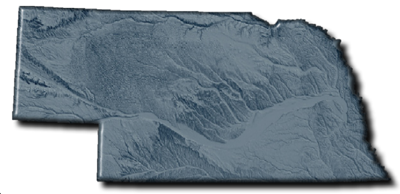
Nebraska Department of Natural Resources



2008 Annual Evaluation of Availability of Hydrologically Connected Water Supplies

Determination of Fully Appropriated

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Report Organization

This report is divided into nine sections. Section One is the report summary. Section Two is the introduction to the report and contains the purpose, background, and organization. The pertinent statutory and regulatory language can be found in Section Three and in Appendix B. Detailed descriptions of the methodologies used in the analyses can be found in Section Four. Sections Five through Eight are the evaluations of the Big Blue River basins, Lower Niobrara River Basin, Lower Platte River Basin, and Missouri Tributary basins, respectively. Each basin evaluation includes a description of the nature and extent of present water uses, the geographic area considered to have hydrologically connected ground water and surface water (i.e., the “10/50 area”), preliminary conclusions about the adequacy of the long-term water supply, and whether the preliminary conclusions would change if no additional constraints were placed on water development in the basin. Section Nine is a summary of the basin subsections and the report conclusions. The appendices contain additional detailed information not found within the main body of the report.

1.0 SUMMARY

The Department of Natural Resources (Department) has evaluated the expected long-term availability of surface water supplies and hydrologically connected ground water supplies of the Blue River basins, Lower Niobrara River Basin, Lower Platte River Basin, and Missouri Tributary basins. Based on the evaluation, the Niobrara River Basin upstream of Spencer Hydropower is fully appropriated. The Blue River basins, Lower Platte River Basin, Missouri Tributary basins, and Niobrara River Basin below Spencer Hydropower are preliminarily not fully appropriated at the present time. Analysis of future water supplies in the Lower Platte River Basin indicates that, if no additional constraints are placed on ground water and surface water development and reasonable projections are made of the extent of future development, then the effects on long-term water supply would cause the basin to become fully appropriated in the future.

2.0 INTRODUCTION

2.1 Purpose

The purpose of this report is to fulfill the requirements of section 46-713 of the Ground Water Management and Protection Act (Act) (Neb. Rev. Stat. §§ 46-701 through 46-753). The Act requires the Department to report annually its evaluation of the expected long-term availability of hydrologically connected water supplies. This annual evaluation is required for every river basin, subbasin, or reach that has not either initiated the development of an integrated management plan (IMP) or implemented an IMP. No reevaluations were made in this report for basins, subbasins, or reaches that have IMPs, or for which IMPs are being prepared.

The evaluation and preliminary conclusions of this report are grouped into four river basins: the Blue River basins, Lower Niobrara River Basin, Lower Platte River Basin, and Missouri Tributary basins. The report was written this way to reduce repetition; however, each appropriate basin, subbasin, and reach was analyzed separately.

As required by law, the report also describes the nature and extent of present water uses in the basin, shows the geographic area considered to have hydrologically connected surface water and ground water supplies, and predicts how the Department's preliminary conclusions might change if no new legal restrictions are placed on water development in the basin. The report does not address the sufficiency of ground water supplies that are not hydrologically connected to surface water streams. The report includes a description of the criteria and methodologies used to determine which basins, subbasins, or reaches are preliminarily considered to be fully appropriated and which water supplies are hydrologically connected. The report is required to include a summary of relevant data provided by any interested party concerning the social, economic, and environmental impacts of additional hydrologically connected surface water and ground water uses on resources that are dependent on streamflow or ground water levels but are not protected by appropriations or regulations. Appendix A contains the notice of request for any relevant data from any interested party and the comments received.

2.2 Background

This report addresses requirements that were added to the Act by passage of LB 962 in 2004. That bill was influenced by actions taken as a result of prior legislative activity. In 2002, the Nebraska Unicameral passed LB 1003, mandating the creation of a Water Policy Task Force to address conjunctive use management issues, inequities between surface water and ground water users, and water transfers/water banking. The forty-nine Task Force members, appointed by the Governor from a statutorily specified mix of organizations and interests, were asked to discuss issues, identify options for resolution of issues, and make recommendations to the legislature and governor relating to any water policy changes deemed desirable.

In December 2003, the Task Force provided the Legislature with the "*Report of the Nebraska Water Policy Task Force to the 2003 Nebraska Legislature*". That report provided draft legislation and suggested changes to statutes. The Legislature considered the Task Force recommendations in its 2004 session and subsequently passed LB 962, which incorporated most of the Task Force recommendations. Governor Mike Johanns signed the bill into law on April 15, 2004.

The provisions of LB 962 require a proactive approach in anticipating and preventing conflicts between surface water and ground water users. Where conflicts already exist, it establishes principles and timelines for resolving those conflicts. It also adds more flexibility to statutes governing transfer of surface water rights to a different location of use and updates a number of individual water management statutes.

Some of the key provisions of LB 962 that are part of current statutes include the following:

- Certain river basins were declared to be fully appropriated or overappropriated. The law automatically placed into fully appropriated status any natural resource district undertaking any integrated management process under previous law for integrated management of hydrologically connected ground water and surface water.

- Portions of the Platte River Basin were declared to be overappropriated by the legislature because the level of water resources development is not sustainable over the long term.

- The Department must make an annual determination by January 1, 2006, and by January 1 of each subsequent year, as to which basins, subbasins, or reaches not previously designated as fully appropriated or overappropriated have since become fully appropriated. The Department must also complete an annual evaluation of the expected long-term availability of hydrologically connected water supplies in the basins, subbasins, or reaches and issue a report describing the results of the evaluation.

- When a basin, subbasin, or reach is declared overappropriated or determined to be fully appropriated, stays on new uses of ground water and surface water are automatically to be imposed. The Department and the natural resources districts (NRDs) involved are required to develop and implement jointly an integrated management plan (IMP) within three to five years of that designation.

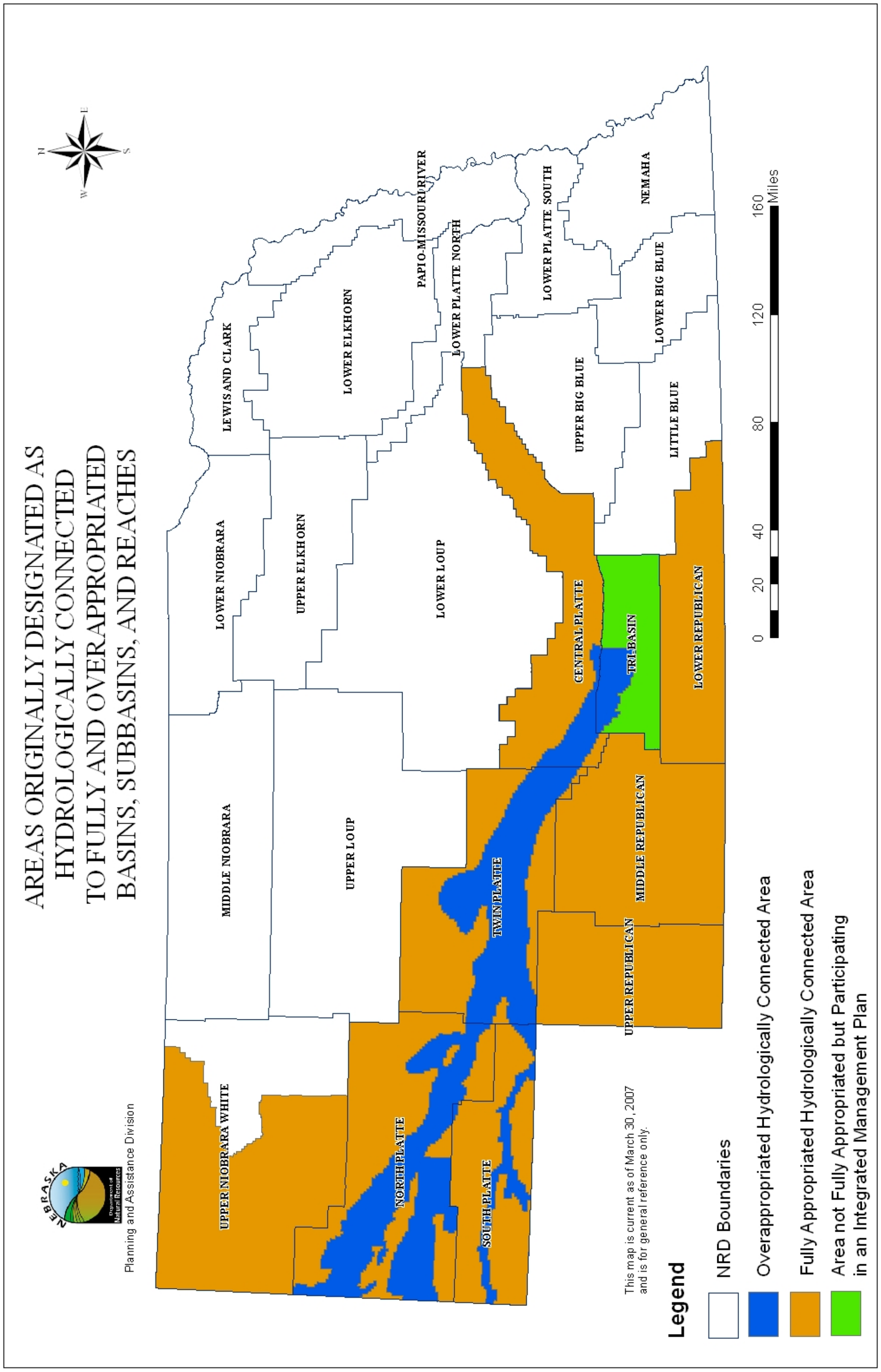
- A key goal of each IMP must be to manage all hydrologically connected ground water and surface water for the purpose of sustaining a balance between water uses and water supplies so that the economic viability, social and environmental health, safety, and welfare of the basin, subbasin, or reach can be achieved and maintained for both the near and long term. In the overappropriated portions of the state, the IMP must provide for a reduction in current levels of water use so that it is possible to achieve a balance between water uses and water supplies.

- IMPs may rely on a number of voluntary and regulatory controls, including incentives, allocation of ground water withdrawals, rotation of use, and reduction of irrigated acres, among others.

- If disputes between the Department and the NRDs over the development or implementation of an IMP cannot be resolved, the Governor will appoint a five-member Interrelated Water Review Board to resolve the issue.

Subsequent to the passage of LB 962, a number of basins, subbasins, or reaches have been designated as fully or overappropriated (Figure 2-1). Previous statutorily required reports on the evaluation of hydrologically connected water supplies are available upon request from the Department. This volume is the third statutorily required annual report.

Figure 2-1 Areas originally designated as hydrologically connected to fully and overappropriated basins, subbasins, and reaches



3.0 LEGAL REQUIREMENTS

3.1 Section 46-713(1)(a) – Annual Evaluation and Report Required

A river basin's hydrologically connected water supplies include the surface water in the watershed or catchment that runs off to the stream and the ground water that is in hydrologic connection with the stream. For all evaluated basins, the geographic areas of hydrologically connected surface water and ground water, if any, are shown on a basin-wide map that is included in each basin subsection. On each of those maps, the surface watershed basin is shown by a solid line, and the hydrologically connected ground water portion of the basin is depicted by a shaded area.

Surface water supplies are considered to be hydrologically connected to a stream or stream reach if the surface water drains to that stream or reach. In accordance with Department rule 457 N.A.C. 24.001.02, the Department considers the area within which ground water is hydrologically connected to a stream to be that area in which "pumping of a well for 50 years will deplete a river or base flow tributary thereof by at least 10% of the amount pumped in that time" (i.e., the "10/50 area"). For purposes of evaluation, a river basin may be divided into two or more subbasins or reaches. Only those basins that have not initiated development of or implemented an IMP are required to be evaluated.

In preparing its annual report, the Department is required by section 46-713(1)(d) to rely on the best scientific data, information, and methodologies readily available to ensure that the conclusions and results contained in the report are reliable. A list of the information the Department uses can be found in rule 457 N.A.C. 24.002 (Appendix B). The Department is also required to provide enough documentation in the report to allow others to replicate and assess the Department's data, information, methodologies, and conclusions independently. That documentation can be found throughout the report. The raw data used for these calculations and the spreadsheets with the calculations will be provided by the Department upon request.

3.2 Section 46-713(1)(b) – Preliminary Conclusions Following Basin Evaluations

As a result of its annual evaluation, the Department is to arrive at a preliminary conclusion as to whether or not each river basin, subbasin, and reach evaluated is currently fully appropriated without the initiation of additional uses. The Department is also required to determine if and how its preliminary conclusions would change if no additional legal constraints were imposed on future development of hydrologically connected surface water and ground water. This determination is based on reasonable projections of the extent and location of future development in a basin.

3.3 Section 46-713(3)-Determination that a Basin is Fully Appropriated

The Department must make a final determination that a basin, subbasin, or reach is fully appropriated if the current uses of hydrologically connected surface and ground water in the basin, subbasin, or reach cause, or will in the reasonably foreseeable future cause, either (a) the surface water supply to be insufficient to sustain over the long term the beneficial or useful purposes for which existing natural-flow or storage appropriations were granted, (b) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the river or stream involved, or (c) reduction in the flow of a river or stream sufficient to cause noncompliance by Nebraska with an interstate compact or decree, other formal state contract or agreement, or applicable state or federal laws. Since these factors must be considered in making the final determination, they must also be part of the Department's considerations in reaching its preliminary conclusions.

The Department considered whether or not condition (c) would be met with regard to interstate compacts by reviewing the terms of any compacts in each basin and determining when noncompliance would occur if there were sufficient reductions in streamflow. There were no decrees, formal state contracts, or agreements in any of the basins evaluated this year; there is one interstate compact covering the Blue River basins.

With regard to noncompliance with state and federal law, it was determined that only the state and federal laws prohibiting the taking of threatened and endangered species could raise compliance issues that would trigger condition (c). The federal Endangered Species Act, 16 U.S.C. §§ 1530 *et seq.* (ESA), prohibits the taking of any federally listed threatened or endangered species of animal by the actual killing or harming of an individual member of the species (16 U.S.C. § 1532) and by degrading or destroying a species' habitat so much that the species cannot survive (50 CFR § 17.3). The state Nongame and Endangered Species Conservation Act, Neb. Rev. Stat. §§ 37-801 *et seq.* (NNESCA), also prohibits the actual killing or harming of an individual member of a listed species, but it is not clear whether the degradation of a species' habitat is considered a taking under state law. The Department reviewed information from the Nebraska Game and Parks Commission about the possible existence of species listed as threatened and endangered in the river basins that the Department evaluated; whether those species actually live in the rivers or streams; and, for those species that live in the streams, whether those species' habitat requirements include an identified level of streamflow. The Department reached a preliminary conclusion that reductions in flow will not cause noncompliance with either federal or state law at this time in any of the basins evaluated.

Prior to making its final determination, the Department must also hold a public hearing on its preliminary conclusions and consider any testimony and information given at the public hearing or hearings.

4.0 METHODOLOGIES

Overview

This section provides an overview of the methodologies used in the Department's basin evaluations and is separated into seven subsections. The first subsection will outline the legal requirements established in section 46-713 of the Ground Water Management and Protection Act and regulation 457 N.A.C. 24.001 (Appendix B) as they relate to the analysis. Subsection two will discuss the various methods available to assess stream depletions in hydrologically connected regimes and explain when specific methods were implemented by the Department. Subsection three will discuss the specific methods implemented by the Department to calculate the extent of the 10/50 area. The fourth subsection will proceed through the steps to calculate lag impacts from current wells and estimate long-term sustainability of water supplies. Subsection five will discuss implementation of the "erosion rule" (i.e., regulation 457 N.A.C. 24.001.01C) to evaluate impacts to surface water appropriations. Subsection six discusses how each basin, subbasin, or reach is evaluated to ensure compliance with state and federal laws. Subsection seven provides the details of the methods used to predict depletions from potential future development.

4.1 Legal Obligation of the Department

4.1.1 The Legal Requirements of Section 46-713

The methodologies used for evaluation within this report were developed to meet the requirements of section 46-713 of the Act. The criteria set forth in section 46-713 require the Department to 1) describe the nature and extent of surface and ground water uses in each river basin, subbasin, or reach; 2) define the geographic area within which surface water and ground water are hydrologically connected; 3) define the extent to which current uses will affect available near-term and long-term water supplies; and 4) determine how preliminary conclusions, based on current development, would change if no additional legal constraints were imposed on reasonable projections of future development.

The description of the nature and extent of surface and ground water uses is developed based on information obtained through published reports from the University of Nebraska-Conservation and Survey Division (CSD), the U.S. Geological Survey, natural resources districts, Department databases, and other sources as noted in the text. The information represents the most current publications available. These data include information on transmissivity, specific yield, saturated thickness, depth to water, surficial geology, bedrock geology, water table elevation change, and test-hole information. These data are available on the UNL-Conservation and Survey Division and U.S. Geological Survey websites, http://csd.unl.edu/ and http://waterdata.usgs.gov/ne/nwis/gw, respectively. All data utilized in this report are available from the Department upon request.

The Department is tasked with assessing the geographic area within which surface water and ground water are hydrologically connected. Regulation 457 N.A.C. 24.001.02 states that the geographic area within which the ground and surface water are hydrologically connected is determined by calculating where, in each river basin, a well would deplete a river's flow by 10% of the amount of water the well could pump over a fifty-year period (i.e., "the 10/50 area").

The Department's evaluation of the extent to which current uses will affect available near-term and long-term water supplies considers current well development and the twenty-five year lag impacts from that current development on surface water flows. For purposes of this report, lag impacts are defined as the delayed effect that the consumptive use of water associated with well pumping will have on hydrologically connected streamflow and the associated impact on surface water appropriations.

The Department is also required to assess how its preliminary conclusions, based on current development, might change by predicting future development. The predictions of future development account for existing wells and wells that may be added in the next twenty-five years. In projecting the quantity of wells that may be added to the number of currently developed wells, the Department considers the following: 1) availability of lands suitable for irrigation; 2) well-construction moratoriums established by natural resources districts; and 3) trends in well development over the previous ten-year period.

4.1.2 Regulation 457 N.A.C. 24.001

Regulation 457 N.A.C. 24.001 generally states that a basin is fully appropriated if current uses of hydrologically connected surface water and ground water in a basin cause, or will cause in the reasonably foreseeable future, (a) the surface water to be insufficient to sustain over the long term the beneficial purposes for which the existing surface water appropriations were granted, (b) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the basin's river or stream, or (c) reduction in streamflow sufficient to cause Nebraska to be in noncompliance with an interstate compact or decree, formal state contract, or state or federal laws.

In short, regulation 457 N.A.C. 24 states that the surface water supply is deemed to be insufficient if, at current levels of development, the most junior irrigation right in a basin, subbasin, or reach has been unable to divert sufficient surface water over the last twenty years to provide 85% of the amount of water a corn crop needs (the net corn crop irrigation requirement, or NCCIR) during the irrigation season (May 1 through September 30), or if the most junior irrigation right in a basin, subbasin, or reach is unable to divert 65% of the amount of water a corn crop needs during the key growing period of July 1 through August 31. For the purposes of this report, this is deemed the "65/85 rule".

If the requirements of the 65/85 rule are not satisfied, then the final step in a preliminary conclusion of whether a basin is fully appropriated is to apply what has been termed the “erosion rule” (457 N.A.C. 24.001.01C). This rule takes into account the fact that appropriations may be granted even though sufficient water is not available at the time they are granted to provide enough water for diversion to satisfy the requirements of the 65/85 rule. If an appropriation is unable to divert enough water to satisfy the requirements of the 65/85 rule, a second evaluation is completed to determine if the right has been “eroded”. According to regulation 457 N.A.C. 24.001.01B, in the event that the junior water right is not an irrigation right, the Department will utilize a standard of interference appropriate for the type of water use to determine whether flows are sufficient for that use, taking into account the purpose for which the appropriation was granted.

4.2 Methods Available for Assessing Stream Depletions

There are several methods for estimating the extent and magnitude of stream depletions. Historically, three broad categories have been used to study ground water flow systems, i.e. sand tank models, analog models, and mathematical models, which include analytical models and numerical models. The first two methods were primarily used prior to the advent of modern, high-speed, digital computers. Since the advent of computers, analytical and numerical models have become the preferred methods for evaluating ground water flow. Limitations of each method must be considered by the user when considering the results of analyses and the appropriateness of each method for a given task.

4.2.1 Numerical Modeling Methods

With user-friendly interfaces and high-speed computers, numerical models have fast become the preferred method of evaluating regional ground water flow. One widely used numerical model developed by the U.S. Geological Survey is MODFLOW (McDonald and Harbaugh, 1988). For the purposes of this report, if an acceptable MODFLOW model suitable for regional analysis is available, then it will be utilized to assist in analysis. The only area for which an existing model was utilized in this year's evaluation was the Upper Big Blue Basin. The model was used to evaluate areas of hydrologic connection between surface water and ground water within the basin.

The remaining basins discussed in this report are not currently represented in a suitable numerical model. Development of a numerical model requires a substantial amount of quality-assured data. Current data collection efforts may allow for suitable model development for these basins in the future. However, at present, analytical methods are the best available tool for the analysis of stream depletions within these basins.

4.2.2 Analytical Methods

Analytical methods for the analysis of streamflow depletions have been developed by Glover and Balmer (1954), Maasland and Bittinger (1963), Gautuschi (1964), and others to evaluate the impacts of wells on streams. The Jenkins (1968) method for calculation of stream depletion factors (SDF) (Appendix C) lends itself best to the basin-wide aspect of the task described by this report. This method is based on simplifying assumptions and was built upon previously published equations. The Jenkins method has been utilized by other states, including Colorado and Wyoming, for water administration purposes. For this report, the Jenkins method was used in the evaluation of the Lower Niobrara River Basin, the Lower Platte River Basin, and Missouri Tributary basins.

Modified versions of the Jenkins method have been developed to address more complex situations, such as the presence of boundary conditions (Miller and Durnford, 2005) and a streambed (Zlotnik, 2004). The modifications require additional data that are often not available for the basins in this evaluation. However, the dominant factors in determining the impact of a pumping well on a stream are the distance of the well from the stream and the length of time that the well is pumped. Thus, the impact of any other differences between actual hydrologic and geologic conditions and the idealized assumptions used in the Jenkins method decreases as the distance from the stream and any relevant boundary conditions and duration of pumping increase. Therefore, when looking at regional impacts, the simplifying assumptions of the Jenkins method are much less significant. This concept is supported by comments from Dick Luckey (USGS, 2006). For this reason, and because of a lack of published data necessary for the calculations, no modifications were made to the Jenkins method for the Department's analysis.

In some areas of the state, particularly in the glaciated eastern sections, information regarding hydrologic conditions is inadequate, and no method currently available can be used to determine the 10/50 area or the lag impact of ground water pumping from wells. These areas were not evaluated in the current report.

4.2.3 Peer Review of the Methodology

The methodology developed by the Department and described in Sections 4.3 and 4.4 was independently peer reviewed by the Nebraska Water Science Center of the U.S. Geological Survey in October 2005. The Center concluded, "The NWSC reviewers found the document technically sound." A copy of the peer review transmittal letter is in Appendix D.

4.3 Development of the 10/50 Areas

The 10/50 area is defined as the geographic area within which ground water is hydrologically connected to surface water. A well constructed in the 10/50 area would deplete a river's flow by at least 10% of the water pumped over a fifty-year period. The 10/50 areas are not dependent on the quantity of water pumped, but rather on each basin's geologic characteristics and the distance between each well and the stream.

4.3.1 Use of Numerical Models

The Department reviewed available numerical models to assess their validity in defining the 10/50 areas. The Upper Big Blue Natural Resources District developed a numerical MODFLOW ground water model using Cooperative Hydrology Study (COHYST) data to delineate the extent of the 10/50 area hydrologically connected to the Little Blue River. The Department reviewed the ground water model and deemed it suitable for use in this report. Documentation of this ground water model is available in Appendix E.

4.3.2 Use of Analytical Methods

In areas where an acceptable numerical model has not been developed but where sufficient geologic data exist, the Jenkins SDF methodology was used to define the 10/50 area. The following steps were taken to calculate the extent of the 10/50 area:

1. Collect and prepare data (data will be provided by the Department upon request).

2. Evaluate available data to determine if the principal aquifer is present and if sufficient data exist to determine that a given stream reach is in hydrologic connection with the principal aquifer.
3. Complete Jenkins SDF calculations to delineate the 10/50 boundary for these basins.
4. Develop the 10/50 area.

In all other areas, where sufficient data do not exist or the principal aquifer is not present, the 10/50 area could not be determined.

Step 1: Data Preparation

The following data are necessary for determining the extent of the 10/50 area:

- Aquifer transmissivity
- Aquifer specific yield
- Locations of perennial streams
- Point grid of distances to streams

The aquifer properties used in the study were found in the report "Mapping of Aquifer Properties – Transmissivity and Specific Yield – for Selected River Basins in Central and Eastern Nebraska", published by the Conservation and Survey Division (CSD, 2005).

The location and extent of perennial streams were found in the permanent streams GIS coverage available from the U.S. Geological Survey National Hydrography Dataset. The main stems of each river and of its tributaries were included in the calculations for individual basins.

A point grid with a spacing of one mile was developed to identify specific distances from the stream and to store those locations which were within the 10/50 area.

Step 2: Identify Principal Aquifers and Hydrologic Connection to Perennial Streams

The extent of hydrologic connection between aquifers and streams was primarily determined from maps generated by the Conservation and Survey Division (CSD, 2005). Other supporting evidence from published reports was also used in some cases to delineate the extent of hydrologic connection between aquifers and streams, and this information is referenced where used. Areas that lie outside of the hydrologically connected areas were not incorporated into the analysis.

Step 3: Perform Jenkins SDF Calculations

The Jenkins SDF method utilizes the following two terms, for which solutions are derived graphically using the curve shown in Figure 4-1.

Depletion percentage term: v/Qt

Dimensionless term: $\frac{t}{SDF}$

Where v = volume of stream depletion during time t

Qt = net volume pumped during time t

t = time during the pumping period since pumping began

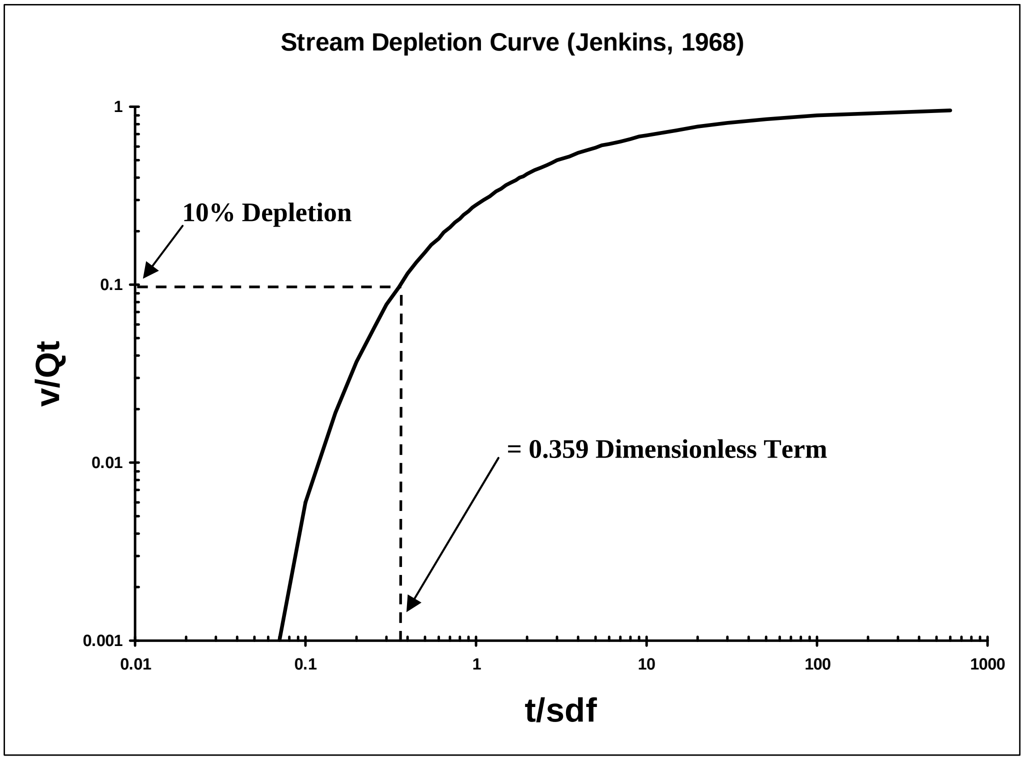
$$SDF = \frac{a^2 * S}{T}$$

where a = perpendicular distance between the well and stream

S = average specific yield of the aquifer between the well and the stream

T = average transmissivity of the aquifer between the well and the stream

Figure 4-1 Stream depletion curve from Jenkins (1968)

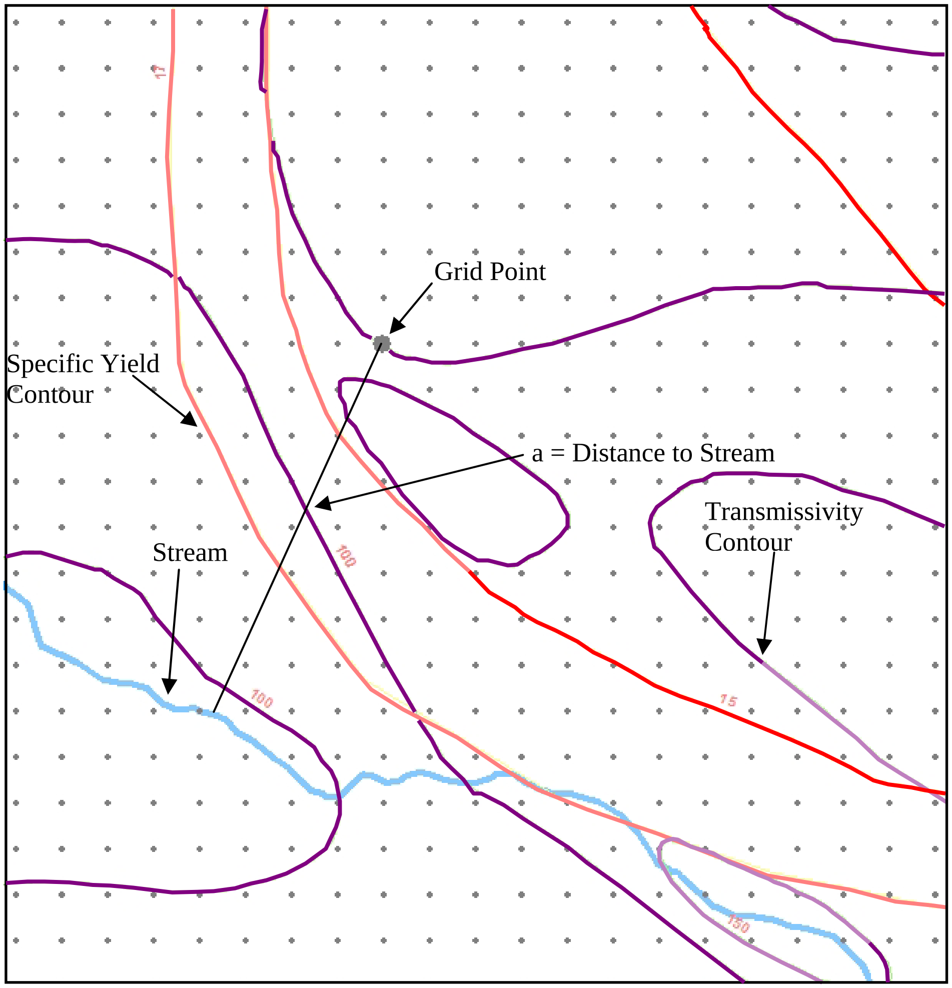


As illustrated in Figure 4-1, the dimensionless term will equal 0.359 when the depletion percentage is equal to 10%. The aquifer properties at each grid point and the distance of each grid point from the nearest perennial stream will be utilized to calculate the dimensionless term (Figure 4-2).

The known values for the 10/50 calculation are as follows:

- t is 50 years or 18,262 days.
- T is the aquifer transmissivity.
- S is the aquifer specific yield.
- a is the perpendicular distance from the grid point to the nearest perennial stream.

Figure 4-2 An example of the data and method used in determination of the 10/50 area



Step 4: Developing the 10/50 Area

Once the value for the dimensionless term is derived, those grid points with a dimensionless term value greater than 0.359 are included as part of the 10/50 area. All points that meet this requirement are merged to develop the complete 10/50 area for the basin.

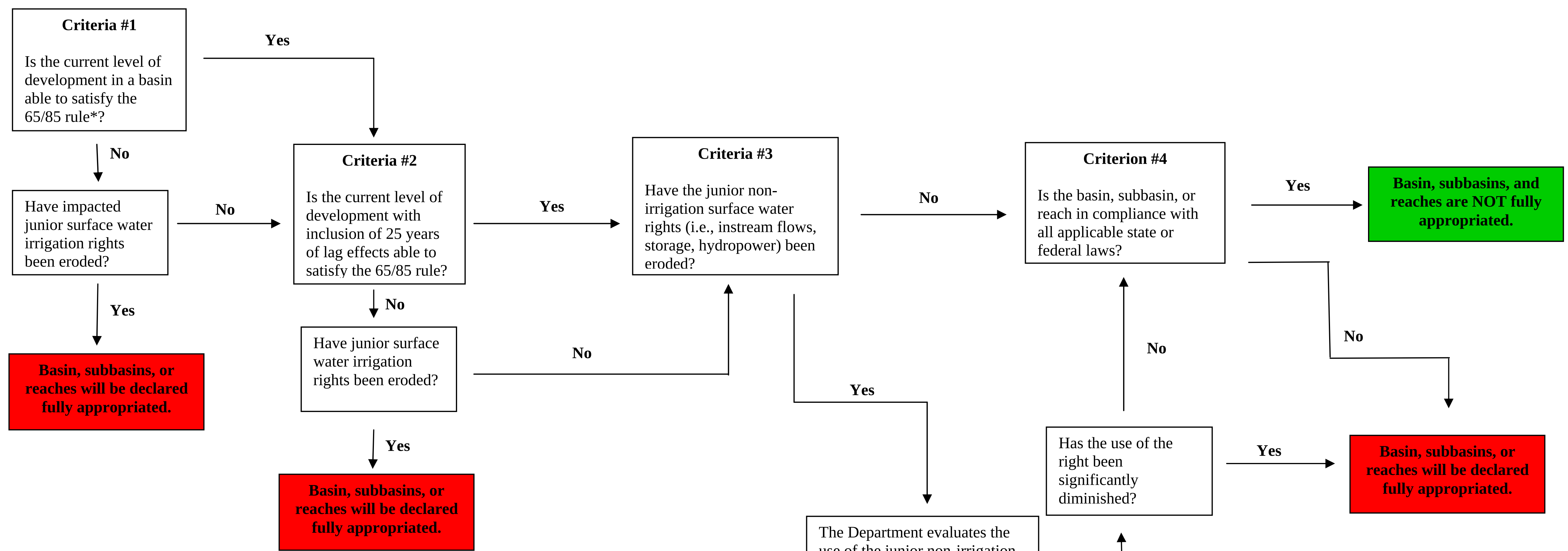
4.4 Evaluating Current Development within a Basin

When determining the status of a basin, the Department evaluates five criteria. The five criteria are 1) that current levels of surface water and ground water development, without consideration of lag impacts from wells, are able to satisfy the 65/85 rule; 2) that current levels of surface water and ground water development, with consideration of twenty-five year lag impacts, are able to satisfy the 65/85 rule; 3) that erosion of non-irrigation surface water rights based on the standard of interference established by the Department has not occurred; 4) that the basin, subbasin, or reach is in compliance with all applicable state and federal laws; and 5) that future development (including lag impacts) of ground water in the basin will not cause the basin to be unable to satisfy the 65/85 rule.

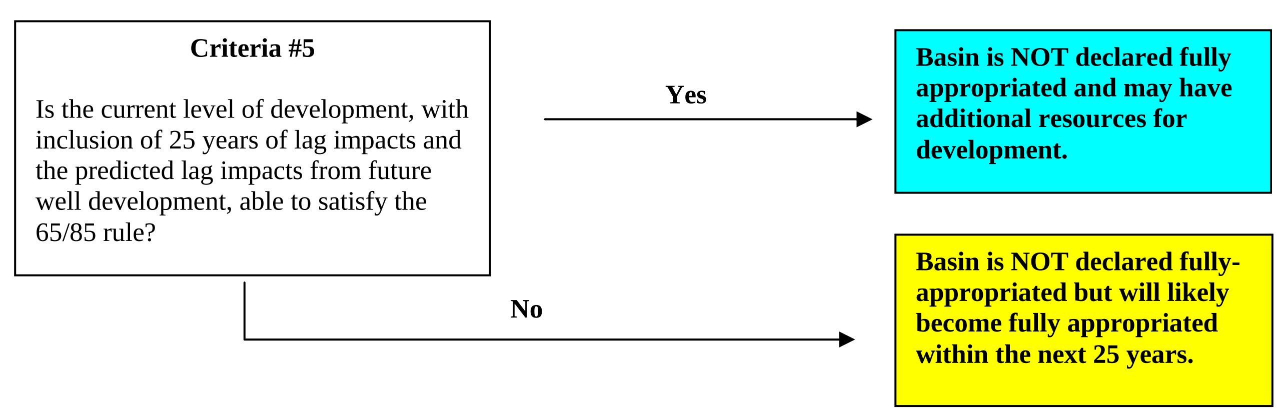
If criteria one and/or two are unable to be satisfied, then an additional test, the “erosion rule”, is applied to junior irrigation rights. This is used to evaluate whether the ability to divert water by the most junior surface water appropriation has been eroded. Methods for implementation of the erosion rule are discussed in detail in Section 4.5. Figure 4-3 illustrates the evaluation process for determining whether a basin is fully appropriated.

