframe.

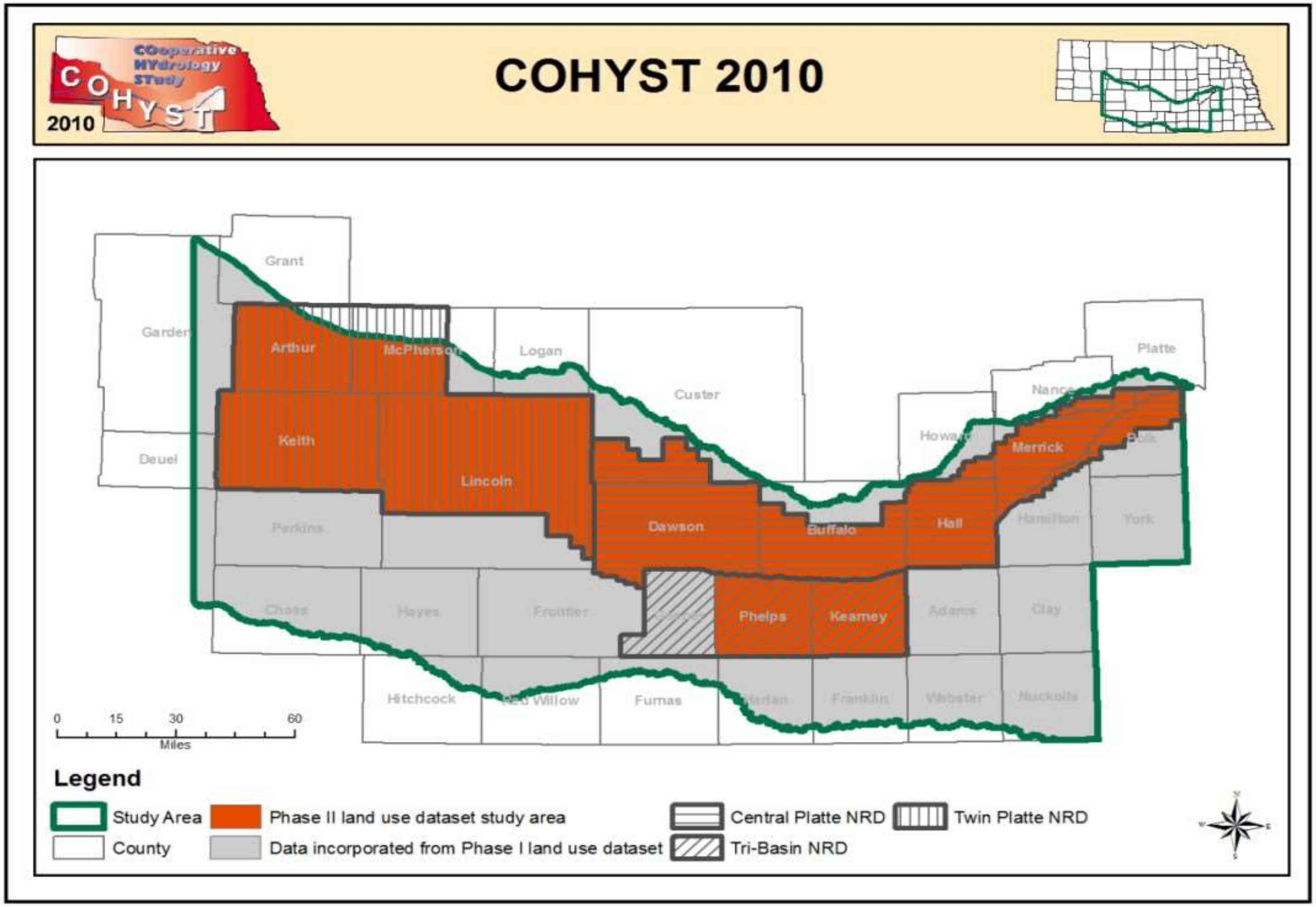


Figure 4.2-1. Study Area for COHYST 2010 Land Use Dataset Development.

4.2.2 Method for Development of New Land Use Dataset in Platte River Basin

The method to estimate land use within the Platte River Basin, excluding Gosper County, utilizes the following generalized approach.

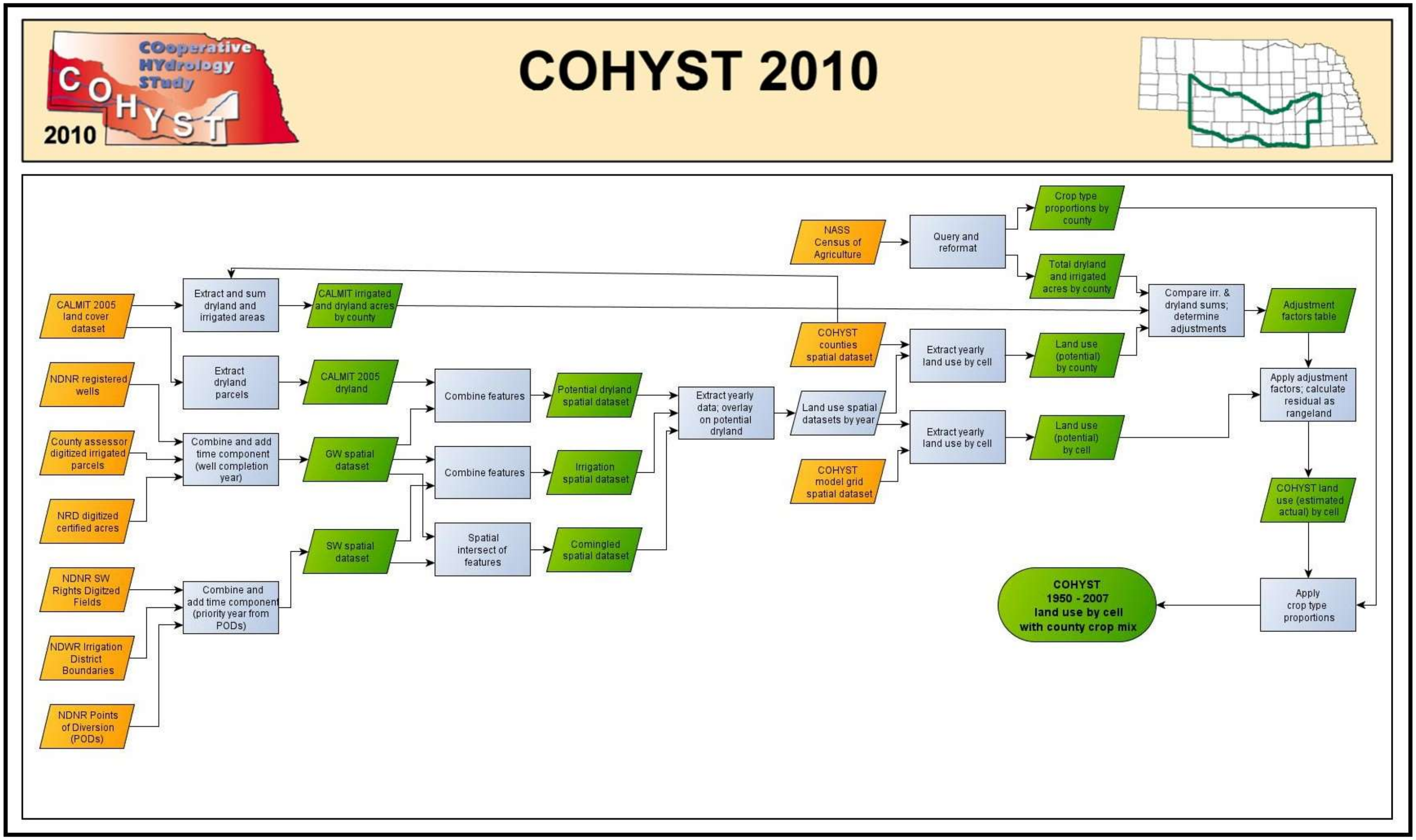
- Use digitized land parcels, well completion information and surface water appropriation dates to develop a spatial database of potentially irrigated (i.e. irrigable) lands through time.
- Use Center for Advanced Land Management Information Technologies (CALMIT) dryland and existing certified acres to create a potential dryland layer.
- Use the Census of Agriculture to define acreage trends through time by county.
- Use remote sensing data to determine county specific ratio relating the degree of agreement between the potential and trend data with the measured (remotely sensed) irrigated acres.
- Propagate the relationship by applying the county specific ratio through time to build an estimate of actual irrigated acres for model calibration and tracking and accounting.
- Apply crop types shown by Census of Agriculture distributions through time.

A more detailed description of the methods is shown as a flowchart in **Figure 4.2-2** and is described below. Basic information about all data sources used in this procedure are identified in **Appendix 4-D.** These data sources are considered to satisfy the objective that the best available data are used.

4.2.2.1 Irrigable Lands Dataset

The first step was to create a spatial database of potentially irrigated (i.e. irrigable) lands. The NRD digitized certified acres (groundwater) and NDNR digitized surface water rights were considered the best data sources and were used whenever possible to complete this task.

However, some data gaps existed and in these cases different data sources were applied. The Tri- Basin NRD, for example, did not have a certified acres spatial dataset; hence, spatial



Note: Input datasets are shown in orange and derived datasets are shown in green.

Figure 4.2-2. Flowchart of Methods used to Create the COHYST 2010 Land Use Dataset.

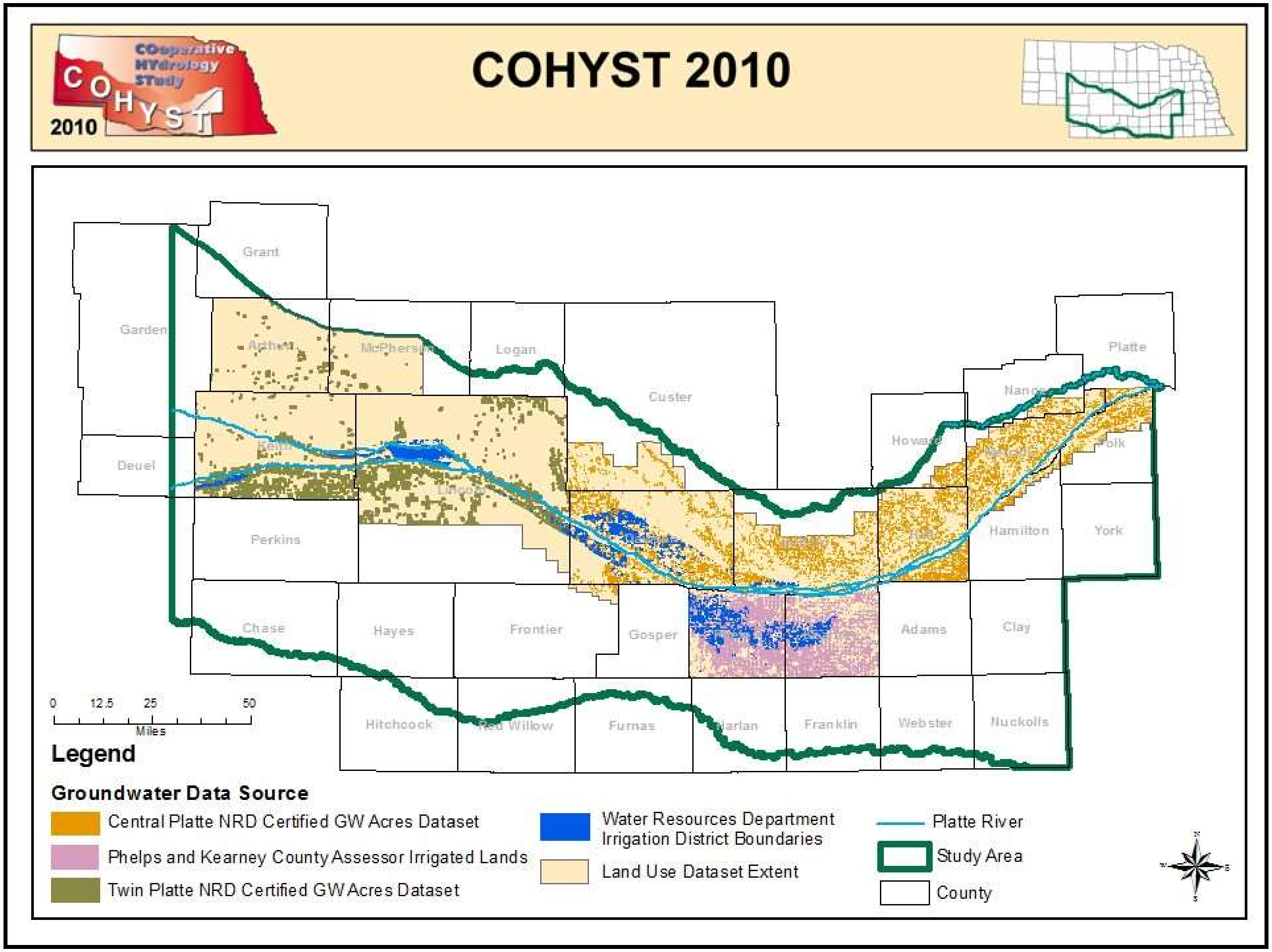
datasets of taxable irrigated lands were acquired from the Kearney and Phelps County assessor's offices and were used as a substitute for NRD certified acres.

In addition, some irrigation district boundaries were not available in the NDNR surface water rights spatial dataset. These areas were filled in with boundaries extracted from the Nebraska Water Resources Department irrigation district map. **Figure 4.2-3** shows the data sources used to create the irrigable lands spatial dataset.

The next step was to add a time component to the irrigable lands to show the first year the land became irrigable. To do this, the irrigable lands spatial dataset was related to the NDNR registered well database, and from this the first completion year of the wells associated with individual parcels was tied to each feature. In addition, surface water digitized parcels were related to the NDNR points of diversion, and from this the priority year of the surface water appropriations was tied to each feature. Whenever possible, the relationships were established through the tables, as this showed a definitive association between the well registration or surface water appropriation and irrigable parcels. The Central Platte NRD, and Kearney and Phelps county assessor records did not provide well information within the table so a tabular relationship could not be established. As such, a spatial relationship based on proximity to well was developed, and from this relationship, the completion date of the first installed well was tied to each feature (**Appendix 4-E**).

4.2.2.2 Dryland Dataset

The creation of a historical dryland acres' dataset posed challenges as there was no dataset that showed the spatial extent of dryland at a field scale through time. As such, assumptions were made concerning the location of dryland parcels. The primary assumption was that currently irrigable land had the potential to be dryland farmed prior to the installation of a well. A secondary assumption was that current dryland had the potential to be dryland farmed historically. To apply the assumptions, an initial dryland spatial dataset was created from dryland parcels in the CALMIT 2005 land cover dataset (i.e. current dryland). The irrigable lands spatial dataset (i.e. currently irrigable) was then merged with the CALMIT dryland parcels, and the resulting dataset represented the maximum extent of historic dryland. A time component



Note: NDNR surface water rights digitized fields cannot be shown due to legalities.

Figure 4.2-3. Map Showing Input Data Sources Used to Create Potentially Irrigable Lands Dataset.

was an implicit part of the dataset: the land was considered dryland until a well installation or surface water appropriation occurred, at this point the affected parcels were converted to irrigable land.

4.2.2.3 Comingled Irrigated Lands Dataset

Comingled acres were developed by overlaying maps of the groundwater parcels on the surface water parcels for each year back to 1950. Parcels were considered comingled if they appeared on both maps, and were considered comingled back in time to the year no overlap occurred.

4.2.2.4 Annual Dataset Creation and Cell Partitioning

Annual irrigable and comingled datasets were created by querying the year of interest and creating a subset of features that satisfied the query. The features were then overlaid on the dryland spatial dataset. For overlapping areas, the irrigable land superseded the dryland, and the comingled land superseded the irrigable land. The process was repeated for each year from 1950-2007.

Figures 4.2-4 through 4.2-6 show snapshots of yearly land use at 1950, 1985, and 2007, respectively. The maps show that in 1950 a large portion of irrigation relied on surface water sources and most of the groundwater irrigated land occurred near the Platte River in the central and eastern portions of the study area. There was very little comingled land at that time. Over time, groundwater irrigation expanded outward from the Platte River, especially in the central and east portions of the study area. By 1985, roughly half of surface water irrigated lands had become comingled, and by 2005, the clear majority of surface water lands had become comingled.