Figure 4-3 Basin evaluation flow chart

Evaluation of Current Development



Evaluation of Future Development



***In general terms, the 65/85 rule states that the surface water supply is deemed to be insufficient if, at current levels of development, the most junior irrigation right in a basin, subbasin, or reach has been unable to divert sufficient surface water over the last twenty years to provide 85% of the amount of water a corn crop needs (the net corn crop irrigation requirement) during the irrigation season (May 1 through September 30) or if the most junior irrigation right in a basin, subbasin, or reach is unable to divert 65% of the amount of water a corn crop needs during the key growing period of July 1 through August 31.**

Failure to satisfy criteria one, two, three, or four will cause a basin to be declared fully appropriated. Failure to satisfy criterion five alone will not cause a basin to be declared fully appropriated, however, but such failure would indicate that future development may cause the basin to become fully appropriated if current development trends continue.

4.4.1 The Role of Surface Water Administration Doctrine

The administration of surface water plays a key role in evaluating the sustainability of development within a basin, subbasin, or reach. Surface water appropriations in Nebraska are administered under the doctrine of prior appropriation. The basis for the doctrine is "first in time, first in right." When there is a surface water shortage in a basin, subbasin, or reach, the surface water appropriation with a senior priority date has the right to use any available water for beneficial use, up to its permitted limit, before any upstream junior surface water appropriation can use water. To exercise a senior right, the senior water appropriation will put a call on the stream, and the Department will investigate the streamflows and, if necessary, issue closing orders to the upstream junior water appropriations, starting with the most junior right.

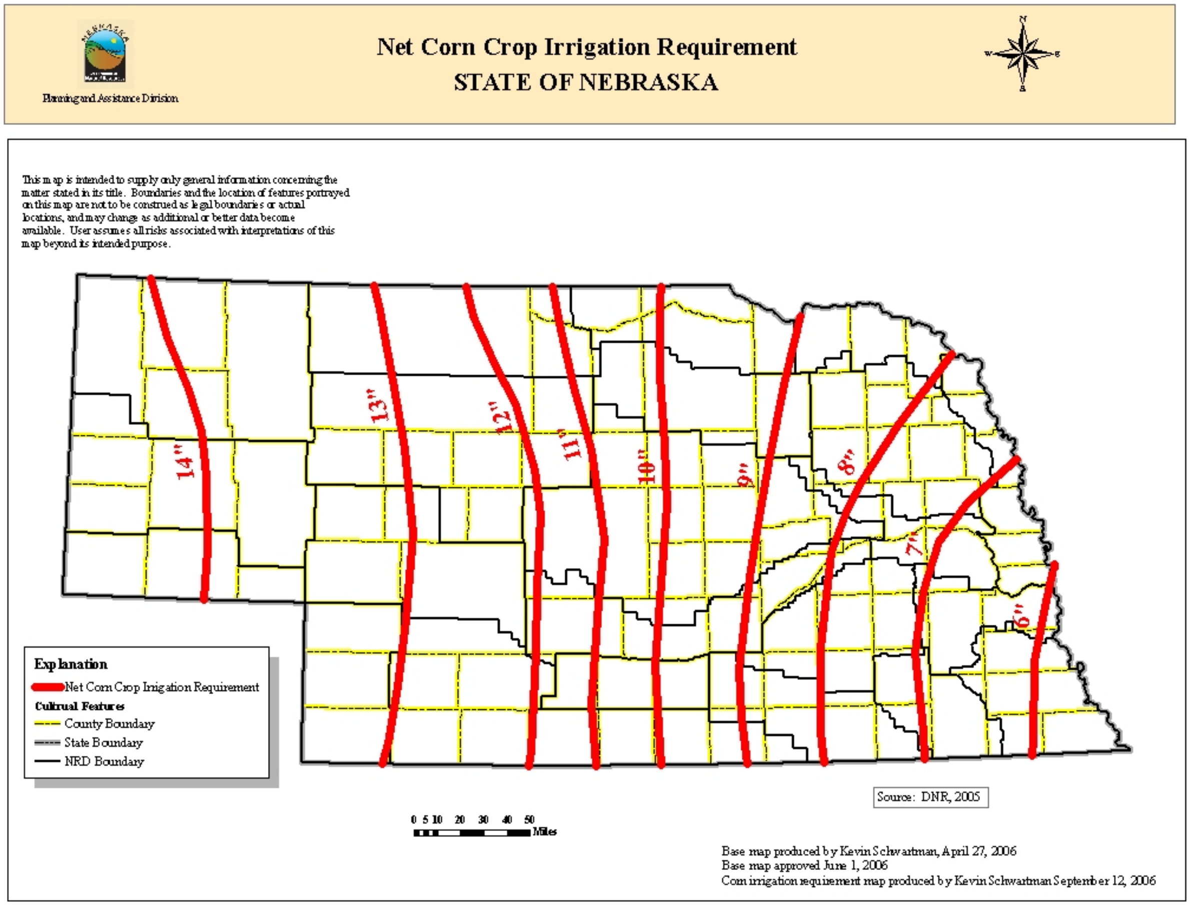
Although additional surface water development in a basin will deplete the overall surface water supplies during times when there is excess surface water, under the priority system a junior right cannot cause a senior surface water appropriation's supply to be reduced. When the Department administers for a calling senior surface water appropriation, all upstream junior surface water appropriations, starting with the most junior appropriator, are shut off in order of priority, no matter how far upstream, until the calling senior surface water appropriation is satisfied. Therefore, in areas where surface water administration is already occurring, additional surface water development will not reduce the number of days surface water is available for diversion by a senior surface water appropriation. In areas that have not experienced surface water administration, it is not feasible to predict the point at which additional surface water development may cause surface water administration to occur.

The priority doctrine of first in time, first in right which governs surface water administration ensures that, if there is sufficient water for the most junior irrigation appropriation, then all irrigation appropriations will be satisfied. Therefore, the Department analyzed the water available to the most junior appropriator in each basin evaluation. When making the calculation of the number of days that surface water was available to the most junior irrigation surface water appropriator, the Department assumed that, if the junior appropriator was not closed, then he or she could have diverted at the full permitted diversion rate.

4.4.2 The Net Corn Crop Irrigation Requirement

The net corn crop irrigation requirement (NCCIR) was developed to estimate the average minimum consumptive allocation of water necessary to yield a profitable corn crop to an individual operator. The NCCIR is used to determine the number of diversion days required for the most junior surface water appropriation to satisfy irrigation needs under the 65/85 rule (see Section 4.1.2). In developing the NCCIR, corn is used as the baseline crop because the most frequent beneficial use of water in all of the basins evaluated is for the irrigation of corn. The NCCIR accounts for the average evapotranspiration and average precipitation in an area and generally decreases from northwest to southeast across the state (Figure 4-4). The NCCIR distribution for each basin is set out in individual basin subsections. The method of developing the NCCIR is described in Appendix F.

Figure 4-4 Net corn crop irrigation requirement



4.4.3 Determination of Diversion Requirements

To determine a junior irrigator's diversion requirements, the NCCIR is converted to the number of days necessary for an operator to divert water to yield a profitable corn crop using these assumptions: 1) a downtime of 10%, due to mechanical failures and other causes; 2) a diversion rate of 1 cubic foot per second (cfs) per 70 acres (or 0.34 inches/day), as this is the most common rate approved by the Department for surface water appropriations; and 3) an irrigation efficiency of 80%. The steps to determine the number of days necessary for a specific operator to divert include the following:

1) Determine the geographic location of the operator.

2) Interpolate between the NCCIR contours to determine the specific need of the operator.

3) Multiply the NCCIR by 0.65 and 0.85 to find the 65% and 85% requirements.

4) Calculate the gross irrigation requirement by dividing the values from step 3 by 0.8 (the irrigation efficiency).

5) Divide the gross irrigation requirement by 0.34 inches per day (rate of diversion) and by 0.9 (to account for downtime) to determine the number of days of diversion necessary for an operator.

$$\text{Number of days necessary} = \frac{\text{gross requirement}}{(0.34)(0.9)}$$

The results of this calculation for the most junior surface water appropriator in a basin are used to evaluate whether a basin is fully appropriated by comparing these results to the average number of days over the previous twenty-year period (1987-2006) that surface water was available for diversion. If the number of days necessary to meet either the 65% or 85% criteria is less than the average number of days available for diversion, then the basin, subbasin, or reach may be declared fully appropriated.

This test is the first criterion in the five-tiered test described at the beginning of Section 4.4. If the basin satisfies this test, then the second criterion is evaluated: the addition of lag impacts from current development.

4.4.4 Calculating Lag Impacts from Current Well Development

The second criterion assessed to determine whether a basin is fully appropriated is to estimate the lag impacts from current well development. In those basins for which the appropriate geologic and hydrologic data were available, the following steps were taken to compute the lag impact from current development:

1. Define the ground water boundary for the study area.
2. Extract all high capacity wells from the Department's database with a completion date prior to December 31, 2006.
3. Account for current year's development.
4. Estimate the volume of water pumped from each well.
5. Calculate the twenty-five year lag impacts.
6. Create lag-adjusted flow record.
7. Determine number of diversion days available.

In those basins for which the appropriate geologic and hydrologic data were not available, the lag impacts were not calculated, due to uncertainty of the degree of hydrologic connection. In many of those cases, the number of days in which surface water is available for diversion far exceeds the number of days necessary to meet the net corn crop irrigation requirement, and the final conclusion would likely not change even with the addition of lag impacts.

Step 1: Define the Study Area Boundaries

The study area surface water boundary for each river basin is defined by the watershed boundary. The study area ground water boundary is defined by certain features that include the location of perennial baseflow streams, location of non-hydrologically connected areas, and ground water table highs that prevent flow to the stream of interest.

An individual well may fall into multiple basin study areas. If a well falls within multiple basin study areas, its total stream depletion is divided by the number of basin study areas that it intersects. For example, if a well falls into two basin study areas, the depletion is divided by 2. This prevents overestimation of depletions in overlapping areas. A sufficient number of wells in an overlapping area will likely, on average, be halfway between the two basins. Because SDF methodology is distance-based, splitting the depletion in half and assigning half of the total depletion to each basin is justified.

Step 2: Identify High Capacity Wells within the Study Area

In calculating lag impacts, the Department evaluates only high capacity wells, considered to be those wells with a pumping rate of greater than 50 gallons per minute (gpm). High capacity wells include active irrigation, industrial, public water supply, and unprotected public water supply wells (public water supply wells without statutory spacing protection). Other wells, such as decommissioned or inactive high capacity wells, livestock watering wells, and domestic wells were not included, because the database is not complete for those well types. This omission is not considered significant, because these wells use relatively small amounts of water. All active high capacity wells with a completion date prior to December 31, 2006, were used in the analysis.

Step 3: Account for Current Year (2007) Development

Wells are not registered simultaneously with their completion date, so it was necessary to estimate the number of high capacity wells that will be registered as constructed between January 1, 2007, and December 31, 2007. The first step in estimating the number of high capacity wells for 2007 is to average the well development rates within a basin over the previous three-year period (2004-2006), taking into account known limitations, such as moratoriums, on well development. Based on the rates, additional wells are randomly located geographically within the study area on soils that have been defined by the U.S. Department of Agriculture as irrigable. To ensure that land was available for development, a 1,400-foot-radius circle (slightly larger than the radius of an average center pivot) was drawn around each active high capacity well existing in the Department's water well registration database. All lands within the circles were removed from the inventory of irrigable land available for development. In addition, all irrigable land areas of less than 40 acres in size that were available for new development were excluded. The wells extracted from the Department's water well registration database with a completion date prior to December 31, 2006, and those estimated to be developed in each basin for 2007 were then combined to serve as the basis for current well development.

Step 4: Estimate the Volume Pumped by Each Well

The volume pumped from a well for consumptive use (Qt) is determined by multiplying the NCCIR (see Section 4.4.2) by the number of acres irrigated by the well. The number of acres irrigated by each well was estimated to be 90 acres, for reasons documented in Appendix G (DNR, 2005). Industrial and public water supply wells are treated the same as irrigation wells for this analysis.

Example:

If	Location of well: Custer County, Nebraska
	NCCIR requirement (from Figure 4-4): 11 inches/year
	Number of acres served: 90 acres
Then	Qt: 11 inches/year * 90 acres = 990 acre-inches/year or 82.5 acre-feet/year

Step 5: Calculate Twenty-Five Year Lag Impacts

The Jenkins SDF methodology is utilized to estimate the twenty-five year lag impacts to streamflows due to current well development. The Jenkins SDF methodology allows for calculation of the streamflow depletion percentage of each well in the basin. The terms used in this methodology include the depletion percentage term and the dimensionless term, both defined below:

Depletion percentage term: v/Qt

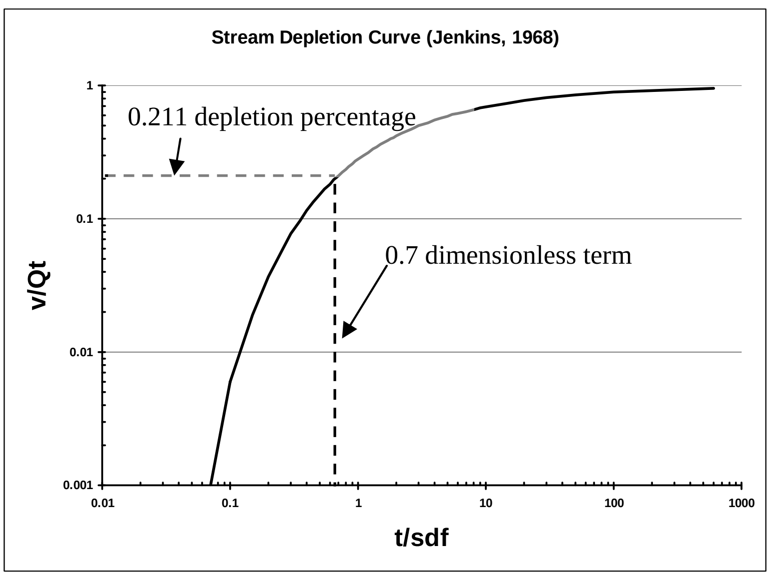
Dimensionless term: $\frac{tT}{a^2S}$ or $\frac{t}{SDF}$

The goal of this analysis is to solve for the 'v' term, or the volume of stream depletion (in acre-feet/year) over the twenty-five year period. First, the dimensionless term is calculated using the following known variables:

- t is the time since the well was completed (2007-well completion year).
- T is the aquifer transmissivity.
- S is the aquifer specific yield.
- a is the perpendicular distance from the well to the nearest perennial stream.

Next, the dimensionless term is used to determine the percentage of depletion (v/Qt). For example, if the dimensionless term is equal to 0.7, then the depletion percentage is equal to 0.211, or 21.1% (see Figure 4-5).

Figure 4-5 Determining depletion percentage from the dimensionless term



Finally, the stream depletion is calculated as follows:

v = Qt * percentage depletion

Where v = stream depletion in acre-feet/year

Qt = volume pumped in acre-feet/year

percentage depletion = value corresponding to the dimensionless term, from the graph in Figure 4-5

The depletion percentage is multiplied by the volume pumped, as calculated in Step Four, to determine total stream depletion. These results can be converted from annual acre-feet of depletion to cubic feet per second (cfs) by dividing by 724.46 (the conversion factor for acre-feet/year to cfs).

The next step is to calculate the twenty-five year lag impacts. The twenty-five year lag impacts for all current wells are calculated in a similar way, except that the time period for each well (t) is increased by twenty-five years (9,125 days). The total depletions calculated in 2007 are subtracted from the total depletions calculated in 2032 (twenty-five years into the future) to determine the lag impacts. An example of this process is illustrated below (Table 4-1).

Table 4-1 Example calculation of twenty-five year lag impacts

<table>
<tr><th>Year</th><th>Cumulative Depletion (cfs)</th><th>Additional Annual Depletion (cfs)</th><th>Lag (cfs)</th></tr>
<tr><td>2006</td><td>100</td><td rowspan="2">10</td><td rowspan="4">20</td></tr>
<tr><td>2007</td><td>110</td></tr>
<tr><td>2031</td><td>300</td><td rowspan="2">30</td></tr>
<tr><td>2032</td><td>330</td></tr>
</table>

Step 6: Create Lag-Adjusted Flow Record

The twenty-five year lag impacts from all current wells within a basin are summed to generate a total stream depletion figure for the basin. A daily historic flow record is developed from stream gage data for the previous twenty-year period to represent variations in climate and precipitation in the basin. The sum of the lag impacts is subtracted from the daily historic record to develop a new flow record, here termed the “lag-adjusted flow record”.

Step 7: Determine the Number of Days Available for Diversion

The lag-adjusted flow record is used to calculate the average number of days available to the most junior appropriator within the basin for diversion. The new average number of days available for diversion is compared to the number of days necessary for the most junior surface water appropriator to divert in the basin. If the number of days necessary to meet either the 65% or 85% criterion is less than the average number of days available for diversion, then the basin, subbasin, or reach may be declared fully appropriated.

4.5 Determine Erosion of Rights

If a basin has failed either the first or second criterion (described in Sections 4.4.3 and 4.4.4), then the next step in the Department’s analysis is to apply what has been termed “the erosion rule” (457 N.A.C. 24.001.01C). This rule takes into account the fact that appropriations may be granted even though there is insufficient water at the time the appropriation is granted to satisfy the requirements of 65/85 rule. If an appropriation is unable to divert enough water to satisfy the requirements of the 65/85 rule, then the second evaluation is completed to determine if the right has been “eroded”, i.e., if enough water was not available to satisfy the rule at the time the appropriation was granted. As set forth in regulation 457 N.A.C. 24.001.01B, in the event that the junior water right is not an irrigation right, the Department will utilize a standard of interference appropriate for the type of use to determine whether flows are sufficient for the use, taking into account the purpose for which the appropriation was granted.

4.5.1 Potential Erosion of Irrigation Rights

The erosion rule is applied through the use of historic streamflow data in a two-step process. The first step is to calculate the average number of days the most junior surface water appropriator would have been able to divert during the twenty-year period before the priority date of the appropriation. The second step is to calculate the average number of days the same junior surface water appropriator has been able to divert during the previous twenty years (i.e., 1987-2006). If the number of days available for diversion has decreased, then the right has been eroded. When making these calculations, the Department takes into account the lag effect of wells existing at the time of the priority date, as well as lag impacts from current well development.

The steps for determining whether a right has been eroded are as follows:

1. Gather the daily streamflow records from the twenty-year period prior to the appropriation being granted.
2. Gather the daily streamflow records for 1987-2006 to serve as the current twenty-year period.
3. Determine the twenty-five-year lagged ground water depletions from wells existing on the date the junior surface water appropriation was granted, and subtract them from the daily streamflow record for the twenty-year period prior to the granting of the appropriation.
4. Determine the twenty-five-year lagged ground water depletions from wells existing at the end of the current twenty-year period (using methodologies described in Section 4.4.4), and subtract them from the daily streamflow record for the current twenty-year period (1987-2006).

5. Assume that surface water administration would occur if the flow requirement of a senior surface water appropriation was greater than the depleted historical daily flow.
6. Conduct a month-by-month comparison of the average number of days available for the junior surface water appropriation to divert during the twenty-year period prior to the appropriation and the average number of days available to divert during the current twenty-year period.

If the average number of days available to the junior surface water appropriation for diversion during the current period (1987-2006) is less than the number of days available to the junior surface water appropriation for the twenty-year period prior to the appropriation, then the appropriation is deemed to be eroded.

4.5.2 Potential Erosion of Instream Flow Rights

In the Lower Platte Basin, the junior water rights that require water administration are instream flow permits. Since the purpose of the instream flow permits is not for irrigation, but rather to maintain—but not enhance–habitat for the fish community existing at the time of the priority date on the permit, the Department determined that an appropriate standard of interference would be to determine whether the instream flow requirements that could be met at the time the water rights were granted can still be met today.

To determine if water use development has interfered with the ability of these water rights to obtain water for instream flow purposes, the Department applied the erosion rule in the same manner as described above. One important difference in evaluating the erosion of an instream flow permit, however, is that the number of days available to the appropriation is evaluated throughout the entire year, rather than only during the irrigation season. Results from the average number of days available for the twenty-year period prior to the appropriation are compared on a month-by-month basis with the average number of days during the current twenty-year period (1987-2006).

4.6 Evaluation of Compliance with State and Federal Laws

To evaluate compliance with state and federal law, it was determined that, currently, only the state and federal laws prohibiting the taking of threatened and endangered species could raise compliance issues under section 46-713(3)(c). The federal Endangered Species Act, 16 U.S.C. §§ 1530 *et seq.*, prohibits the taking of any federally listed threatened or endangered species of animal by the actual killing or harming of an individual member of the species (16 U.S.C. § 1532) and by degrading or destroying a species' habitat so much that the species cannot survive (50 CFR § 17.3). The state Nongame and Endangered Species Conservation Act, Neb. Rev. Stat. §§ 37-801 *et seq.*, also prohibits the actual killing or harming of an individual member of a listed species, but it is not clear whether the degradation of a species' habitat is considered a taking under state law. The Department reviewed information from the Nebraska Game and Parks Commission about the possible existence of species listed as threatened and endangered in the river basins, subbasins, or reaches that the Department evaluated. The Department then determined whether a reduction in streamflow will cause noncompliance with either the federal or state law endangered species.

4.7 Evaluating Predicted Future Development in a Basin

The Department is required by section 46-713 to project the impact of reasonable future development within a basin on the potential for fully appropriated status. The results of this analysis alone cannot cause a basin to be declared fully appropriated. However, the analysis does provide an estimate of the effects of current well development trends on the basin's future status.

The steps necessary to calculate the impacts of future development on streamflows parallel those steps outlined in Section 4.4.4. The specific steps necessary to conduct an analysis of the impacts of future well development on the status of a basin are as follows:

- Gather information on lag impacts of current wells (from calculations performed in Section 4.4.4).
- Project the rate of future well development.
- Incorporate projected future well development into the study area.
- Calculate the depletions of projected future well development.
- Subtract the depletions from projected future well development from the previous twenty-year lag-adjusted flow record (1987-2006), and recalculate the number of days available for diversion for the most junior surface water appropriation.

Step 1: Gather Information on Lag Impacts of Current Wells

The lag impacts from current well development will be determined through completion of the steps outlined in Section 4.4.4 above, and the lag-adjusted flow record developed in Step 7 of Section 4.4.4 will be used in this section. In using the lag-adjusted flow record, the twenty-five year lag impacts of current well development will be accounted for, and the impacts from future wells can be removed directly from this new flow record.

Step 2: Project Future Well Development

When calculating impacts from future wells, it is necessary to estimate the rate of future well development. This estimation is completed by projecting the linear trend of current high capacity well development within a study area over the previous ten years (1997-2006). The yearly estimated well development for the study area is equivalent to the slope of the trend line and takes into account known limitations, such as moratoriums, on well development.

Step 3: Incorporate Future Wells into the Study Area

The number of future wells estimated in Step 2 above must be incorporated into the study area. The future wells are located geographically within the study area by randomly placing each future well on a site where the soils have been defined by the U.S. Department of Agriculture as irrigable. To ensure that land was available for development, a 1,400-foot-radius circle (slightly larger than the radius of an average center pivot) was drawn around every existing well, and all lands already irrigated within the circles were removed from the inventory of irrigable lands that are available for development. In addition, all irrigable land areas of less than 40 acres in size that are available for new development were excluded.

Step 4: Calculate the Lag Impacts of Future Wells

Depletions from future wells are calculated following the same methodology outlined in Section 4.4.4. The depletions of future wells are calculated independently of current well development. The twenty-five year depletions from future well development are removed from the lag-adjusted flow record created in Step 7 of Section 4.4.4 to develop the future lag-adjusted flow record.

Step 5: Create a Historic Flow Record with Lag Impacts from Current and Future Well Development

The historic record, with the twenty-five year lag impacts from all current wells (created at the end of Step 5 in Section 4.4.4) subtracted (i.e., the lag adjusted flow record), is used as the starting point in developing the future lag-adjusted flow record. The depletions from future wells incorporated into the study area are calculated for each year through the twenty-five year period and subtracted from the lag-adjusted flow record.

The sum of the future depletions is subtracted from the lag-adjusted daily flow record for the period 1987-2006 to create a future adjusted flow record to account for all current well lag impacts and potential future well depletions. The future lag-adjusted flow record is then used to calculate the average number of days available for diversion to the most junior appropriator within the basin. This new future lag-adjusted flow record is compared to the number of days necessary for the most junior surface water appropriator to divert in the basin.

In those basins for which the appropriate geologic and hydrologic data were not available, the impacts of future well development were not calculated due to uncertainty of the degree of hydrologic connection. In many of those cases, the number of days in which surface water is available for diversion far exceeds the number of days necessary to meet the NCCIR, and the final conclusion would likely not change even with the addition of lag impacts.

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5.0 BLUE RIVER BASINS

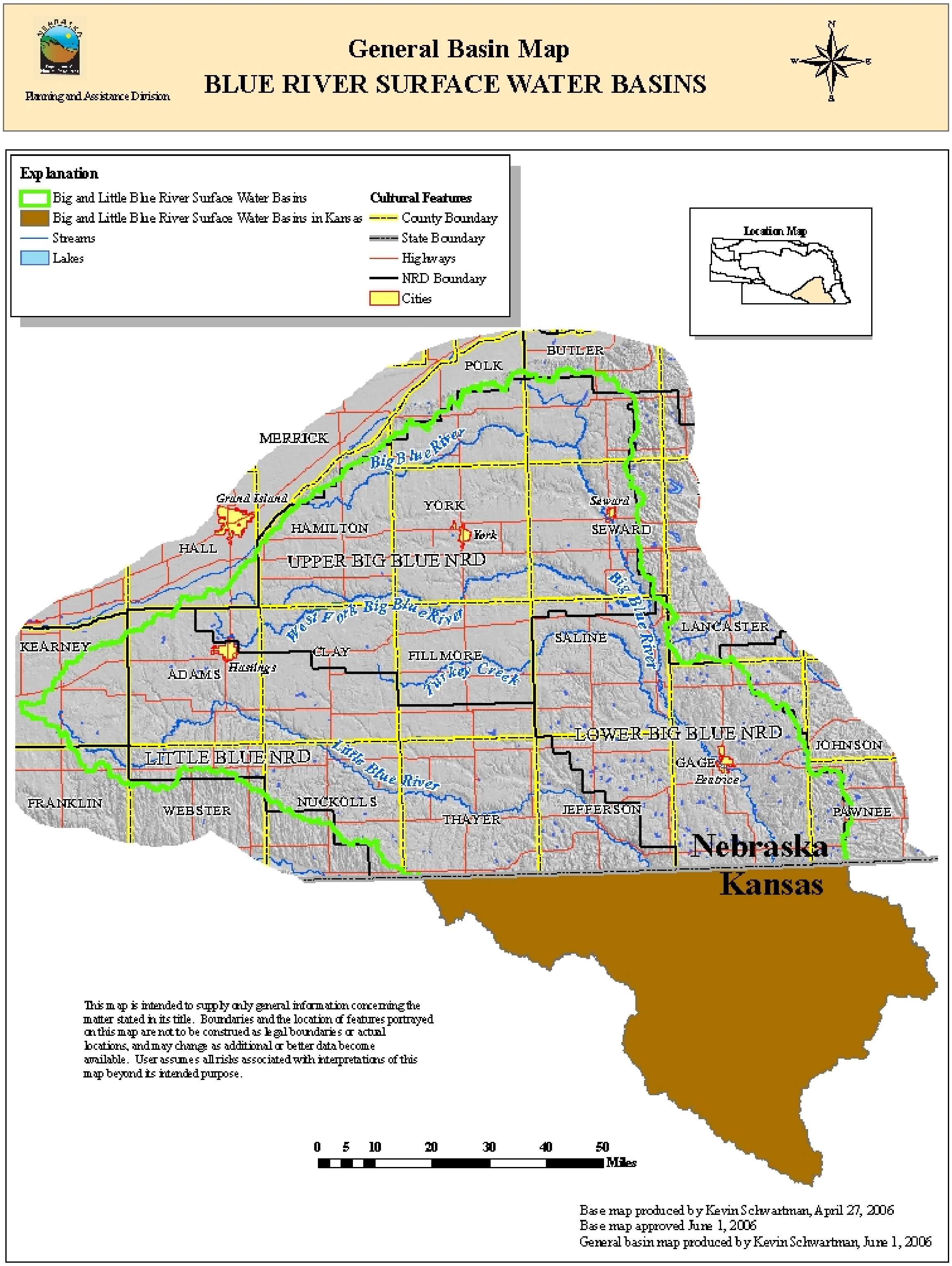
5.1 Summary

Based on the analysis of the sufficiency of the long-term surface water supply in the Blue River basins, the Department has reached a preliminary conclusion that the basins are not fully appropriated. Even though the effects of future ground water depletions on future water supplies were not estimated in the basins, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the net corn crop irrigation requirement. The best available data do not allow for analysis of whether this determination would change if no additional legal constraints are imposed on future development.

5.2 Basin Descriptions

The Blue River basins in Nebraska include all surface areas that drain into the Big Blue River and the Little Blue River and all aquifers that impact surface water flows of the basins (Figure 5-1). The total area of the Blue River surface water basins in Nebraska is approximately 7,100 square miles, of which 4,600 square miles are in the Big Blue River Basin and 2,500 square miles are in the Little Blue River Basin. Natural resources districts with significant area in the basins are the Little Blue Natural Resources District, the Lower Big Blue Natural Resources District, the Upper Big Blue Natural Resources District, and the Tri-Basin Natural Resources District. The basins are the subject of an interstate compact between Kansas and Nebraska that sets state-line target flows.

Figure 5-1 General basin map, Blue River basins



5.3 Nature and Extent of Water Use

5.3.1 Ground Water

Ground water in the basins is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 24,765 ground water wells had been registered within the basins as of December 31, 2006 (Department registered ground water wells database), with an estimated 640 ground water wells to be developed during 2007 (Figure 5-2). The locations of all active ground water wells are shown in Figure 5-3.

Figure 5-2 Current well development by number of registered wells, Blue River basins

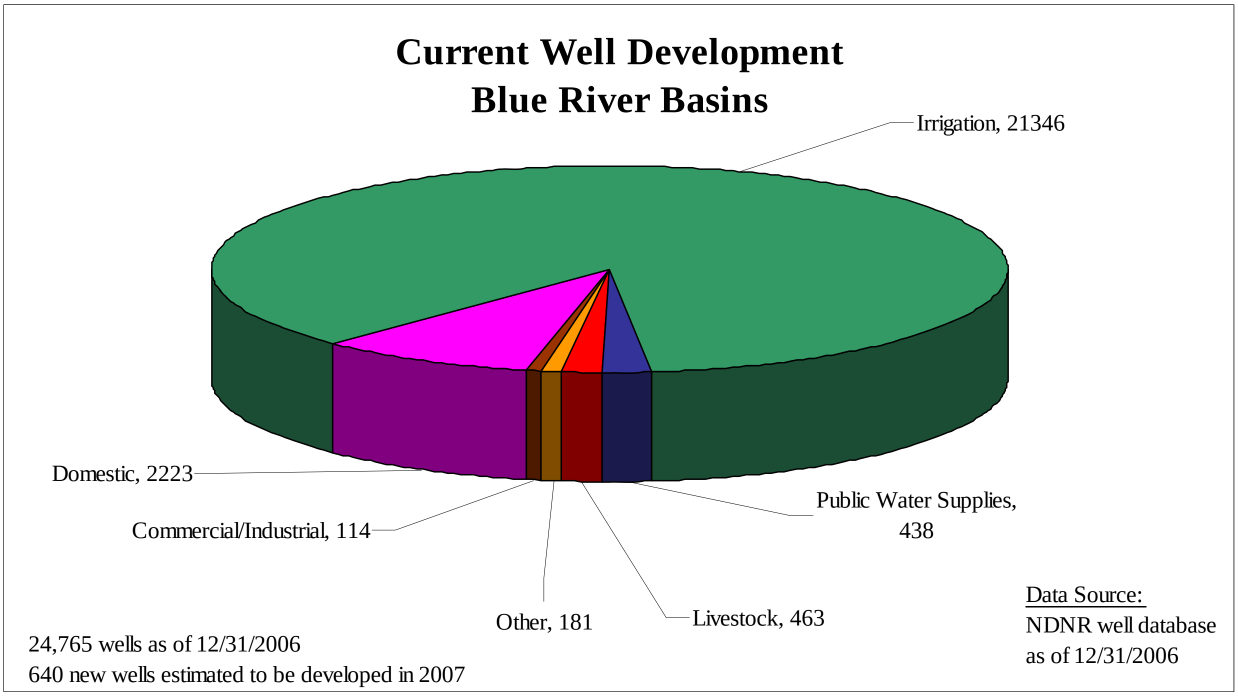
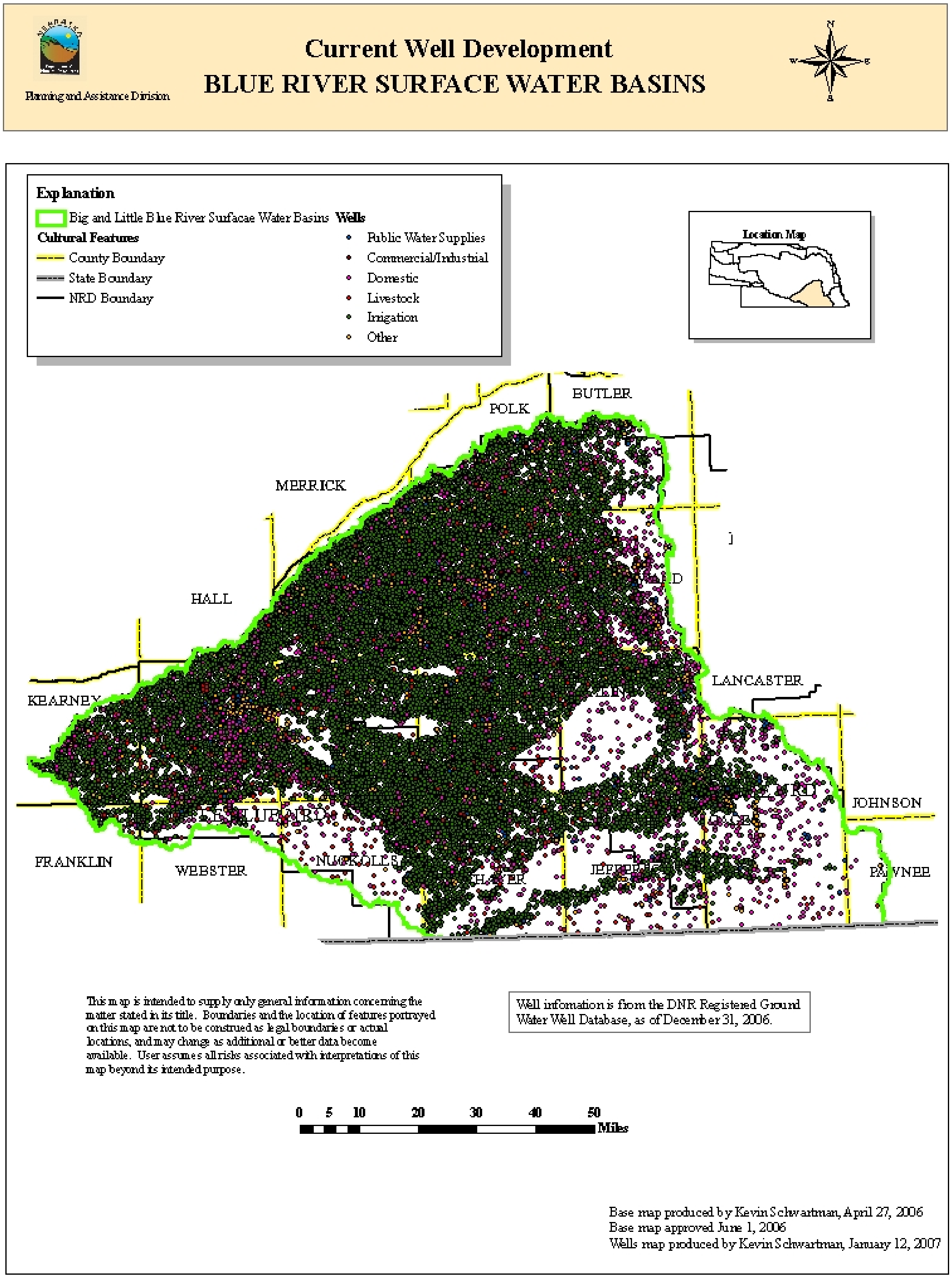


Figure 5-3 Current well locations, Blue River basins



5.3.2 Surface Water

As of December 31, 2006, there were 2,464 surface water appropriations in the basins, issued for a variety of uses (Figure 5-4). Most of the surface water appropriations are for irrigation and storage use and tend to be located on the major streams. The first surface water appropriations in the basins were permitted in 1868, and development has continued through the present day. The approximate locations of the surface water diversion points are shown in Figure 5-5.

Figure 5-4 Surface water appropriations by number of diversion points, Blue River basins

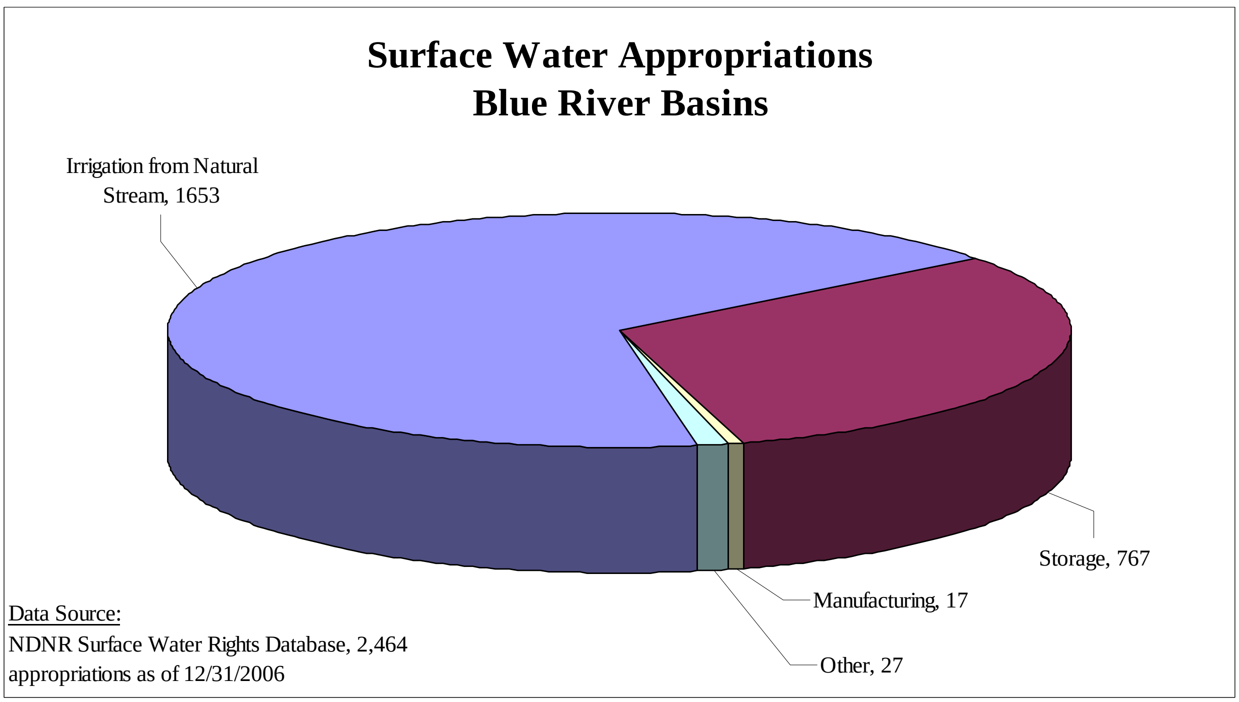
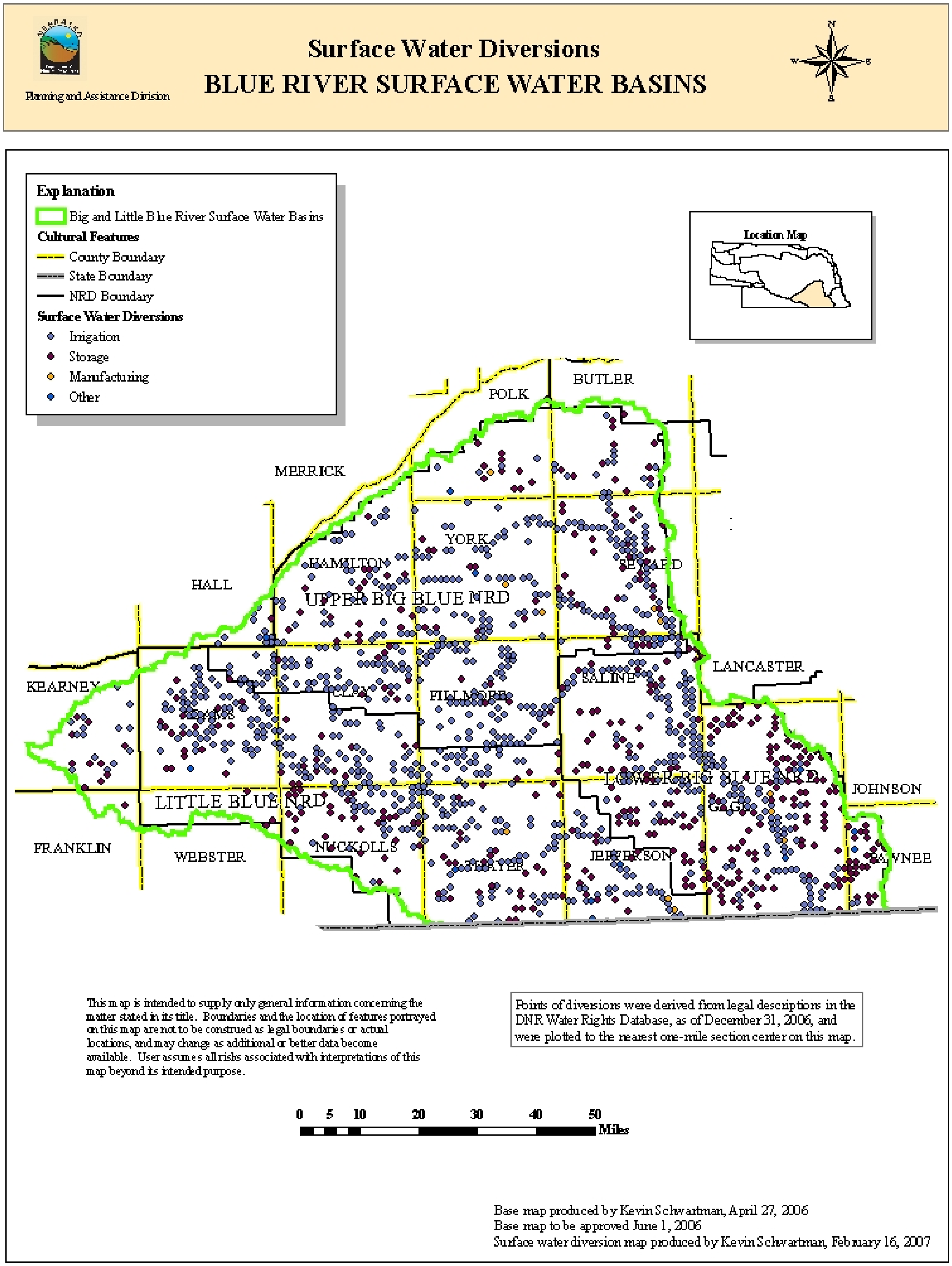


Figure 5-5 Surface water appropriation diversion locations, Blue River basins

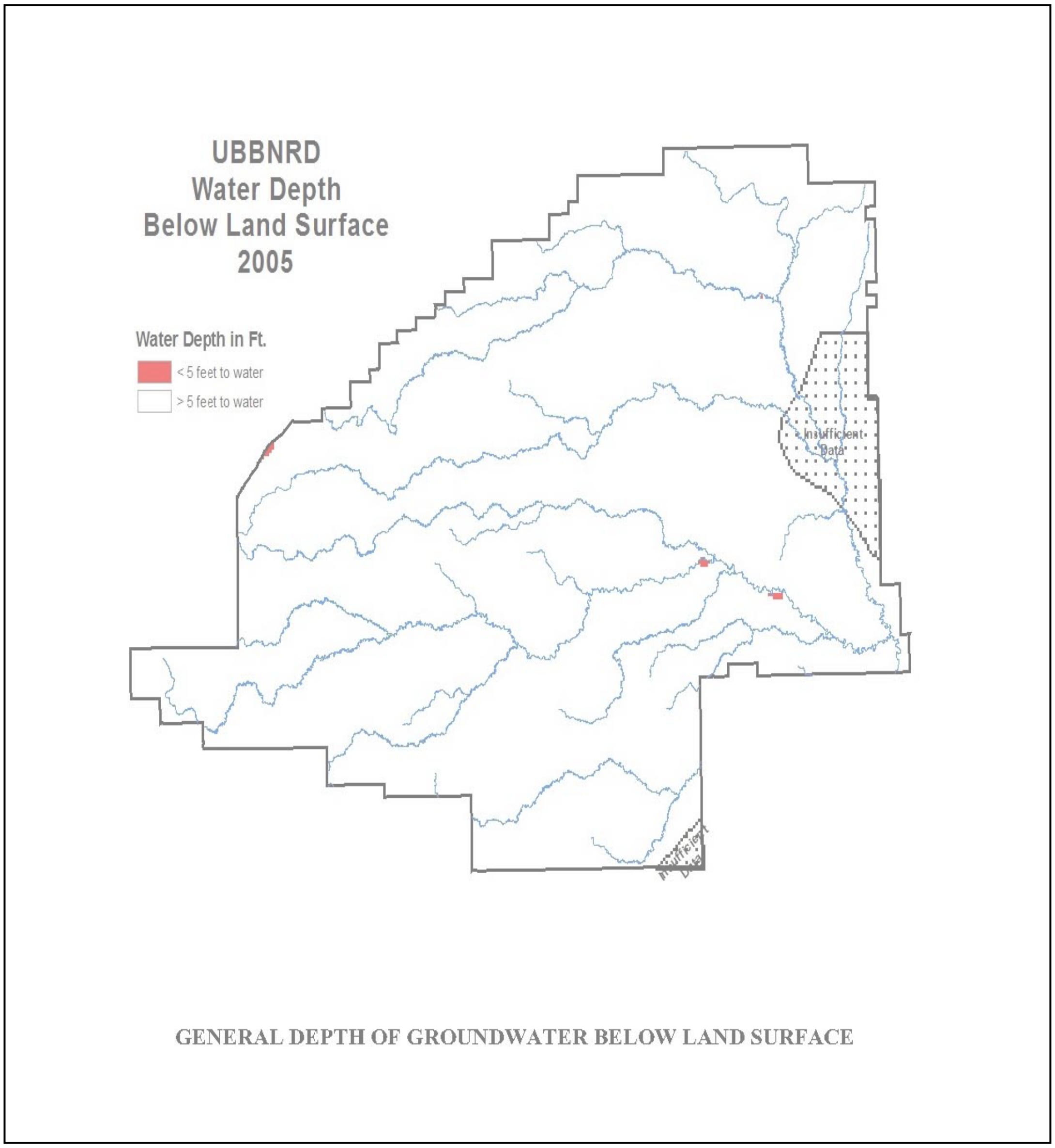


5.4 Hydrologically Connected Area

5.4.1 Big Blue River Basin

The Big Blue River Basin can be divided into two distinct areas based on the presence or absence of glacial deposits. At the present time, the Department cannot determine the 10/50 area for the Big Blue River and its tributaries in these areas. The stream depletion factor (SDF) methodology cannot be used to delineate the 10/50 area because of the restrictive and complex nature of the hydrogeology in the glaciated portions of the basin (CSD, 2005). The geology of the non-glaciated western area of the basin is less complex; however, in all but two small areas, the principal aquifer is not in hydrologic connection with the streams, because the water table is lower than the streambed elevation (Figure 5-6) (Bitner, 2005).

Figure 5-6 Areas of ground water and surface water connection, Upper Big Blue NRD (from Bitner, 2005)



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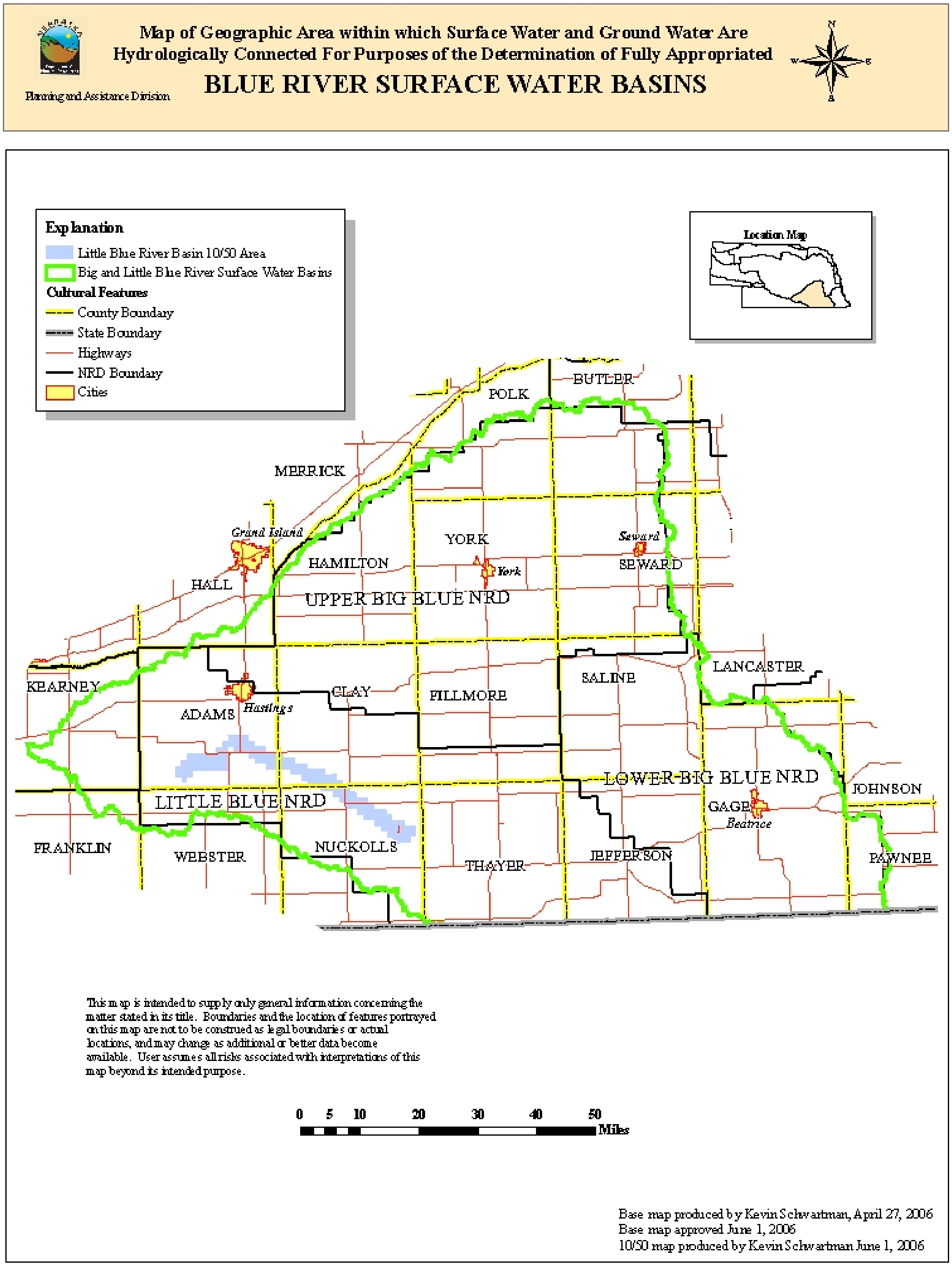
5.4.2 Little Blue River Basin

The Little Blue River Basin can also be divided into two distinct areas based on the presence or absence of glacial deposits. As with the Big Blue River Basin, the stream depletion factor (SDF) methodology cannot be used to delineate the 10/50 area because of the restrictive and complex nature of the hydrogeology in the glaciated portions of the basin (CSD, 2005). The 10/50 area for the other portions of the basin were determined from the results of the MODFLOW ground water model developed by the Upper Big Blue Natural Resources District (DNR, 2005) (Figure 5-7).

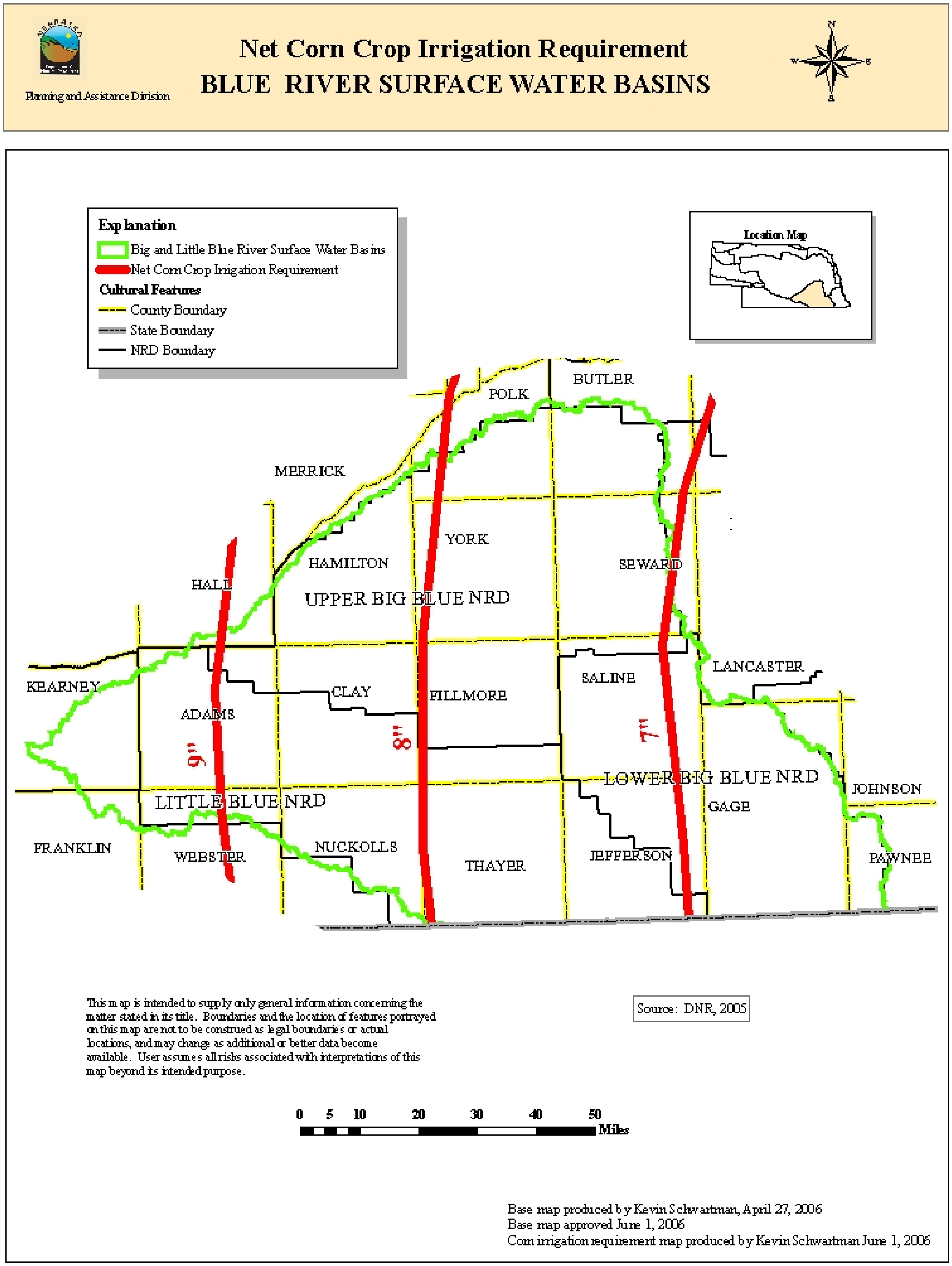
Figure 5-7 10/50 area, Little Blue River Basin



5.5 Net Corn Crop Irrigation Requirement

Figure 5-8 is a map of the net corn crop irrigation requirement for the Blue River basins (DNR, 2005). The greatest NCCIR of a junior surface water appropriation in the Big Blue River Basin is 9.0 inches, and the greatest NCCIR in the Little Blue River Basin is 9.7 inches. To assess the number of days required to be available for diversion, a surface water diversion rate equal to 1 cfs per 70 acres, a downtime of 10%, and an irrigation efficiency of 80% were assumed. Based on these assumptions, it will take the junior surface water appropriation in the Big Blue River Basin 23.9 days annually to divert 65% of the NCCIR and 31.3 days to divert 85% of the NCCIR. The junior surface water appropriation in the Little Blue River Basin will need 25.8 days annually to divert 65% of the NCCIR and 33.7 days to divert 85% of the NCCIR.

Figure 5-8 Net corn crop irrigation requirement, Blue River basins



5.6 Surface Water Closing Records

Tables 5-1 and 5-2 record all surface water administration that has occurred in the basins between 1987 and 2006.

Table 5-1 Surface water administration in the Big Blue River Basin, 1987-2006

Year	Water Body	Days	Closing Date	Opening Date
2000	Turkey Creek	3	Jun 9	Jun 12
2000	Big Blue River above Lincoln Creek	2	Aug 15	Aug 17
2001	Big Blue River above Lincoln Creek	1	Aug 14	Aug 15
2002	Big Blue River above Lincoln Creek	11	Jul 11	Jul 22
2002	Big Blue River above Lincoln Creek	14	Jul 30	Aug 13
2002	Big Blue River Basin	8	Aug 5	Aug 13
2002	North Fork Big Blue River	1	Aug 14	Aug 15
2003	Big Blue River above Lincoln Creek	49	Jul 16	Sep 3
2003	Big Blue River Basin	11	Jul 17	Jul 28
2003	Big Blue River Basin	8	Aug 11	Aug 19
2004	Big Blue River above Lincoln Creek	16	Aug 3	Aug 19
2005	Big Blue River above Lincoln Creek	14	Jul 12	Jul 26
2005	Big Blue River Basin	13	Jul 13	Jul 26
2005	Big Blue River above West Fork	8	Jul 18	Jul 26
2005	Big Blue River above Lincoln Creek	11	Aug 4	Aug 15
2005	Big Blue River Basin	6	Aug 9	Aug 15
2005	Big Blue River above West Fork	5	Aug 10	Aug 15
2006	Big Blue River above West Fork	13	Jul 1	Jul 14
2006	Big Blue River above West Fork	22	Jul 17	Aug 8
2006	Big Blue River Basin	11	Jul 3	Jul 14
2006	Big Blue River Basin	5	Jul 19	Jul 24
2006	Big Blue River Basin	9	Jul 29	Aug 7

Table 5-2 Surface water administration in the Little Blue River Basin, 1987-2006

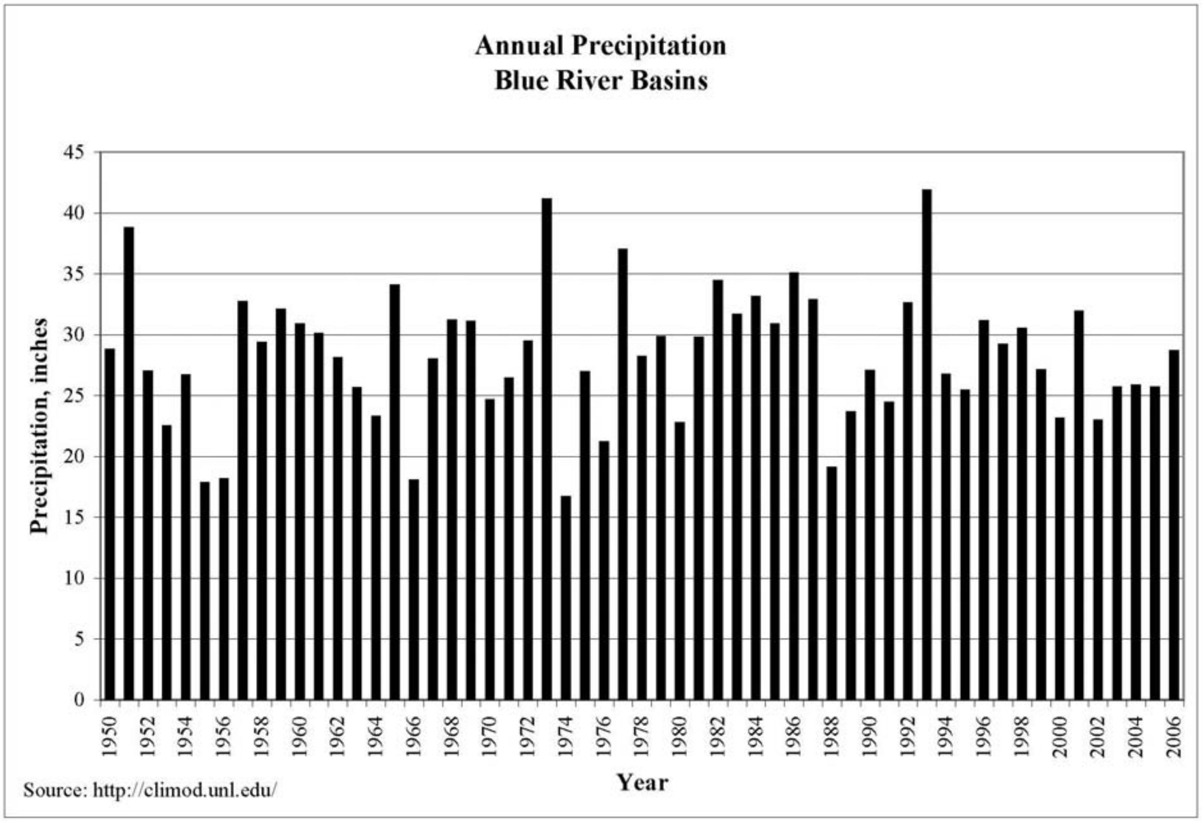
Year	Water Body	Days	Closing Date	Opening Date
1988	Little Blue River Basin	50	Aug 11	Sep 30
1989	Rose Creek	4		
1991	Little Blue River Basin	45	Aug 16	Sep 30
1991	Rose Creek	94	Jun 28	Sep 30
2002	Little Blue River Basin	11	Jul 18	Jul 29
2002	Little Blue River Basin	13	Aug 6	Aug 19
2002	Little Blue River Basin	7	Sep 9	Sep 16
2004	Little Blue River Basin	10	Sep 13	Sep 23
2005	Little Blue River Basin	15	Jul 11	Jul 26
2005	Little Blue River Basin	7	Aug 8	Aug 15
2006	Little Blue River Basin	9	Jul 5	Jul 14
2006	Little Blue River Basin	1	Jul 20	Jul 21
2006	Little Blue River Basin	7	Jul 31	Aug 7
2006	Little Blue River Basin	8	Aug 9	Aug 17

5.7 Evaluation of Current Development

5.7.1 Future Water Supply

In order to complete the long-term evaluation of surface water supplies, a future twenty-year water supply for the basins must be estimated. The basins' water sources are precipitation, which runs off as direct streamflow and infiltrates into the ground to discharge as baseflow, and ground water movement into the basins, which discharges as baseflow. Using methodology published in the *Journal of Hydrology* (Wen and Chen, 2005), a nonparametric Mann-Kendall trend test of the weighted average precipitation in the basins was completed. The analysis showed no statistically significant trend in precipitation ($P > 0.95$) over the past fifty years (Figure 5-9). Data do not exist to test whether there is a changing trend in ground water movement into the basin. Therefore, using the previous twenty years of streamflow data as the best estimate of the future surface water supply is a reasonable starting point for applying the lag depletions from ground water wells.

Figure 5-9 Annual precipitation, Blue River basins



5.7.2 Depletions Analysis

The future depletions due to current well development that could be expected to affect streamflow in the Big Blue River Basin and the glaciated portion of the Little Blue River Basin were not estimated for the same reasons as those described in Section 5.4. Even though a MODFLOW ground water model, developed by the Upper Big Blue Natural Resources District, exists for the other portions of the Little Blue River Basin, it is not sufficient to estimate future depletions at the current time.

5.7.3 Evaluation of Current Levels of Development against Future Water Supplies

The comparison of the near-term water supply days available for diversion to the number of days surface water is required to be available to divert 65% and 85% of the NCCIR is detailed in Tables 5-3 and 5-4. There is no estimate at this time of the long-term number of days available for diversion in the basins, due to limited understanding of the extent of hydrologic connection and an inadequacy of current data and models in predicting future stream depletions. Even though the future impacts on current water supplies were not estimated, it is unlikely that the basins will become fully appropriated in the future, since the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the net corn crop irrigation requirement.

Table 5-3 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion in the Big Blue River Basin

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	23.9	55.0 (31.1 days above the requirement)
May 1 – September 30 (85% Requirement)	31.3	145.8 (114.5 days above the requirement)

Table 5-4 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion in the Little Blue River Basin

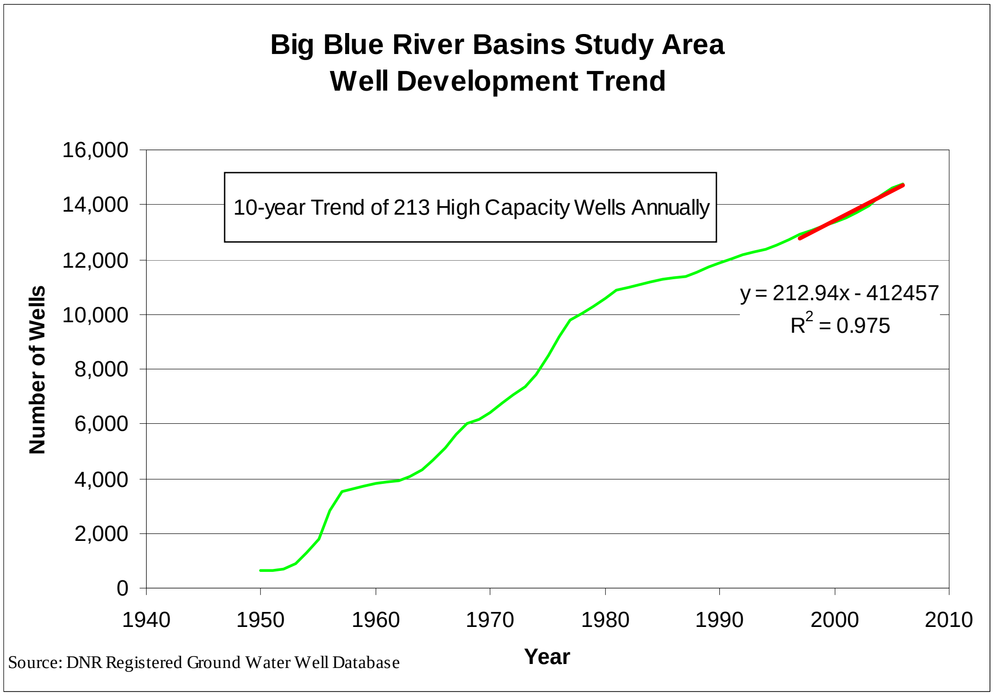
	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	25.7	56.7 (31.0 days above the requirement)
May 1 – September 30 (85% Requirement)	33.6	143.7 (110.1 days above the requirement)

5.8 Evaluation of Predicted Future Development

Estimates of the number of high capacity wells (wells pumping greater than 50 gpm) that would be completed over the next twenty-five years, if no new legal constraints on the construction of such wells were imposed, were calculated based on extrapolating the present-day rate of increase in well development into the future (Figure 5-10). The present-day rate of development is based on the linear trend of the previous ten years of development. Based on the analysis of the past ten years of development, the rate of increase in high capacity wells was calculated to be 213 wells per year in the basins.

For the same reasons as those stated above in Section 5.7.2, no estimates of depletions due to current and future ground water development were computed. Even though the effects on future water supplies were not estimated, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the NCCIR. Therefore, it is unlikely that the basins will become fully appropriated.

Figure 5-10 High capacity well development, Blue River basins



The future water supply in the basins may actually improve in the future if water can be made available to augment state-line flows to meet Big Blue River Compact targets. A cooperative study by the Department, the U.S. Bureau of Reclamation, and the basin NRDs is examining the value of augmentation water and identifying potential projects to supply augmentation water.

5.9 Sufficiency to Avoid Noncompliance

The State of Nebraska is a signatory member of the Kansas – Nebraska Big Blue River Compact (Compact). The purposes of the Compact are to promote interstate comity; to achieve an equitable apportionment of the waters of the Big Blue River Basin; to encourage continuation of the active pollution-abatement programs in each of the two states; and to seek further reduction in pollution of the waters of the Big Blue River Basin.

The Compact sets state-line flow targets from May 1 through September 30. The state-line targets, measured in cubic feet of water per second, are shown in Table 5-5. If the flow targets are not met, the State of Nebraska is required to take the following actions:

1. Limit surface water diversions by natural flow appropriators to their decreed appropriations;
2. Close natural flow appropriators with priority dates junior to November 1, 1968, in accordance with the doctrine of priority;
3. Ensure that no illegal surface water diversions are taking place; and
4. Regulate wells installed after November 1, 1968, within the alluvium and valley side terrace deposits downstream of Turkey Creek in the Big Blue River Basin and downstream of Walnut Creek in the Little Blue River Basin, unless it is determined by the Compact Administration that such regulation would not yield any measurable increase in flows at the state line gage.

For the present time, the Compact Administration has found that the regulation of those wells will not yield measurable increases in flow at the state line.

Table 5-5 State-line flow targets for the Big Blue River

Month	Big Blue River Target Flow	Little Blue River Target Flow
May	45 cfs	45 cfs
June	45 cfs	45 cfs
July	80 cfs	75 cfs
August	90 cfs	80 cfs
September	65 cfs	60 cfs

As long as Nebraska administers surface and ground water in compliance with the Compact, decreased streamflow, in and of itself, will not cause Nebraska to be in noncompliance; therefore, any depletion would not cause Nebraska to be in noncompliance. However, decreased streamflows could increase the number of times the state would have to administer water to remain in compliance, thereby reducing the number of days available for junior irrigators to divert.

5.10 Ground Water Recharge Sufficiency

The streamflow is sufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the stream, for reasons explained in Appendix H.

5.11 Current Studies being Conducted to Assist with Future Analysis

The geologic complexity of the basins requires more sophisticated efforts in investigating the extent of hydrologic connection between ground water and surface water supplies. Development of a ground water model for the Big Blue and Little Blue River basins was begun in 2005 by the NRDs within those basins. This work is an expansion of the ground water model developed by the Upper Big Blue NRD for the 2006 report. It will utilize new hydrogeologic mapping and related information being collected for this effort.

5.12 Conclusions

Based upon the evaluation of available information, the Department has reached a preliminary conclusion that the surface water and ground water supplies in hydrologic connection in the Blue River basins are not fully appropriated. The best available data do not allow for analysis of whether this determination would change if no additional legal constraints are imposed on future development of hydrologically connected surface water and ground water.

Bibliography of Hydrogeologic References for Big and Little Blue River Basins

Bitner, R.J. 2005. A groundwater model to determine the area within the Upper Big Blue Natural Resources District where groundwater pumping has the potential to increase flow from the Platte River to the underlying aquifer by at least 10 percent of the volume pumped over a 50-year period. Upper Big Blue Natural Resources District. York.

Conservation and Survey Division. 2005. *Mapping of Aquifer Properties-Transmissivity and Specific Yield-for Selected River Basins in Central and Eastern Nebraska.* Lincoln.

Nebraska Department of Natural Resources. 2005. *2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies*. Lincoln.

Wen, F.J., and X.H. Chen. 2005. Streamflow trends and depletion study in Nebraska with a focus on the Republican River Basin. *Water Resources Research* (In Review).

6.0 LOWER NIOBRARA RIVER BASIN

6.1 Summary

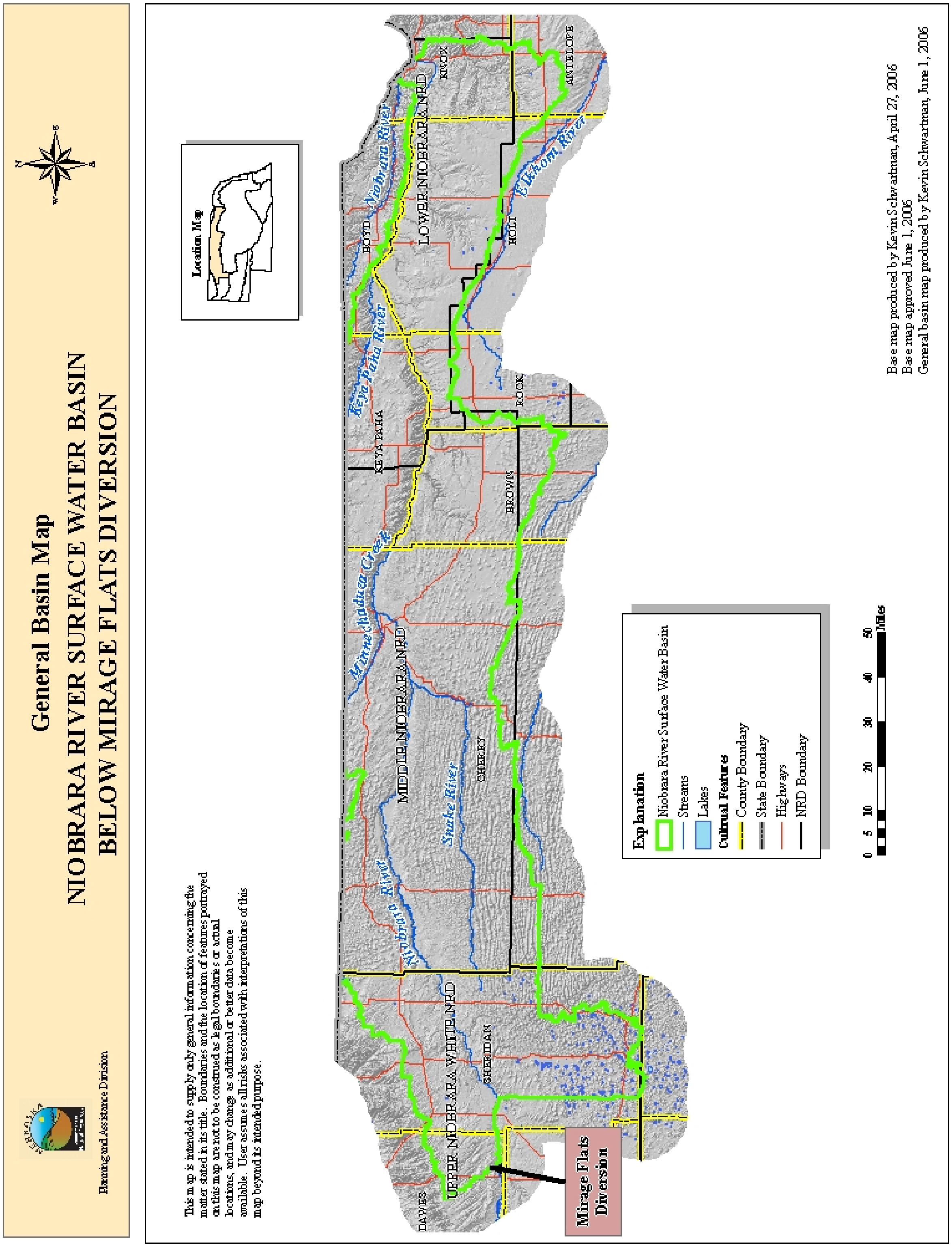
Based on the analysis of the sufficiency of the long-term surface water supply in the Lower Niobrara River Basin, the Department has reached a preliminary conclusion that the basin is fully appropriated upstream of the Spencer Hydropower facility. The designation as fully appropriated is the result of two factors. The first factor is that the current number of days available for diversion is less than the necessary crop irrigation requirements for junior irrigators within the basin. The second factor is that those irrigation rights which are junior to the calling senior right are currently receiving less water than was available for the twenty-year period prior to the granting of the appropriations. This preliminary conclusion differs from the preliminary conclusion found in last year's report in part because, prior to 2007, no call had been made to administer for the rights of the Spencer Hydropower facility. On March 5, 2007, the Department received a written request from Nebraska Public Power District (NPPD) to administer the water rights on the Niobrara River when flows fall below those to which NPPD's permits are entitled in order to generate electricity. Therefore, irrigators junior to the Spencer Hydropower rights were closed while administration was occurring on the river upstream of Spencer Hydropower. Some irrigators chose to pay NPPD to subordinate its water rights, in accordance with Nebraska law. Those irrigators were not closed, and the amount of water for which NPPD could call was lowered accordingly.