GIS processes were then used to calculate the fraction of land use in model grid cells for each year, and to create tables of results. This work was expedited by writing a Python program to perform GIS and tabular operations (**Appendix 4-F**).

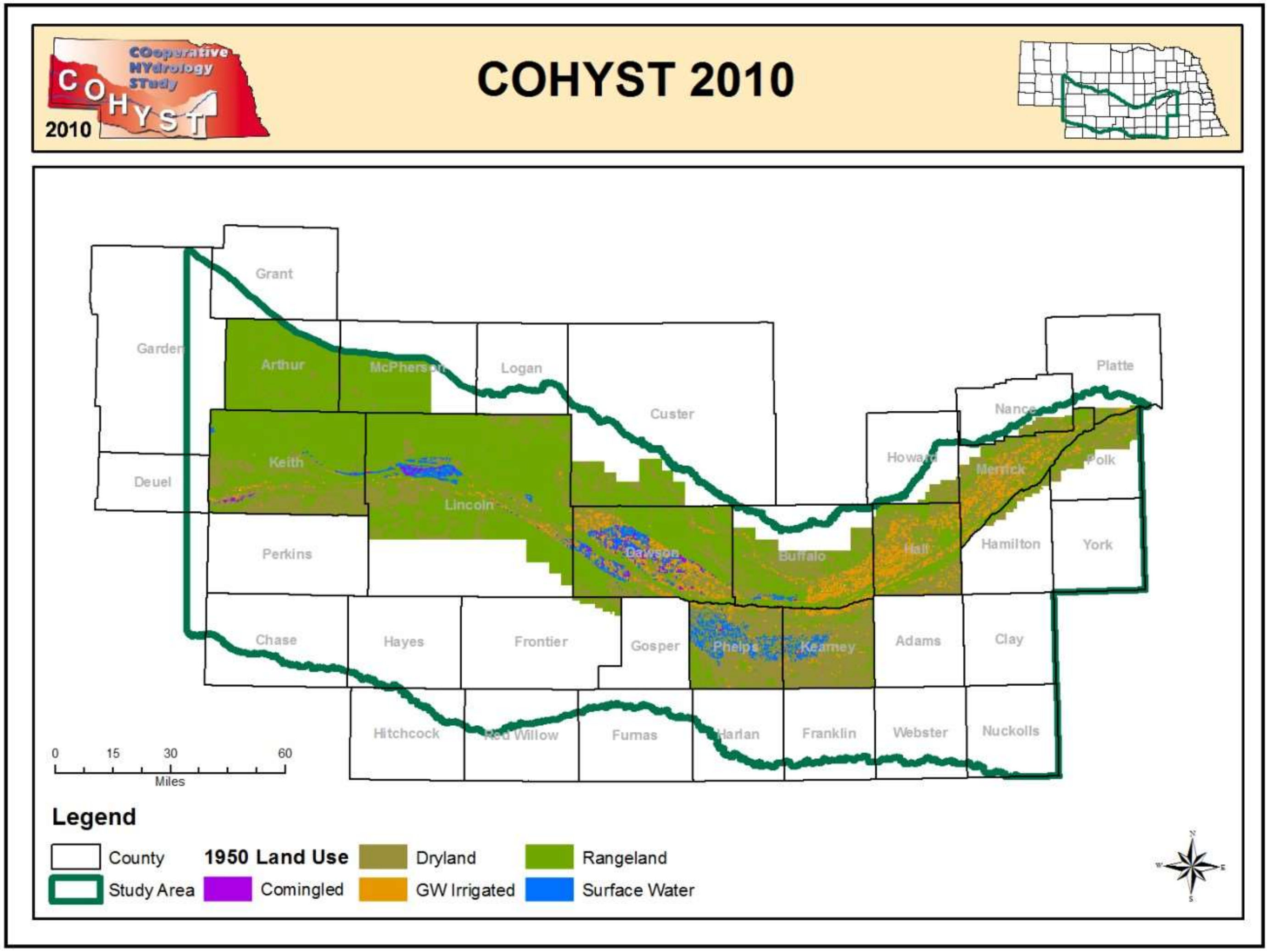


Figure 4.2-4. Year 1950 Land Use in COHYST 2010 Acres Redevelopment Area.

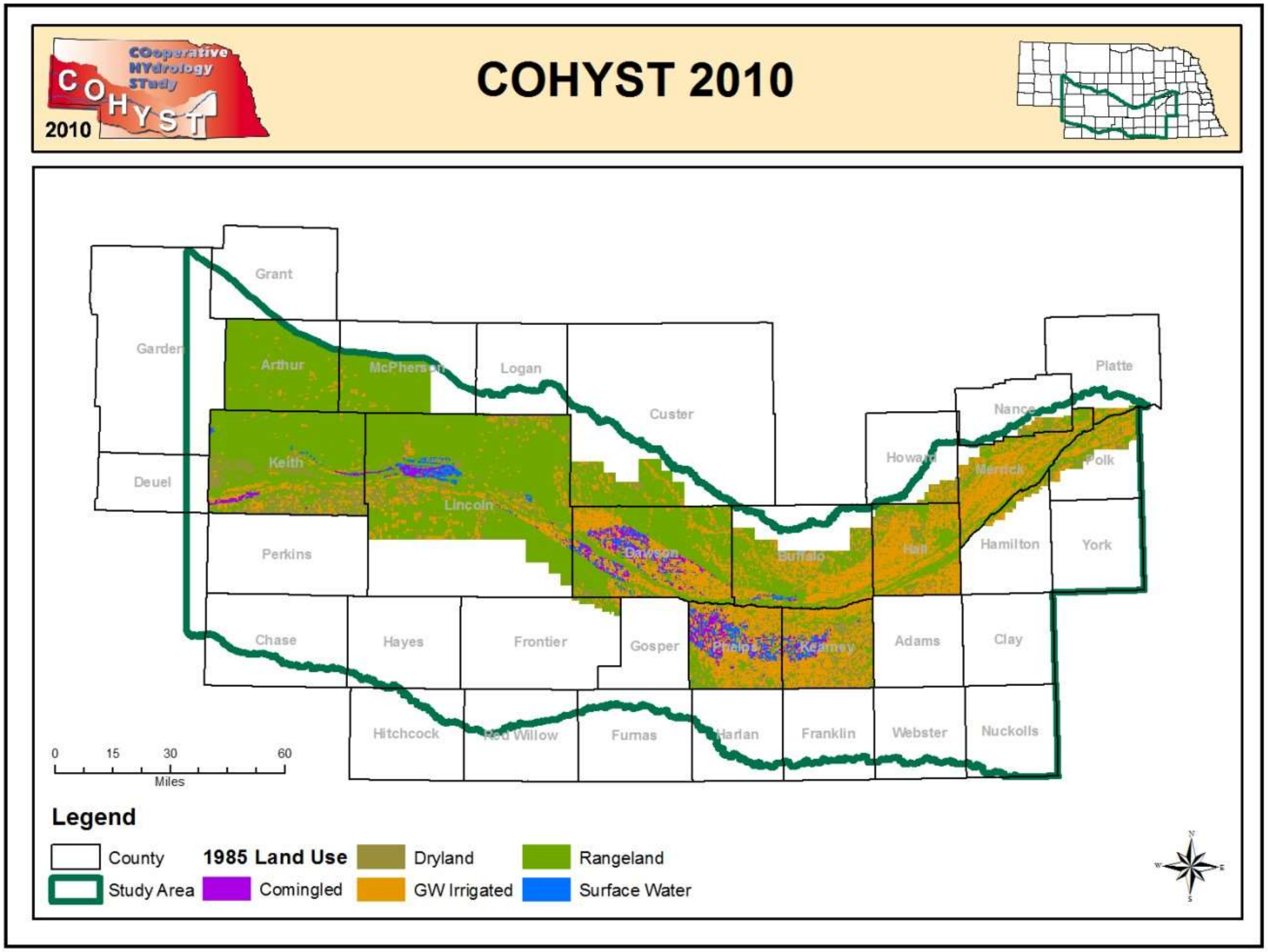


Figure 4.2-5. Year 1985 Land Use in COHYST 2010 Acres Redevelopment Area.

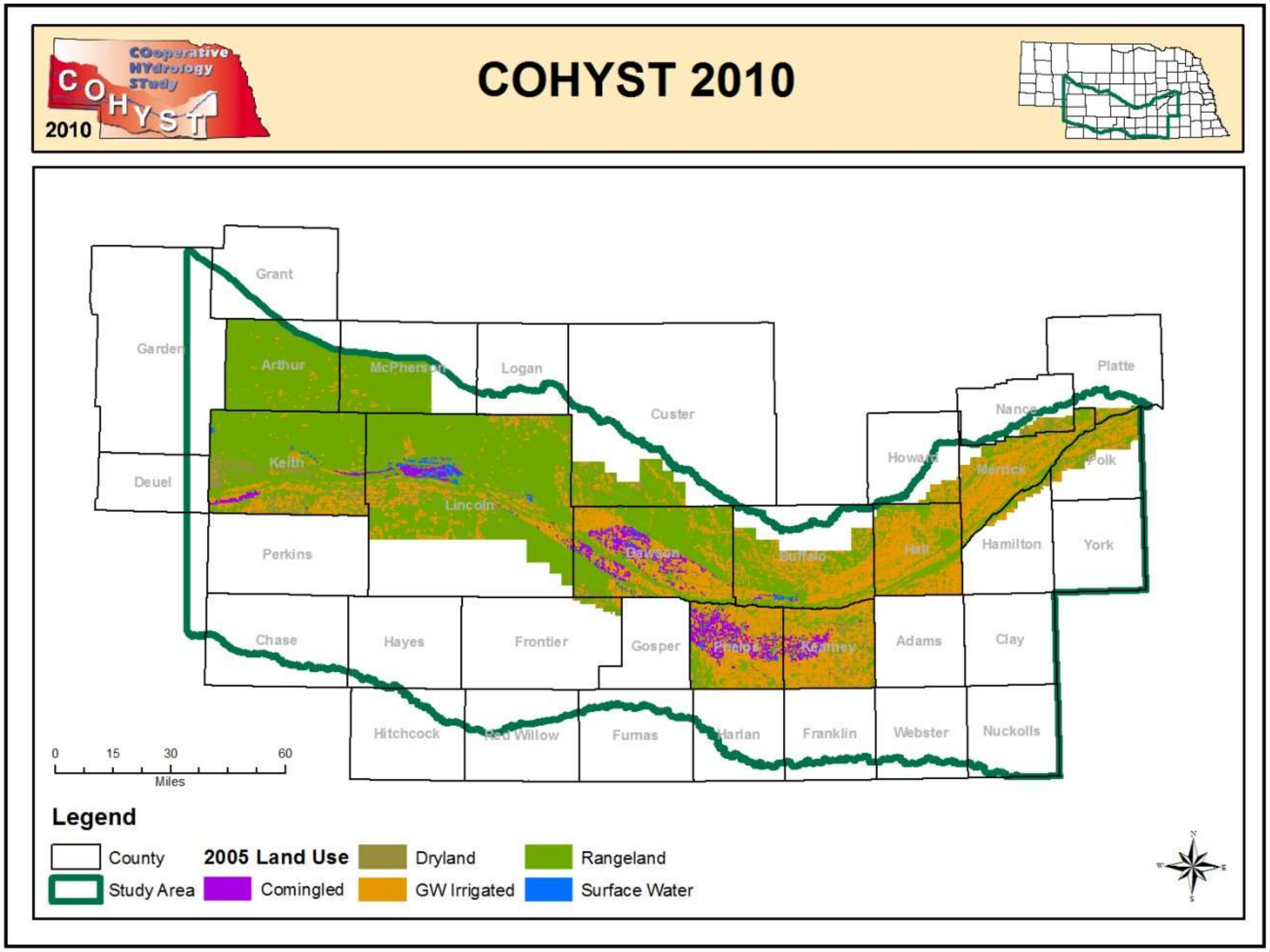


Figure 4.2-6. Year 2005 Land Use in COHYST 2010 Acres Redevelopment Area.

4.2.2.5 County-Scale Adjustments

Method. The methods used in the land use redevelopment were beneficial because the results showed historical irrigation and dryland potential at a field scale. Not all irrigable parcels, however, were irrigated in a given year; as such it was important to scale the potential irrigation according to estimates of actual irrigation for the given year. The NASS Census of Agriculture was the only data source that provided a record of estimated actual irrigation and dryland through the entirety of the study timeframe, but these data were only available at the county scale and were not considered the most accurate estimates due to the nature of the data, which are derived from producer reported acres. Remotely sensed data (CALMIT, NRD infrared imagery analysis) were considered the most accurate representation of actual acres, but these data were only available for the years 1983, 1997, 2001, 2005 (CALMIT) and 2007 (infrared for some NRDs).

The land use redevelopment utilized the best components of all data resources. The GIS irrigable land data based on certified acres (aggregated to county scale) were used to define upper limit of what could be irrigated in each year, with the dryland having a roughly inverse relationship to this. The NASS Census of Agriculture county data were used to develop the trends through time, while setting the upper limits equal to the potential irrigation and dryland estimates given by the GIS method. The remotely sensed data (also aggregated to a county scale) represented the actual irrigation for the years that these data were available, and created fixed points from which trends can be propagated forward or backward. The equations and methods used to build these relationships are further described in **Appendix 4-G.**

The calculated irrigated land and dryland through time is shown in **Figures 4.2-7** and **4.2-8**, respectively. The figures represent the aggregate of irrigated and dryland acres for all study area counties; similar figures for specific counties are shown in **Appendix 4-H**. The figures also show the irrigated and dryland estimates from all data resources used in the calculations (GIS data, NASS Census of Agriculture, remotely sensed data) so that relationships between the data can be evaluated. The calculated irrigated land and dryland adhere to the remotely sensed data

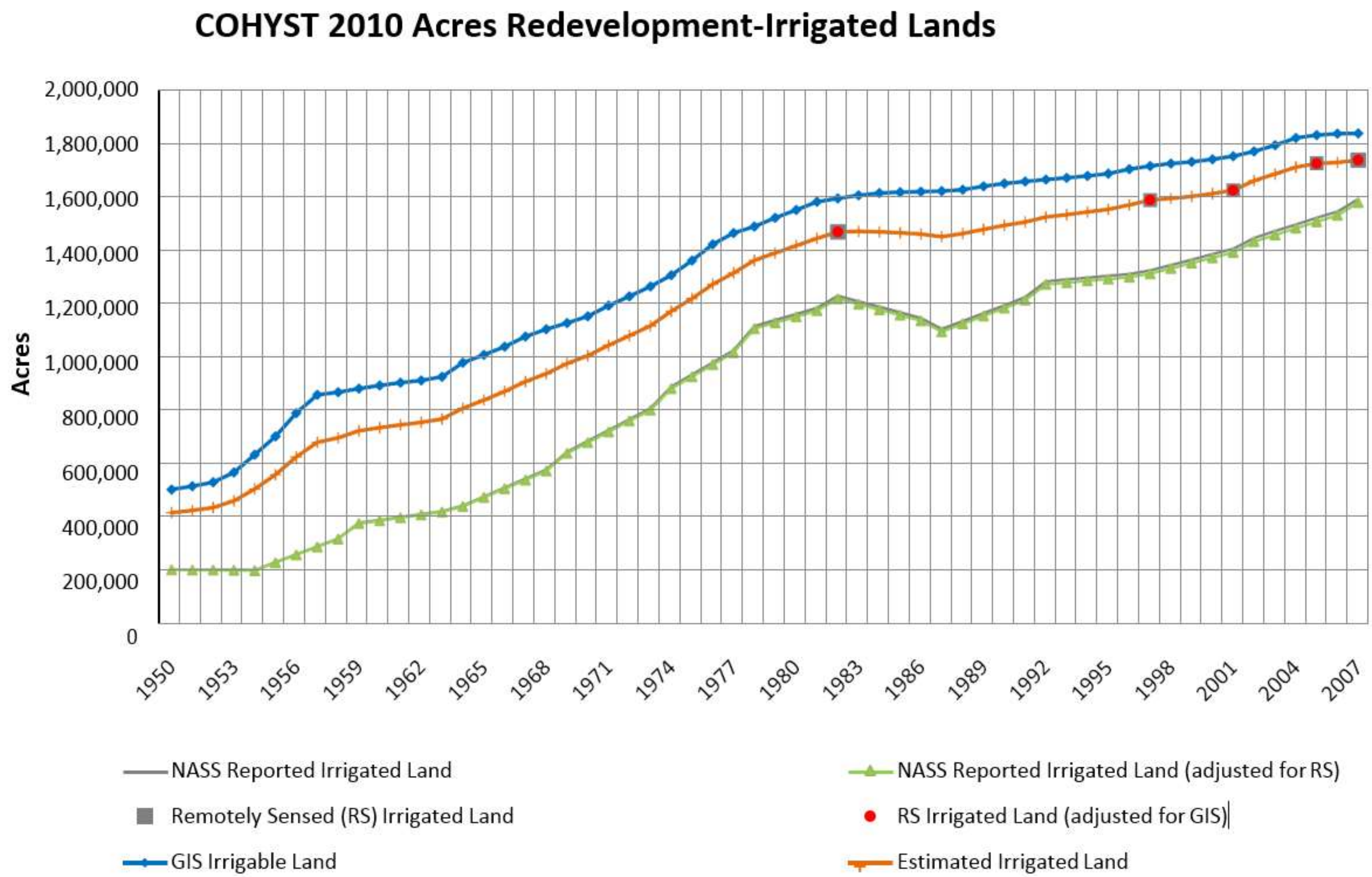


Figure 4.2-7. Estimated Irrigated Land Acreage for the Aggregate Study Area.

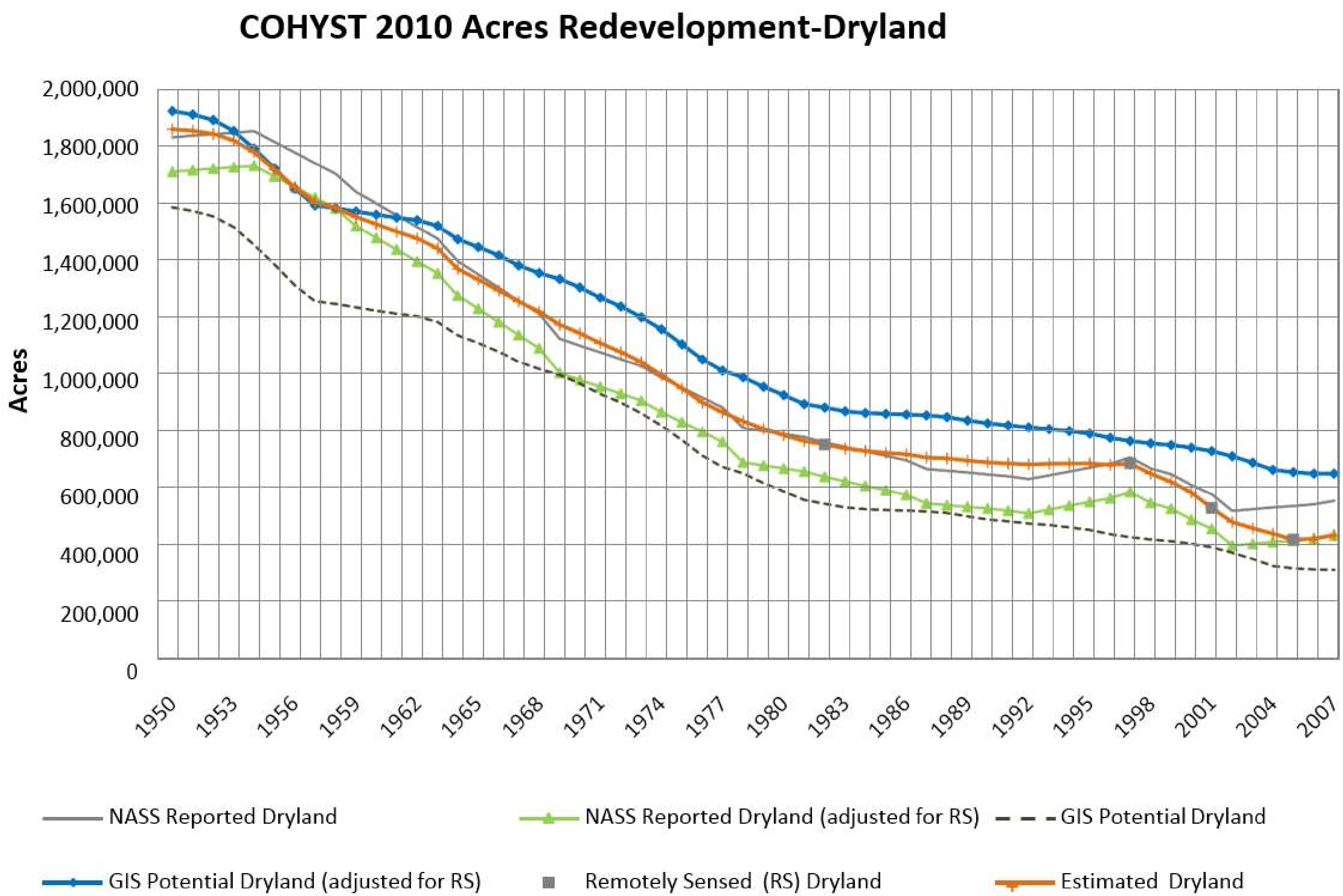


Figure 4.2-8. Estimated Dryland Acreage for the Aggregate Study Area.

fixed points, and show characteristics of the GIS potential and NASS Census of Agriculture trends.

Typically, if the fixed points are closer to the GIS data (i.e. irrigation upper limit) the trends of the GIS data are preserved more than the trends of the NASS Census of Agriculture.

Conversely, if the fixed points are closer to the NASS Census of Agriculture, the trends of the NASS Census of Agriculture are preserved more than the trends of the GIS potential.

Of note, outliers in remotely sensed irrigation data were initially adjusted to correspond with the general trend so that the equations would work properly. The figures show the initial remotely sensed irrigation data in grey, and the adjustments in red. The outliers were prevalent in a few individual counties, but are not distinguishable in the study area aggregate, meaning the outliers became insignificant when evaluated for the whole area. Also, for the equations for dryland to work properly, the initial GIS data and NASS Census of agriculture were scaled up or down so that all remotely sensed data were contained between the trends. Here, the initial data are shown in grey, and the adjusted data are shown in blue (GIS dryland) and green (NASS dryland). These adjustments were very pronounced both at the county scale and study area scale due to the uncertain nature of the historic dryland. Even so, the most important components of the dryland were preserved when developing relationships between all the data sources. The estimated actual dryland adheres to the remotely sensed data points and show characteristics of the GIS data and NASS Census of Agriculture trends for the years where the remotely sensed data were unavailable.

<u>Application to land use</u>. The county scaled adjustments described in the previous section were applied to land use estimates at the cell scale. The irrigation adjustments were applied to the surface water irrigated, groundwater irrigated and comingled categories: the dryland adjustments were applied to the dryland category. The adjustments were applied in a GIS environment as described in **Appendix 4-I**.

Application of county-scaled adjustments to 160 acre cells caused scale issues, most notably with the dryland category, where certain cells would exceed 160 acres. The phenomenon occurred most frequently in cells that contained mostly dryland, and was more prevalent in the earlier years of the model (more dryland). The dryland acres were often multiplied by an adjustment factor greater than 1.0; hence, if the cell was nearly full of dryland, the dryland adjustment could cause an overage in that cell, depending on how large the adjustment factor was for that year and county. Figures showing overages for specific years are shown in **Appendix 4-J**. There were 24 instances where cells with groundwater irrigation exceeded 160 acres, and this was due to a particularly large adjustment factor for irrigated lands.

The overages for cells were calculated and summed by county and year. The summed overage was redistributed to other cells with available rangeland for that county and year. The redistribution was applied to cells with the smallest amount of rangeland first, and then applied to cells with increasing larger portions of rangeland, and the process was continued until the overage was completely redistributed for that county and year. The redistribution was performed in Excel using a Visual Basic program created by Rick Vollertson (**Appendix 4-K**).

In cases where the adjustment factors caused a cell to have less than 160 acres, rangeland acres were added to the cell as a residual, so that all cells would have 160 acres.

Application to crop types. Crop types were derived from NASS Census of Agriculture reports. The Census of Agriculture data is requested from ranchers and farmers roughly every 5 years with 1945 being the first year of the Census for the COHYST region. The census years used in the COHYST land use analysis were 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, 1997, 2002 and 2007. Data for specific crops found in the COHYST region were acquired from published reports and the USDA Internet website (**Appendix 4-L**). A Fortran program was then utilized reclassify the data into COHYST crop types and interpolate the data to create a record for every year from 1950 to 2007 (**Appendix 4-M**). The outputs from the program determined the COHYST "crop mix" for specific counties and specific years (**Appendix 4-N**).

The crop mix was then applied uniformly to cells that contained dryland or irrigated lands, and the results were copied into the final land use dataset. The final land use dataset was a series of tables that showed both the land use and crop type distributions by cell-year.

Quality assurance. Quality assurance (QA) of the data was performed at several points during the process. The spatial join of wells to fields process was QA'd by visually comparing well locations to parcel locations to ensure that the years tied to the features made sense. The GIS processes were QA'd at several points by summing acres to ensure that all cells had 160 acres after overages were removed and residual rangeland was added. Tabular data were sorted ascending and descending at several points to ensure that all rows had values. The final output was QA'd by plotting the sum of irrigated land and dryland for a given county and year against the irrigation and dryland plots where the adjustment factors had been originally derived. Almost all counties successfully passed this QA; however, small discrepancies were noted with a few counties (Platte, Hamilton, Frontier). After further investigation, it was concluded that the discrepancies occurred as the result of "edge effects", where the cell based approach produced stair-stepped edges along county lines and the original approach (where adjustment factors were derived) calculated areas based on smooth edges along county lines. These counties only contained a small fraction of area in the study area (**Appendix 4-O**). No further action was taken since the discrepancy was explainable. All other QA testing passed with no problems.

4.2.3 Method for Development of New Land Use Dataset Outside Platte River Basin

For Gosper County and for all counties outside the Platte drainage, acreages for groundwater, surface water and non-irrigated crops were taken from the work product of Rich Kern, NDNR (2009). These acreages estimates were made by a different method than described above, and eliminate the 1997 discontinuity (which is not considered a critical flaw for counties not in the Platte).

The acreage estimates were made by crop type for each 160-acre cell over the period of 1950-2005. The acreages reflect changes in land uses from Census of Agriculture county crop statistics (U.S. Department of Commerce, 1949-92, and U.S. Department of Agriculture, 1997), mapped 1997 land use (Dappen and Tooze, 2001), mapped 2001 land use (Dappen and Merchant, 2003) and mapped 2005 land use (Dappen, Merchant, Ratcliffe, and Robbins, 2007). The details of the method used to develop the COHYST land use database can be found in **Appendix 4-P.**

4.2.3.1 Census of Agriculture Data

The Census of Agriculture reports contain county-level crop statistics on approximately a 5-year recurring basis. Beginning with the 1954 Census, irrigated acres by selected crops were reported. For the 1949 Census, only total irrigated acres were reported and irrigated acres by crop had to be estimated. Not all crops were reported for all years, so dryland and irrigated acres are estimated in some cases. This typically happened with minor crops. As more acres went into production, the Census included these crops. Some counties are only partially within the COHYST area. For these counties, the Census data were reduced by a factor based on the proportion of the county that is in the study area. The Census data were also interpolated between Census years using a linear computation process to estimate irrigated and dryland acres by crops. This analysis is discussed in detail in **Appendix 4-M**.

4.2.3.2 1950 through 1997 Land Use Data

The location of irrigated cropland, dryland, and rangeland within a county for 1950-97 was estimated based on the CALMIT 1997 land use data (Dappen and Tooze, 2001), location of surface-water irrigated land, registered irrigation wells (Cooperative Hydrology Study, 2001b), and topographic regions (Conservation and Survey Division, 1998). Six land uses were assumed not to change over time, including urban, open water, woodlands, wetlands, other agricultural land, and roads. While minor changes may have occurred over time, these land uses, when combined, cover less than 7 percent of the study area, with wetlands and woodlands being the dominant land uses that were not assumed to change over time. Two minor 1997 land uses, dryland potatoes and dryland sugar beets, were assumed to be irrigated, because these crops are typically irrigated. The remaining 18 land uses were modified over time as described below.

The 1997 land uses (Dappen and Tooze, 2001), original output was at 2.5 meter resolution. CALMIT aggregated the 2.5 meter output into 10-acre cells for COHYST. The 10 acre cell dataset was the starting data for the COHYST 2009 work and was aggregated to 160-acre cells to cover the entire COHYST area. The number of acres of each of the 27 land uses in 1997 was calculated for each 160-acre cell. The 160-acre cells are coincident with the 160-acre cells of the model cells described in this report.

The process of estimating 1950-97 land use by 160-acre cell started with 1997 land use (Dappen and Tooze, 2001) and worked backwards in time. For example, if total acres for a particular land use in a county were less in 1996 than in 1997, random fields, weighted as described below, were removed from the 1997 dataset to develop the 1996 dataset. The land use with the largest decrease going back in time was processed first. The fields that were removed were tracked for later re-assignment of land use. After all the land uses in a county that had decreased from 1997 to 1996 were processed, land uses that increased were processed, beginning with the land use that had the largest increase. These land uses were assigned to random fields, also weighted, that had been previously removed. If more area of land uses increased than what had been removed, the additional land uses were added by assuming rangeland was being converted to the new land use.

The random process of removing or adding acres by cells was weighted based on topographic regions. The 18 variable land uses were grouped into three general categories: row crops (including alfalfa), grain/fallow, and rangeland, and a weighting was assigned to the likelihood of a category being present within a topographic region. For example, the “row crop” land use category was given large weights for cells in valleys and plains and small weights for cells in the Sand Hills, sand dunes, and bluffs/escarpments. This meant that the weighted random process was much more likely to add a row crop field to cells in a valley or plain, and was similarly much more likely to remove it from cells in the Sand Hills, sand dunes, or bluffs/escarpments.

The weighting was generally based on the premise that for choosing new ground to develop for crop land, flat ground near large streams would be most preferred, and hilly or steep ground far from large streams would be least preferred.

The re-assignment process also considered the location of surface-water irrigated lands and registered irrigation wells. Irrigated cropland was preferentially kept on surface-water irrigated lands by rejecting removal of an irrigated land use or favoring addition of an irrigated land use on surface-water irrigated lands. In a similar manner, the number of irrigation wells in an area was used to weight retention or removal of irrigated land uses from 1997 to 1996.

Once the 1996 land use dataset was built from the 1997 land use dataset, the 1995 dataset was built from the 1997 dataset in the same manner. Then the 1994 dataset was built from the 1997 dataset, and so on until the 1950 land use dataset was built. The decision to always start with the 1997 land use had the advantage of keeping any bias in any year from propagating to other years.

4.2.3.3 1998 through 2005 Land Use Data

The years 1998, 1999, 2000, and 2001 were developed using interpolation of the CALMIT 1997 and 2001 datasets. The years 2002, 2003, 2004, and 2005 were developed using interpolation of the 2001 and 2005 datasets. As noted earlier the CALMIT datasets for were provided as 10-acre size cell data which needed to be aggregated to the model 160 acre cells. The process of interpolating the yearly data were completed using well registration data, surface water irrigated acres' data, and the CALMIT land use data for the 160 acre cells.

4.2.3.4 Summary of 1950 through 2005 Land Use Data

The final land use data were complete for the full period by combining datasets and completing quality assurance checks of the dataset. The acreage summary for this land use dataset is shown in **Figure 4.2-9**. Years 1950, 1985 and 2005 results from the 2009 Land use dataset are shown in **Figures 4.2-10, 4.2-11,** and **4.2-12,** respectively. These figures show maps for the COHYST 2010 area with a display of the surface water irrigation, groundwater irrigation, and the non- irrigated dryland and rangeland. As an example, the changes in land use over time for Gosper County is shown in **Figure 4.2-13.** This is the only remaining acreage dataset used for areas within the Platte drainage that originated from the NDNR 2009 work.