The basin downstream of the Spencer Hydropower facility is not currently included in the fully appropriated designation for the Lower Niobrara River Basin. The effects of future ground water depletions on future water supplies were estimated for the basin downstream of the Spencer Hydropower facility, but, due to a lack of administration, the number of days available for diversion in the future was could not be estimated.

6.2 Basin Description

The Lower Niobrara River Basin in Nebraska is defined in this report as the surface areas in Nebraska that drain into the Niobrara River Basin and have not previously been determined to be fully appropriated. This general basin area extends from the Mirage Flats diversion dam in the west downstream to the confluence of the Niobrara River and the Missouri River and includes all aquifers that impact surface water flows in the basin (Figure 6-1). The total area of the Niobrara River surface water basin is approximately 8,900 square miles. Natural resources districts with significant area in the basin are the Upper Niobrara White Natural Resources District, the Middle Niobrara Natural Resources District, and the Lower Niobrara Natural Resources District.

Figure 6-1 General basin map, Lower Niobrara River Basin



6.3 Nature and Extent of Water Use

6.3.1 Ground Water

Ground water in the basin is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 7,023 ground water wells had been registered within the basin as of December 31, 2006 (Department registered ground water wells database), with an estimated 310 ground water wells to be developed during 2007 (Figure 6-2). The locations of all active ground water wells can be seen in Figure 6-3.

Figure 6-2 Current well development by number of registered wells, Lower Niobrara River Basin

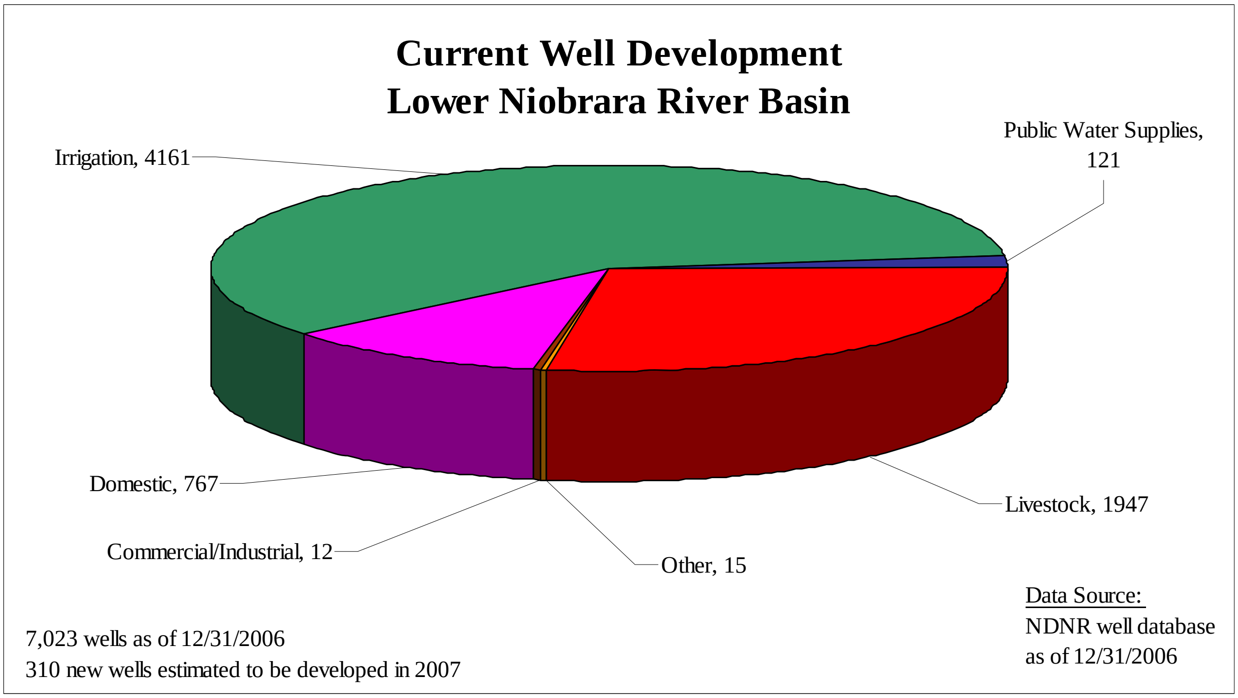
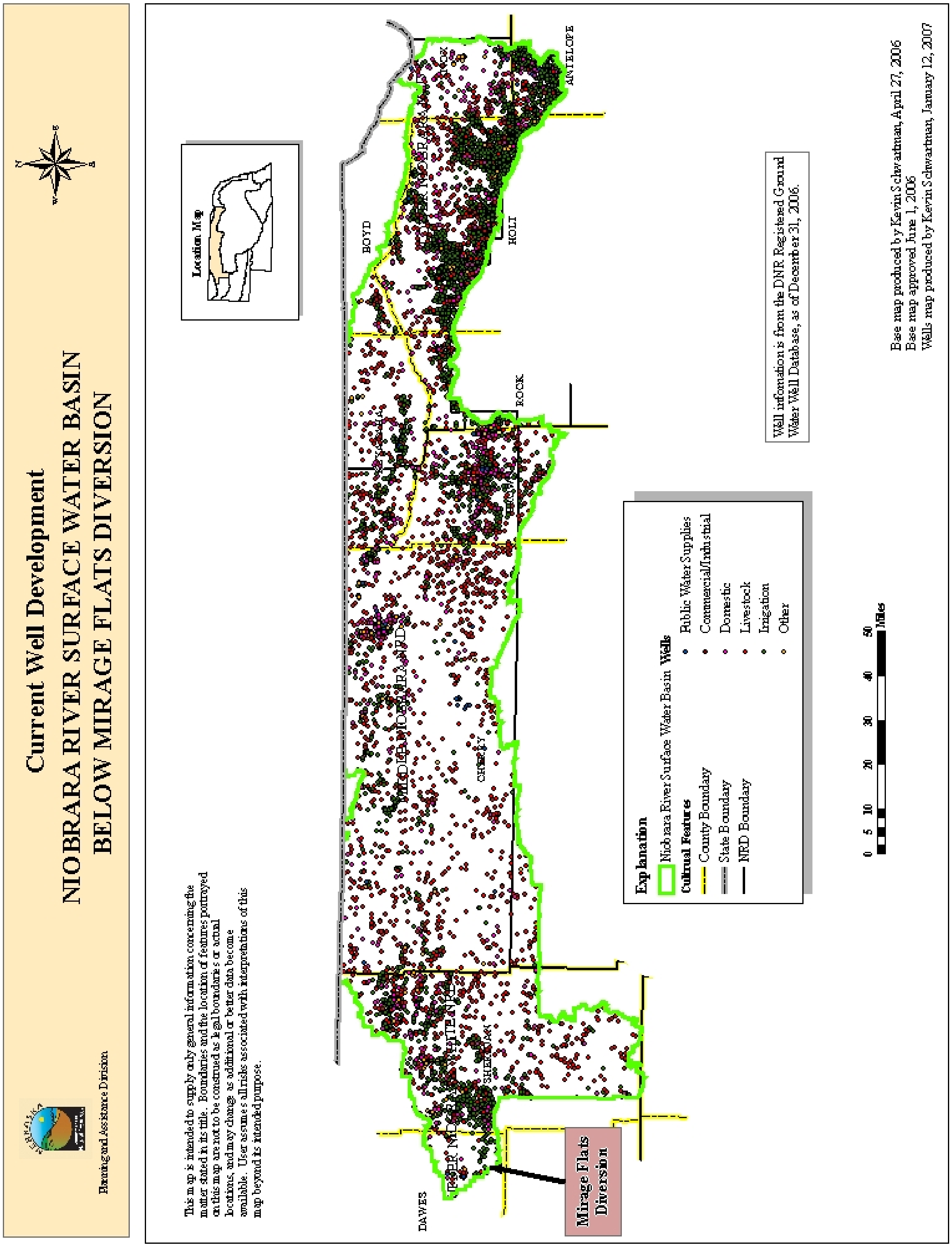


Figure 6-3 Current well locations, Lower Niobrara River Basin



6.3.2 Surface Water

As of December 31, 2006, there were 845 surface water appropriations in the basin issued for a variety of uses (Figure 6-4). Most of the surface water appropriations are for irrigation use and storage and tend to be located on the major streams. There is an instream flow appropriation in the basin located on Long Pine Creek and a hydropower appropriation on the Niobrara River near Spencer. The first surface water appropriations in the basin were permitted in 1894, and development has continued through the present day. The approximate locations of the surface water diversion points are shown in Figure 6-5.

Figure 6-4 Surface water appropriations by number of diversion points, Lower Niobrara River Basin

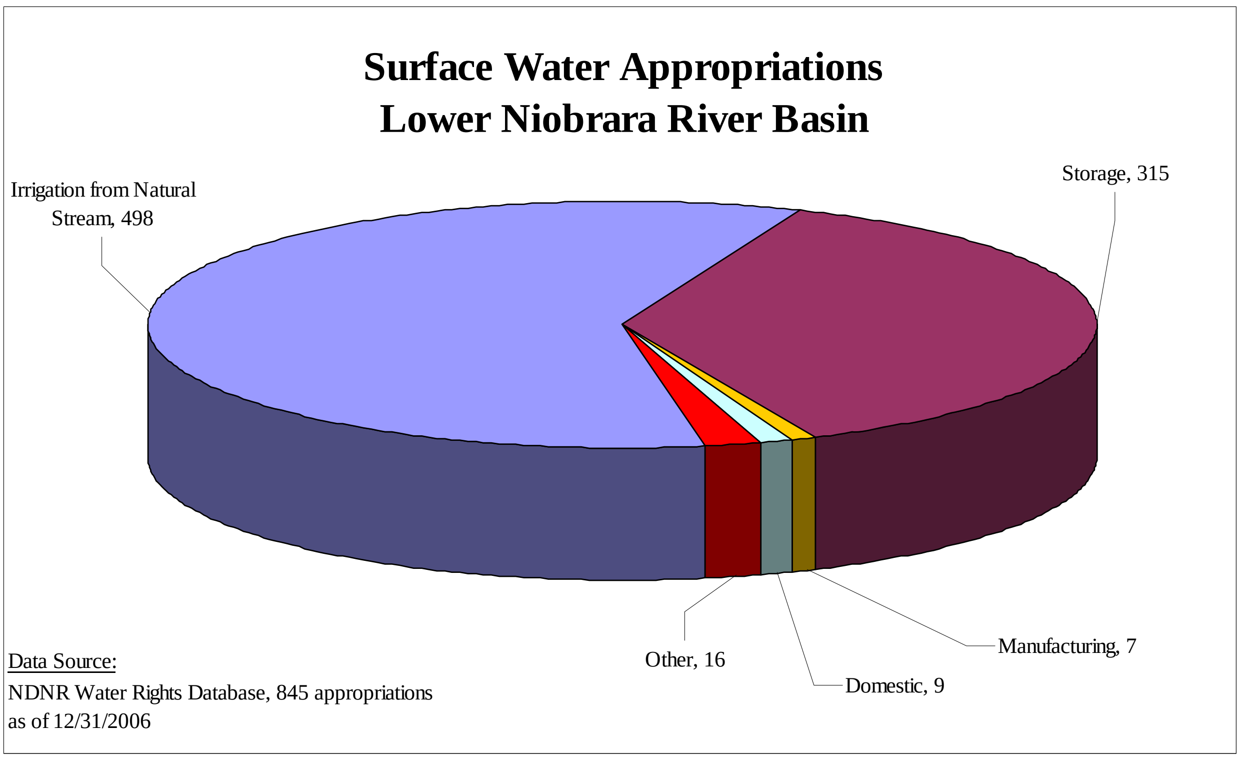
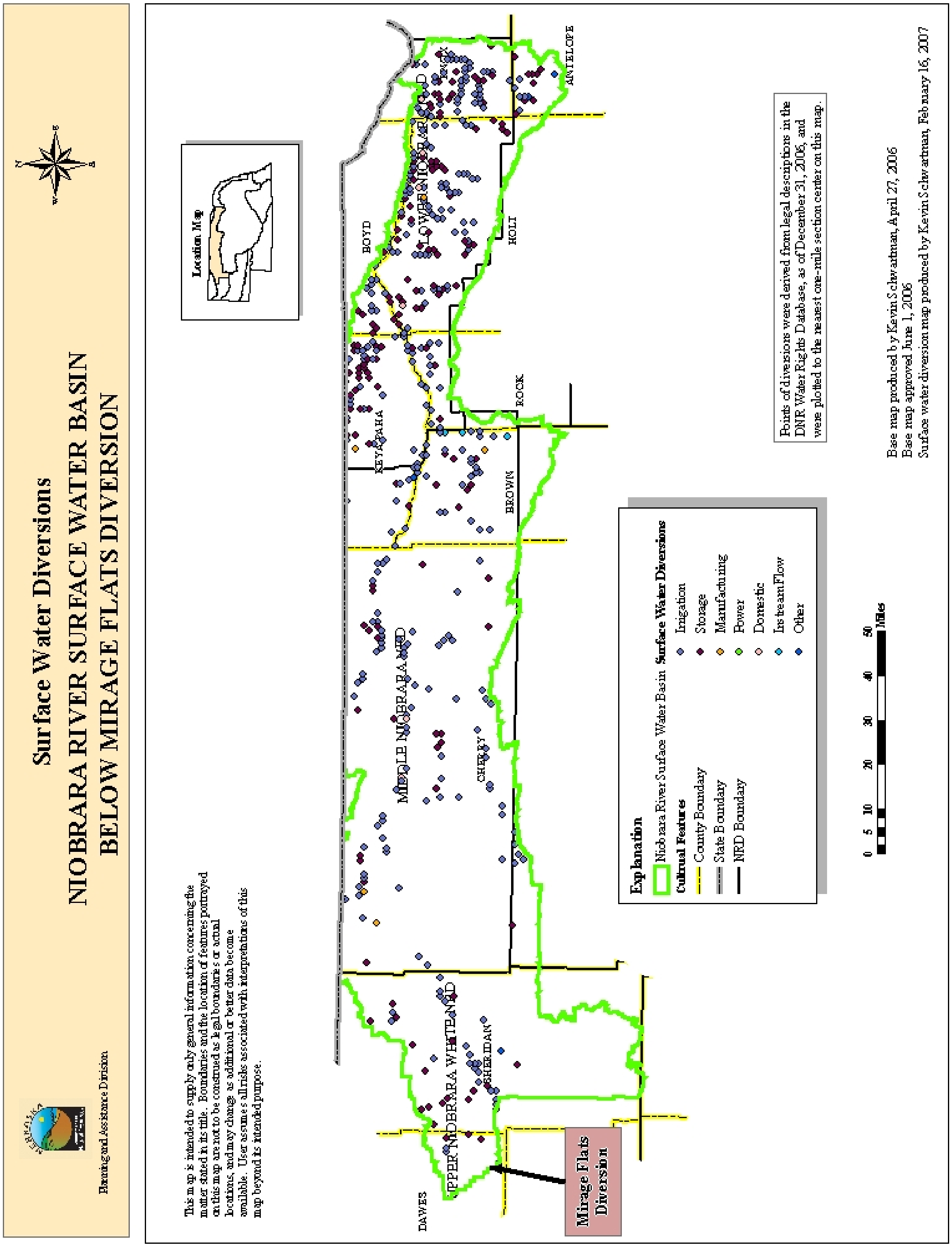


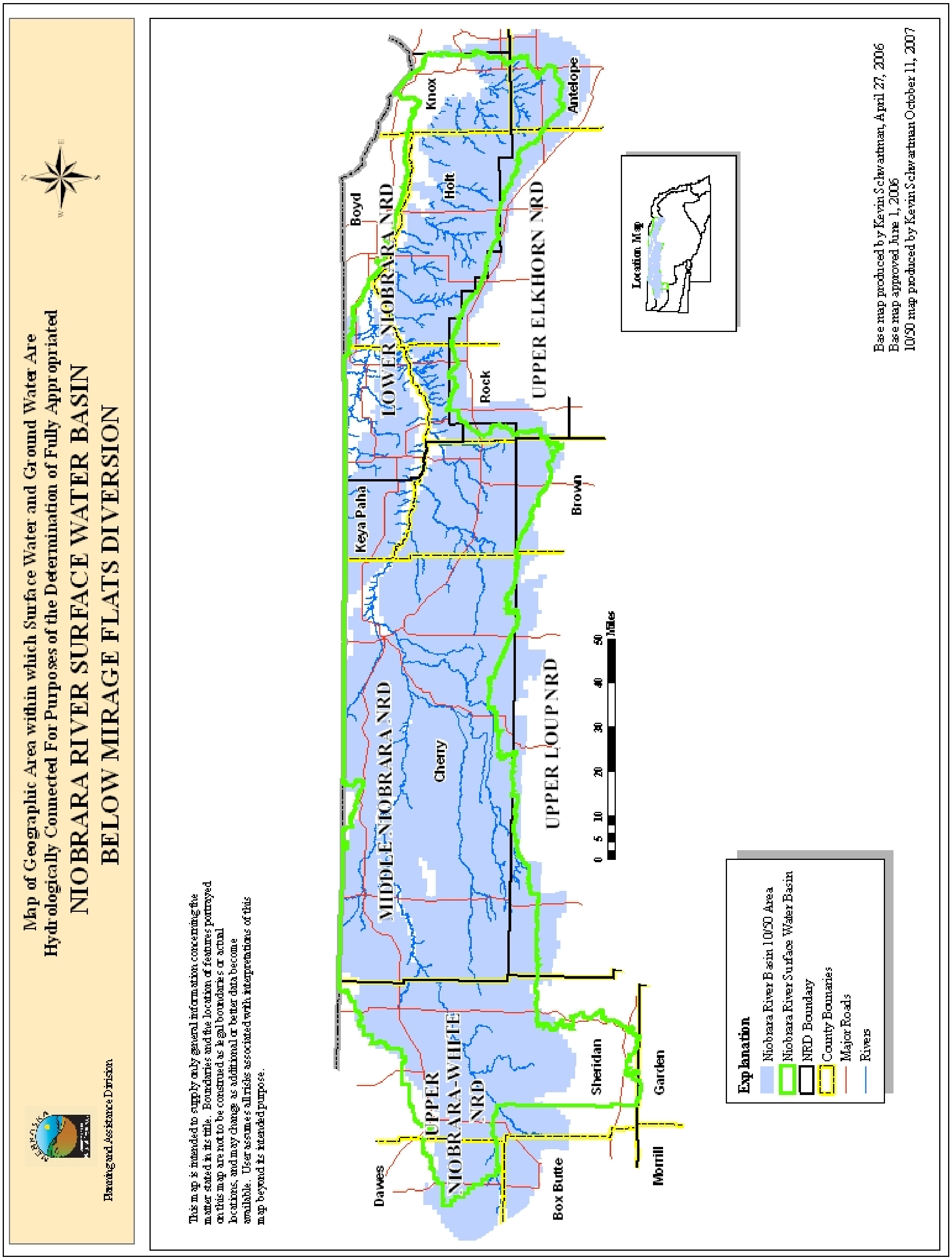
Figure 6-5 Surface water appropriation diversion locations, Lower Niobrara River Basin



6.4 Hydrologically Connected Area

No sufficient numeric ground water model is available in the Lower Niobrara River Basin to determine the 10/50 area. Therefore, the 10/50 area was determined using stream depletion factor (SDF) methodology. Figure 6-6 specifies the extent of the 10/50 area. A description of the SDF methodology used appears in the "Methodology" section of this report.

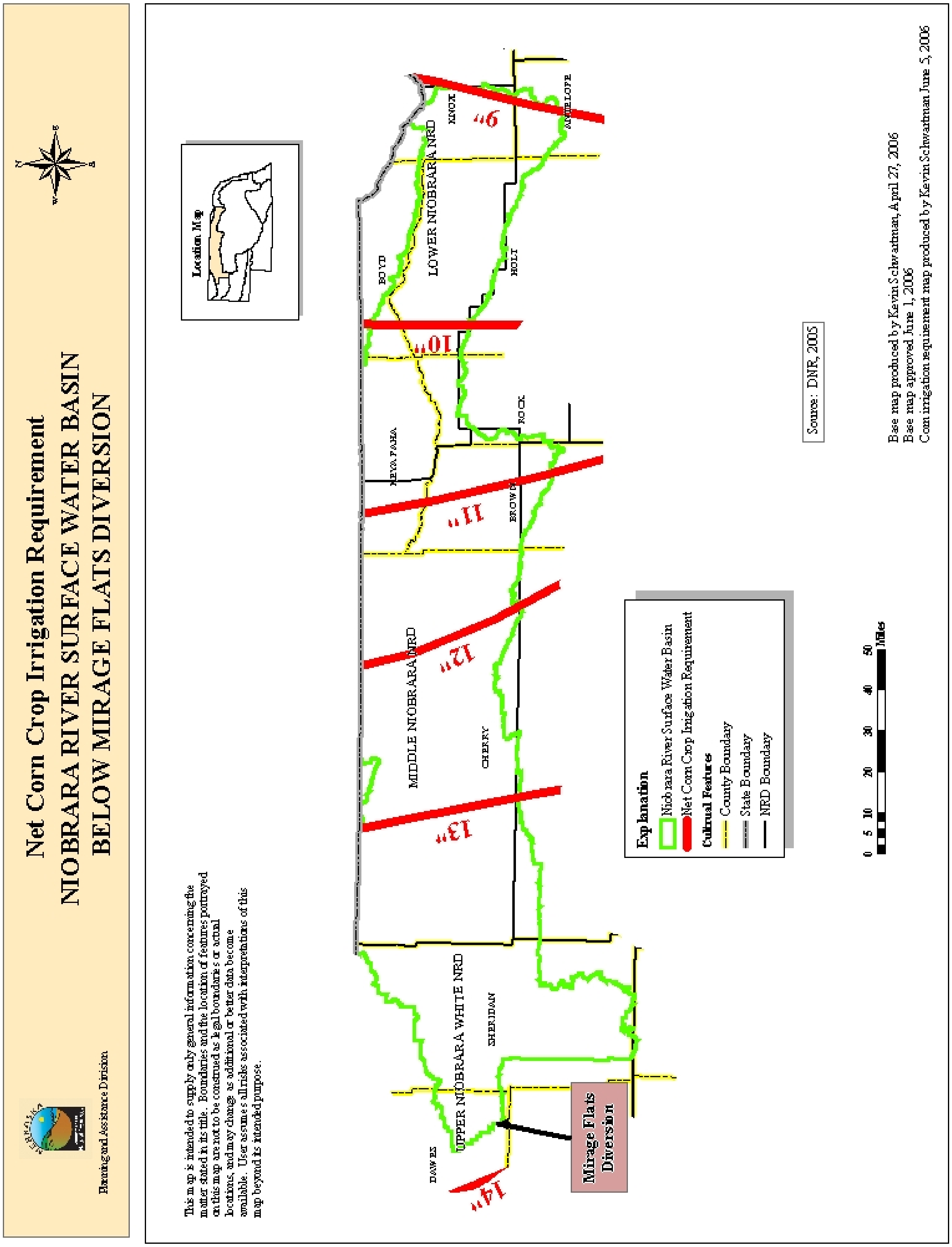
Figure 6-6 10/50 area, Lower Niobrara River Basin



6.5 Net Corn Crop Irrigation Requirement

Figure 6-7 is a map of the net corn crop irrigation requirement for the basin (DNR, 2005). The NCCIR in the basin ranges from 8.9 to 13.9 inches. To assess the number of days required to be available for diversion, a surface water diversion rate equal to 1 cfs per 70 acres, a downtime of 10%, and an irrigation efficiency of 80% were assumed. Based on these assumptions, it will take the junior surface water appropriation in the Niobrara River Basin upstream of Spencer Hydropower 36.9 days annually to divert 65% of the NCCIR and 68.1 days to divert 85% of the NCCIR. Junior surface water appropriations in the Niobrara River Basin downstream of Spencer Hydropower will require between 23.6 and 25.6 days annually to divert 65% of the NCCIR and between 30.9 and 33.4 days to divert 85% of the NCCIR.

Figure 6-7 Net corn crop irrigation requirement, Lower Niobrara River Basin



6.6 Surface Water Closing Records

Table 6-1 records all surface water administration that has occurred in the basin between 1987 and 2006.

Table 6-1 Surface water administration in the Lower Niobrara River Basin, 1987-2006

Year	Water Body	Days	Closing Date	Opening Date
1991	North Branch Verdigre Creek	3	Jul 26	Jul 29

In May 2007, the entire Niobrara River Basin upstream of the Spencer Hydropower facility was closed to appropriations junior to NPPD's permits due to NPPD's call for administration. The closing orders were lifted soon after that, when NPPD took the hydropower plant offline for regularly scheduled maintenance. NPPD then withdrew its call until August 1, in order to allow those irrigators who chose to do so time to enter into subordination agreements with NPPD.

6.7 Evaluation of Current Development

6.7.1 Current Water Supply

The previous twenty-year period was used as an estimate of the expected future twenty-year flows. In 2007, NPPD, the owner of the Spencer Hydropower facility and holder of surface water permits for power production, notified the Department that, beginning in 2007 and continuing into the future, it will request administration for its water rights. Thus, to analyze the availability of water for irrigation rights above the Spencer Hydropower facility, the Department analyzed the last twenty years of flows to predict the expected number of days that irrigation rights junior to the Spencer Hydropower facility would be turned off for the senior Spencer Hydropower right. When the senior appropriation (Spencer Hydropower) is satisfied, it is assumed that all junior irrigation rights are able to divert.

The results of the analysis conducted for the Lower Niobrara River Basin upstream of Spencer Hydropower and downstream of Spencer Hydropower are shown in Tables 6-2 and 6-3.

Table 6-2 Estimated number of days surface water is available for diversion upstream of Spencer Hydropower with current development

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1987	4	16
1988	2	34
1989	0	0
1990	0	13
1991	0	34
1992	5	6
1993	16	37
1994	2	17
1995	0	62
1996	0	64
1997	6	43
1998	8	41
1999	8	45
2000	0	13
2001	3	19
2002	0	5
2003	0	15
2004	0	0
2005	0	27
2006	0	0
Average	2.7	24.6

Table 6-3 Estimated number of days surface water is available for diversion downstream of Spencer Hydropower with current development

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1987	62	153
1988	62	153
1989	62	153
1990	62	153
1991	59	150
1992	62	153
1993	62	153
1994	62	153
1995	62	153
1996	62	153
1997	62	153
1998	62	153
1999	62	153
2000	62	153
2001	62	153
2002	62	153
2003	62	153
2004	62	153
2005	62	153
2006	62	153
Average	61.9	152.9

The comparison of the near-term water supply days available for diversion to the number of days surface water is required to be available to divert 65% and 85% of the NCCIR is detailed tables 6-4 and 6-5. The results indicate that the Lower Niobrara River Basin upstream of Spencer Hydropower provides to the most junior water right an average of 2.7 days available for diversion between July 1 and August 31 and 24.6 days available for diversion between May 1 and September 30. The Lower Niobrara River Basin downstream of Spencer Hydropower provides 61.9 days available for diversion between July 1 and August 31 and 152.9 days available for diversion between May 1 and September 30. The results indicate that the current water supply is unable to satisfy all the surface water appropriations upstream of Spencer Hydropower but is able to satisfy all surface water appropriations downstream of Spencer Hydropower.

Table 6-4 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion, Lower Niobrara River Basin upstream of Spencer Hydropower

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	36.9	2.7 days (34.2 days below the requirement)
May 1 – September 30 (85% Requirement)	48.3	24.6 days (23.7 days below the requirement)

Table 6-5 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion, Lower Niobrara River Basin downstream of Spencer Hydropower

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	23.6 to 25.6	61.9 days (at least 36.3 days above the requirement)
May 1 – September 30 (85% Requirement)	30.9 to 33.4	152.9 days (at least 119.5 days above the requirement)

6.7.2 Erosion of Irrigation Rights Upstream of Spencer Hydropower

The erosion rule was applied to evaluate whether, at the time that junior surface water irrigation appropriations upstream of Spencer Hydropower were granted, flows could have satisfied the 65/85 rule and, therefore, whether the junior rights have been eroded. The results of the analysis are shown in Table 6-6 below. The results indicate that a junior surface water irrigation appropriation granted in 2001 would have been able to divert on average 4.0 days between July 1 and August 31 and 31.0 days between May 1 and September 30 for the twenty-year period prior to 2001. This is greater than the average number of days that are currently available for diversion (2.7 days between July 1 and August 31 and 24.6 days between May 1 and September 30) by 1.3 days and 6.5 days, respectively. Thus, the junior irrigation rights have been eroded. As a result of the analysis, the Niobrara River upstream of Spencer Hydropower is designated fully appropriated.

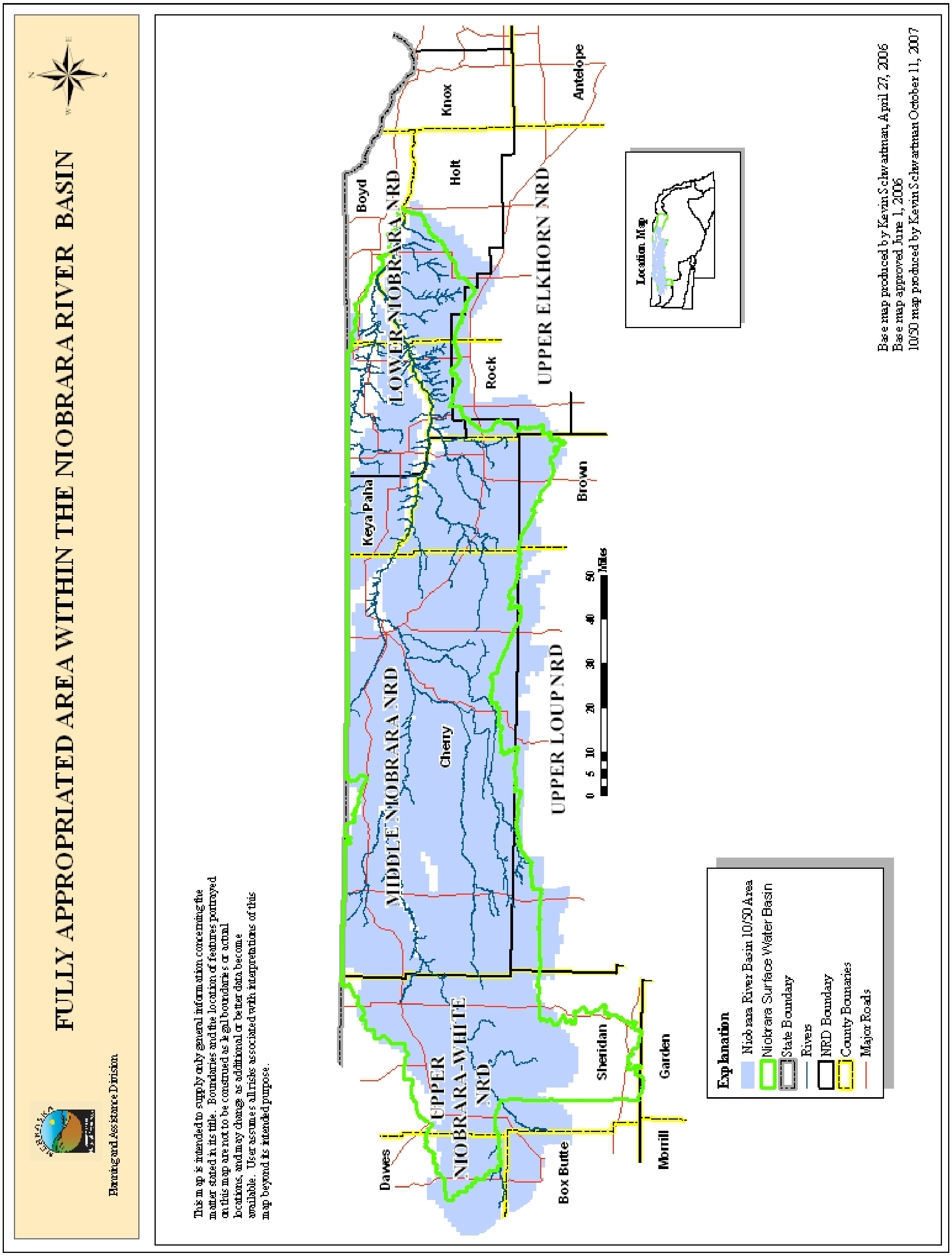
Table 6-6 Comparison between the number of days available to junior appropriators for diversion at the time appropriations were obtained and the number of days currently available for diversion, in the Lower Niobrara River Basin upstream of Spencer Hydropower

	Number of Days Required to Meet the Net Corn Crop Irrigation Requirement	**Number of Days Available to a Junior Irrigator between 1982-2001**	**Number of Days Currently Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	36.9	4.0	2.7
May 1 – September 30 (85% Requirement)	48.3	31.0	24.6

6.7.3 Fully Appropriated Area

Based on the analysis of current water supplies, the hydrologically connected subbasin upstream of the Spencer Hydropower facility is considered to be fully appropriated (Figure 6-8). The calculation of lag impacts from existing wells was not completed for the subbasin upstream of the Spencer Hydropower facility, because the addition of impacts from wells would only further decrease future water supplies.

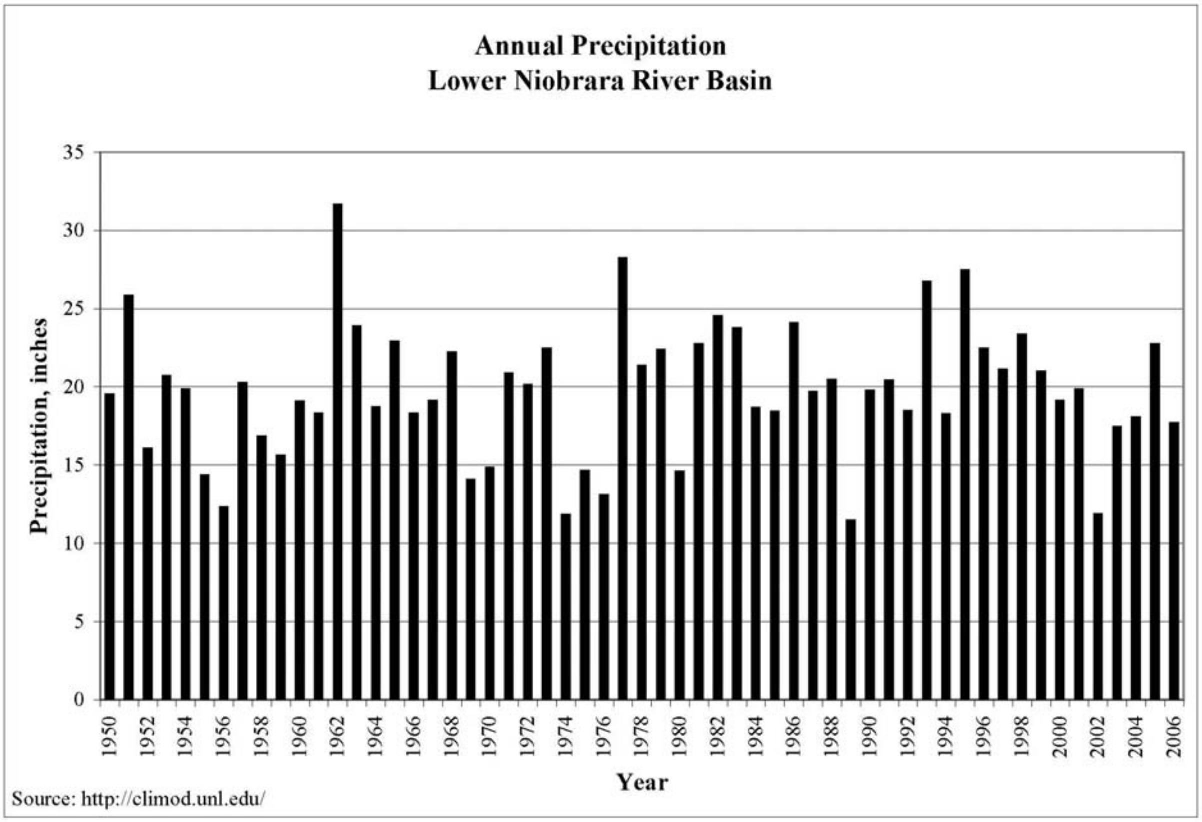
Figure 6-8 Area designated as fully appropriated within the Niobrara River Basin



6.7.4 Future Water Supply for Niobrara Subbasin Downstream of Spencer Hydropower Facility

In order to complete the long-term evaluation of surface water supplies for the Lower Niobrara River Basin downstream of Spencer Hydropower, a future twenty-year water supply for this portion of the basin must be estimated. The basin's water sources are precipitation, which runs off as direct streamflow and infiltrates into the ground to discharge as baseflow, ground water movement into the basin, which discharges as baseflow, and streamflow from the upper Niobrara River. Using methodology published in the *Journal of Hydrology* (Wen and Chen, 2005), a nonparametric Mann-Kendall trend test of the weighted average precipitation in the basin was completed. The analysis showed no statistically significant trend in precipitation ($P > 0.95$) over the past fifty years (Figure 6-9). No statistical analyses of ground water movement into the basin or streamflow from the upper Niobrara River were made due to the lack of data. Therefore, using the previous twenty years of streamflow data as the best estimate of the future surface water supply is a reasonable starting point for applying the lag depletions from ground water wells.