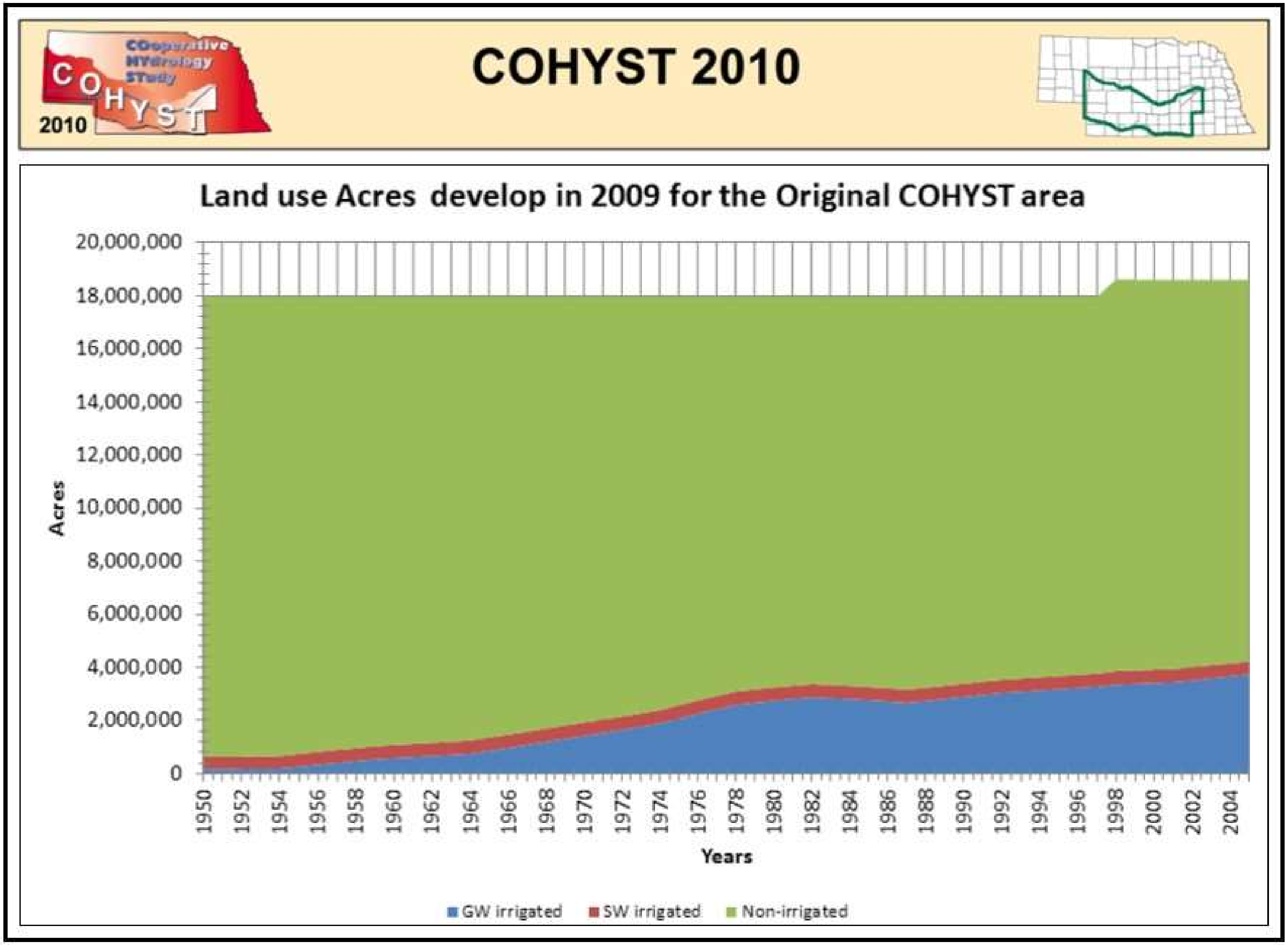


Figure 4.2-9. Land Use Acreage Irrigated and Non-Irrigated in Original COHYST Area.

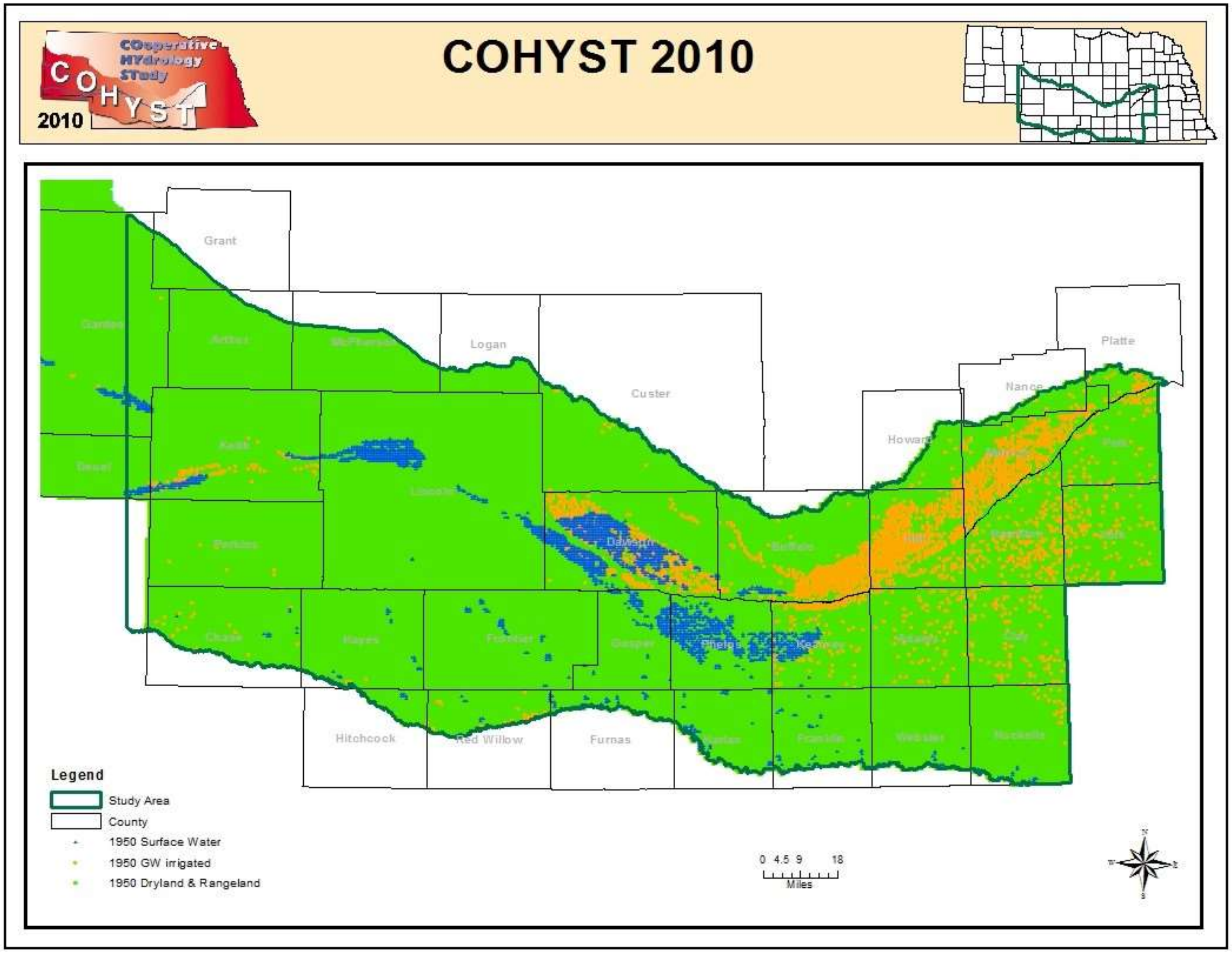


Figure 4.2-10. Land Use in 1950 for the COHYST Area.

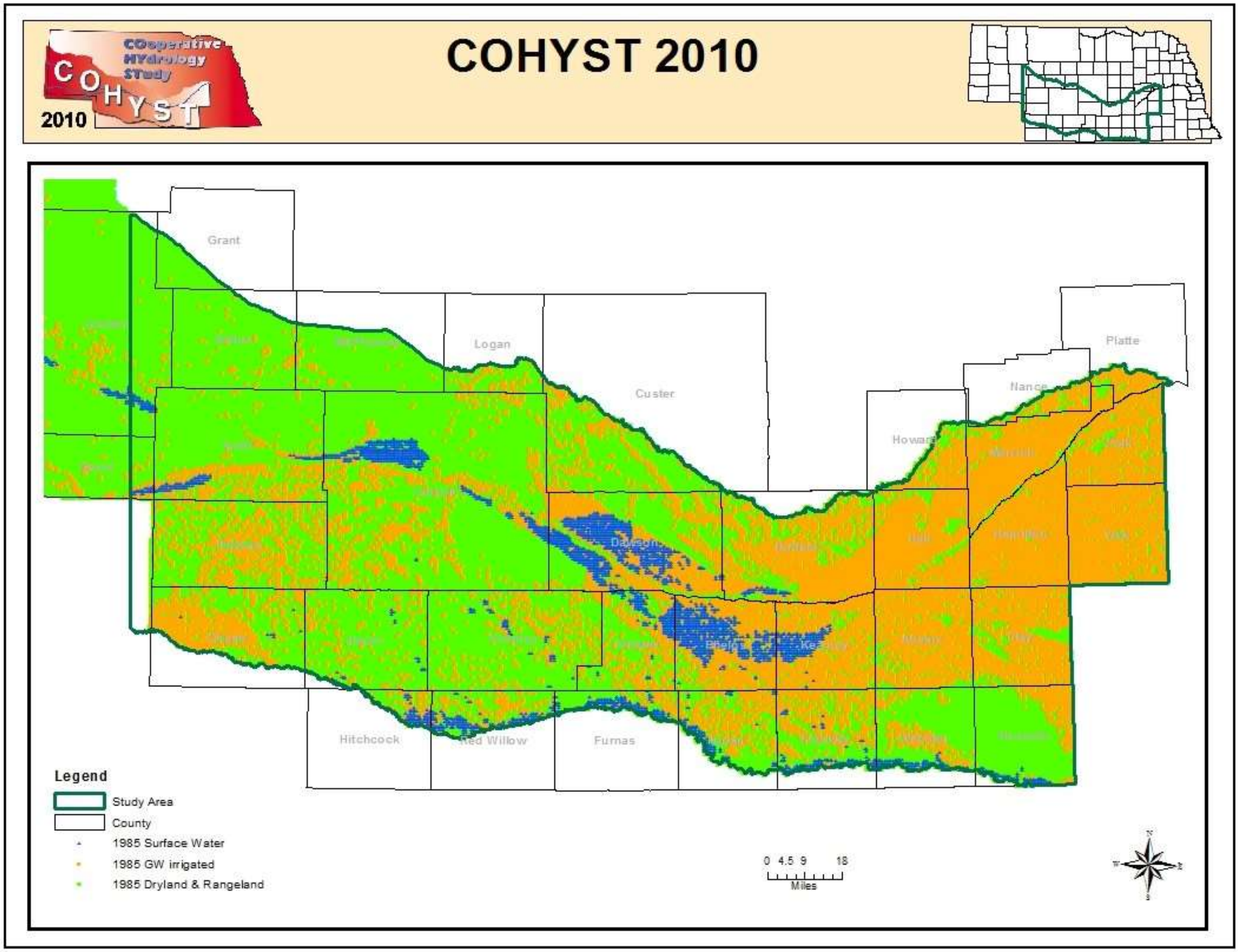


Figure 4.2-11. Land Use in 1985 for the COHYST Area.

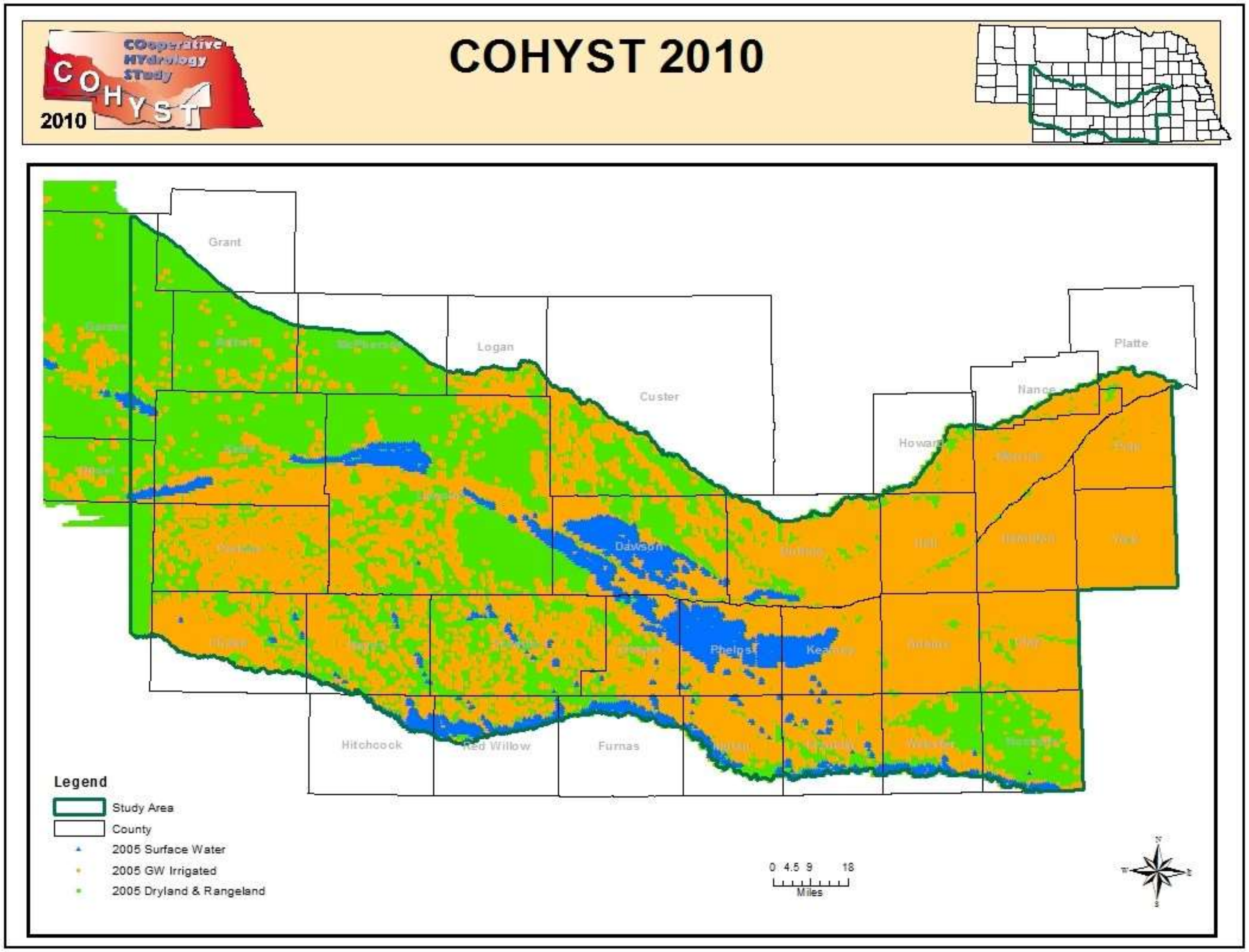
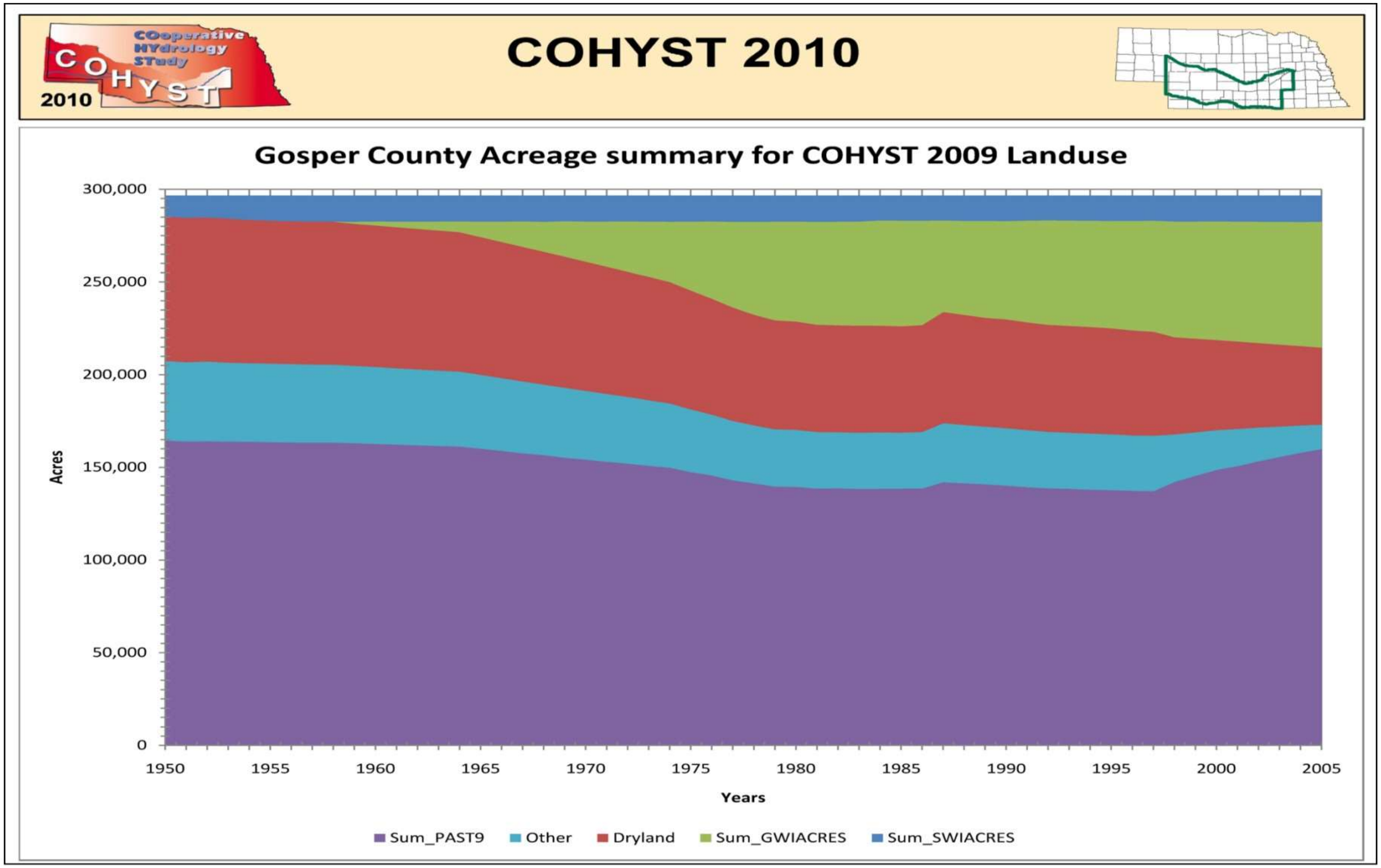


Figure 4.2-12. Land Use in 2005 for COHYST Area.



Note: Legend Description – PAST9 is rain feed grassland acres used for pasture or hay. Other includes Urban, Water, Roads, and Wetland acres. Dryland is all cultivated acres that are rain feed. GWIACRES are the groundwater irrigated acres and SWIACRES are the surface water irrigated acres.

Figure 4.2-13. Changes in Land Use Over Time for Gosper County.

4.2.4 Comparison to an Actual Farm

A board member of CPNRD kindly provided his records relating to his farm, as to how many acres he irrigated each year since 1982, and what crop distribution he planted. The model cell in which most of this farm is located was identified, and the land use data used in the model evaluation was extracted.

The comparison of the model inputs to the real world demonstrated an anticipated result, which is that there is no meaningful correspondence between model inputs about land use, and the land use on actual individual farms. This is the necessary result of a method that simply scales data obtained at a county level down to farm-sized model cells, with the only farm-specific data used being evidence of whether the land has a well or is served by a canal (in which case it assumed to have been irrigated and to have a crop distribution typical of the County's irrigated lands). Examples of how the actual farm practice differed from the model inputs include the following.

- The model inputs simulated a large increase in irrigated acreage at the subject farm in 1953, which corresponds to the drilling and registration of an irrigation well. In the land use method, this triggers an ability to assign additional irrigated acreage to the cell where the well is located. This was the second large capacity well on the property (the first was drilled in the 1920s) and did not necessarily have any impact on actual irrigated acreage.
- For the 1985-2005 model period, the model inputs show a slow increase in irrigated acreage, from slightly less than 140 acres (out of a 160 acre cell) to slightly more than 140 acres. This reflects the scaling down of county data during a period in which irrigated acreage in the county gradually increased. On the actual farm, 152 acres were reported as irrigated each year.
- For the 1985-2005 model period, the model inputs show variation in crops grown, with corn being dominant by far (usually 100 acres or more), soybeans a distant second (20 to 40 acres), and the rest alfalfa or sorghum (10 acres or less). Again, this is the scaled

down proportion of crops reported countywide. The farm records indicate a pattern in which there was a switch in crop dominance from corn to soybeans and back again.

- Overall the crop split was about 50:50. Alfalfa and sorghum were not grown and in two years the farm was idle, though in the model the cell was irrigated.

All these results demonstrate that the model as now constructed should not be used to evaluate conditions at a specific property, unless extensive work is done to tailor land use and crops to that property, and even then, only if there are water level or other data to confirm that the model results match history. Any cell in the model should only be considered as a "virtual" or computer simulated farm, not a real one.

The farm-specific review did reveal minor aspects of the land use methodology that produced small, anomalous results. For example, on the subject farm there was a 1997 glitch in which a portion of the small amount of simulated dryland was transferred to the "non-production" category; this was transferred back in 1998. Obviously, this had nothing to do with the actual farm (e.g. a road was not built, then taken up). The glitch apparently reflects a result of the adjustment procedure used in the developing the land use dataset, by which over or under predictions of dryland acres (compared to census reports) are reconciled to the actual data. The effect of this glitch is small and considered not significant for purposes of the model applications since, as noted above, farm-specific applications are not appropriate without a great deal of work to modify the model.

4.2.5 Method for Development of Land Use Dataset for 2006 thru 2010

The extension of the COHYST Models to run through 2010 was one of the new tasks for the COHYST 2010 Phase II work. This work effort required developing land use data for each year 2006 thru 2010. To accomplish this the COHYST Sponsors sent out a request for proposals, and contracted with Riverside Technology Inc. to develop for each year land use parcels with descriptions of crop type (corn, soybeans, alfalfa, etc.) plus classify the parcel as irrigated or non-irrigated. Riverside prepared a Land Use Classification Manual that describes the detailed steps and processes used to develop the Land Use Arc-GIS geo-database. The Manual is included as **Appendix 4-Q.** The Arc-GIS geo-database is available on the COHYST Website.

The Riverside analysis provided irrigated acreage parcels for each year 2006 thru 2010. To utilize. these irrigated acreages in the COHYST 2010 models it was necessary to distinguish if the irrigated acres are groundwater irrigated, surface water irrigated, or both (comingled).

The irrigation type assignment process was developed by DNR staff (Amy Zoller) using Arc-GIS coverages. There were two key parcel datasets created for the analysis. The Surface Water parcel dataset was developed from surface water right fields information and point of diversion information. The DNR permits and registration mapping section developed this coverage. The second was a Groundwater parcel dataset which was developed from NRD certified irrigated acreages information, County Assessor irrigated land use information and DNR well registration information. The Surface water and Groundwater parcel datasets were then overlaid to determine Comingled Irrigated acres. These irrigation type data were then added to the Riverside Arc-GSI geo-datasets.

The last step for this 2006 thru 2010 land use analysis was to develop COHYST model cell datasets. This was done by DNR staff using Arc-GIS tools.

4.3 Watershed model

In addition to climate and land use information as described previously, the watershed model relied upon information characterizing model area soils and made use of available records of historical water use.

4.3.1 Soils

Soils information used in the COHYST 2010 model is based on the State Soil Geographic (STATSGO) database developed by the National Cooperative Soil Survey and distributed by the Natural Resources Conservation Service (formerly Soil Conservation Service) of the U.S. Department of Agriculture. The dataset consists of georeferenced digital map data and computerized attribute data. The map data are collected in 1- by 2-degree topographic quadrangle units and merged and distributed as statewide coverages. The soil map units are linked to attributes in the Map Unit Interpretations Record relational data base, which gives the proportionate extent of the component soils and their properties. STATSGO was designed primarily for regional, multicounty, river basin, State, and multistate resource planning, management, and monitoring. Details regarding this dataset can be found in the Description of STATSGO Data at:

https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053629

4.3.2 Municipal, Domestic, and Industrial Water Use

Municipal, Domestic, and Industrial uses (other than some power) in the study area are supplied by groundwater. In some cases, return flows from these uses are discharged to surface water features. While such uses are small compared to irrigation pumping, they are included in the model to meet the project goal of a reasonably complete representation of the hydrologic system. These data also address Integrated Management planning and reporting required by the Platte River Recovery and Implementation Program. As livestock uses are considered minor and not reported by the Program, they were not quantified for the COHYST models.

Appendix 4-R documents the methods used to develop a dataset that consists of monthly values of non-irrigation pumping and return flows for the years 1985 through 2010. The data sources are as follows.

- The Nebraska Department of Natural Resources (including results from a recently conducted state-wide industrial water user's survey).
- The Central Platte, Tri-Basin, and Twin Platte Natural Resource Districts.
- The United States Geological Survey.
- The Nebraska Department of Environmental Quality.
- The United States Census Bureau.

Monthly withdrawals for 36 municipalities were determined using data reports obtained from NDNR and the NRDs, to the extent available. These data were assumed to be based on reliable measurements or estimates (i.e. no independent quality assurance was performed).

Data were compiled separately for 28 self-supplied industries and 9 industries whose use is supplied by a municipality. These uses were determined from reported data or from information obtained by NDNR through an industrial water survey. Where relevant, municipal use was adjusted by subtracting known industrial uses.

The many instances of missing data were filled in by various methods described in **Appendix 4-R**, but primarily by comparison to analogous data. For example, if no data were available for a city for a particular year, an estimate for that year was made through multiplication of an interpolated population estimate times a representative per capita demand estimate. [Population estimates came from the U.S. Census or NDNR, or linear interpolation of such estimates.] Similarly, if monthly data were not available for a year, the annual values were distributed according to the average distribution from other years; or using a distribution from a comparable entity.

Domestic water uses were defined as self-supplied groundwater for persons not supplied by one of the municipal systems. Separately for 32 counties, the quantity of such use was estimated based on the five-year water use reports of the U.S. Geological Survey. Rural uses for individual years were estimated based on interpolated estimates of rural population. Values were distributed monthly using a function typical of a small municipality and were distributed spatially based on the location of non-municipal wells in the NDNR wells data base.

Return flows from municipal and industrial uses were quantified for wastewater returns pursuant to a discharge permit to the extent data were available from the Nebraska Department of Environmental Quality. In the absence of data, it was assumed that wastewater was discharged to lined pond and fully consumed; this assumption is known to be correct for some municipalities but has not been verified for all. Return flows from domestic uses were not quantified.

A description of the data base that resulted from these methods is provided in **Appendix 4-S.** The data are provided in a geo-database available on the COHYST Website.

Storing the information in this format allows the data to be viewed with respect to geographic location such as shown on **Figure 4.3-1**, or to be displayed temporally as shown on **Figure 4.3-2**. The pumping information was incorporated into the groundwater and surface water operations models via the watershed model documented in Section 5. The information which was compiled for this effort did not include surface water used in power production related industries. These types of surface water uses were incorporated directly into the surface water operations model and are discussed in Section 4.4.

4.3.3 QA/QC of Irrigation Water Use

Records of applied irrigation water were acquired for use in evaluating the estimates of irrigation demands generated by the Watershed Model. A database from the Upper Republican NRD contained recorded readings from the District's well metering program from which annual water use by well could be determined. This information, specifically from the Perkins County area, was relied upon during calibration of the watershed model. Information from the Central Platte NRD contained estimates of well pumping which were developed using a power records technique. Review of this information led the modeling team to adjust pumping estimates in the area.

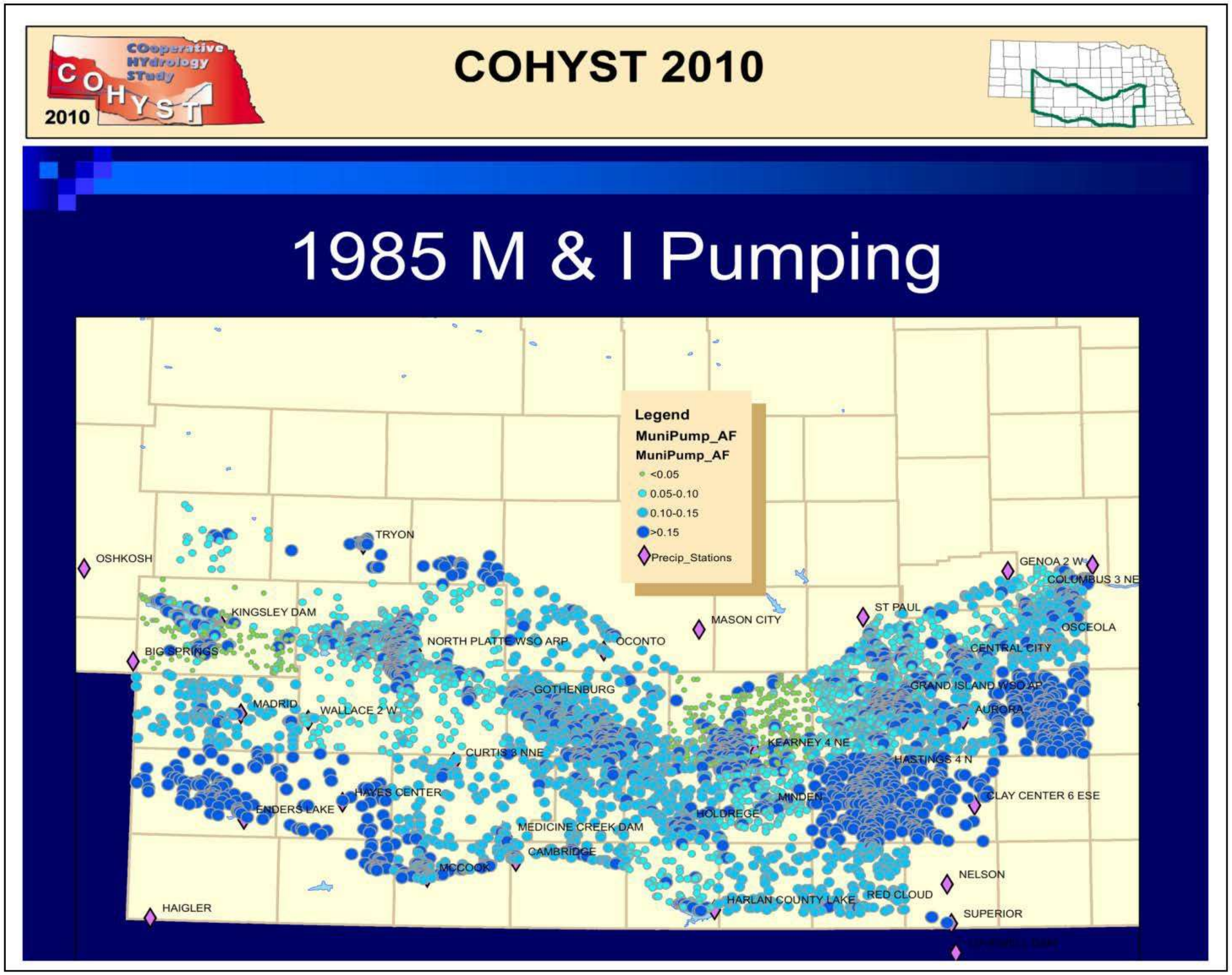


Figure 4.3-1. Location of Municipal and Industrial Centers.