Figure 6-9 Annual precipitation, Lower Niobrara River Basin



6.7.5 Depletions Analysis for Niobrara Subbasin Downstream of Spencer Hydropower Facility

The future depletions analysis was not conducted for the Niobrara River upstream of Spencer Hydropower, since current levels of development are already unable to satisfy the 65/85 rule and the erosion rule. The depletion analysis was performed on the basin downstream of Spencer Hydropower to estimate expected depletions to streamflow. The SDF methodology, as documented in the "Methodology" section, was used to conduct this analysis. The results estimate the future streamflow at the mouth of the Niobrara River would be depleted by 48 cfs in twenty-five years due to lag impacts from current well development.

6.7.6 Evaluation of Current Levels of Development against Future Water Supplies

The comparison of the near-term water supply days available for diversion to the number of days surface water is required to be available to divert 65% and 85% of the NCCIR for the Niobrara River Basin downstream of Spencer Hydropower is detailed in Table 6-7. No estimate of the twenty-year average number of days available for diversion was made, because no surface water administration has historically occurred on the Niobrara River itself downstream of the Spencer Hydropower facility. Even though the future water supplies were not estimated, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the NCCIR. Thus, it is unlikely that this portion of the basin would be fully appropriated.

Table 6-7 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion, Lower Niobrara River Basin downstream of Spencer Hydropower

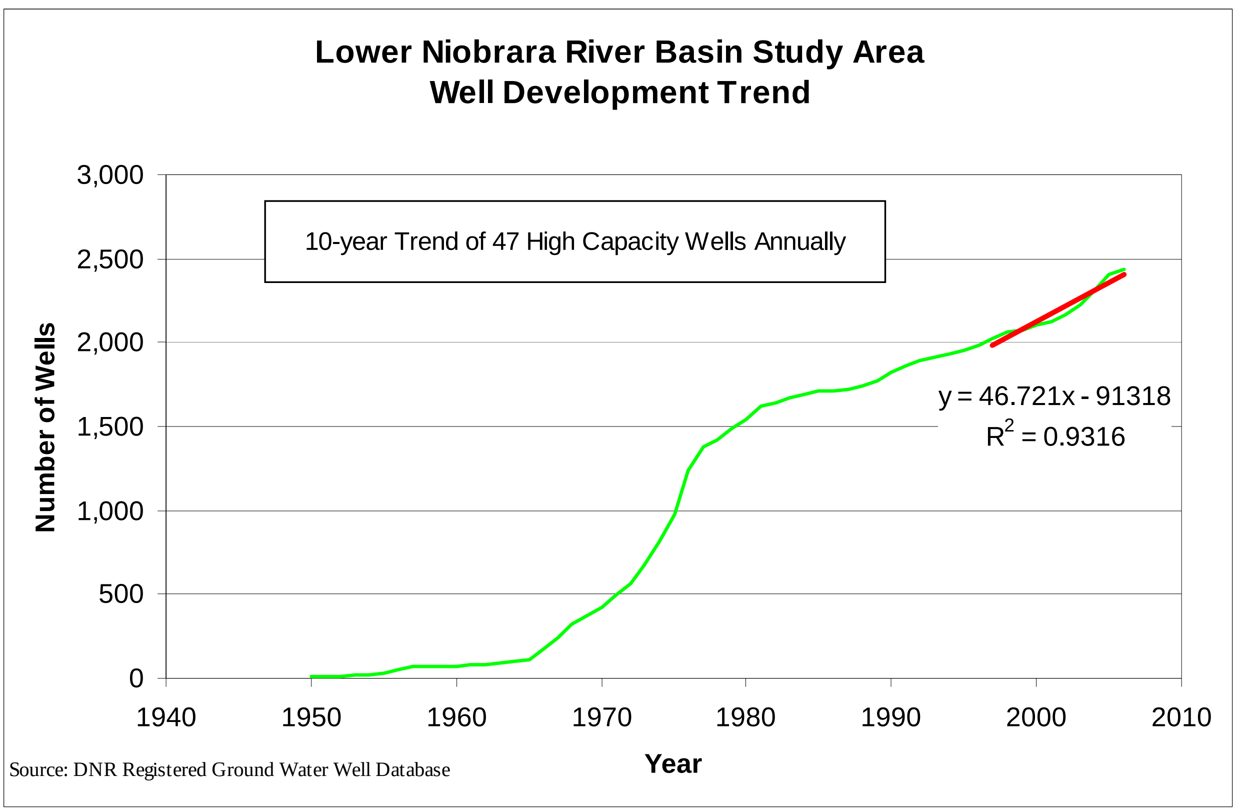
	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	23.6 to 25.6	61.9 days (at least 36.3 days above the requirement)
May 1 – September 30 (85% Requirement)	30.9 to 33.4	152.9 days (at least 119.5 days above the requirement)

6.8 Evaluation of Predicted Future Development for Niobrara Subbasin Downstream of Spencer Hydropower Facility

As a result of designating the basin above Spencer Hydropower as fully appropriated, estimates of the number of high capacity wells (wells pumping greater than 50 gpm) that would be completed over the next twenty-five years, if no new legal constraints on the construction of such wells were imposed, were calculated only for the Niobrara River Basin downstream of Spencer Hydropower. The estimated number of high capacity wells was calculated based on extrapolating the present-day rate of increase in well development into the future (Figure 6-10). The present-day rate of development is based on the linear trend of the previous ten years of development. Based on the analysis of the past ten years of development, the rate of increase in high capacity wells is estimated to be 47 wells per year in the basin.

For the depletion analysis, it is assumed that further ground water development will most likely be in the form of high capacity wells for irrigation purposes. Each future well was placed in an area where the soil is classified as irrigable by the U.S. Department of Agriculture and at least 1,400 feet away from existing high capacity wells, which is slightly larger than the radius of an average center pivot.

Figure 6-10 High capacity well development, Lower Niobrara River Basin downstream of Spencer Hydropower



The future depletions due to current and future well development that could be expected to affect streamflow in the basin were estimated using SDF methodology. The results estimate the future streamflow at the mouth of the Niobrara to be depleted by 125 cfs in ten years, 166 cfs in fifteen years, 232 cfs in twenty years, and 299 cfs in twenty-five years.

For the same reasons stated in Section 6.7.5 above, no estimates of future water supplies were computed. Even though the effects on future water supplies were not estimated, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the NCCIR in the Niobrara River Basin downstream of Spencer Hydropower. Therefore, it is unlikely that the lag effect will cause this portion of the basin to be fully appropriated.

6.9 Analysis of Long Pine Instream Flow Surface Water Appropriation

The future surface water supply for the instream flow appropriation in the basin was evaluated by applying the erosion rule on a monthly basis. The twenty-year estimate of the future average number of days when the instream flow appropriation would be met at the time of the appropriation application was compared to the twenty-year average estimate of the number days when the instream flow appropriations would be met using the future depleted surface water supply. The results are shown in Table 6-8. Results show no erosion in any month. The long-term surface water supply in the basin is sufficient for the instream flow appropriation in the basin.

Table 6-8 Long Pine Creek instream flow appropriation evaluation

Month	Estimate of Future Days When Flows Met at Time of Application	Estimate of Future Days Flows Met Using Long-Term Water Supply
October	31.0	31.0
November	30.0	30.0
December	31.0	31.0
January	31.0	31.0
February	28.0	28.0
March	31.0	31.0
April	30.0	30.0
May	31.0	31.0
June	30.0	30.0
July	31.0	31.0
August	31.0	31.0
September	30.0	30.0

6.10 Sufficiency to Avoid Noncompliance

There are no compacts on any portions of the Lower Niobrara River Basin in Nebraska.

6.11 Ground Water Recharge Sufficiency

The streamflow is sufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the stream, for reasons explained in Appendix H.

6.12 Current Studies being Conducted to Assist with Future Analysis

A substantial portion of the Niobrara River Basin on the south side of the river is included in the Elkhorn-Loup ground water model (ELM), which is currently being developed to evaluate the ground water-surface water relationship and the water supply of the Elkhorn and Loup River Basins. Although not developed specifically to evaluate the water supply in the Niobrara River Basin, this model may eventually be adapted to analyze water resources in the basin. Efforts will be made to incorporate results from this model into future reports.

6.13 Relevant Data Provided by Interested Parties

The Department received letters from two interested parties, the National Park Service and the U.S. Fish and Wildlife Service, concerning the social, economic, and environmental impacts of additional hydrologically connected surface water and ground water uses on the Fort Niobrara National Wildlife Refuge, the Niobrara Wilderness Area, and the Niobrara National Scenic River. The letters can be found in Appendix A and are included in this report for informational purposes, as required by Section 46-713(1)(c). The two federal agencies urged the Department to consider their potential, unquantified, federally reserved water rights in its evaluation of the Lower Niobrara River Basin; however, current methodology requires an interest to be represented by a quantifiable amount to be considered in the evaluation.

6.14 Conclusions

Based upon the evaluation of available information, the Department has reached a preliminary conclusion that the Lower Niobrara River Basin upstream of Spencer Hydropower is fully appropriated. The designation as fully appropriated is a result of two factors: 1) the current number of days available for diversion is less than the necessary to satisfy all water user including irrigators and the Spencer Hydropower facility and 2) irrigation rights that are junior to the calling senior right have been eroded. The Niobrara River Basin downstream of Spencer Hydropower is not currently included in the fully appropriated designation.

Bibliography of Hydrogeologic References for Lower Niobrara River Basin

Conservation and Survey Division. 2005. *Mapping of Aquifer Properties-Transmissivity and Specific Yield-for Selected River Basins in Central and Eastern Nebraska.* Lincoln.

Nebraska Department of Natural Resources. 2005. *2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies*. Lincoln.

Wen, F.J., and X.H. Chen. 2005. Streamflow trends and depletion study in Nebraska with a focus on the Republican River Basin. *Water Resources Research* (In Review).

7.0 LOWER PLATTE RIVER BASIN

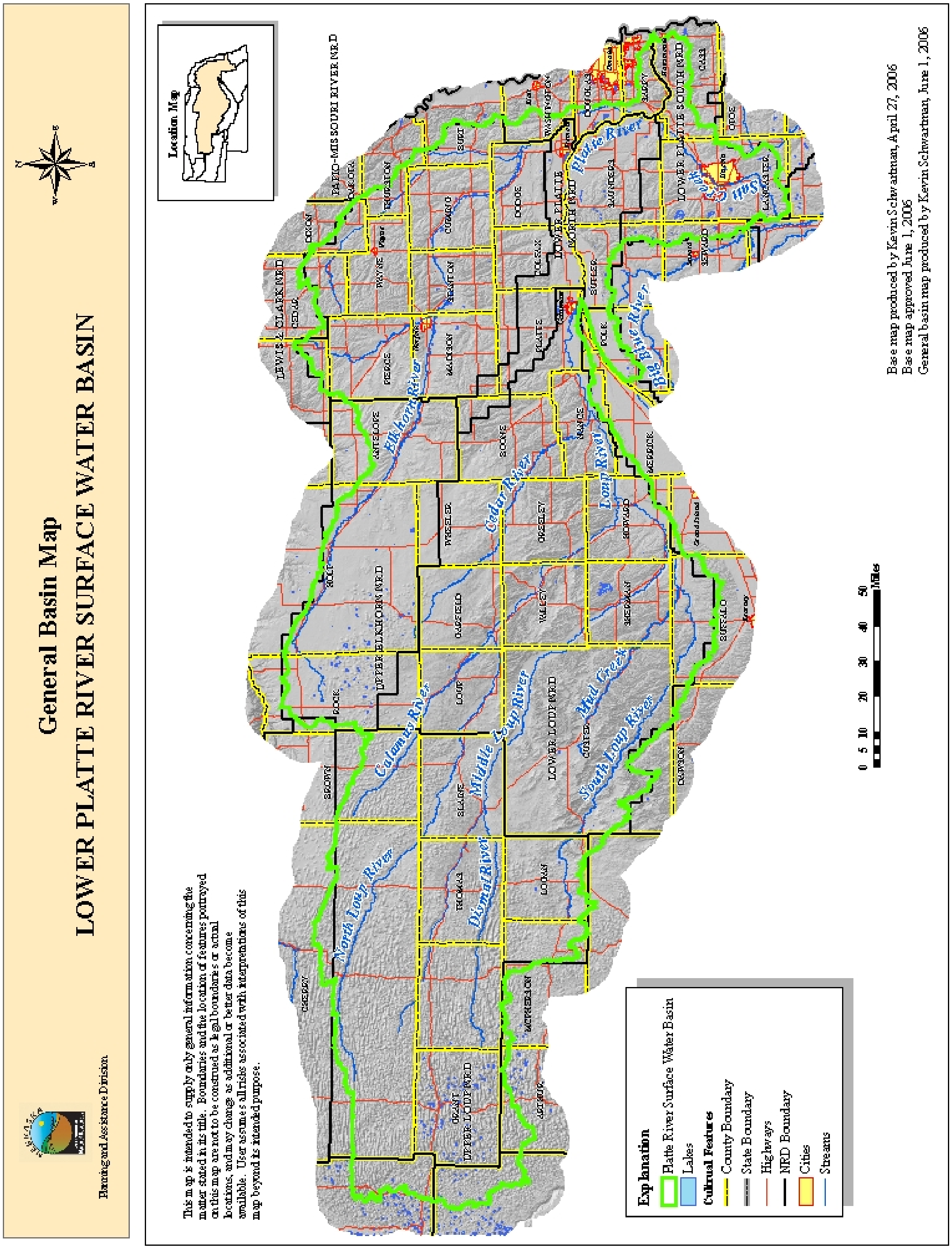
7.1 Summary

Based on the analysis of the sufficiency of the long-term surface water supply in the Lower Platte River Basin, the Department has reached a preliminary conclusion that, without the initiation of additional uses, the basin is not presently fully appropriated. However, based on currently available data and on reasonable projections of the extent and location of future development in the basin, the analysis also shows that this preliminary conclusion would change to a conclusion that the entire basin is fully appropriated if no additional constraints are placed on surface water and ground water development.

7.2 Basin Description

The Lower Platte River is defined as the reach of the Platte River from its confluence with the Loup River to its confluence with the Missouri River. The Lower Platte River Basin is defined as all surface areas that drain into the Lower Platte River, including those areas that drain into the Loup River and the Elkhorn River, and all aquifers that impact surface water flows of the basin (Figure 7-1). The total area of the Lower Platte River surface water basin is approximately 25,400 square miles, of which approximately 15,200 square miles are in the Loup River subbasin and approximately 7,000 square miles are in the Elkhorn River subbasin. Natural resources districts with significant area in the basin are the Lower Platte South Natural Resources District; the Lower Platte North Natural Resources District; the Upper Elkhorn Natural Resources District; the Lower Elkhorn Natural Resources District; the Upper Loup Natural Resources District; the Lower Loup Natural Resources District; and the Papio-Missouri River Natural Resources District.

Figure 7-1 General basin map, Lower Platte River Basin



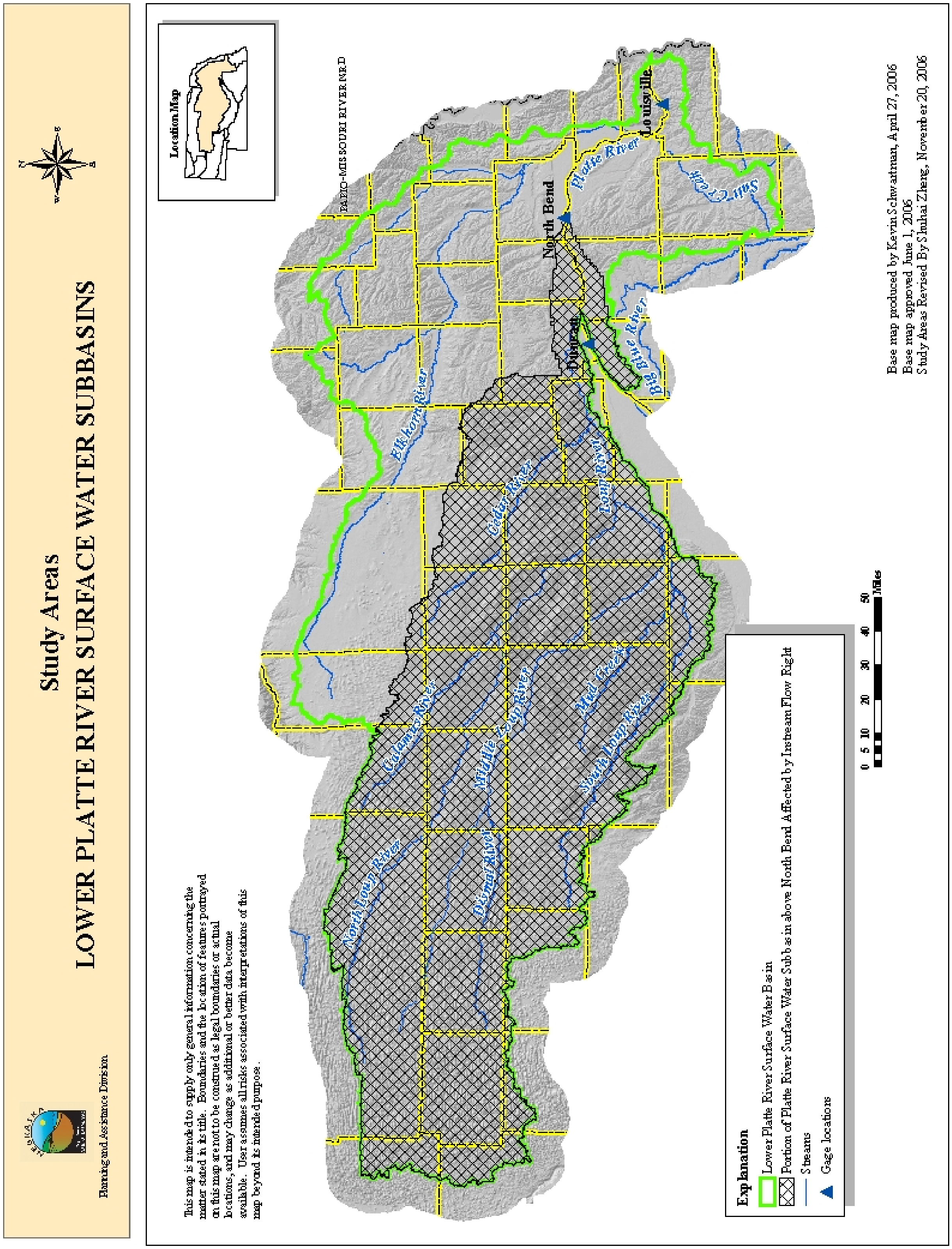
7.2.1 Subbasin Relationships

When considering the Lower Platte River Basin, it is important to understand the relationship between the senior appropriations and the junior surface water appropriations in the Loup and Elkhorn River subbasins with regard to the appropriations in the Lower Platte River subbasin. In general, when a senior water right calls for water, all water rights upstream of the senior right will be shut off to get water to the senior appropriator. Starting with the most junior appropriator, the Department will shut off as many junior appropriators as necessary to provide water to the senior appropriator. For senior appropriations along the Lower Platte River, this includes junior appropriators in the Loup and Elkhorn subbasins, because those subbasins provide flows to the reaches of the Lower Platte River that require administration for senior appropriators.

The senior appropriations requiring administration in the Lower Platte River Basin are the instream flow rights. The instream flow rights have a priority date of November 30, 1993, and, when these appropriations are not being fulfilled, all surface water appropriations junior to that priority date will be closed. The instream flow appropriations are measured at the North Bend gage and the Louisville gage. When instream flow appropriations are not met at the North Bend gage, all junior surface water appropriations above that gage, including those in the Loup River Basin, are closed to diversion (Figure 7-2). When instream flow appropriations are not met at both the North Bend and the Louisville gages, all junior surface water appropriations above both gages, including those in both the Loup and Elkhorn River subbasins, are closed to diversion. In circumstances where the instream flow appropriation is being met at the North Bend gage but not at the Louisville gage, all junior appropriations above the Louisville gage, including those in both the Loup and Elkhorn River subbasins, are closed to diversion.

Administration for the instream flow rights did not begin until 1997. Therefore, to evaluate a twenty-year record, the Department had to determine how many days in which there would have been administration if the instream flow rights had been in existence for the entire period of evaluation (1987-2006). Between 1987 and 2006, the junior surface water appropriations above North Bend, including those in the Loup River subbasin, would have been closed, due to the instream flow appropriations not being met during July and August (the 65% time period from the 65/85 rule), for a total of 592 days. The junior surface water appropriations downstream of North Bend but upstream of Louisville would have been closed, due to the instream flow appropriation not being met during July and August, for a total of 555 days.

Figure 7-2 Map of the Platte River Basin highlighting the subbasin above the North Bend gage



7.3 Nature and Extent of Water Use

7.3.1 Ground Water

Ground water in the basin is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 41,374 ground water wells had been registered within the basin as of December 31, 2006 (Department registered ground water wells database), with an estimated 1,800 ground water wells to be developed during 2007 (Figure 7-3). The locations of all active ground water wells can be seen in Figure 7-4.

Figure 7-3 Current well development by number of registered wells, Lower Platte River Basin

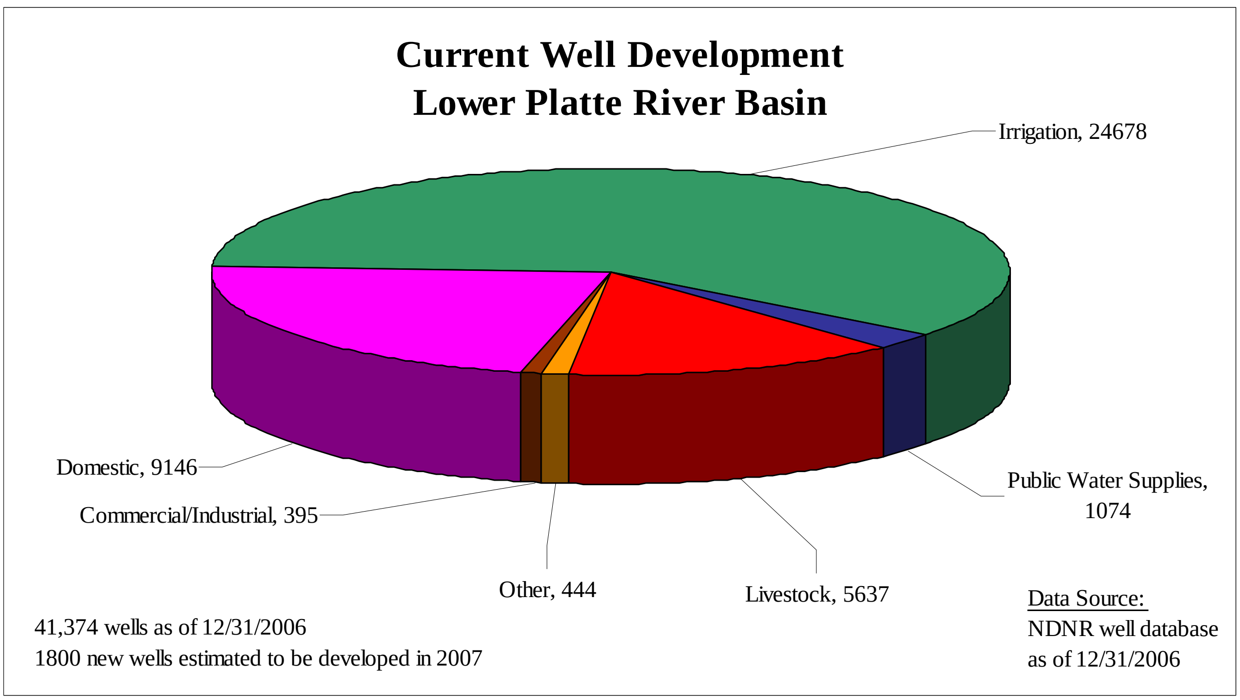
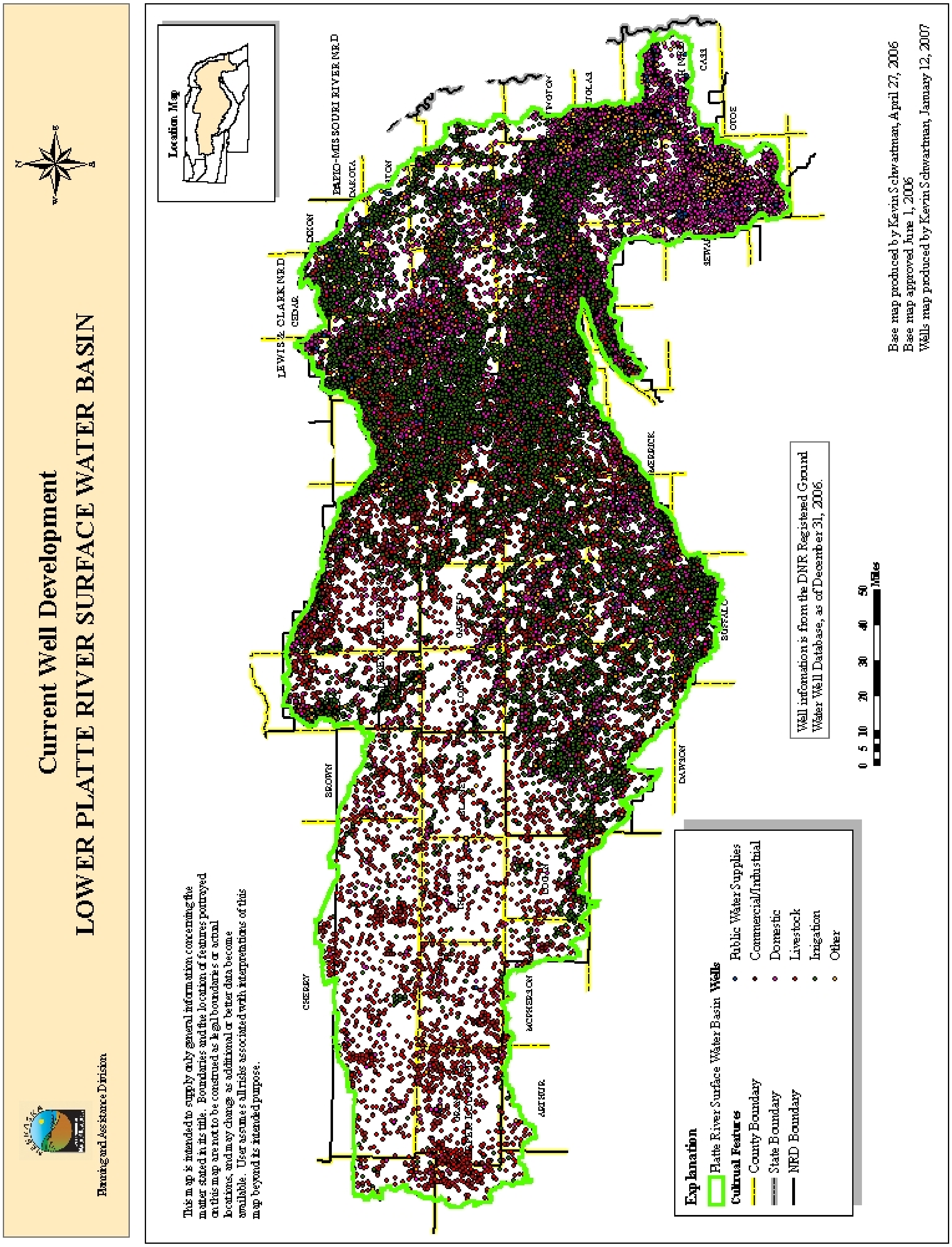


Figure 7-4 Current well locations, Lower Platte River Basin



7.3.2 Surface Water

As of December 31, 2006, there were 2,864 surface water appropriations in the basin, issued for a variety of uses (Figure 7-5). Most of the surface water appropriations are for irrigation use and tend to be located on the major streams. There are two instream flow appropriations and two hydropower appropriations in the basin. The instream flow appropriations are located on the Platte River and are measured at North Bend and Louisville. The hydropower appropriations are located on the Loup River and the Cedar River. The first surface water appropriations in the basin were permitted in 1890, and development has continued through the present day. The approximate locations of the surface water diversion points are shown in Figure 7-6.

Figure 7-5 Surface water appropriations by number of diversion points, Lower Platte River Basin

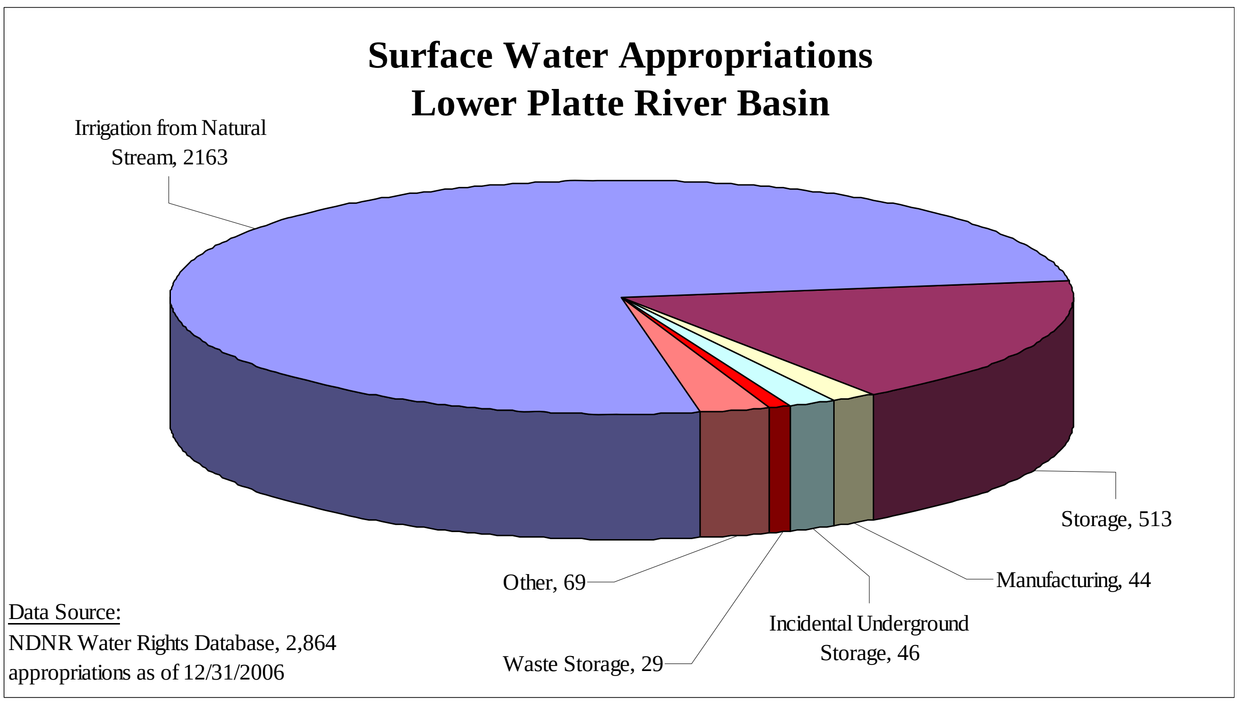
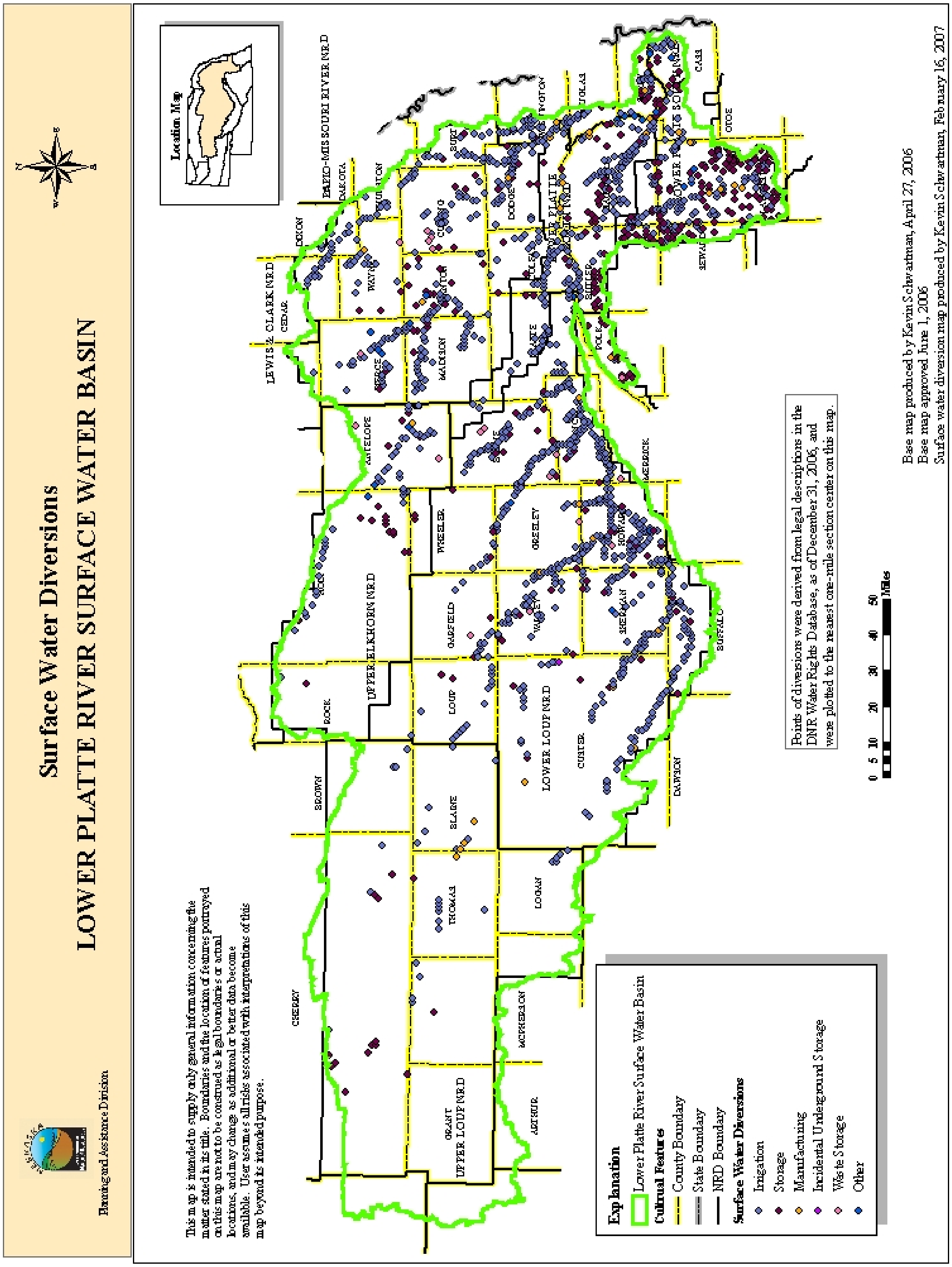


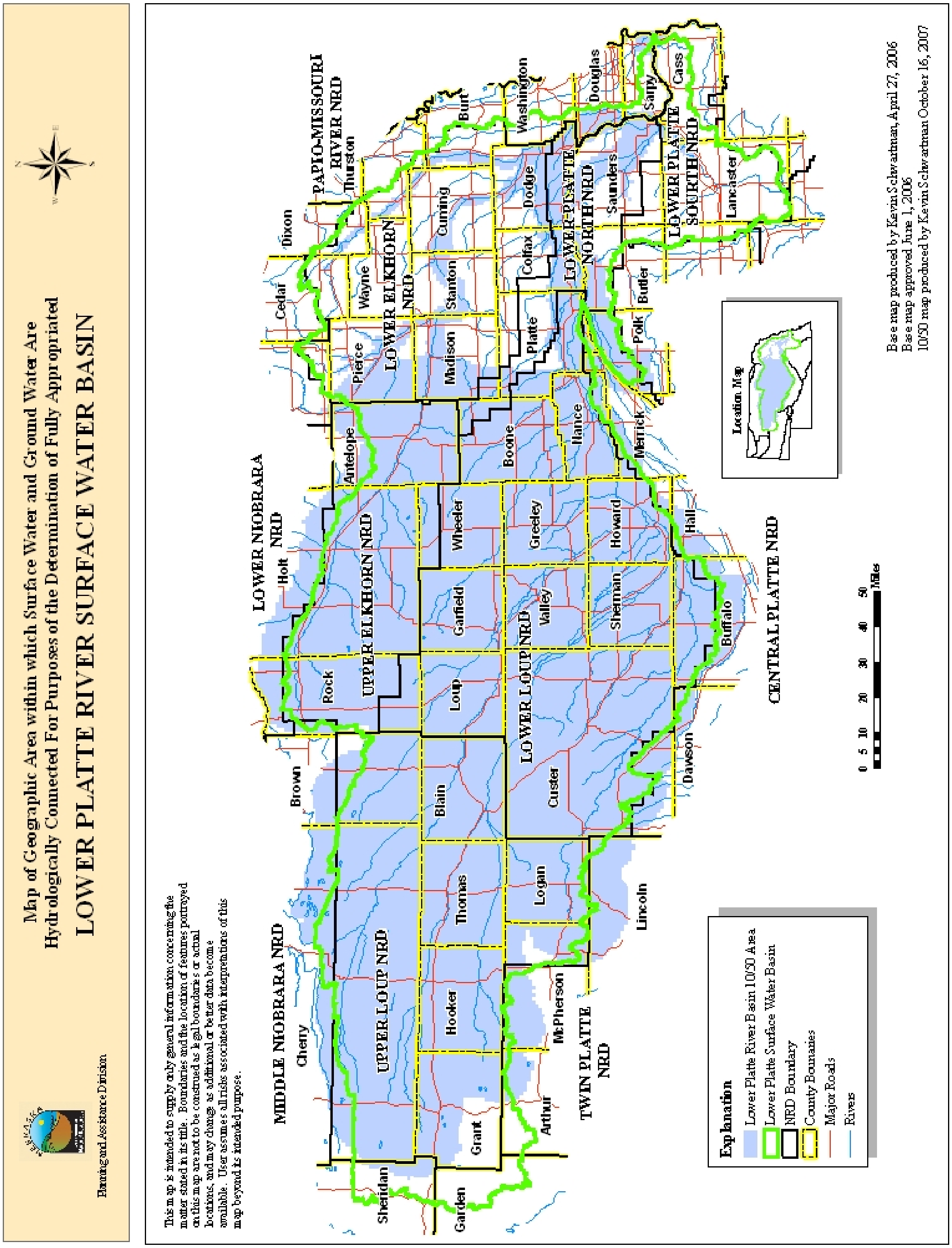
Figure 7-6 Surface water appropriation diversion locations, Lower Platte River Basin



7.4 Hydrologically Connected Area

No sufficient numeric ground water model is available in the Lower Platte River Basin to determine the extent of the 10/50 area. Therefore, the 10/50 area was determined using stream depletion factor (SDF) methodology. Figure 7-7 specifies the extent of the 10/50 area. A description of the SDF methodology used appears in the "Methodology" section of this report.