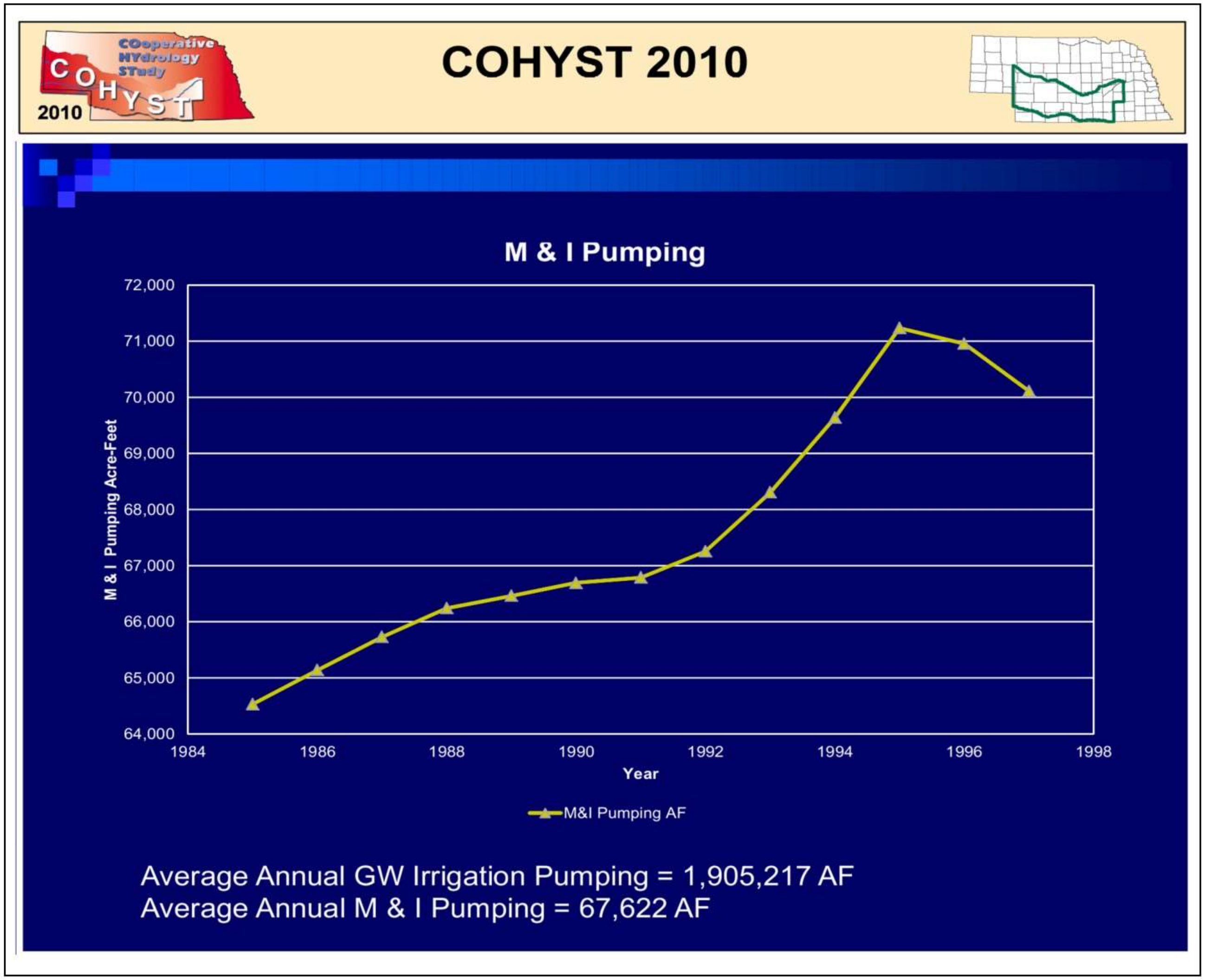


Figure 4.3-2. Municipal and Industrial Pumping Over Time.

4.4 Surface Water Model

Daily values of streamflow, canal diversions, reservoir conditions and other surface water data used in the COHYST 2010 models were obtained from the United States Geological Survey (USGS), Nebraska Department of Natural Resources (NDNR), Central Nebraska Public Power and Irrigation District (CNPPID), Nebraska Public Power District (NPPD), Twin Platte Natural Resources District (TPNRD), and the Central Platte Natural Resources District (CPNRD). Figure 2.2-4 in Section 2 provided a map showing the irrigation canal network in the study area. **Figure 4.4-1** shows the major reservoirs, river gages, canal diversions and gaged canal returns.

4.4.1 Data Compilations

Appendix 4-T identifies the source data that were used by COHYST 2010 to provide calibration targets, inflow boundary conditions (e.g. for the North Platte River at Lewellen and the South Platte River at Julesburg), and specified flows used as inputs during calibration of the historic model. The Appendix provides the following.

- Identification of gaging stations for the North Platte, South Platte, and Platte River main stems which were used to obtain daily flow data for the period of study, including data source and gage number.
- As above for tributaries, canal diversions, and gaged returns.
- Links to system layouts provided by the irrigation districts.
- A tabular summary of physical canal data.
- Identification of records for reservoirs.

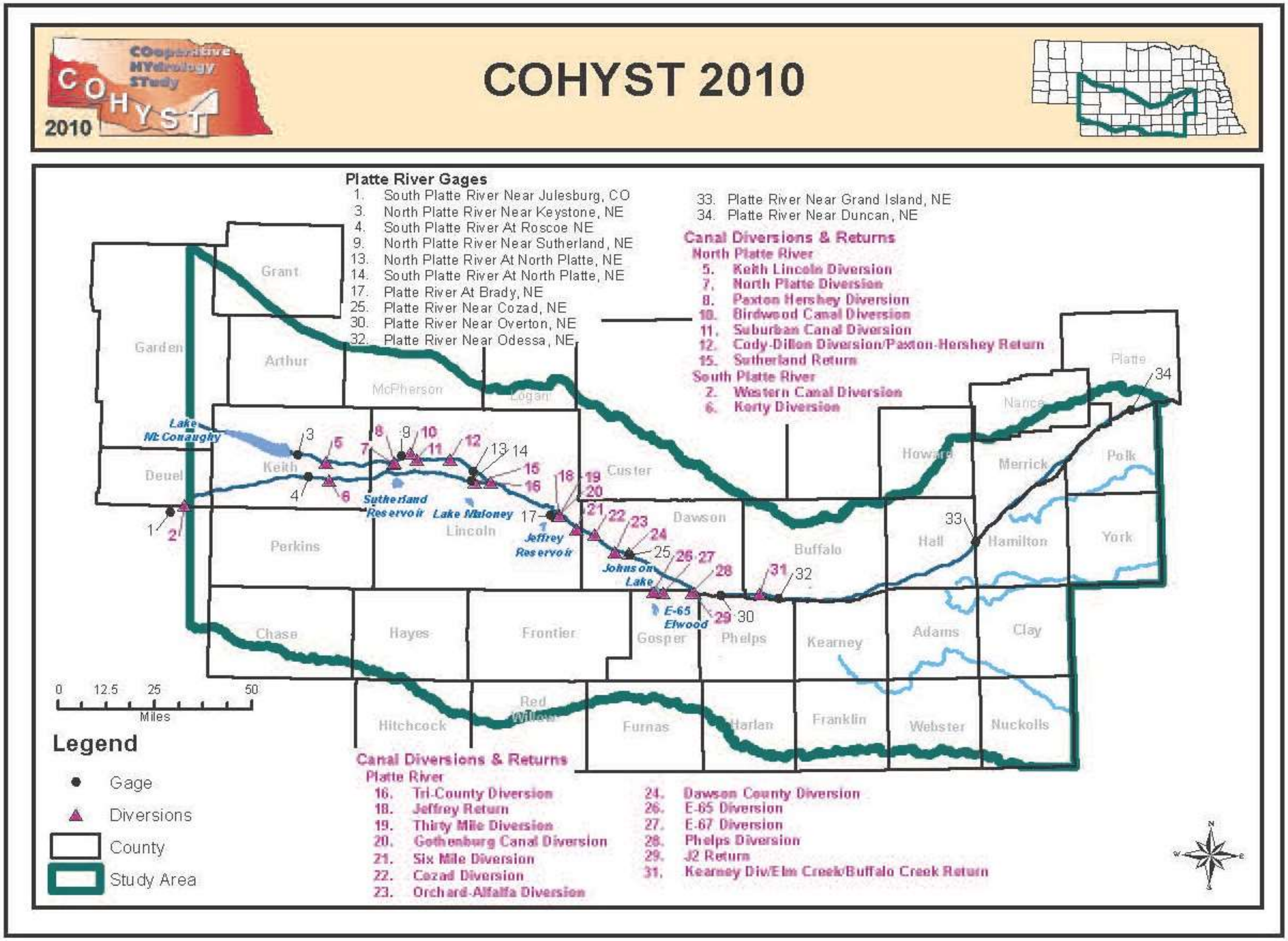


Figure 4.4-1. Major Surface Water Features of the COHYST 2010 Model.

In addition, surface water appropriation data were obtained from the NDNR water rights database at http://nednr.nebraska.gov/dynamic/waterrights/SelectSearchOptions.aspx (NDNR, 2009). Storage water and natural flow data for the irrigation canals were obtained from the NDNR Platte Water Accounting Program (PWP) database. PWAP is an accounting program used by the NDNR Bridgeport Field Office to allocate natural flow and track storage water.

4.4.2 Created Data Sets

Several important datasets were created in whole or part as COHYST 2010 work products.

4.4.2.1 Seepage Datasets

The limited data on seepage rates from surface water features were inventoried, and the following datasets were identified.

- Synoptic Studies: NPPD and CPNRD conducted several synoptic studies of the Gothenburg, Cozad, Thirty Mile, Dawson, and Kearney Canals in 2004, 2007, and 2008. Inflows, outflows, and turnout deliveries were gaged to estimate seepage rates for short reaches of the main supply canals and a limited number of the major laterals.
- Sutherland System: NPPD conducted an optimization evaluation of the Sutherland system in 1993 that used a combination of geophysics and water budget calculations to estimate seepage rates for the supply canals, as well as Sutherland Reservoir (Harza, 1993).
- Sutherland Reservoir: NPPD developed a stage/seepage function using limited reservoir data and water budget calculations from 2002 and 2003.
- Tri-County System: CNPPID conducted a system analysis in that estimated seepage rates for the supply canal and reservoirs based on reach-by-reach water budget calculations (Unpublished data provided by CNPPID staff).
- Tri-County System: CNPPID staff provided seepage rate estimates for system elements based on operational observations over the last 10 years (Steinke, 2013).
- Elwood Reservoir: CNPPID conducted a study of Elwood reservoir operations that

estimated seepage rates from historic data. An elevation-seepage function was also developed for Elwood Reservoir (CH2M Hill, 1993).

4.4.2.2 Sutherland Gage

A second dataset created for the project was to fill in missing data for the North Platte River near Sutherland (6691000) gage. This gage was maintained by the USGS from 1930 through 1991, with the DNR assuming operation of the gage in 1991. Missing data was found in the record during the non-irrigation season for all or portions of Water Years 1993-1999. The historic daily non-irrigation season flows for the North Platte River at Keystone (6690500), the North Platte River at North Platte (6693000), and Birdwood Creek near Hershey, NE (6692000) were used to synthesize the missing data for the North Platte River at Sutherland gage. The synthesis of these data are described in **Appendix 4-U**. The synthesized gage data were used to complete the calibration dataset for the North Platte River at Sutherland gage. Because the data are synthesized, the Sutherland gage is considered a secondary calibration target.

4.4.2.3 Historic Reach Gains/Losses

Table 3.5-1 in Section 3 explains the use of reach gain/loss data in the COHYST 2010 model. As indicated, the net calculated reach gain or loss is calculated as the difference when gaged inflows (positive) and outflows (negative) are summed. A complete tabulation of the reach gain/loss data is available on the COHYST Website.

4.4.2.4 System Water Budgets

Available historic stream, diversion, reservoir, and return gage data were used to compute annual system water budgets for both the CNPPID Tri-County system and the NPPD Sutherland system. These annual system budgets were developed for use in gross calibration of each system’s operating rules, canal loss rates, and irrigation deliveries (CNPPID Tri-County system only). The budgets are provided in **Appendix 4-V**.

4.5 Groundwater Model

Several datasets were developed solely to support construction and calibration of the groundwater model. These datasets provide information on hydrostatigraphy, regional water table conditions, and calibration targets that were used as inputs to or measures of the COHYST2010 MODFLOW simulation. Section 4.5.1 describes how geologic and hydrogeologic information were compiled to create the hydrostratigraphic data that were used to define and guide adjustments to the modeled aquifer. Section 4.5.2 describes the regional water level data that were used to define the initial conditions to the groundwater model. Section 4.5.3 describes the construction of hydraulic conductivity zones and initial estimates of hydraulic conductivity. New calibration head targets were developed for the final calibrated groundwater model Run 28 and are described in Section 7 of this report.

4.5.1 Hydrostratigraphy Dataset

Physical properties of the alluvial and High Plains aquifers in the COHYST area were extensively investigated in previous COHYST studies, culminating in the development of in the Hydrostratigraphic units report prepared by Cannia, Woodward and Cast (2006) (COHYST website). Data described in the report are the source of the aquifer geometry and initial aquifer properties for COHYST 2010. Additional key references are Gutentag et al., 1984, which describes the geology and hydrology of the aquifer; and Weeks, et al (1988), which provides additional aquifer information.

More detailed geologic information came from analysis of several thousand test hole logs from historical drilling programs by the Nebraska Conservation and Survey Division (NCSD) and the U.S. Geological Survey (USGS). Thirty-four new test holes were drilled by the NCSD for COHYST and interpreted to fill in gaps in the historical data.

Additional information came from database of registered wells maintained by the NDNR, digital elevation files from the USGS and ground water level measurements made available by the USGS. Much of the compiled information is organized and available through the COHYST website.

A dataset was compiled for purposes of providing an initial characterization of the aquifer thickness and lithology. While the hydrotratigraphy data were used extensively in the early construction of the COHYST 2010 model, in the final calibrated model the data were used only for constructing the aquifer bottom elevation and the zones for the specific yield.

4.5.2 Initial Heads Data Set

The groundwater model requires an initial head dataset to represent the model starting conditions. The specific need is for an estimate of the October 1984 water table elevation for each of the 77,339 half-mile active model grid cells. This dataset should have the following characteristics.

- To produce a robust starting point for the groundwater that minimizes hydrologic inconsistencies geographically and through simulation time;
- Be consistent with available water level observations from individual wells used in model calibration; and
- Provide a reasonably accurate estimate of the condition of the groundwater system at a point in time across the model area to improve the accuracy of the model's trajectory through the simulation period.

Development of the dataset relied on water level observations from the calibration dataset discussed in Section 4.5.3 and the NCSD 1979 statewide water table map (COHYST Website). Use of the map was important because the observation well data were sparse in many areas and because the map provided a basis for interpolation between actual data points. However, heads determined from the 1979 map did not agree with point observations in many areas for both 1979 and the fall of 1984; (**Figures 4.5-1** and **4.5-2**). This reflects both the uncertainty inherent in characterizing a system at varying scales and the challenge of estimating water levels at a point in time when the system is under continued and dynamic stresses.

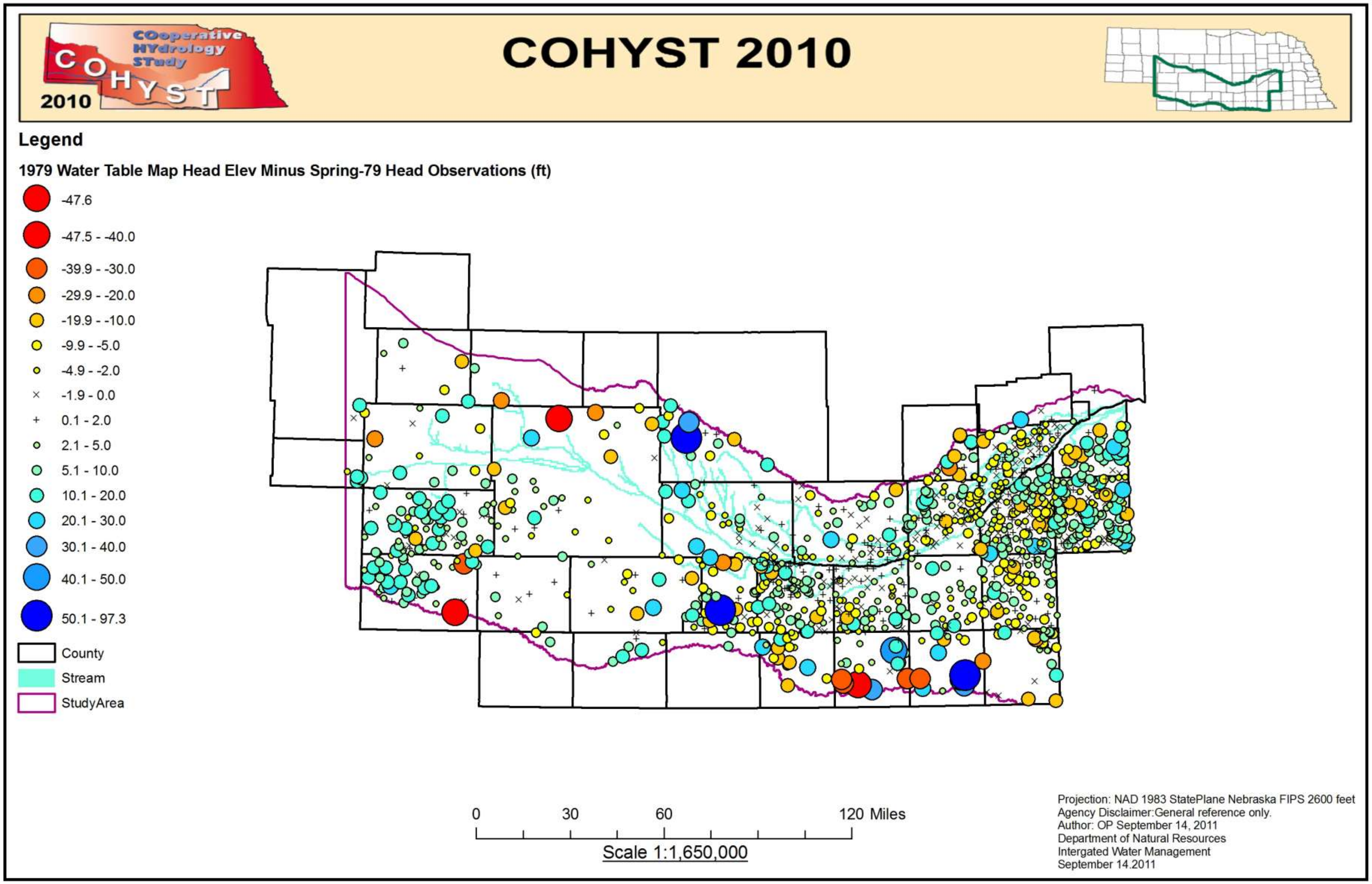


Figure 4.5-1. Differences Between Spring 1979 Head Observations and 1979 Water Table Map Head Elevations.

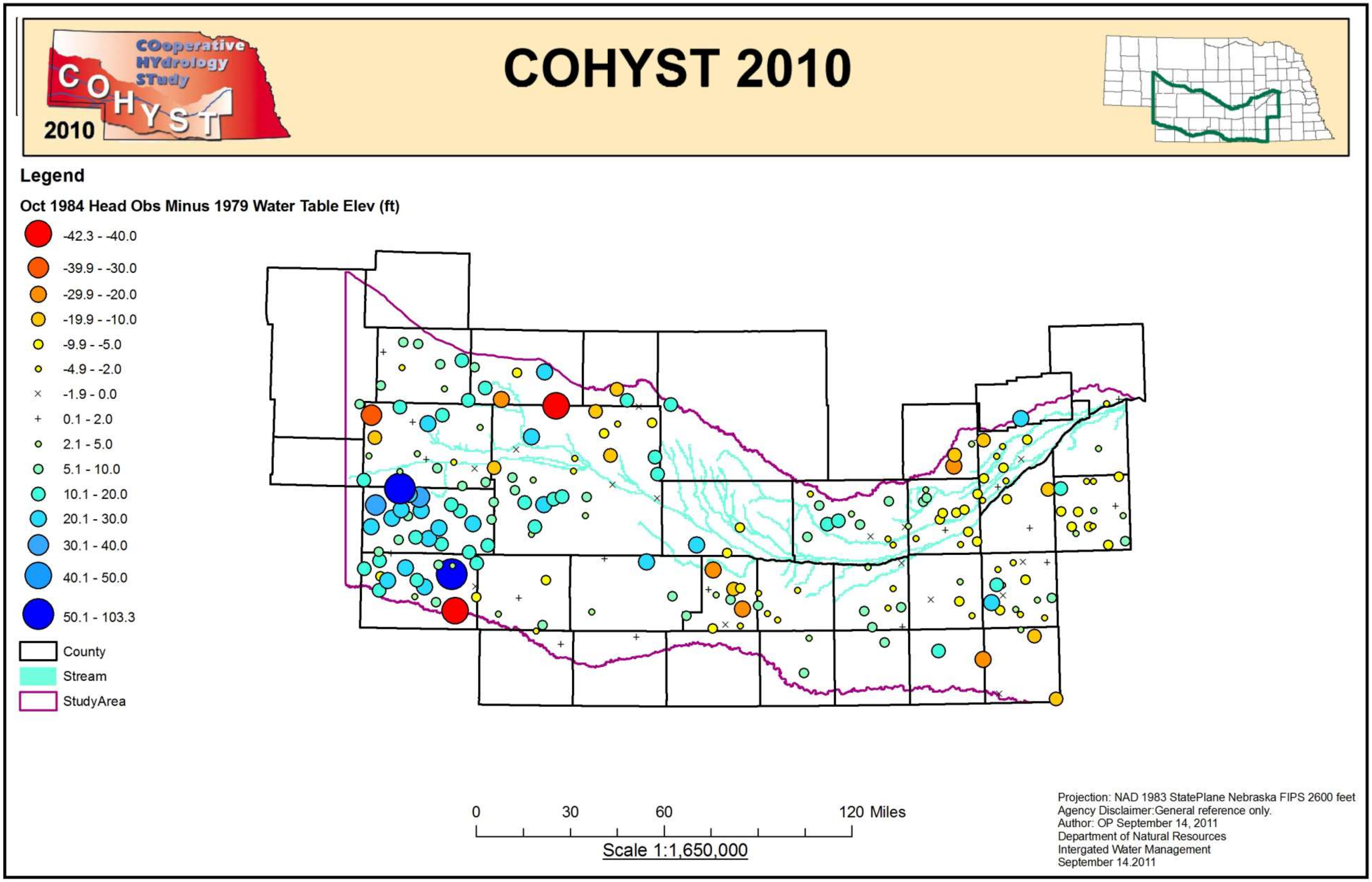


Figure 4.5-2. Differences Between October 1984 Head Observations and 1979 Water Table Map Head Elevations.

It was assumed that the 1979 water table map could sufficiently represent regional trends in water table configuration, i.e. water levels largely driven by topography, recharge, and discharge zones, to serve as an approximate starting point for an initial heads dataset. This configuration was modified with selected October 1984 water level measurements to reflect temporal, and perhaps more local, variations in the water table. Additionally, the elevations of perennial stream and river reaches, as represented in the model stream (STR) package, were used to further constrain the initial head configuration. A set of GIS operations, including filtering and spatial interpolation, were used to create a composite dataset from these components. This resulting dataset was compared against the October 1984 point well measurements (**Figure 4.5-3**). Because the final dataset is a composite from several source datasets, it is expected that a perfect match in all point locations would be unreasonable. Information on the observation well sites, data used, selection criteria, GIS methods and the extensive quality assurance performed is provided in **Appendix4-W**.

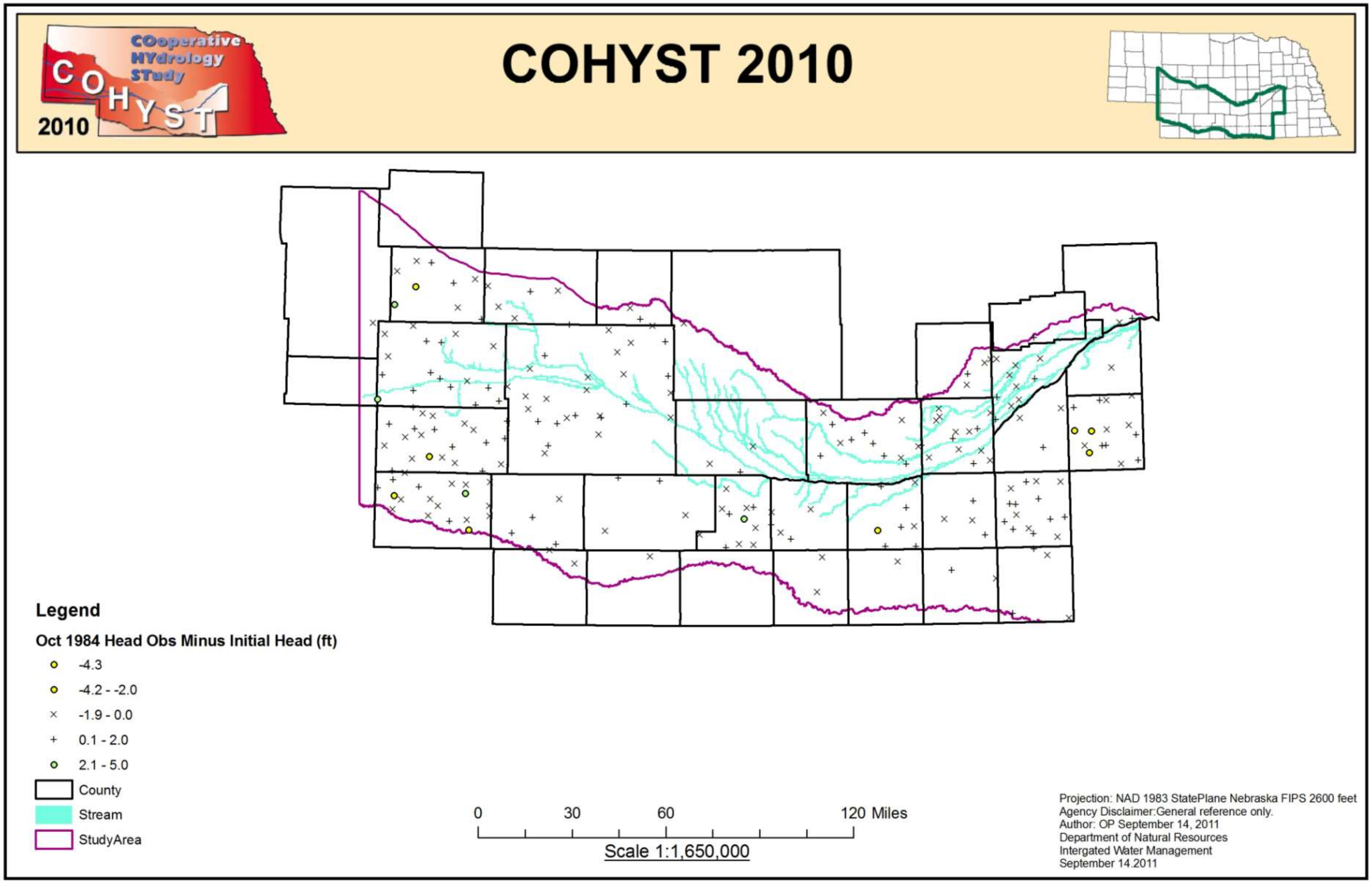


Figure 4.5-3. Differences Between October 1984 Head Observations and Constructed Initial Heads.

4.5.3 Initial Estimate of Hydraulic Conductivity

Data extracted from Nebraska's database of registered wells were used to calculate the ratio of the specific capacity and developed aquifer thickness (spcap_b in the following formula) by:

spcap_b=pumping rate/(pumping level-static level)/(well depth-static level)

The initial results included a number of high outliers that were discarded. **Figure 4.5-4** shows the distribution of the raw ratio. The map illustrates the high variability of the results but also shows that important geologic features (e.g., as shown in Richmond, 1994) are evident in the data despite the variability.

Smoothing was needed before the data could be used to prepare model input. The final, smoothed map was produced by kriging, using the raw data with a nugget incorporated in the variogram. Hydraulic conductivity was estimated from the smoothed values of spcap_b after the method in Driscoll (1986, Appendix 16.D) by multiplying spcap_b by 1500. That method provided the estimate in gpd/ft/ft which was then converted to feet per day. **Figure 4.5-5** shows the resulting hydraulic conductivity estimates.

Hydraulic conductivity zones were constructed from the hydraulic conductivity estimates. The zones were constructed by dividing the area based on the estimated K values:

zone 1 : < 28 feet/day

zone 2 : 28-51 feet/day

zone 3 : 51-90 feet/day

zone 4 : 90-160 feet/day

zone 5 : > 150 feet/day.

In this breakdown, zones 1 and 2 represent mostly the Tertiary aquifers while zones 4 and 5 represent mostly gravelly areas of the Quaternary aquifer. Zone 3 is transitional.

The initial zone map was edited by removing thin peninsulas and islands of less than 2 square miles area. **Figure 4.5-6** shows the initial zone map.

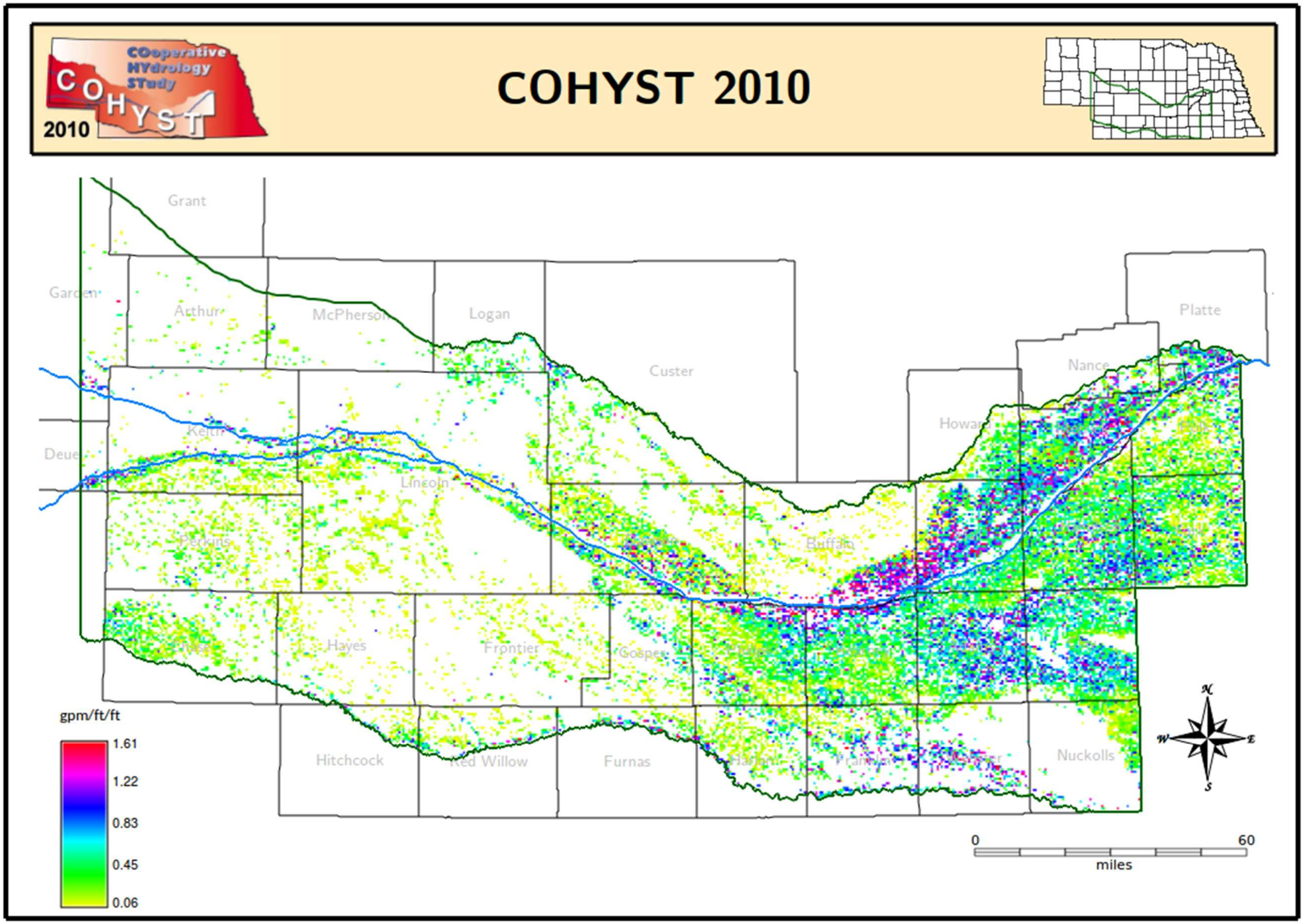


Figure 4.5-4. Ratio of Specific Capacity to Aquifer Thickness.