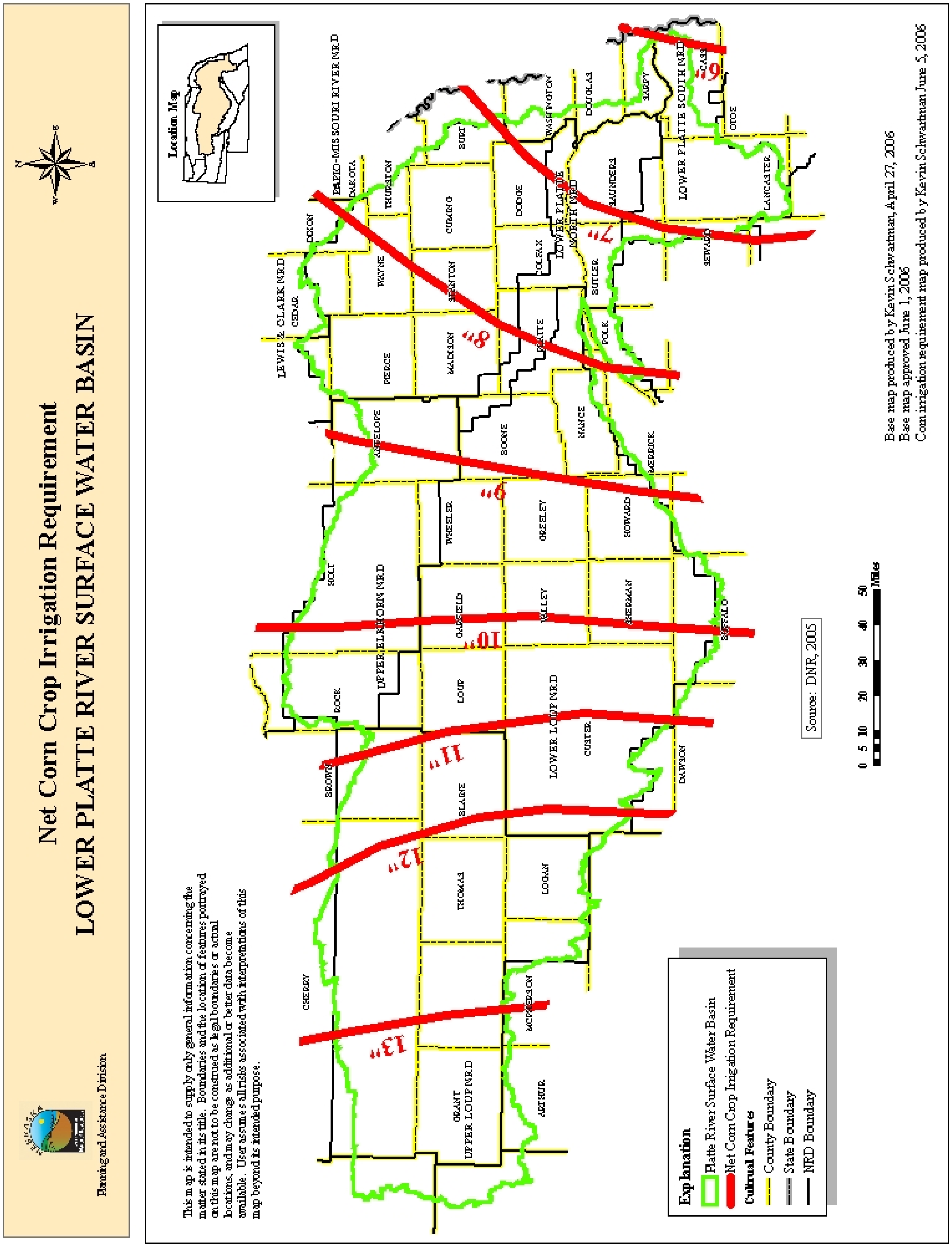
Figure 7-7 10/50 area, Lower Platte River Basin



7.5 Net Corn Crop Irrigation Requirement

Figure 7-8 is a map of the net corn crop irrigation requirement for the Lower Platte River Basin (DNR, 2005). The greatest NCCIR for a junior surface water appropriation above the North Bend gage is 10.67 inches. To assess the number of days required to be available for diversion, a surface water diversion rate equal to 1 cfs per 70 acres, a downtime of 10%, and an irrigation efficiency of 80% were assumed. Based on these assumptions, it will take the most junior surface water appropriation 28.3 days annually to divert 65% of the NCCIR and 37.0 days to divert 85% of the NCCIR.

Figure 7-8 Net corn crop irrigation requirement, Lower Platte River Basin



7.6 Surface Water Closing Records

Tables 7-1 and 7-2 record all surface water administration that has occurred in the basin above the North Bend and Louisville gages, respectively, between 1987 and 2006.

Table 7-1 Surface water administration in the Lower Platte River Basin above the North Bend gage, 1987-2006

Year	Water Body	Days	Closing Date	Opening Date
2000	Lower Platte River Basin above North Bend	53	Aug 8	Sep 30
2001	Lower Platte River Basin above North Bend	11	Aug 7	Aug 18
2002	Lower Platte River Basin above North Bend	6	Jun 6	Jun 12
2002	Lower Platte River Basin above North Bend	67	Jun 25	Aug 31
2002	Lower Platte River Basin above North Bend	24	Sep 6	Sep 30
2003	Lower Platte River Basin above North Bend	81	Jul 11	Sep 30
2004	Lower Platte River Basin above North Bend	13	May 6	May 19
2004	Lower Platte River Basin above North Bend	7	Jun 29	Jul 6
2004	Lower Platte River Basin above North Bend	58	Jul 27	Sep 23
2005	Lower Platte River Basin above North Bend	48	Jul 12	Aug 29
2005	Lower Platte River Basin above North Bend	28	Sep 2	Sep 30
2006	Lower Platte River Basin above North Bend	35	May 15	Jun 20
2006	Lower Platte River Basin above North Bend	45	Jun 26	Aug 10
2006	Lower Platte River Basin above North Bend	28	Aug 14	Sep 11
2006	Lower Platte River Basin above North Bend	22	Oct 5	Oct 27
2006	Lower Platte River Basin above North Bend	20	Oct 31	Nov 20

Table 7-2 Surface water administration in the Lower Platte River Basin above the Louisville gage, 1987-2006

Year	Water Body	Days	Closing Date	Opening Date
1990	Willow Creek	14	Aug 17	Aug 31
1991	Taylor Creek	4	Jul 30	Aug 3
1991	Taylor Creek	3	Aug 23	Aug 26
1991	Taylor Creek	7	Aug 28	Sep 4
1991	Union Creek	7	Aug 28	Sep 4
2000	Lower Platte River Basin above Louisville	53	Aug 8	Sep 30
2001	Lower Platte River Basin above Louisville	11	Aug 7	Aug 18
2002	Lower Platte River Basin above Louisville	6	Jun 6	Jun 12
2002	Lower Platte River Basin above Louisville	59	Jun 25	Aug 23
2002	Lower Platte River Basin above Louisville	4	Aug 27	Aug 31
2002	Lower Platte River Basin above Louisville	24	Sep 6	Sep 30
2003	Lower Platte River Basin above Louisville	66	Jul 14	Sep 18
2004	Lower Platte River Basin above Louisville	13	May 6	May 19
2004	Lower Platte River Basin above Louisville	7	Jun 29	Jul 6
2004	Lower Platte River Basin above Louisville	58	Jul 27	Sep 23
2005	Lower Platte River Basin above Louisville	14	Jul 12	Jul 26
2005	Lower Platte River Basin above Louisville	31	Jul 29	Aug 29
2005	Lower Platte River Basin above Louisville	28	Sep 2	Sep 30
2006	Lower Platte River Basin above Louisville	35	May 16	Jun 20
2006	Lower Platte River Basin above Louisville	45	Jun 26	Aug 10
2006	Lower Platte River Basin above Louisville	28	Aug 14	Sep 11
2006	Lower Platte River Basin above Louisville	22	Oct 5	Oct 27
2006	Lower Platte River Basin above Louisville	20	Oct 31	Nov 20

7.7 Evaluation of Current Development

7.7.1 Current Water Supply

The current water supply is estimated by using the previous twenty years (1987-2006) of flows and comparing them to the flows necessary to satisfy the senior surface water appropriation (the instream flow appropriations). The results of the analysis conducted for the Lower Platte River Basin above North Bend and above Louisville, respectively, are shown in Tables 7-3 and 7-4. The results indicate that the current surface water supply in the Lower Platte River Basin above North Bend provides an average of 32.4 days available for diversion between July 1 and August 31 and 102.3 days available for diversion between May

1 and September 30 (Table 7-5). The results for the Lower Platte River Basin above Louisville indicate an average of 34.3 days available for diversion between July 1 and August 31 and 105.0 days available for diversion between May 1 and September 30 (Table 7-6).

Table 7-3 Estimate of the current number of days surface water is available for diversion above North Bend

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1987	47	138
1988	10	69
1989	14	47
1990	16	77
1991	6	66
1992	62	153
1993	62	153
1994	56	143
1995	52	134
1996	62	153
1997	40	131
1998	62	153
1999	61	152
2000	32	94
2001	28	111
2002	2	48
2003	6	72
2004	20	75
2005	10	71
2006	0	6
Average	32.4	102.3

Table 7-4 Estimate of the current number of days surface water is available for diversion above Louisville

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1987	48	139
1988	10	69
1989	15	49
1990	18	79
1991	10	71
1992	62	153
1993	62	153
1994	59	149
1995	53	144
1996	62	153
1997	43	134
1998	62	153
1999	62	153
2000	35	97
2001	34	118
2002	5	51
2003	11	77
2004	22	78
2005	12	73
2006	0	6
Average	34.3	105.0

Table 7-5 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above North Bend

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion with Current Development**
July 1 – August 31 (65% Requirement)	28.3	32.4 (4.1 days above the requirement)
May 1 – September 30 (85% Requirement)	37.0	102.3 (65.3 days above the requirement)

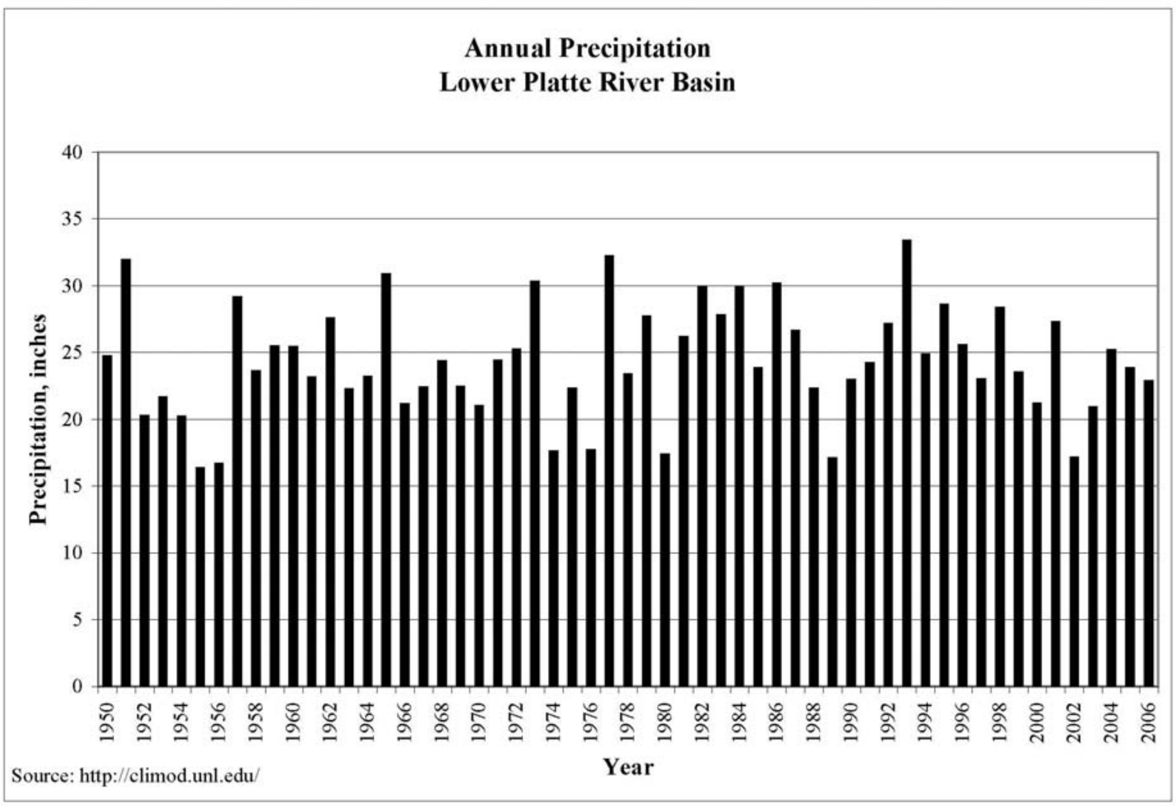
Table 7-6 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above Louisville

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion with Current Development**
July 1 – August 31 (65% Requirement)	28.3	34.3 (6.0 days above the requirement)
May 1 – September 30 (85% Requirement)	37.0	105.0 (68.0 days above the requirement)

7.7.2 Future Water Supply

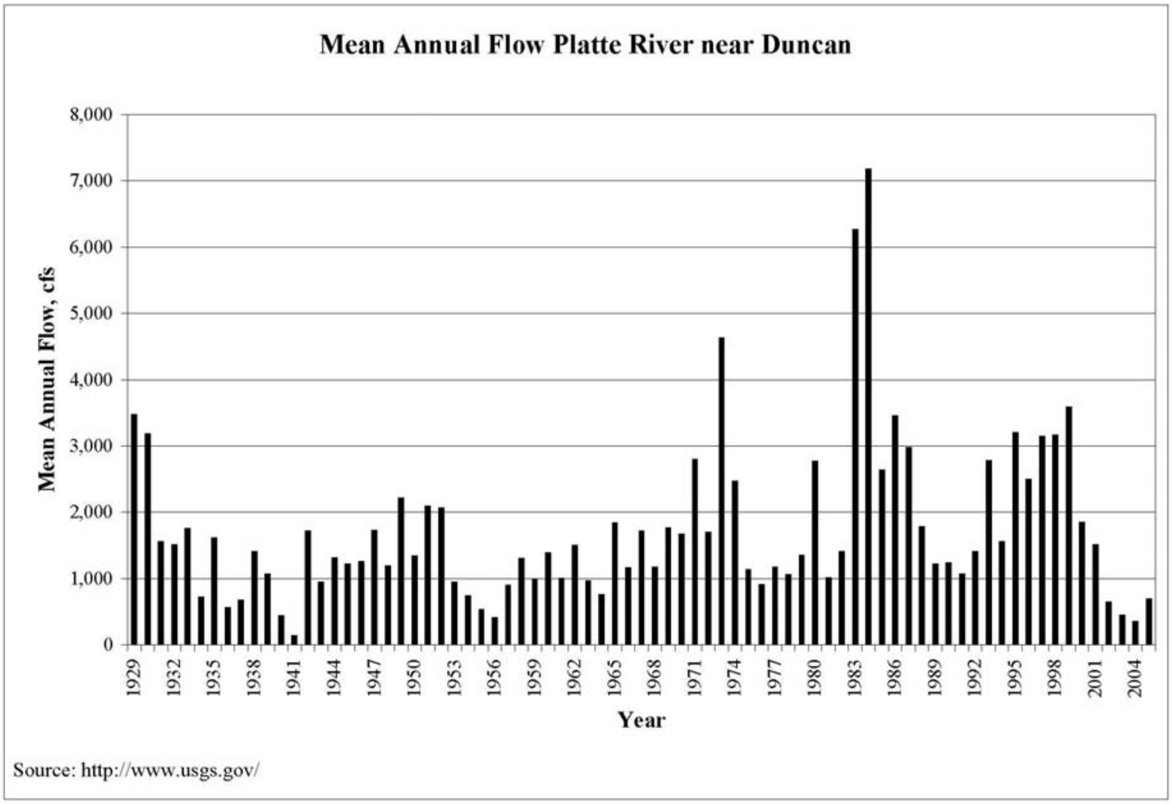
In order to complete the long-term evaluation of surface water supplies, a future twenty-year water supply for the basin must be estimated. The basin's major water sources are precipitation, which runs off as direct streamflow and infiltrates into the ground to discharge as baseflow, ground water movement into the basin, which discharges as baseflow, and streamflow from the middle Platte River. Using methodology published in the *Journal of Hydrology* (Wen and Chen, 2005), a nonparametric Mann-Kendall trend test of the weighted average precipitation in the basin was completed. The analysis showed no statistically significant trend in precipitation (P > 0.95) over the past fifty years (Figure 7-9). The same type of statistical analysis of streamflow from the middle Platte River, for the Platte River at Duncan (inflow to the Lower Platte Basin), also showed no statistically significant trend (P > 0.95) (Figure 7-10). Therefore, using the previous twenty years of precipitation and streamflow data as the best estimate of the future surface water supply is a reasonable starting point for applying the lag depletions from ground water wells.

Figure 7-9 Annual precipitation, Lower Platte River Basin[1]



[1] The results include precipitation stations covering the Loup, Elkhorn, and Platte River Basins.

Figure 7-10 Mean annual flow, Platte River near Duncan



7.7.3 Depletions Analysis

The future depletions due to current well development that could be expected to affect streamflow in the basin were estimated using SDF methodology. The results estimate the future streamflow at North Bend to be depleted by 158 cfs in twenty-five years and flows at Louisville to be depleted by 391 cfs in twenty-five years. The future depletion at Louisville includes 160 cfs[1] from the Metropolitan Utilities District wellfield being developed upstream of the confluence of the Platte and Elkhorn Rivers.

[1]This is the amount of water that is permitted to be pumped from the stream by the wellfield, not the water for which the permit calls as an instream flow.

7.7.4 Evaluation of Current Levels of Development against Future Water Supplies

The estimates of the twenty-year average number of days available for diversion are calculated by comparing the depleted future water supply with the flows necessary to satisfy the senior surface water appropriations (instream flow rights) that have caused administration of junior appropriations in the basin. The results of the analyses are shown in Tables 7-7 and 7-8. The results of the analyses as compared to the numbers of days surface water is required to be available to divert 65% and 85% of the NCCIR are detailed in Tables 7-9 and 7-10. In all cases, the long-term surface water supply estimate, given current levels of development, is sufficient to meet the needs of the surface water irrigation users.

Table 7-7 Estimate of days surface water is available for diversion above North Bend with current development and twenty-five year lag impacts

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1	41	132
2	6	63
3	14	45
4	14	75
5	4	64
6	61	148
7	62	153
8	50	132
9	49	129
10	61	152
11	38	129
12	61	150
13	61	152
14	25	86
15	20	95
16	1	43
17	4	70
18	16	65
19	6	67
20	0	5
Average	29.7	97.8

Table 7-8 Estimate of days surface water is available for diversion above Louisville with current development and twenty-five year lag impacts

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1	42	133
2	6	63
3	14	46
4	16	77
5	7	68
6	61	149
7	62	153
8	53	141
9	52	140
10	61	152
11	42	133
12	62	151
13	62	153
14	31	92
15	27	103
16	4	46
17	8	74
18	17	66
19	7	68
20	0	5
Average	31.7	100.7

Table 7-9 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above North Bend with current development and lag impacts

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion at Current Development with 25 Years of Lag Impacts**
July 1 – August 31 (65% Requirement)	28.3	29.7 (1.4 days above the requirement)
May 1 – September 30 (85% Requirement)	37.0	97.8 (60.8 days above the requirement)

Table 7-10 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above Louisville with current development and lag impacts

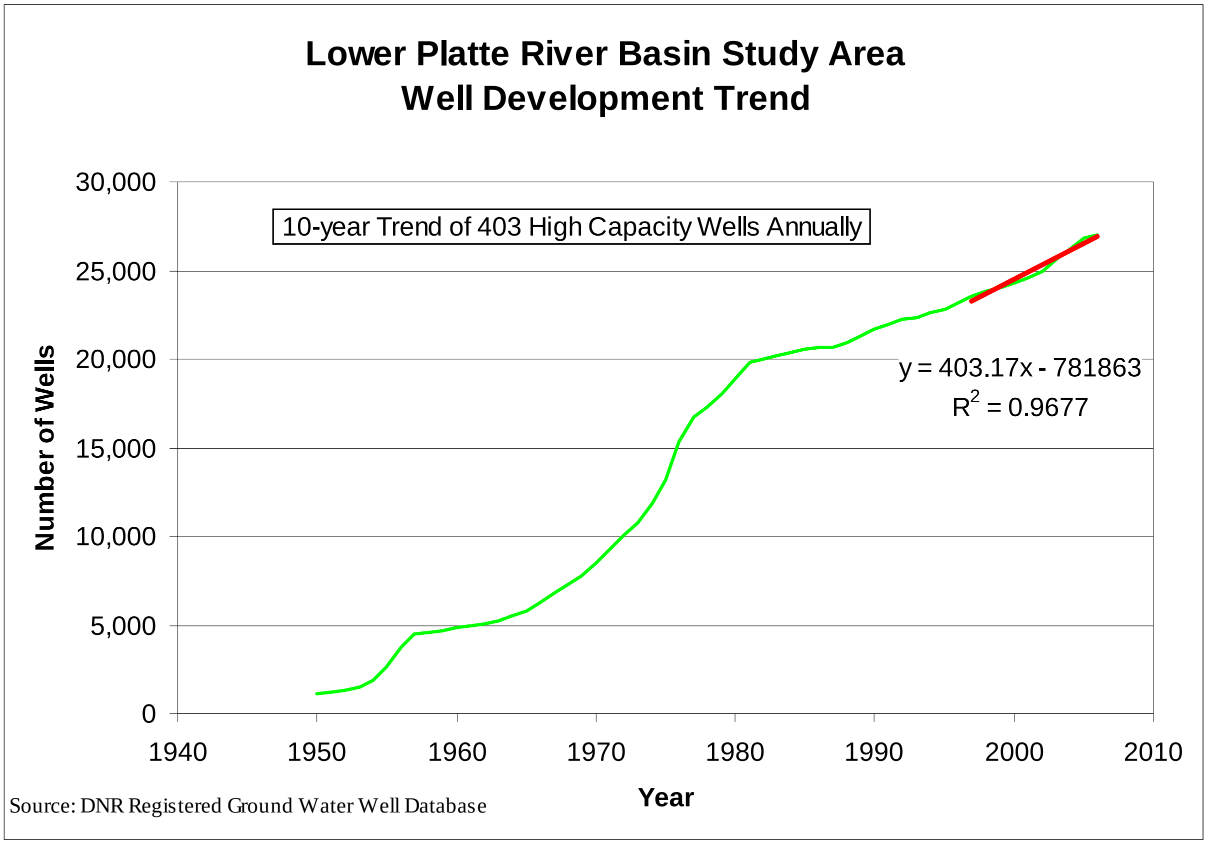
	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion at Current Development with 25 Years of Lag Impacts**
July 1 – August 31 (65% Requirement)	28.3	31.7 (3.4 days above the requirement)
May 1 – September 30 (85% Requirement)	37.0	100.7 (63.7 days above the requirement)

7.8 Evaluation of Predicted Future Development

Estimates of the number of high capacity wells (wells pumping greater than 50 gpm) that would be completed over the next twenty-five years, if no new legal constraints on the construction of such wells were imposed, were calculated based on extrapolating the present-day rate of increase in well development into the future (Figure 7-11). The present-day rate of development is based on the linear trend of the previous ten years of development. Based on the analysis of the past ten years of development, the rate of increase in high capacity wells is estimated to be 403 wells per year in the basin.

At the present time, the Lower Loup Natural Resources District and Lower Platte North Natural Resources District have moratoriums on well development. The Lower Loup Natural Resources District's moratorium is effective until January 1, 2008. The Lower Platte North Natural Resources District's moratorium is effective for six months from the declaration date of May 14, 2007. Therefore, the yearly development figures for the Lower Loup Natural Resources District, 134 wells per year, and Lower Platte North Natural Resources District, 11 wells per year, were not included in the estimate of 2007 development, but the rates of development were included for the rest of the analysis.

Figure 7-11 High capacity well development, Lower Platte River Basin



The future depletions due to current and future well development that could be expected to affect streamflow in the basin were estimated using SDF methodology. The results estimate the future streamflow at North Bend to be depleted by 550 cfs in ten years, 790 cfs in fifteen years, 1,147 cfs in twenty years, and 1,536 cfs in twenty-five years. The results estimate the future streamflow at Louisville to be depleted by 1,037 cfs in ten years, 1,406 cfs in fifteen years, 1,968 cfs in twenty years, and 2,768 cfs in twenty-five years. The future depletion at Louisville includes 160 cfs of depletion from the Metropolitan Utilities District wellfield located upstream of the confluence of the Elkhorn and Platte Rivers.

The estimate of the twenty-year average number of days surface water is available for diversion with additional future development is calculated by comparing the future lag-adjusted flow with the flows necessary to satisfy the senior surface water appropriation. The results of the analyses are shown in Tables 7-11 and 7-12. The results of the analyses as compared to the numbers of days surface water is required to be available to divert 65% and 85% of the NCCIR are detailed in Tables 7-13 and 7-14. The results indicate that, based on current information, the Department's conclusion that the basin is not fully appropriated would change to a preliminary determination of fully appropriated if no additional constraints are placed on future development of surface water and ground water in the basin.

Table 7-11 Estimated number of days surface water is available for diversion above North Bend with current and predicted future development

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1	38	129
2	3	48
3	11	35
4	8	66
5	2	61
6	49	105
7	62	153
8	42	94
9	44	116
10	51	142
11	30	119
12	45	112
13	50	141
14	9	46
15	0	51
16	0	7
17	0	23
18	8	19
19	0	39
20	0	1
Average	22.6	75.4

Table 7-12 Estimated number of days surface water is available for diversion above Louisville with current and predicted future development

Year	July 1 though August 31 Number of Days Surface Water is Available for Diversion	May 1 through September 30 Number of Days Surface Water is Available for Diversion
1	48	139
2	3	48
3	11	36
4	9	67
5	5	64
6	49	105
7	62	153
8	44	115
9	47	119
10	52	143
11	34	124
12	52	119
13	57	148
14	12	51
15	2	61
16	2	13
17	0	32
18	9	31
19	0	47
20	0	1
Average	24.9	80.8

Table 7-13 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above North Bend with current and predicted future development

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion with Future Development and 25 Years of Lag Impacts**
July 1 – August 31 (65% Requirement)	28.3	22.6 (5.7 days below the requirement)
May 1 – September 30 (85% Requirement)	37.0	75.4 (38.4 days above the requirement)

Table 7-14 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion above Louisville with current and predicted future development

	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion with Future Development and 25 Years of Lag Impacts**
July 1 – August 31 (65% Requirement)	28.3	24.9 (3.4 days below the requirement)
May 1 – September 30 (85% Requirement)	37.0	80.8 (43.8 days above the requirement)

7.9 Instream Flow Surface Water Appropriation Analysis

During the non-irrigation season, the junior water rights in the Lower Platte River system are the Nebraska Game and Parks Commission's instream flow rights. The purpose of these rights is to maintain habitat for the fish community. Therefore, the Department determined that an appropriate standard of interference would be to determine whether the instream flow requirements that could be met at the time the water rights were granted can still be met today.

To calculate what the instream flow permits could have expected as average monthly flow occurrence, the twenty-year period prior to the permits' being granted (1974-1993) was used. In conducting this analysis, the lag impacts were calculated for development through 1993 and subtracted from the daily flows (see Section 4.5 for more detail). The average number of days that flows were available for each month at the time the appropriations were obtained was compared with the current average number of days that flows are available for each month. The results are shown in Table 7-15 and 7-16.

Results indicate that the North Bend instream flow appropriation has been eroded for the months of January and May by 2.5 days and 1.3 days, respectively. However, further evaluation of the streamflows at the North Bend gage shows that, for three years in the record, every January flow value on the record was not an actual flow measurement but was only an estimate, due to poor measurement conditions at the gage. For all other months and years, actual flow values were available. When those three years of poor data are removed from the analysis, the month of January shows no significant erosion. The Louisville instream flow appropriation has not been eroded by more than one day for any month, with the exception of March, which has been eroded by 1.7 days. The long-term surface water supply estimate in the basin is sufficient for the instream flow appropriations in the basin, assuming the current level of development and twenty-five year lag impacts.

Table 7-15 Number of days North Bend instream flow appropriation expected to be met

Month	Number of Days Flows Met at Time of Application [1]	Number of Days Flows Met With Current Development [2]
October	26.1	29.5
November	28.6	29.3
December	26.3	26.5
January	28.3	25.8
February	27.4	26.6
March	31.0	30.6
April	30.0	29.9
May	30.5	29.2
June	26.4	27.0
July	17.6	19.7
August	16.2	16.6
September	17.7	20.9

Table 7-16 Number of days Louisville instream flow appropriation expected to be met

Month	Number of Days Flows Met at Time of Application [1]	Number of Days Flows Met With Current Development [2]
October	16.7	19.3
November	21.9	23.1
December	20.5	23.4
January	22.8	24.6
February	24.2	24.1
March	30.8	29.1
April	28.5	28.1
May	27.6	27.0
June	23.5	25.2
July	14.7	18.6
August	13.4	13.2
September	15.0	17.0

[1] The number of days instream flows would be expected to be met at the time of application (1974-1993) with lag effects of well development at the time of the appropriation

[2] The number of days instream flows would be expected to be met at current time (1987-2006) with lag effects of current well development

7.10 Sufficiency to Avoid Noncompliance

Surface water development in the basin must comply with the Nebraska Nongame and Endangered Species Conservation Act (NNESCA) due to the presence of pallid sturgeon and sturgeon chub in the Lower Platte River. To promote compliance with NNESCA, the Department and the Nebraska Game and Parks Commission have a developed policy regarding the procedure for issuing new surface water appropriations and amending existing appropriations. This policy limits the number of surface water appropriations that can be issued without further study of the effects on these species. At this time, there is sufficient water supply in the basin to comply with NNESCA and the ESA. Because future development will be limited so as to continue compliance with NNESCA, the long-term surface water supply in the basin is sufficient.

7.11 Ground Water Recharge Sufficiency

The streamflow is sufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the stream, for reasons explained in Appendix H.

7.12 Current Studies being Conducted to Assist with Future Analysis

Three major studies are currently being conducted within the Lower Platte River Basin. The first is the Eastern Nebraska Water Resources Assessment (ENWRA). ENWRA is an effort between several agencies to categorize the aquifer characteristics and the water supply of the glaciated portion of eastern Nebraska, which includes large areas of the Lower Platte River Basin. This extensive body of work will provide critical data for use in future reports.

The second is the Elkhorn-Loup ground water model (ELM) study. The ELM study is working to develop a ground water model for a substantial portion of the Lower Platte River Basin, to evaluate the ground water and surface water relationship and the water supply of much of the Elkhorn and all of the Loup River basins. Although not developed specifically to evaluate water supply for the Lower Platte River Basin, this model could be utilized to analyze water resources in the basin. Efforts will be made to incorporate results from this model into future reports.

The third study being conducted is an evaluation of streambed conductance for the Elkhorn River. This study is a joint effort of several agencies and will work to develop vertical hydraulic conductivity values for potential use in future depletions analysis of the Elkhorn River Basin.

7.13 Conclusions

Based upon the evaluation of available information, the Department has reached a preliminary conclusion that the Lower Platte River Basin is not fully appropriated. The Department has also determined that, if no additional legal constraints are imposed on future development of hydrologically connected surface water and ground water and reasonable projections are made about the extent and location of future development, this preliminary conclusion would change to a conclusion that the basin is fully appropriated, based on current information. There is no estimated date for when the Department will conclude that the basin is fully appropriated.

Bibliography of Hydrogeologic References for Lower Platte River Basin

Conservation and Survey Division. 2005. *Mapping of Aquifer Properties-Transmissivity and Specific Yield-for Selected River Basins in Central and Eastern Nebraska.* Lincoln.

Nebraska Department of Natural Resources. 2005. *2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies*. Lincoln.

Wen, F.J., and X.H. Chen. 2005. Streamflow trends and depletion study in Nebraska with a focus on the Republican River Basin. *Water Resources Research* (In Review).

8.0 MISSOURI TRIBUTARY BASINS

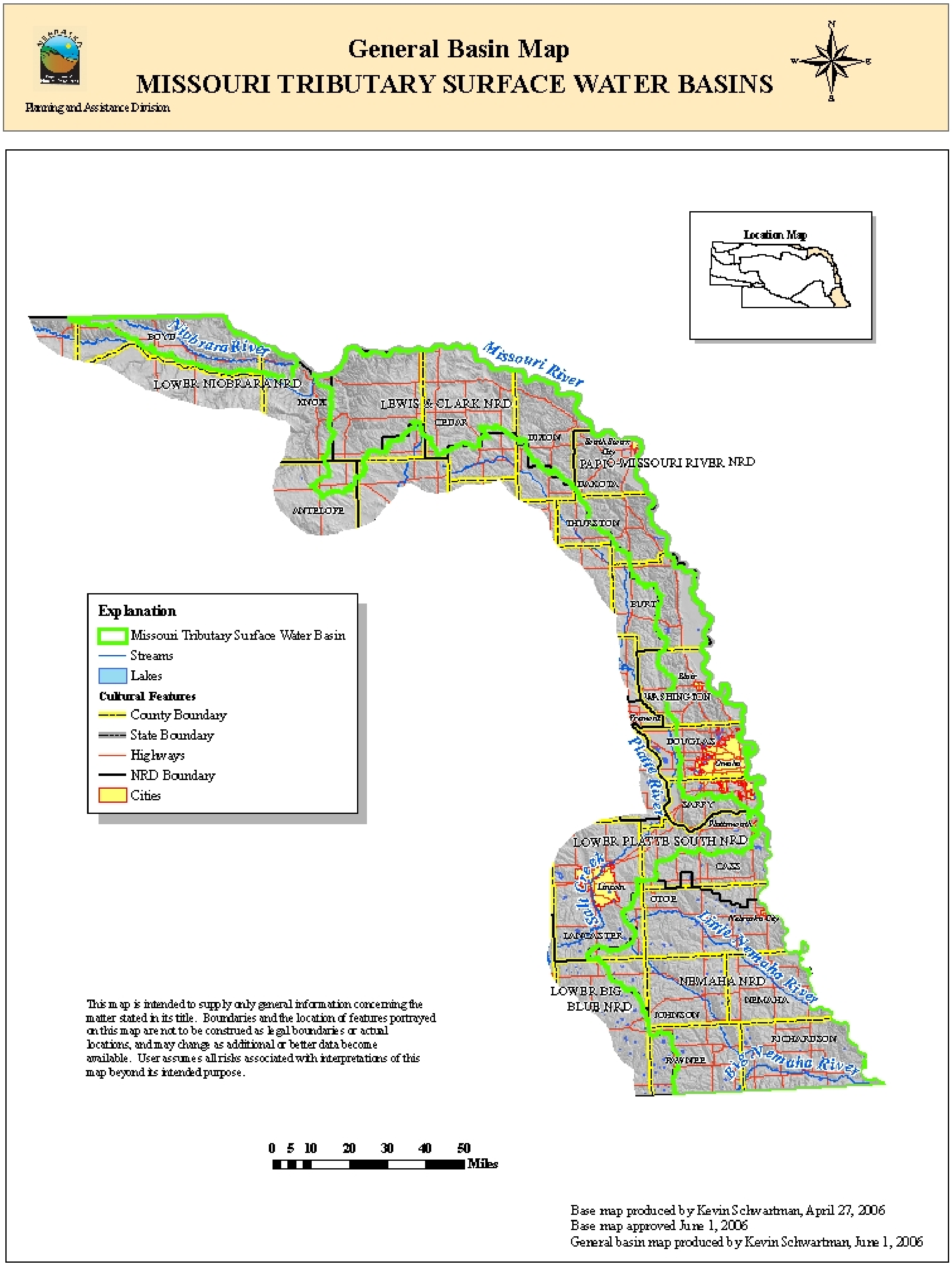
8.1 Summary

Based on the analysis of the sufficiency of the long-term surface water supply in the Missouri Tributary basins, the Department has reached a preliminary conclusion that the basins are not fully appropriated. Even though the effects of future ground water depletions on future water supplies were not estimated in the basins, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the net corn crop irrigation requirement. The best available data do not allow for analysis of whether this determination would change if no additional legal constraints are imposed on future development.

8.2 Basin Descriptions

The Missouri Tributary basins include all surface areas that drain directly into the Missouri River, with the exception of the Niobrara River and Platte River basins, and all aquifers that impact surface water flows of the basins (Figure 8-1). Specific streams in these basins include Ponca Creek, Bazile Creek, Weeping Water Creek, the Little Nemaha River, and the Big Nemaha River. The total area of the Missouri Tributary surface water basins is approximately 6,200 square miles, of which approximately 450 square miles drain into the Missouri River above the Niobrara River confluence, approximately 3,000 square miles drain into the Missouri River between the Niobrara River confluence and the Platte River confluence, and 2,800 square miles drain into the Missouri River below the Platte River confluence. Natural resources districts with significant area in the basins are the Lower Niobrara Natural Resources District, the Lewis and Clark Natural Resources District, the Papio-Missouri River Natural Resources District, and the Nemaha Natural Resources District.

Figure 8-1 General basin map, Missouri Tributary basins



8.3 Nature and Extent of Water Use

8.3.1 Ground Water

Ground water in the basins is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 5,650 ground water wells had been registered within the basins as of December 31, 2006 (Department registered ground water wells database), with an estimated 290 ground water wells to be developed during 2007 (Figure 8-2). The locations of all active ground water wells can be seen in Figure 8-3.

Figure 8-2 Current well development by number of registered wells, Missouri Tributary basins

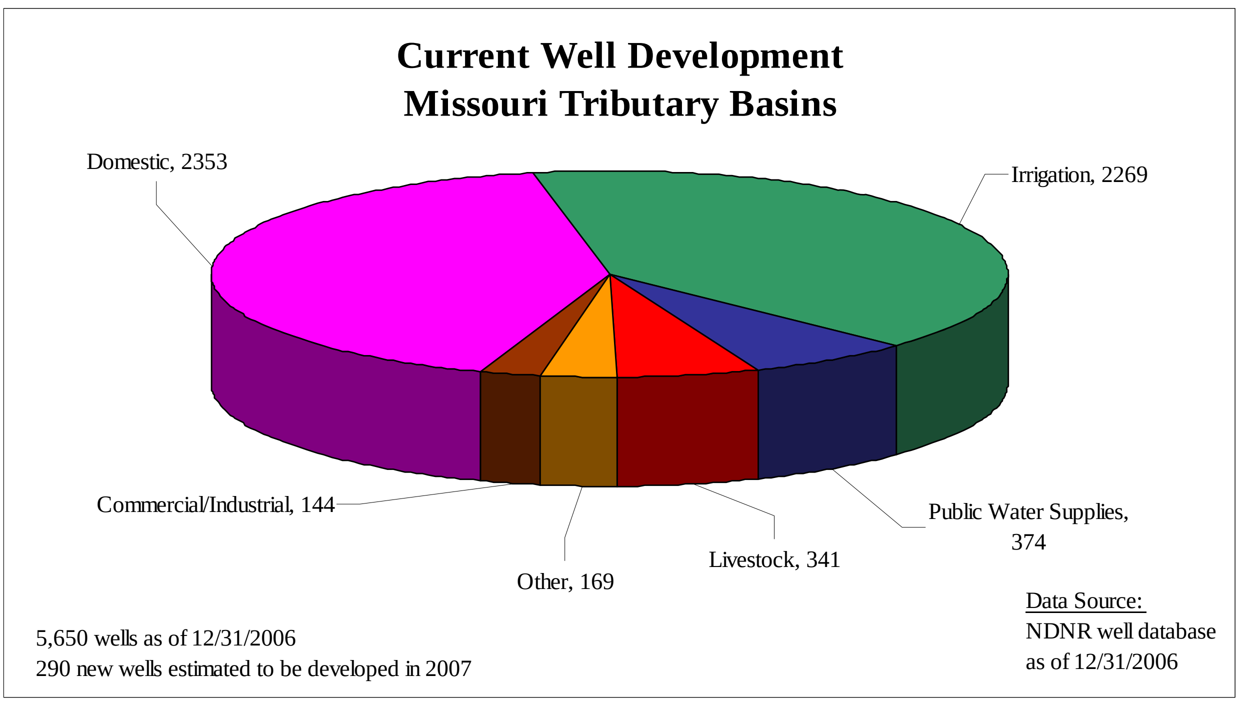
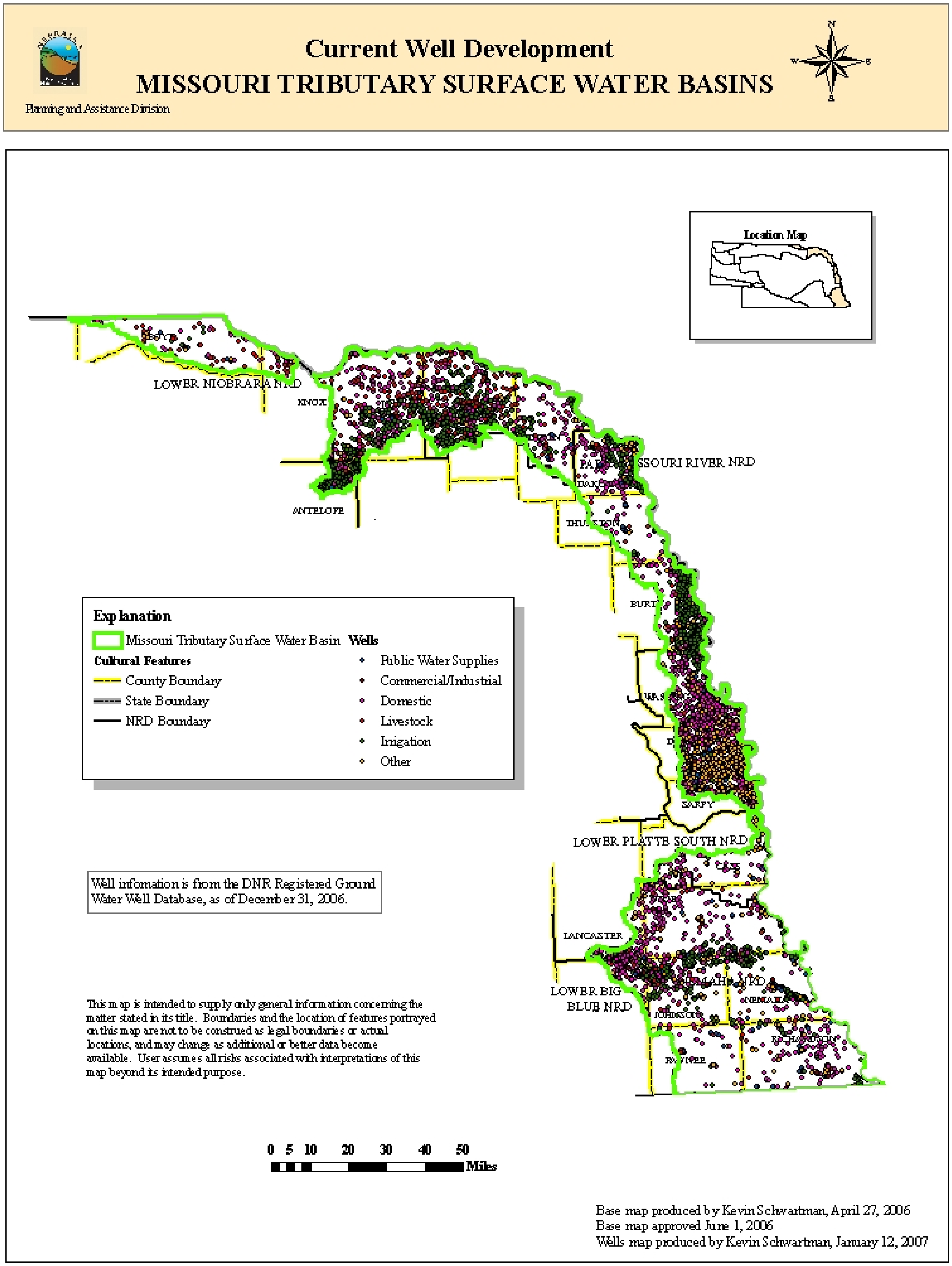


Figure 8-3 Current well locations, Missouri Tributary basins



8.3.2 Surface Water

As of December 31, 2006, there were 1,378 surface water appropriations in the basins issued for a variety of uses (Figure 8-4). Most of the surface water appropriations are for storage and irrigation use and tend to be located on the major streams. The first surface water appropriations in the basins were permitted in 1881, and development has continued through the present day. The approximate locations of the surface water diversion points are shown in Figure 8-5.

Figure 8-4 Surface water appropriations by number of diversion points, Missouri Tributary basins

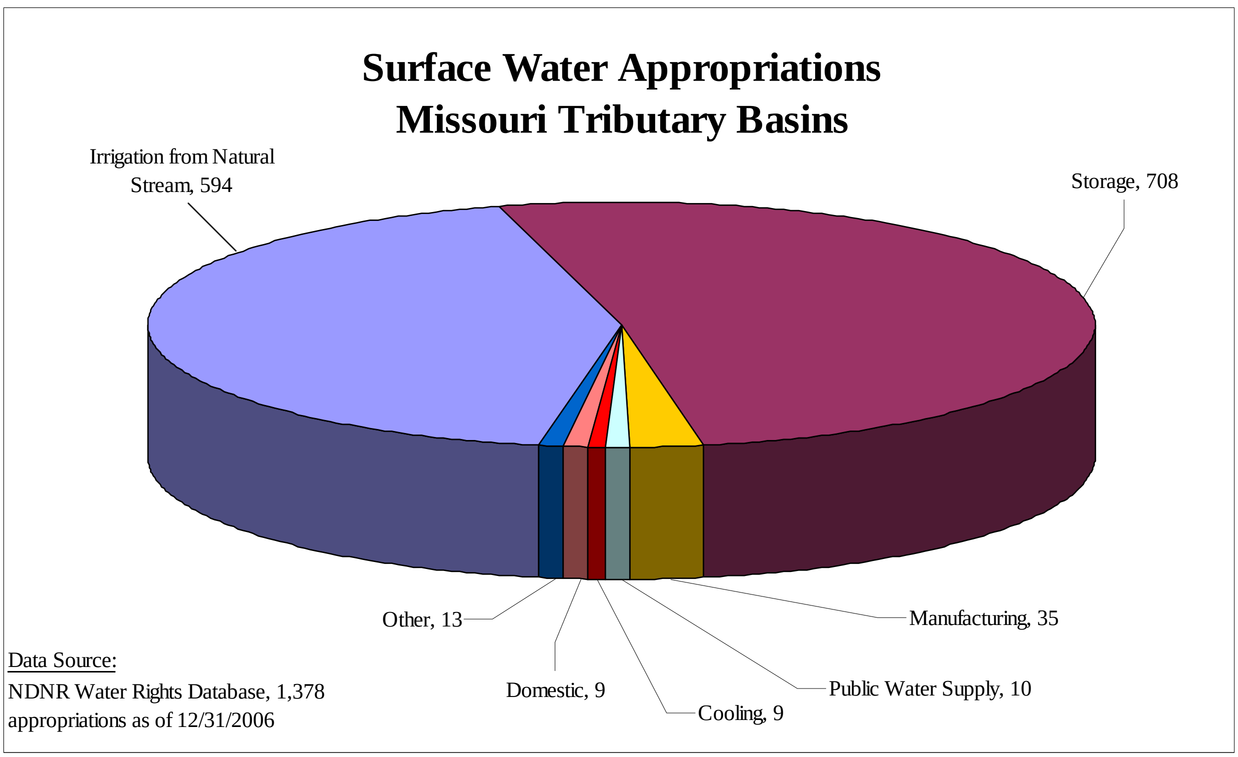
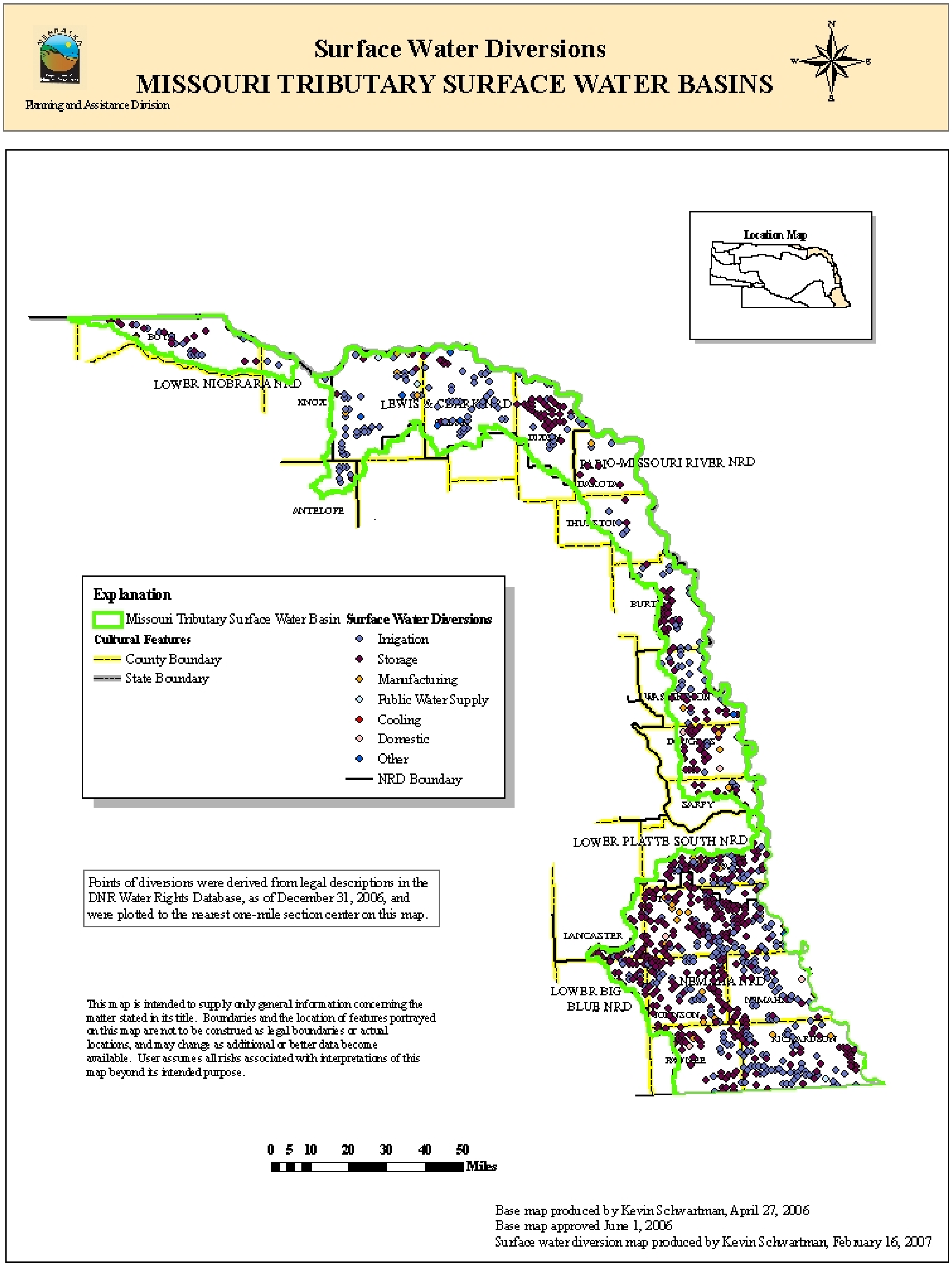


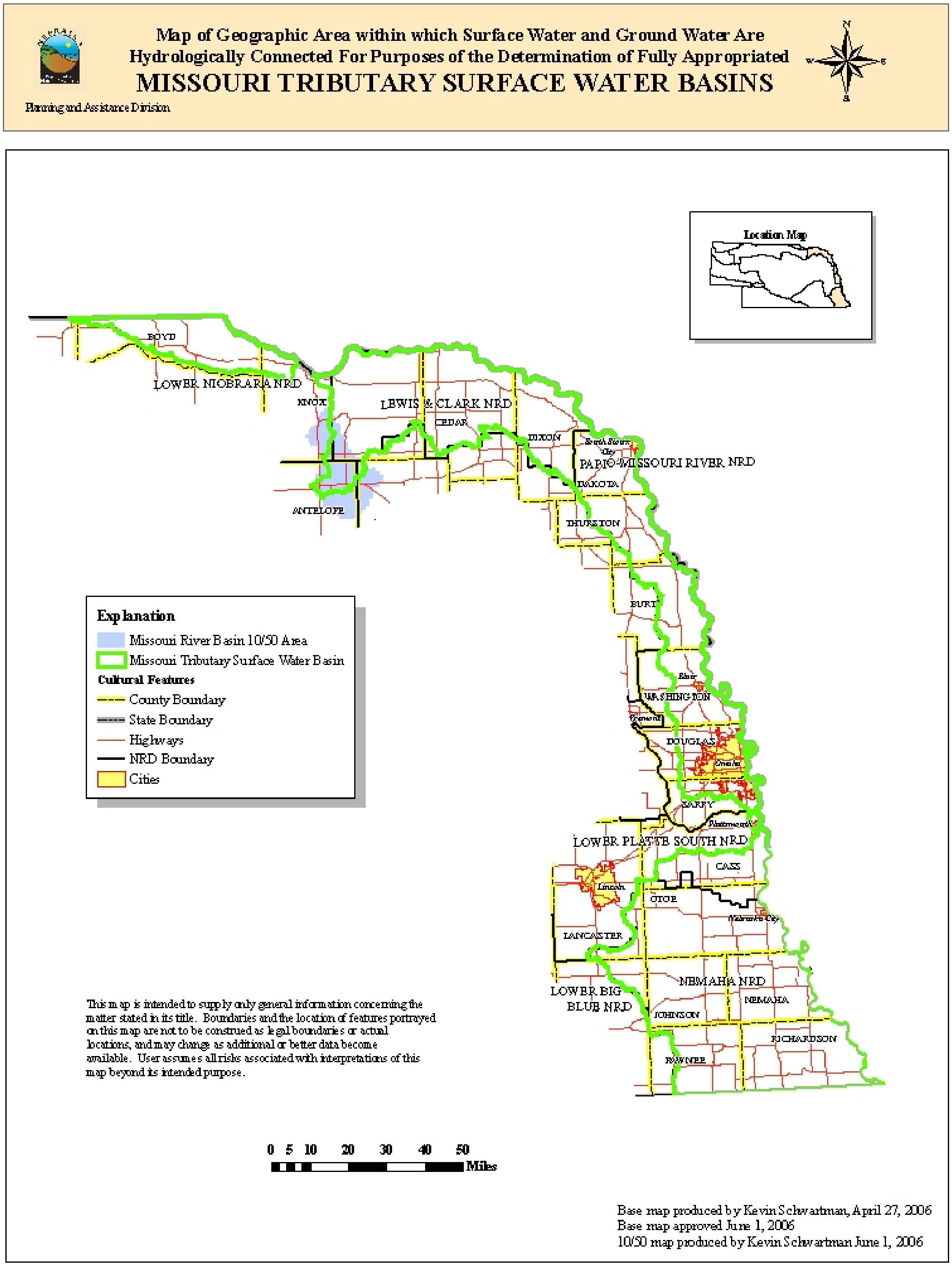
Figure 8-5 Surface water appropriation diversion locations, Missouri Tributary basins



8.4 Hydrologically Connected Area

No sufficient numeric ground water model is available in the Missouri Tributary basins to determine the 10/50 area. The stream depletion factor (SDF) methodology can be applied only where sufficient data and appropriate hydrogeologic conditions exist. In most of the basins, the principal aquifer is absent or very thin due to the glaciated nature of the area (CSD, 2005). Additionally, where a principal aquifer is present, the complex hydrogeologic nature of the area makes the degree of connection between the ground water system and the surface water system either poor or uncertain (CSD, 2005). The area surrounding the headwaters of Bazile Creek is the only portion of the basins where the principal aquifer is both present and known to be in hydrologic connection with the streams, and, consequently, the 10/50 area can be calculated (CSD, 2005) (Figure 8-6).

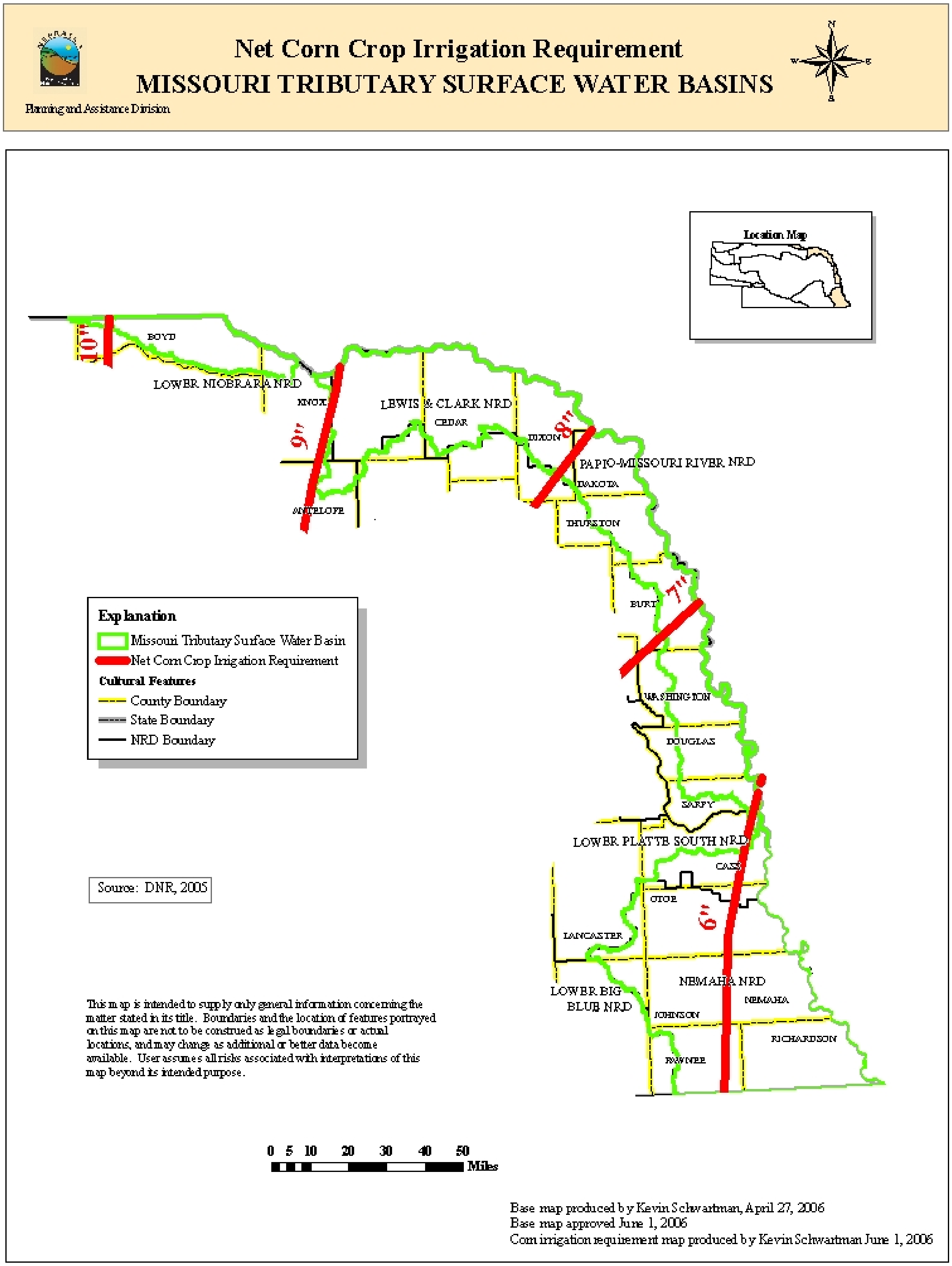
Figure 8-6 10/50 area, Missouri Tributary basins



8.5 Net Corn Crop Irrigation Requirement

Figure 8-7 is a map of the net corn crop irrigation requirement for the basins (DNR, 2005). The NCCIR in the basins ranges from 5.3 to 10.0 inches. To assess the number of days required to be available for diversion, a surface water diversion rate equal to 1 cfs per 70 acres, a downtime of 10%, and an irrigation efficiency of 80% were assumed. Based on these assumptions, it will take a junior surface water appropriation between 14.1 and 26.6 days annually to divert 65% of the NCCIR and between 18.4 and 34.7 days to divert 85% of the NCCIR.

Figure 8-7 Net corn crop irrigation requirement, Missouri Tributary basins



8.6 Surface Water Closing Records

Table 8-1 records all surface water administration that has occurred in the basins between 1987 and 2006.

Table 8-1 Surface water administration in the Missouri Tributary basins, 1987-2006

Year	Water Body	Days	Closing Date	Opening Date
1988	Menominee Creek	???*	Jun 27	
1989	Little Nemaha River	25		
1989	North Fork Big Nemaha River	14		
1989	Long Branch	5		
1990	North Fork Little Nemaha River	14	July	July
1991	Little Nemaha River	7	Jul 2	Jul 9
1991	Little Nemaha River	19	Jul 18	Aug 6
1991	North Fork Little Nemaha River	1	Jul 8	Jul 9
2002	Weeping Water Creek	21	Jul 30	Aug 20
2004	Weeping Water Creek	3	Aug 23	Aug 26
2005	Weeping Water Creek	3	Jul 15	Jul 18

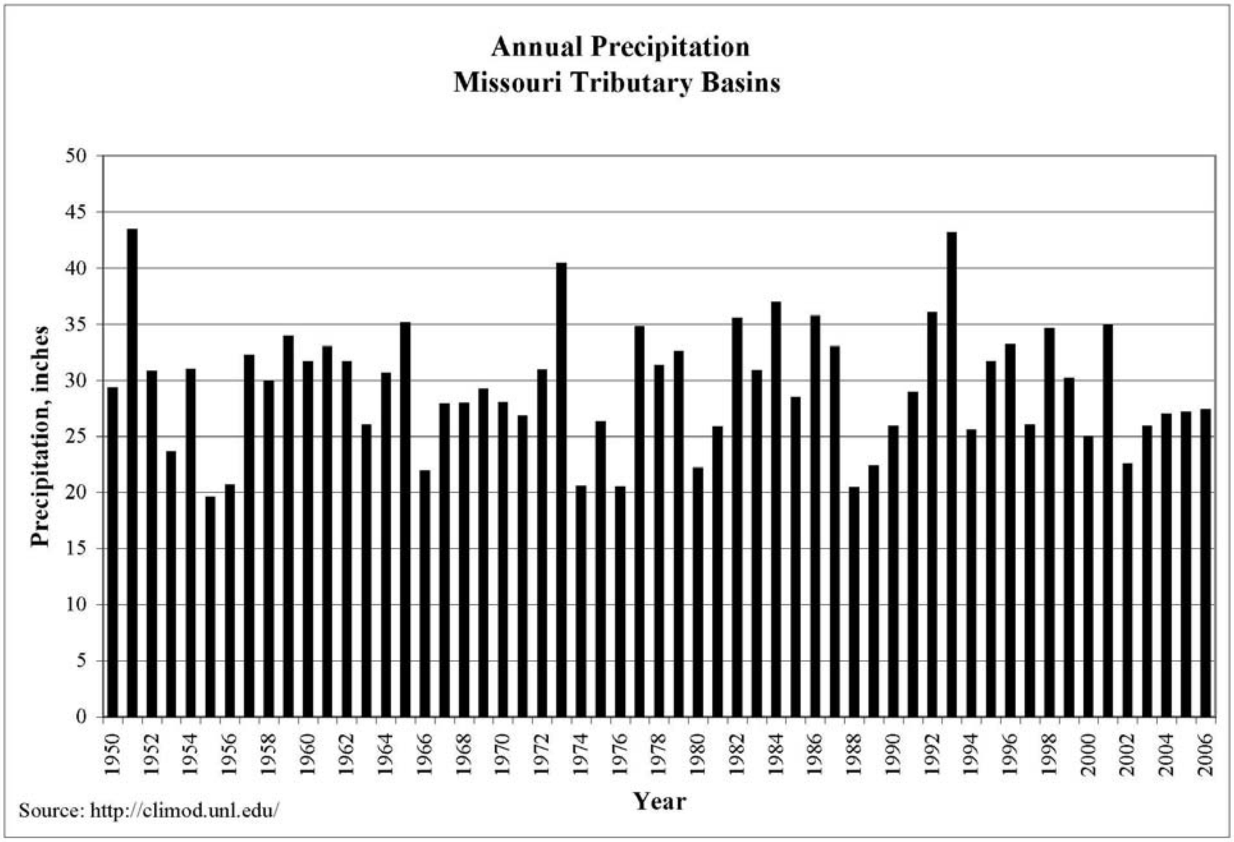
* Ending date could not be determined from administration records.

8.7 Evaluation of Current Development

8.7.1 Future Water Supply

In order to complete the long-term evaluation of surface water supplies, a future twenty-year water supply for the basins must be estimated. The basins' water sources are precipitation, which runs off as direct streamflow and infiltrates into the ground to discharge as baseflow, and ground water movement into the basins, which discharges as baseflow. Using methodology published in the *Journal of Hydrology* (Wen and Chen, 2005), a nonparametric Mann-Kendall trend test of the weighted average precipitation in the basins was completed. The analysis showed no statistically significant trend in precipitation ($P > 0.95$) over the past fifty years (Figure 8-8). Data do not exist to test whether there is a changing trend in ground water movement into the basin. Therefore, using the previous twenty years of streamflow data as the best estimate of the future surface water supply is a reasonable starting point for applying the lag depletions from ground water wells.

Figure 8-8 Annual precipitation, Missouri Tributary basins



8.7.2 Depletions Analysis

The future depletions due to current well development that could be expected to affect streamflow in the basins were not estimated, for the same reasons as those described in Section 8.4.

8.7.3 Evaluation of Current Levels of Development against Future Water Supplies

The comparison of the near-term water supply days available for diversion to the number of days surface water is required to be available to divert 65% and 85% of the NCCIR is detailed in Table 8-2. No estimate of the twenty-year average days available for diversion in the basins has been made, due to the inadequacy of current data and models in predicting future stream depletions. Even though the future water supplies were not estimated, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the NCCIR.

Table 8-2 Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is available for diversion in the Missouri Tributary basins

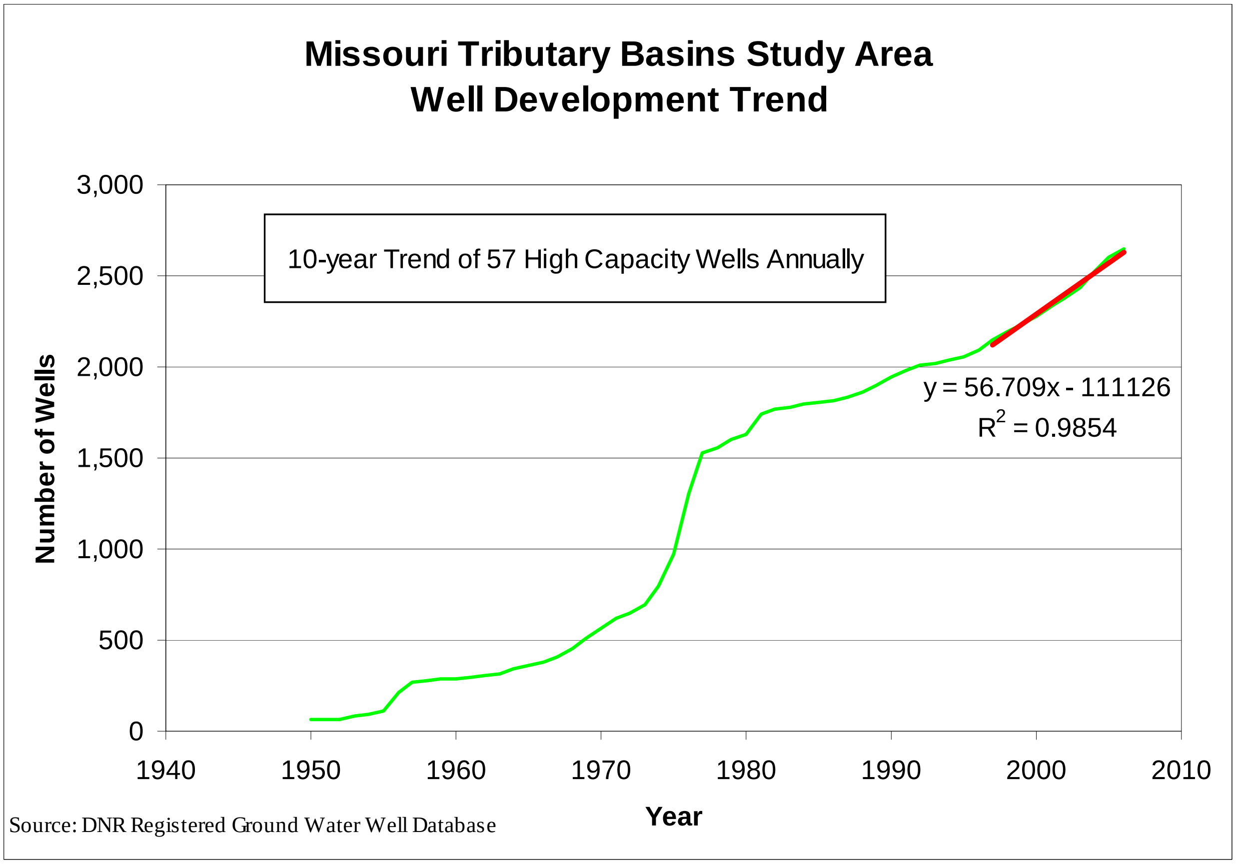
	Number of Days Necessary to Meet the 65% and 85% of Net Corn Crop Irrigation Requirement	**Near-Term Supply Average Number of Days Available for Diversion (1987-2006)**
July 1 – August 31 (65% Requirement)	14.1 to 26.6	58.8 or greater (at least 32.2 days above the requirement)
May 1 – September 30 (85% Requirement)	18.4 to 34.7	149.8 or greater (at least 115.1 days above the requirement)

8.8 Evaluation of Predicted Future Development

Estimates of the number of high capacity wells (wells pumping greater than 50 gpm) that would be completed over the next twenty-five years, if no new legal constraints on the construction of such wells were imposed, were calculated based on extrapolating the present-day rate of increase in well development into the future (Figure 8-9). The present-day rate of development is based on the linear trend of the previous ten years of development. Based on the analysis of the past ten years of development, the rate of increase in high capacity wells is calculated to be 57 wells per year in the basins.

For the same reasons as those stated above in Section 8.7.2, no estimates of depletions due to current and future ground water development were computed. Even though the effects on future water supplies were not estimated, the current number of days in which surface water was available for diversion far exceeds the number of days necessary to meet the NCCIR.

Figure 8-9 High capacity well development, Missouri Tributary basins



8.9 Sufficiency to Avoid Noncompliance

There are no compacts on any portions of the Missouri Tributary basins in Nebraska.

8.10 Ground Water Recharge Sufficiency

The streamflow is sufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge form the stream (Appendix H).

8.11 Current Studies Being Conducted to Assist with Future Analysis

An effort to categorize the aquifer characteristics and the water supply of the glaciated portion of eastern Nebraska, which includes large areas of the Missouri Tributary basins, is underway. This extensive body of work will provide future reports with critical data on the hydrologically connected areas and impacts of future development.

8.12 Conclusions

Based upon the evaluation of available information, the Department has reached a preliminary conclusion that the Missouri Tributary basins are not fully appropriated. The best available data do not allow for analysis of whether this determination would change if no additional legal constraints are imposed on future development of hydrologically connected surface water and ground water.

Bibliography of Hydrogeologic References for Missouri Tributaries River Basin

Conservation and Survey Division. 2005. *Mapping of Aquifer Properties-Transmissivity and Specific Yield-for Selected River Basins in Central and Eastern Nebraska.* Lincoln.

Nebraska Department of Natural Resources. 2005. *2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies*. Lincoln.

Wen, F.J., and X.H. Chen. 2005. Streamflow trends and depletion study in Nebraska with a focus on the Republican River Basin. *Water Resources Research* (In Review).

9.0 BASIN SUMMARIES AND RESULTS

9.1 Blue River Basins

The Blue River basins are located in south-central Nebraska and consist of all of the surface water areas that drain into the Big Blue River and the Little Blue River and all aquifers that impact surface water flows of the basins.

The basins can be divided into two distinct areas, based on whether or not they were glaciated. In areas that were glaciated, the restrictive and complex nature of the hydrogeology does not allow for the use of stream depletion factor (SDF) methodologies. Therefore, the Department was unable to delineate the 10/50 area for the glaciated portions of the basins. The Big Blue River and its tributaries in the non-glaciated areas of the basin are not thought to be in hydrological connection with the aquifers in the area; consequently, no 10/50 area was delineated. In the non-glaciated portions of the Little Blue River Basin, a numerical ground water model was used to delineate the 10/50 area.