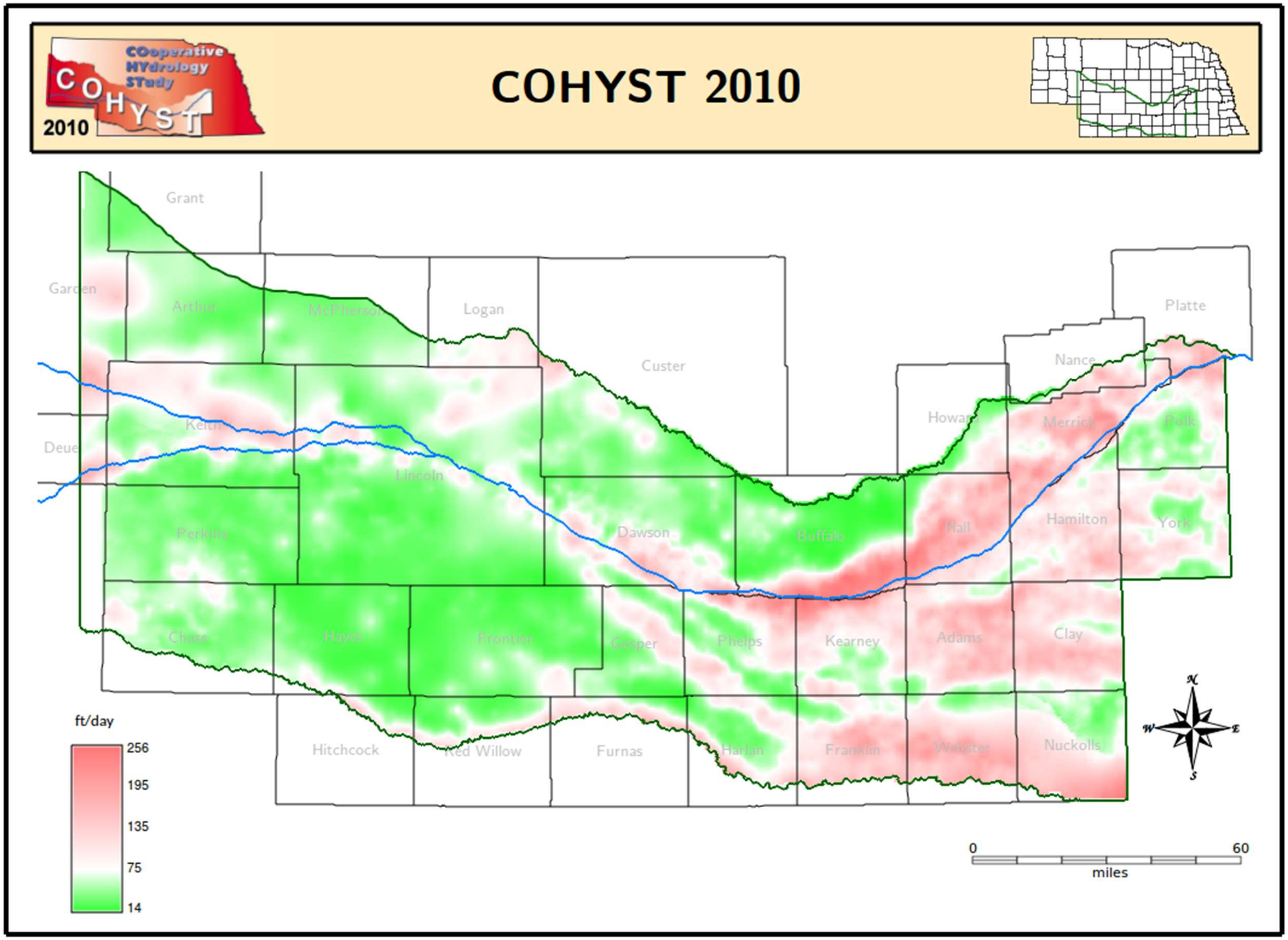


Figure 4.5-5. Hydraulic Conductivity Estimated from Specific Capacity.

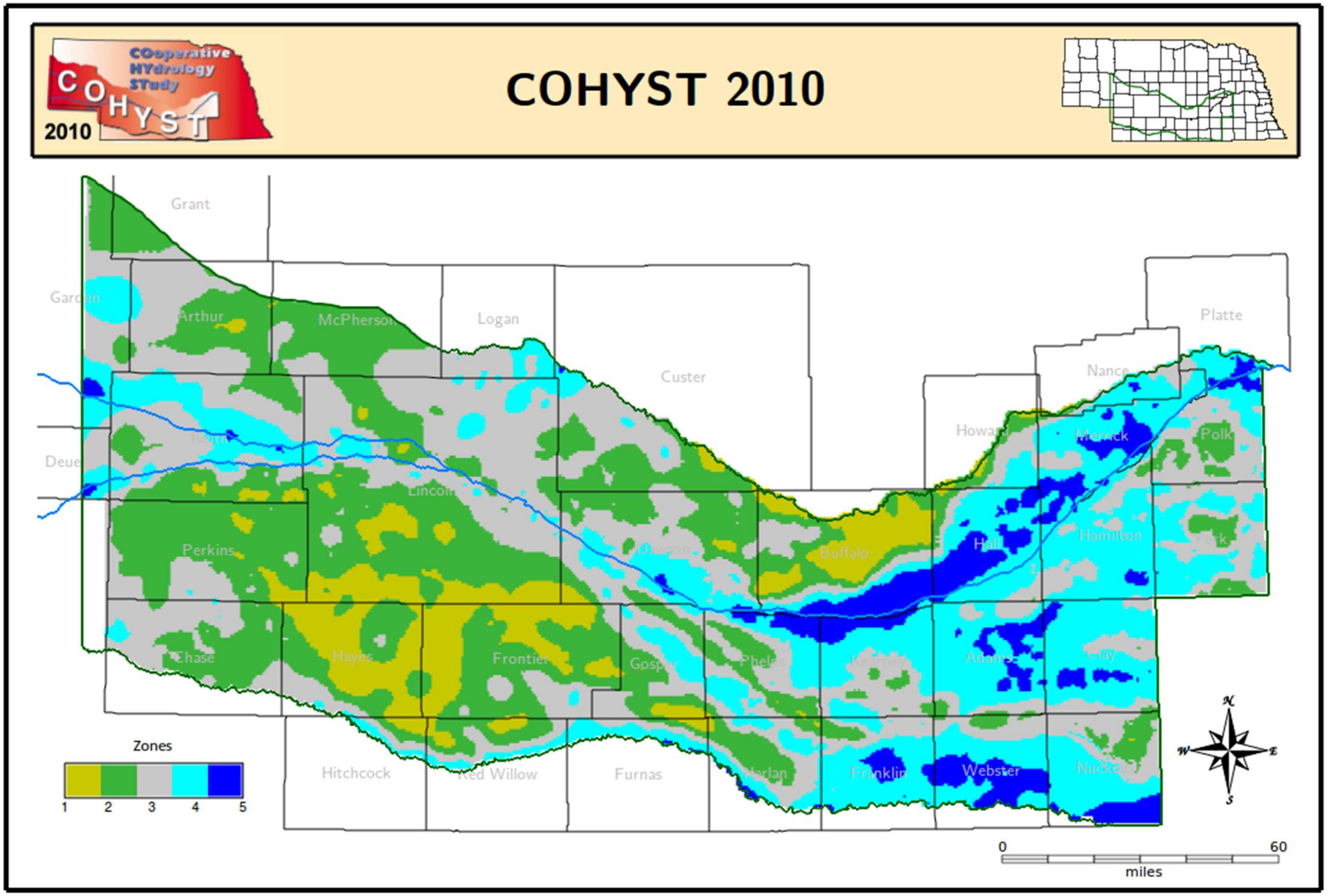


Figure 4.5-6. Initial Five Hydraulic Conductivity Zones.

The initial zones were modified during the calibration of the 2013 COHYST model. Zones one and five were subdivided to produce zones seven and six, respectively. The division separated areas where the water level hydrographs illustrated different behavior.

We expected that the zonation in areas that were substantially penetrated by wells were well-represented by the specific capacity data, but that zonation in the areas that were only partly penetrated could be different. Zones eight, nine and ten were developed by subdividing zones two, three and four at the point where 60% of the section is produced by wells. That division produced the ten zone arrangement used in the 2013 calibration, shown in **Figure 4.5-7**.

4.5.4 Initial Estimates of Specific Yield

Figure 4.5-8 illustrates the position of the 1979 water table within the hydrostratigraphic units and the initial specific yield zones.

Zone one consists of the area mostly in the east part of the model where the water table as of spring, 1979 was within HSU2. Zone two occupies the area where the 1979 water table was generally in HSU1 but was locally in HSU3 or HSU6. Zone three is the area mostly in the southwest part of the model where the 1979 water table was within HSU5.

The initial values of specific conductivity were based on the average estimated specific yield of the hydrostratigraphic unit that contains the water table: 23% in zone one, 11% in zone two, and 15% in zone 3.

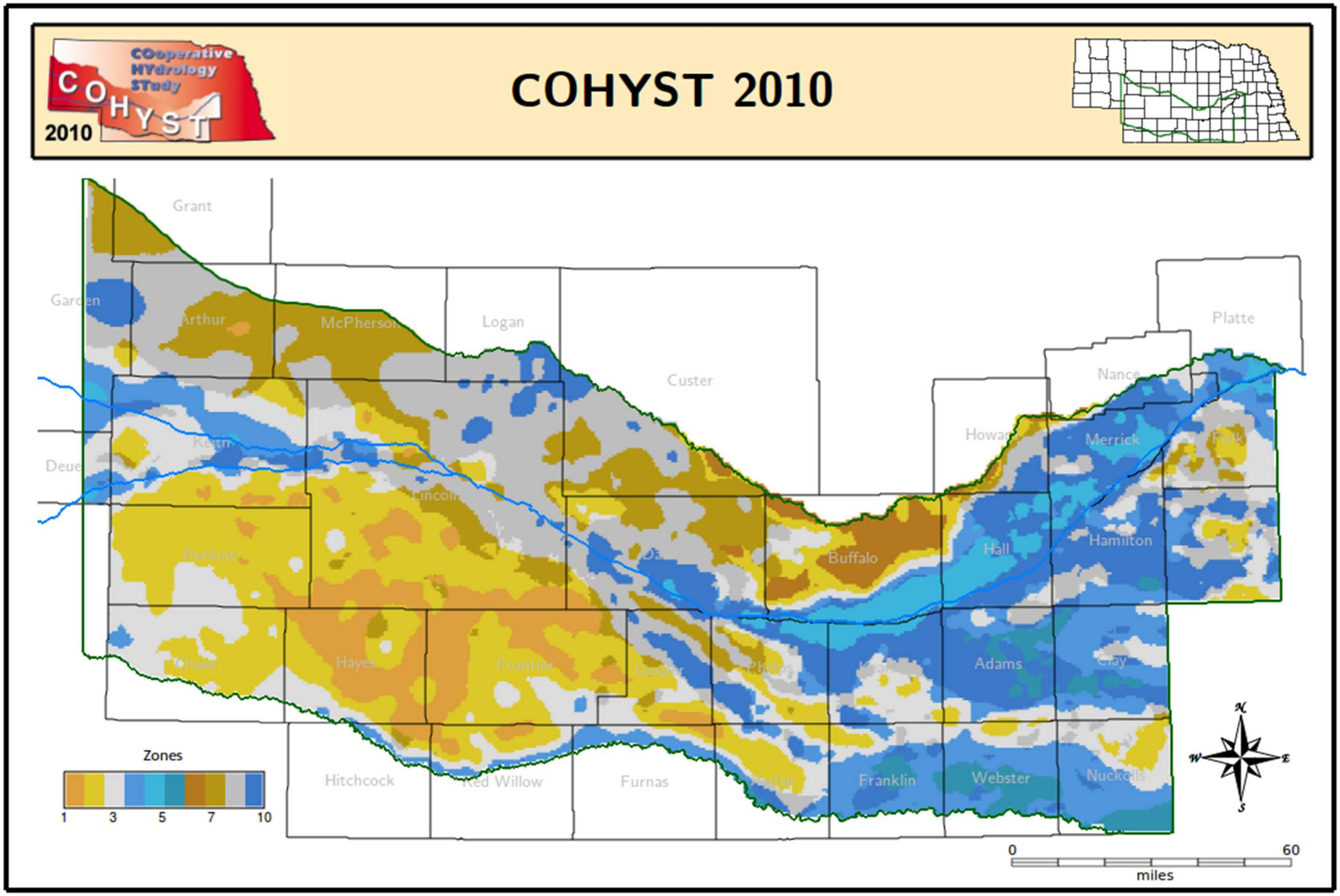


Figure 4.5-6. Ten Hydraulic Conductivity Zones used in the 2013 Calibration of the COHYST2010 Groundwater Model.

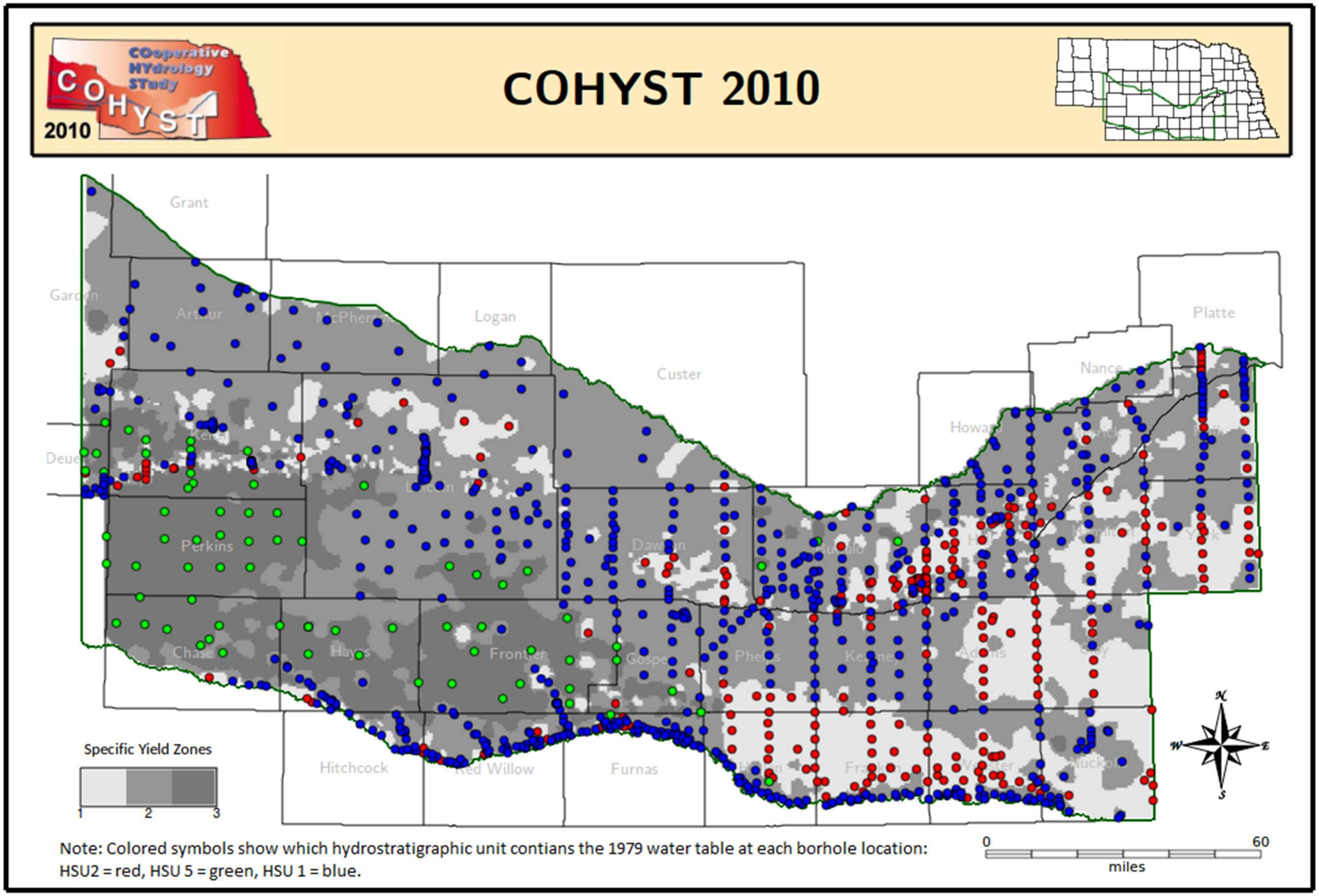


Figure 4.5-7. Initial Specific Yield Zones.