The numerical ground water model was not able to provide data on the lag impacts from ground water development; thus, no lag effects were calculated. However, because the Department determined that the near-term availability of surface water for diversion for each basin far exceeds the number of days necessary to meet 65% and 85% of the net corn crop irrigation requirement for the applicable time periods, the Department was able to reach a preliminary conclusion that no portion of the basins is fully appropriated without the lag-effect calculation. Because of the inability to calculate the lag effects of existing and future ground water development, the long-term surface water availability was not determined. Although reductions in flows may require water administration more often in the future, low flows do not cause noncompliance with the terms of the Kansas-Nebraska Big Blue River Compact.

9.2 Lower Niobrara Basin

The Lower Niobrara River Basin is located in the north-central portion of Nebraska and consists of all of the surface water areas that drain into the Niobrara River that had not previously been determined to be fully appropriated, from the Mirage Flats diversion dam to the confluence of the Niobrara River and the Missouri River, and all aquifers that impact surface water flows of the basin.

No sufficient numerical ground water model is available in the Lower Niobrara River Basin. Therefore, the stream depletion factor (SDF) methodology was used to determine the 10/50 area.

Based upon the evaluation of available information, the Department has reached a preliminary conclusion that the Lower Niobrara River Basin upstream of Spencer Hydropower is fully appropriated. The designation as fully appropriated is a result of two factors: 1) the current number of days available for diversion is less than the necessary crop irrigation requirements for junior irrigators within the basin and 2) the irrigation rights that are junior to the calling senior right currently receive less water than was available for the twenty-year period prior to when the junior appropriations were granted.

The basin downstream of Spencer Hydropower is not currently included in the fully appropriated designation. The long-term surface water availability downstream of Spencer Hydropower cannot be estimated at this time, because no surface water administration has occurred in that portion of the basin in the last twenty years.

9.3 Lower Platte River Basin

The Lower Platte River Basin is located in the central and eastern portions of Nebraska and consists of all the surface water areas that drain into the Platte River from its confluence with the Loup River to its confluence with the Missouri River, including those areas that drain into the Loup River and the Elkhorn River, and all aquifers that impact surface water flows of the basin.

No sufficient numerical ground water model is available in the Lower Platte River Basin. Therefore, SDF methodology was used to determine the 10/50 area.

The Department has reached a preliminary conclusion that no portion of the basin is fully appropriated. The long-term availability of surface water for diversion exceeds the number of days necessary to meet 65% and 85% of the net corn crop irrigation requirement for the applicable time periods, and the instream flow appropriations in the basin (the junior rights for which administration occurs in the non-irrigation season) have not been eroded. However, based on reasonable projections of the extent and location of future development in the entire basin, the analysis also shows that this preliminary conclusion would change if no additional constraints were placed on future surface water and ground water development.

9.4 Missouri Tributary Basins

The Missouri Tributary basins are located in the north-central and eastern portions of Nebraska and consist of all of the surface water areas that drain directly into the Missouri River, with the exception of the Niobrara River and Platte River basins, and all aquifers that impact surface water flows of the basins.

No sufficient numerical ground water model is available in the Missouri Tributary basins to determine the 10/50 area. Much of the basins were glaciated, and, in those areas, the restrictive and complex nature of the hydrogeology does not allow for the use of existing methodologies. Therefore, the Department was unable to delineate the 10/50 area for the glaciated portions of the basins. The non-glaciated area surrounding the headwaters of Bazile Creek is the only portion of the basins where the principal aquifer is both present and in hydrologic connection with the streams, and, therefore, the 10/50 area was delineated using SDF methodology.

The Department has reached a preliminary conclusion that no portion of the basins is fully appropriated. The near-term availability of surface water for diversion far exceeds the number of days necessary to meet 65% and 85% of the net corn crop irrigation requirement for the applicable time periods. The long-term surface water availability was not determined, due to a lack of geologic and hydrologic data and the inability to calculate the lag effects of existing and future ground water development.

9.5 Results of Analyses

Tables 9-1 and 9-2 summarize the results of the analysis for sufficiency of water availability for irrigation in each basin. These results indicate that, during the period of July 1 through August 31, the water supply is sufficient to meet the net corn crop irrigation requirement in all basins except the Niobrara River Basin upstream of Spencer Hydropower.

Table 9-1 Summary of comparison between the number of days required to meet 65% of the net corn crop irrigation requirement and number of days in which surface water is available for diversion, July 1 – August 31

	Days Necessary to Meet 65% of Net Corn Crop Irrigation Requirement	**Average Number of Days Available for Diversion at Current Development**	**Average Number of Days Available for Diversion at Current Development with Twenty-Five Years of Lag Impacts**	**Average Number of Days Available for Diversion with Future Development and Twenty-Five Years of Lag Impacts**
Big Blue River Basin	23.9	55.0	55.0[1]	Not Calculated[2]
Little Blue River Basin	25.7	56.7	56.7[1]	Not Calculated[2]
Lower Platte River Basin above North Bend, including the Loup River Basin	28.3	32.4	29.7	22.6
Lower Platte River Basin above Louisville, including the Elkhorn River Basin	28.3	34.3	31.7	24.9
Lower Niobrara River Basin upstream of Spencer Hydropower	36.9	2.7	Not Calculated[3]	Not Calculated[3]
Lower Niobrara River Basin downstream of Spencer Hydropower	23.6 – 25.6	61.9 or greater	Not Calculated[4]	Not Calculated[4]
Missouri Tributary Basins	14.1 – 26.6	58.8 or greater	58.8 or greater[1]	Not Calculated[2]

[1] This number is the near-term average number of days in which surface water is available for diversion (1987–2006) without inclusion of twenty-five year lag impacts, due to the lack of geologic and hydrologic data and the inability to estimate lag depletions.

[2] This number was not estimated, due to the lack of geologic and hydrologic data and the inability to estimate future depletions.

[3] This number was not estimated, due to a fully appropriated designation being placed on the basin.

[4] This number was not estimated, due lack of surface water administration in this portion of the basin.

Table 9-2 Summary of comparison between the number of days required to meet 85% of the net corn crop irrigation requirement and number of days in which surface water is available for diversion, May 1 – September 30

	Days Necessary to Meet 85% of Net Corn Crop Irrigation Requirement	Average Number of Days Available for Diversion at Current Development	Average Number of Days Available for Diversion at Current Development with Twenty-Five Years of Lag Impacts	Average Number of Days Available for Diversion with Future Development and Twenty-Five Years of Lag Impacts
Big Blue River Basin	31.3	145.8	145.8[1]	Not Calculated[2]
Little Blue River Basin	33.6	143.7	143.7[1]	Not Calculated[2]
Lower Platte River Basin above North Bend, including the Loup River Basin	37.0	102.3	97.8	75.4
Lower Platte River Basin above Louisville, including the Elkhorn River Basin	37.0	105.0	100.7	80.8
Lower Niobrara River Basin upstream of Spencer Hydropower	48.3	24.6	Not Calculated[3]	Not Calculated[3]
Lower Niobrara River Basin downstream of Spencer Hydropower	30.9 – 33.4	152.9 or greater	Not Calculated[4]	Not Calculated[4]
Missouri Tributary Basins	18.4 – 34.7	149.8 or greater	149.8 or greater[1]	Not Calculated[2]

[1] This number is the near-term average number of days in which surface water is available for diversion (1987–2006) without inclusion of twenty-five year lag impacts, due to the lack of geologic and hydrologic data and the inability to estimate lag depletions.

[2] This number was not estimated, due to the lack of geologic and hydrologic data and the inability to estimate future depletions.

[3] This number was not estimated, due to a fully appropriated designation being placed on the basin.

[4] This number was not estimated, due lack of surface water administration in this portion of the basin.

Appendix A

NOTICE TO PUBLIC

RELATING TO ANNUAL REPORT REQUIRED PURSUANT TO Neb. Rev. Stat. § 46-713

The Nebraska Department of Natural Resources ("Department") hereby provides notice that the Department, in accordance with Section 46-713(1)(c), shall include in the annual report required to be issued by January 1 of 2008, for informational purposes only, a summary of relevant data provided by any interested party concerning the social, economic, and environmental impacts of additional hydrologically connected surface water and ground water uses on resources that are dependent on streamflow or ground water levels but are not protected by appropriations or regulations. Anyone wishing to provide relevant data must submit such relevant data by June 1, 2007, to the Department. The address for the Department of Natural Resources is 301 Centennial Mall South, P.O. Box 94676, Lincoln, Nebraska, 68509-4676, Attention: Jesse Bradley. FAX: (402) 471-2900.

The Department must complete an evaluation of the expected long-term availability of hydrologically connected water supplies for both existing and new surface water uses and existing and new ground water uses in each of the state's river basins and shall issue a report that describes the results of the evaluation by January 1, 2008, pursuant to Neb. Rev. Stat. § 46-713 (Reissue 2004). Based on the information reviewed in the evaluation process, the Department shall arrive at a preliminary conclusion for each river basin, subbasin, and reach evaluated as to whether such river basin, subbasin, or reach presently is fully appropriated without the initiation of additional uses.

For further information regarding the Department, and its activities, please refer to the Department's web site, at http://www.dnr.state.ne.us.

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APR 10 2007

DEPARTMENT OF NATURAL RESOURCES

Proof of publication

AFFIDAVIT

State of Nebraska, County of Douglas, ss:

Joyce Sawatzki, being duly sworn, deposes and says that he/she is an employee of The Omaha World-Herald, a legal daily newspaper printed and published in the county of Douglas and State of Nebraska, and of general circulation in the Counties of Douglas, and Sarpy and State of Nebraska, and that the attached printed notice was published in the said newspaper on the 2nd, 3rd, 4th, 5th, 6th, 7th & 8th days of April, 2007, and that said newspaper is a legal newspaper under the statutes of the State of Nebraska. The above facts are within my personal knowledge. The Omaha World-Herald has an average circulation of 188,248 Daily and 235,161 Sunday, in 2007.

(Signed) *Joyce Sawatzki* Title: **Account Executive**

Subscribed in my presence and sworn to before me this *9th* day of *April*, 2007.

Connie J. Lee
Notary Public

Printer's Fee $ *1883.70*
Affidavit ______
Paid By ______

CONNIE J. LEE
MY COMMISSION EXPIRES
January 22, 2010

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Mountain-Prairie Region

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SEP 28 2007
DEPARTMENT OF NATURAL RESOURCES

SEP 25 2007

Dr. Ann Bleed, Director
Nebraska Department of Natural Resources
301 Centennial Mall South
Lincoln, Nebraska 68509

RE: 2008 Annual Evaluation of Availability of Hydrologically Connected Water Supplies Report

Dear Dr. Bleed:

The U.S. Fish and Wildlife Service (Service) would like to provide comments for the 2008 Annual Evaluation of Availability of Hydrologically Connected Water Supplies Report that the Department of Natural Resources (DNR) produces to fulfill the requirements of Section 46-713 of the Ground Water Management Protection Act (Nebraska Revised Statutes, Sections 46-701 through 46-753). The evaluation is required on every river basin, subbasin, or reach that has not either initiated the development of an integrated management plan or implemented an integrated management plan.

The language in Nebraska Revised Statues, Section 46-713(c), states:

> "In addition to the conclusion about whether a river basin, sub-basin, or reach is fully appropriated, the department shall include in the report, *for information purposes only*, a summary of relevant data provided by any interested party concerning the social, economic, and environmental impacts of additional hydrologically connected surface water and ground water uses on resources that are dependent on streamflow or ground water levels but are not protected by appropriations or regulations. " (emphasis added)

The Service encourages the DNR to acknowledge Federal interests within the Niobrara River Basin and not use the information that has been provided for informational purposes only, but to engage in a working relationship to make sure all public and private interests are addressed. We would like the DNR to acknowledge the existence of unquantified Federal reserved water rights within the basin and ensure that all water users are aware that federal management in our respective areas may impact water development and the users in the area.

Unlike the Upper Niobrara White Natural Resource District, currently the Middle and Lower Niobrara Natural Resource Districts have no moratoriums/stays on new surface water appropriations and no restrictions on groundwater irrigation development. The Service would like the DNR to consider unquantified Federal reserved water rights to determine if the Niobrara River Basin is fully appropriated.

In addition to the Executive Orders that established the Fort Niobrara National Wildlife Refuge, there are other designations governing the Service's management of the property. The Service must adhere to applicable federal laws, in addition to state laws, in order to protect it's resources. Below is a brief history of the refuge and these designations.

On April 22, 1880, the Fort Niobrara post was established by the United States Army and was abandoned in 1907. On January 11, 1912, President William H. Taft by Executive Order No. 1461 established Fort Niobrara National Wildlife Refuge which reserved 13,279 acres from the public domain as a preserve and breeding ground for native birds. The refuge was expanded by additional Executive Order Nos. 1642, 3256, and 7301 respectively dated November 14, 1912; March 31, 1920; and February 21, 1936. In addition, the Migratory Bird Conservation Act was included in Executive Order No. 7301. There is historical evidence that the said land was also utilized to establish a bison population, planting of grain crops for migratory birds, pronghorn management and administrative efficiency.

In 1976, Public Law 94-557 established the Niobrara Wilderness Area as a component of the National Wilderness Preservation System. The area is to be managed within the intent, rules and regulations governing Wilderness Area management. In 1982, five miles of the Niobrara River within the Refuge boundary was designated as a National Canoe Trail and the entire stretch of river that flows through the refuge is designated as a National Scenic River.

In February 1996, the Service through our Solicitor's office reserved the right to seek a Federal reserved water right to protect federal property. We believe the recognition and possible adjudication of U.S. Fish and Wildlife Service Federal reserved water rights with a priority date of 1912 for Fort Niobrara National Wildlife Refuge clearly impacts future development in the Niobrara River Basin and should be analyzed in DNR's current permit reviews and incorporated into a determination that the Niobrara River Basin may be fully appropriated under Section 46-713(3).

If you have questions or would like to discuss our concerns, please contact me at (303) 236-4491.

Sincerely,

Megan A. Estep
Chief, Water Resources Division

cc:
Larry Hutchinson, Nebraska Game and Parks Commission, Fisheries Division
2200 North 33rd Street, Lincoln, NE 68503
Thomas Graf, Office of the Solicitor, Rocky Mountain Regional Office, 755 Parfet Street, Room 151, Lakewood, CO 80215
Peter Fahmy, Office of the Solicitor, Rocky Mountain Regional Office, 755 Parfet Street, Room 151, Lakewood, CO 80215
Paul Hedren, Superintendent, Niobrara National Scenic River, P.O. Box 591, O'Neill, NE 68763
Bill Hansen, National Park Service, Water Resources Division, 1201 Oakridge Drive, Suite 250, Fort Collins, CO 80525
John Cochnar, U.S. Fish & Wildlife Service, Nebraska Ecological Services Field Office, 203 West Second Street, Federal Building, Second Floor, Grand Island, NE 68801
Todd Frerichs, Acting Project Leader, Fort Niobrara National Wildlife Refuge, HC 14, Box 67, Valentine, NE 69201
Mark Lindvall, Project, Leader, Valentine National Wildlife Refuge, HC 14, Box 67, Valentine, NE 69201
Middle Niobrara NRD, 526 East 1st Street, Valentine, NE 69201
Niobrara River Council, 280 North Main Street, P.O. Box 206, Valentine, NE 69201

United States Department of the Interior

NATIONAL PARK SERVICE
Headquarters
Missouri National Recreational River
Niobrara National Scenic River
P.O. Box 591
O'Neill, Nebraska 68763

IN REPLY REFER TO:

L54 (NIOB)

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SEP 10 2007

DEPARTMENT OF
NATURAL RESOURCES

September 7, 2007

Ann Bleed, Director
Nebraska Department of Natural Resources
301 Centennial Mall South
Lincoln, Nebraska 68509

Re: National Park Service Comments for Inclusion in the 2008 Annual Evaluation of Availability of Hydrologically Connected Water Supplies

Dear Director Bleed:

We would like to provide comments for the 2008 Annual Evaluation of Availability of Hydrologically Connected Water Supplies that the Department of Natural Resources (DNR) produces to fulfill the requirements of section 46-713 of the Ground Water Management and Protection Act (Neb. Rev. Stat., Sec. 46-701 through 46-753). This evaluation is required on every river basin, subbasin, or reach that has not either initiated the development of an integrated management plan (IMP) or implemented an IMP. It is our understanding that LB 962 requires that the DNR include a summary of relevant data provided by any interested party concerning the social, economic, and environmental impacts of additional hydrologically connected surface water and ground water on resources that are dependent on streamflow or ground water levels but are not protected by appropriations or regulations.

We would like the DNR to acknowledge the existence of an unquantified inchoate Federal reserved water rights for instream flows on the Niobrara River within the 76-mile reach of the Niobrara National Scenic River and 20-mile reach of the Missouri National Recreational River in your 2008 report. The priority date for these rights would be May 24, 1991, which is the date these two segments were designated by Congress as wild and scenic rivers under the Wild and Scenic Rivers Act. We believe it is in the public interest to notify water users in the Niobrara River Basin that water rights for these two wild and scenic rivers managed by the National Park Service may impact their intentions to develop water in the future.

In addition, it is our understanding that the DNR is required to consider the impact of additional legal constraints under Section 46-713(1)(b) on the future development of hydrologically connected surface and ground water in the Niobrara River Basin. We believe the recognition and possible adjudication of National Park Service Federal reserved water rights (and for the Fort Niobrara National Wildlife Refuge managed by the U.S. Fish and Wildlife Service) clearly impacts future development in the Niobrara River Basin. This is particularly important to the DNR's consideration that the Niobrara River Basin in fully appropriated under Section 46-713(3).

We would also like to point out DNR's responsibilities under Section 46-713(3) to consider the impact of applicable state or federal laws on reductions of flow in the Niobrara River. We believe that DNR must consider its responsibilities to recognize and protect the instream flows necessary to protect and enhance the free-flowing nature, water quality, and outstandingly remarkable values of the Niobrara National Scenic River and the Missouri National Recreational River. We would like you to consider our Federal reserved water rights and these responsibilities under federal law, in addition to your consideration of the Endangered Species Act and the state Nongame and Endangered Species Conservation Act, when evaluating and determining whether the Niobrara River Basin is fully appropriated in your 2008 report.

If you have any questions regarding this letter please contact me at 402-336-3970 or Bill Hansen of our Water Rights Branch at (970) 225-3532.

Sincerely,

Paul L. Hedren

Paul L. Hedren
Superintendent

Cc: Manager, Upper Niobrara – White NRD
Manager, Middle Niobrara NRD
Manager, Lower Niobrara NRD
Niobrara Council
Hansen, Lord – WRD
Fahmy - SOL
✓Jesse Bradley – DNR
Estep – U. S. Fish and Wildlife Service
Stransky - AGFO

Appendix B

SUBJECT OF TITLE	STATUTORY AUTHORITY	CODE SECTION
Determination of Fully Appropriated Basins, Sub-Basins or Reaches	§ 46-713	024
Engineering Drawings and Specifications for Dams	§ 46-257 § 61-206	012
Height of Dam	§ 33-105 § 61-206	008
Incidental and Intentional Underground Water Storage	§ 46-226.01 § 46-297 § 61-206	016
Induced Ground Water Recharge	§ 46-233 § 46-235 § 61-206 § 61-207	022
Instream Flows	§ 46-2,110 § 46-2,114 § 61-206 § 61-207	018
Moratorium Area Variances	§ 46-714 § 61-206	023
Outlet Works	§ 46-241 § 61-206	013
Permit to Conduct Water in Stream Channels	§ 46-252 § 61-206 § 61-207	021
Project Maps for the Impoundment of Water	§ 46-237 § 46-241 § 61-206	011
Project Maps for the Use of Water	§ 46-237 § 46-294 § 61-206	010
Relinquishments	§ 61-206	003

SUBJECT OF TITLE	STATUTORY AUTHORITY	CODE SECTION
Temporary Use Permits	§ 46-233 § 61-206	020
Theoretical Horsepower	§ 33-105 § 61-206	007
Transfer the Location of Use	§§ 46-290 – 294 § 61-206	009

NEBRASKA ADMINISTRATIVE CODE

TITLE 456 – DEPARTMENT OF NATURAL RESOURCES
RULES FOR SURFACE WATER

NUMERICAL TABLE OF CONTENTS

SUBJECT OF TITLE	STATUTORY AUTHORITY	CODE SECTION
Project Maps for the Use of Water	§ 46-237 § 46-294 § 61-206	010
Project Maps for the Impoundment of Water	§ 46-237 § 46-241 § 61-206	011
Engineering Drawings and Specifications for Dams	§ 46-257 § 61-206	012
Outlet Works	§ 46-241 § 61-206	013
Claims	§ 46-202 § 61-206 § 84-909(1)	014
Incidental and Intentional Underground Water Storage	§ 46-226.01 § 46-297 § 61-206	016
Authority to Levy Fees	§ 46-206 § 46-207 § 46-2,101 § 46-2,102	017
Instream Flows	§ 46-2,110 § 46-2,114 § 61-206 § 61-207	018
Dam Hazard Classification	§ 46-257 § 61-206	019
Temporary Use Permits	§ 46-233 § 61-206	020
Permit to Conduct Water in Stream Channels	§ 46-252 § 61-206 § 61-207	021

SUBJECT OF TITLE	STATUTORY AUTHORITY	CODE SECTION
Induced Ground Water Recharge	§ 46-233 § 46-235 § 61-206 § 61-207	022
Moratorium Area Variances	§ 46-714 § 61-206	023
Determination of Fully Appropriated Basins, Sub-Basins or Reaches	§ 46-713	024

NEBRASKA ADMINISTRATIVE CODE

TITLE 457 – DEPARTMENT OF NATURAL RESOURCES
RULES FOR SURFACE WATER

ALPHABETICAL TABLE OF CONTENTS

APPROVED

DEC 04 2006

Dave Heineman
DAVE HEINEMAN
GOVERNOR

APPROVED
JON BRUNING
ATTORNEY GENERAL
BY.....................
Assistant Attorney General
DATE....10-30-06..........

Title 457 - DEPARTMENT OF NATURAL RESOURCES
RULES FOR SURFACE WATER

Chapter 24 - DETERMINATION OF FULLY APPROPRIATED BASINS, SUB-BASINS OR REACHES

001 FULLY APPROPRIATED. Pursuant to Neb. Rev. Stat. § 46-713(3) (Reissue 2004, as amended), a river basin, subbasin, or reach shall be deemed fully appropriated if the Department of Natural Resources determines that then-current uses of hydrologically connected surface water and ground water in the river basin, subbasin, or reach cause or will in the reasonably foreseeable future cause (a) the surface water supply to be insufficient to sustain over the long term the beneficial or useful purposes for which existing natural flow or storage appropriations were granted and the beneficial or useful purposes for which, at the time of approval, any existing instream appropriation was granted, (b) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the river or stream involved, or (c) reduction in the flow of a river or stream sufficient to cause noncompliance by Nebraska with an interstate compact or decree, other formal state contract or agreement, or applicable state or federal laws.

001.01A Except as provided in 001.01C below, for purposes of Section 46-713(3)(a), the surface water supply for a river basin, subbasin, or reach shall be deemed insufficient, if, after considering the impact of the lag effect from existing groundwater pumping in the hydrologically connected area that will deplete the water supply within the next 25 years, it is projected that during the period of May 1 through September 30, inclusive, the most junior irrigation right will be unable to divert sufficient surface water to meet on average eighty-five percent of the annual crop irrigation requirement, or, during the period of July 1 through August 31, inclusive, will be unable to divert sufficient surface water to meet at least sixty-five percent of the annual crop irrigation requirement.

For purposes of this rule, the "annual crop irrigation requirement" will be determined by the annual irrigation requirement for corn. This requirement is based on the average evapotranspiration of corn that is fully watered to achieve the maximum yield and the average amount of precipitation that is effective in meeting the crop water requirements for the area.

The inability to divert will be based on stream flow data and diversion records, if such records are available for the most junior surface water appropriator. If these records are not available, the inability to divert will be based on the average number of days within each time period (May 1 to September 30 and July 1 to August 31) that the most junior surface water appropriation for irrigation would have been closed by the Department and therefore could not have diverted during the previous 20 year period. In making this

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By SECRETARY OF STATE

calculation, if sufficient stream flow data and diversion data are not available, it will be assumed that if the appropriator was not closed, the appropriator could have diverted at the full permitted diversion rate. In addition the historical record will be adjusted to include the impacts of all currently existing surface water appropriations and the projected future impacts from currently existing ground water wells. The projected future impacts from ground water wells to be included shall be the impacts from ground water wells located in the hydrologically connected area that will impact the water supply over the next 25 year period.

001.01B In the event that the junior water rights are not irrigation rights, the Department will utilize a standard of interference appropriate for the use, taking into account the purpose for which the appropriation was granted.

001.01C If, at the time of the priority date of the most junior appropriation, the surface water appropriation could not have diverted surface water a sufficient number of days on average for the previous 20 years to satisfy the requirements of 001.01A, the surface water supply for a river basin, subbasin, or reach in which that surface water appropriation is located shall be deemed insufficient only if the average number of days surface water could have been diverted over the previous 20 years is less than the average number of days surface water could have been diverted for the 20 years previous to the time of the priority date of the appropriation.

When making this comparison, the calculations will follow the same procedures as described in 001.01A. When calculating the number of days an appropriator could have diverted at the time of the priority date of the appropriation, the impacts of all appropriations existing on the priority date of the appropriation and the impacts of wells existing on the priority date of the appropriation shall be applied in the same manner as in 001.01A. As in 001.01A above, in making this calculation, if sufficient stream flow data and diversion data are not available, it will be assumed that if the appropriator was not closed, the appropriator could have diverted at the full permitted diversion rate.

Use of the method described in this rule is not intended to express or imply any mandate or requirement that the method used herein must be included in the goals and objectives of any integrated management plan adopted for a river basin, subbasin or reach determined to be fully appropriated under this rule. Further, nothing in this section is intended to express or imply a priority of use between surface water uses and ground water uses.

001.02 The geographic area within which the Department preliminarily considers surface water and ground water to be hydrologically connected for the purpose prescribed in Section 46-713(3) is the area within which pumping of a well for 50 years will deplete the river or a base flow tributary thereof by at least 10% of the amount pumped in that time.

002 INFORMATION CONSIDERED. For making preliminary determinations required by Neb. Rev. Stat. Section 46-713 (Reissue 2004, as amended) the Department will use the best

DEC 4 2006

scientific data and information readily available to the Department at the time of the determination. Information to be considered will include:

Surface water administrative records
Department Hydrographic Reports
Department and United States Geological Survey stream gage records
Department's registered well data base
Water level records and maps from Natural Resources Districts, the Department, the University of Nebraska, the United States Geological Survey or other publications subject to peer review
Technical hydrogeological reports from the University of Nebraska, the United States Geological Survey or other publications subject to peer review
Ground water models
Current rules and regulations of the Natural Resources Districts

The Department shall review this list periodically, and will propose amendments to this rule as necessary to incorporate scientific data and information that qualifies for inclusion in this rule, but was not available at the time this rule was adopted.

APPROVED
DEC 04 2006
Dave Heineman
DAVE HEINEMAN

APPROVED
JON BRUNING
ATTORNEY GENERAL
BY.............................
Assistant Attorney General
DATE 10-30-06

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DEC - 4 2006
By ______ SECRETARY OF STATE

Appendix C

Techniques of Water-Resources Investigations of the United States Geological Survey

Chapter D1

COMPUTATION OF RATE AND VOLUME OF STREAM DEPLETION BY WELLS

By C. T. Jenkins

Book 4

HYDROLOGIC ANALYSIS AND INTERPRETATION

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

First printing 1968

Second printing 1969

Third printing 1977

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

For sale by the Branch of Distribution, U.S. Geological Survey,
1200 South Eads Street, Arlington, VA 22202

PREFACE

The series of manuals on techniques describes procedures for planning and executing specialized work in water-resources investigations. The material is grouped under major subject headings called books and further subdivided into sections and chapters; Section D of Book 4 is on interrelated phases of the hydrologic cycle.

The unit of publication, the chapter, is limited to a narrow-field of subject matter. This format permits flexibility in revision and publication as the need arises.

Provisional drafts of chapters are distributed to field offices of the U.S. Geological Survey for their use. These drafts are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment. After the technique described in a chapter is sufficiently developed, the chapter is published and is sold by the U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202 (authorized agent of Superintendent of Documents, Government Printing Office).

This manual is an expanded version of a paper, "Techniques for computing rate and volume of stream depletion of wells" (Jenkins, 1968a), that was prepared in the Colorado District, Water Resources Division, in cooperation with the Colorado Water Conservation Board and the Southeastern Colorado Water Conservancy District and published in Ground Water, the journal of the Technical Division, National Water Well Association.

CONTENTS

FIGURES

TABLES

COMPUTATION OF RATE AND VOLUME OF STREAM DEPLETION BY WELLS

By C. T. Jenkins

Abstract

When field conditions approach certain assumed conditions, the depletion in flow of a nearby stream caused by pumping a well can be calculated readily by using dimensionless curves and tables. Computations can be made of (1) the rate of stream depletion at any time during the pumping period or the following nonpumping period, (2) the volume of water induced from the stream during any period, pumping or nonpumping, and (3) the effects, both in rate and volume of stream depletion, of any selected pattern of intermittent pumping. Sample computations illustrate the use of the curves and tables. An example shows that intermittent pumping may have a pattern of stream depletion not greatly different from a pattern for steady pumping of an equal volume.

The residual effects of pumping, that is, effects after pumping stops, on streamflow may often be greater than the effects during the pumping period. Adequate advance planning that includes consideration of residual effects thus is essential to effective management of a stream-aquifer system.

Introduction

With increasing frequency, problems of water management require evaluation of effects of ground-water withdrawal on surface supplies. Both rate and volume effects have significance. Effects after the pumping stops (called residual effects in this paper) are important also but have not previously been examined in detail. In fact, residual effects can be much greater than those during pumping. Curves and tables shown in this paper, although applicable to a large range of interactions, are especially oriented to the solution of problems involving very small interactions and to the evaluation of residual effects. Where many wells are concentrated near a stream, the combined withdrawals can have a significant effect on the availability of water in the stream.

In some instances, especially in the evaluation of residual effects, the grid spacing on the charts shown may prove to be too coarse to provide the desired precision. However, this precision can be attained either by interpolating between the tabular values supplied or by using curves prepared by plotting the tabular values on commercially available chart paper that is more finely divided.

The relations between the pumping of a well and the resulting depletion of a nearby stream have been derived by several investigators (Theis, 1941; Conover, 1954; Glover and Balmer, 1954; Glover, 1960; Theis and Conover, 1963; Hantush, 1964, 1965). The relations generally are shown in the form of equations and charts; however, except for the charts shown by Glover (1960), which were in a publication that had limited distribution, the charts are useful as computational tools only in the range of comparatively large effects, and rather formidable equations must be solved to evaluate small effects. The average user retreats in dismay when faced by the mysticism of "line source integral," "complementary error function," or "the second repeated integral of the error function." The primary purpose of this report is to provide tools that will simplify the seemingly intricate computations and to give examples of their use.

Because this writer definitely is a member of the community of "average users," he has exercised what he believes to be his prerogative of reversing the usual order of presentation. In this paper, the working tools—curves, tables, and sample computations—are shown first, and the discussion of their mathematical bases is relegated to the end of the report. The usefulness of the tools will not be greatly enhanced by an understanding of the material at the end of the report; it is shown for the benefit of those who desire to examine the mathematical bases of the tools.

The techniques demonstrated in this paper are not new, but they seem to have been rather well concealed from most users in the past. Their value to water managers is apparent, especially in the estimation of total volume of depletion and of residual effects.

Virtually all the literature that discusses the effects of pumping on streamflow fails to mention that the effects of recharge are identical, except for direction of flow. (See Glover, 1964, p. 48.) Only pumping will be considered in this paper, but the reader should be aware that the terms "recharging" and "accretion" can be substituted for "pumping" and "depletion," respectively.

Definitions and Assumptions

To avoid confusion owing to the use of the same symbol for the dimension time as for transmissivity, symbols for the dimensions time and length are set in Roman type, are capitalized, and are enclosed in brackets. All other symbols, except that designating the mathematical term "second repeated integral," are set in italics.

Stream depletion means either direct depletion of the stream or reduction of ground-water flow to the stream.

The symbols used in the main body of the report are defined below (those that have to do only with the mathematical bases are defined at the end of the report in the section on this subject):

T= transmissivity, [L^2/T];

S= the specific yield of the aquifer, dimensionless;

t= time, during the pumping period, since pumping began, [T];

t_p= total time of pumping, [T];

t_i= time after pumping stops, [T];

Q= the net steady pumping rate, [L^3/T]; the steady pumping rate less the rate at which pumped water returns to the aquifer;

q= the rate of depletion of the stream, [L^3/T];

Qt= the net volume pumped during time t, [L^3];

Qt_p= the net volume pumped, [L^3];

v= the volume of stream depletion during time t, t_p, or t_p+t_i, [L^3];

a= the perpendicular distance from the pumped well to the stream, [L];

sdf= the stream depletion factor, [T].

The term "stream depletion factor" was introduced by Jenkins (1968a). It is arbitrarily defined as the time coordinate of the point where v=28 percent of Qt on a curve relating v and t. If the system meets the assumptions listed in this section, $sdf=a^2S/T$; in a complex system it can be considered to be an effective value of a^2S/T. The value of the sdf at any location in the system depends upon the integrated effects of the following: Irregular impermeable boundaries, stream meanders, aquifer properties and their areal variation, distance from the stream, and imperfect hydraulic connection between the stream and the aquifer.

The curves and tables in this report are dimensionless and can be used with any units. The units in the system must be consistent, however. For example, if Q and q are in acre-feet per day (acre-ft/day), v must be in acre-feet (acre-ft). If a is in feet (ft) and T/S is in gallons per day per foot (gal/day-ft), the value of T/S must be converted to square feet per day (ft^2/day). A T/S value of 10^6gal/day-ft equals (10^6gal/day-ft)$\times$(1ft^3/7.48 gal) equals 134,000 ft^2/day.

The assumptions made for this analysis are the same as other investigators have made and are as follows:

1. T does not change with time. Thus for a water-table aquifer, drawdown is considered to be negligible when compared to the saturated thickness.
2. The temperature of the stream is assumed to be constant and to be the same as the temperature of the water in the aquifer.
3. The aquifer is isotropic, homogeneous, and semi-infinite in areal extent.
4. The stream that forms a boundary is straight and fully penetrates the aquifer.
5. Water is released instantaneously from storage.
6. The well is open to the full saturated thickness of the aquifer.
7. The pumping rate is steady during any period of pumping.

Field conditions never meet fully the idealized conditions described by the above assumptions.

The usefulness of the tools presented in this report will depend to a large extent on the degree to which the user recognizes departures from ideal conditions, and on how well he understands the effects of these departures on stream depletion.

Departure from idealized conditions may cause actual stream depletions to be either greater or less than the values determined by methods presented in this report. Although the user usually cannot determine the magnitude of these discrepancies, he should, where possible, be aware of the direction the discrepancies take.

Jenkins (1968b) has described the use of a model to evalute the effects on stream depletion of certain departures from the ideal. If a model is not available, the user of this report can be guided in estimating the *sdf* by the effects calculated in that report for selected departures from the idealized system. Intuitive reasoning will be useful in estimating the effects of departures from the ideal that are difficult to incorporate in a model. For example, where drawdowns at the well site are a substantial proportion of the aquifer thickness, T will decrease significantly. A decrease in T results in a decrease in the amount of stream depletion relative to the amount of water pumped.

Variations in water temperatures will cause variations in stream depletion, especially by large-capacity wells near the stream. Warm water is less viscous than cold water; hence stream depletion will be somewhat greater in the summer than in the winter, given the same pattern of pumping. Stream stages affect water-table gradients, and hence stream depletion.

Lowering of the water table on a flood plain may result in the capture of substantial amounts of water that would otherwise be transpired. The effect is similar to intercepting another recharge boundary, and the proportion of stream depletion to pumpage is decreased. Interception of a valley wall or other negative boundary will have the opposite effect.

If large-capacity wells are placed close to a stream, and streambed permeability is low compared to aquifer permeability, the water table may be drawn down below the bottom of the streambed. (See Moore and Jenkins, 1966.) Under these conditions, stream depletion depends upon streambed permeability, area of the streambed, temperature of the water, and stage of the stream, and the methods presented in this report are not applicable.

Both during and after pumping, some part and at times all of stream depletion can consist of ground water intercepted before reaching the stream. Thus a stream can be depleted over a certain reach, yet still be a gaining stream over that reach. The flow at the lower end of the reach is less than it would have been had depletion not occurred, and less by the amount of depletion. In order to predict the amount of streamflow at the lower end of the reach, residual effects of previous pumping or recharge must be considered. They can be approximately accounted for by using past records of pumping and recharge to "prestress" the calculations. The depletion due to the pumping under consideration will then be superimposed on the residual depletion, and the resultant value will be the net direct depletion from the stream.

Description of Curves and Tables

Effects during pumping

Curves A and B in figure 1 apply during the period of steady pumping. Curve A shows the relation between the dimensionless term t/sdf and the rate of stream depletion, q, at time t, expressed as a ratio to the pumping rate Q. Curve B shows the relation between t/sdf and the volume of stream depletion, v, during time t, expressed as a ratio to the volume pumped, Qt. The two curves labeled $1-q/Q$ and $1-\frac{v}{Qt}$ are shown to facilitate determination of values of q/Q and $\frac{v}{Qt}$ when the ratios exceed 0.5. The coordinates of curves A and B are tabulated in table 1. The number of significant figures shown for the values in table 1 was determined by needs for some of the computations described in the next section. Precision to more than two significant figures in reporting results probably will never be warranted.

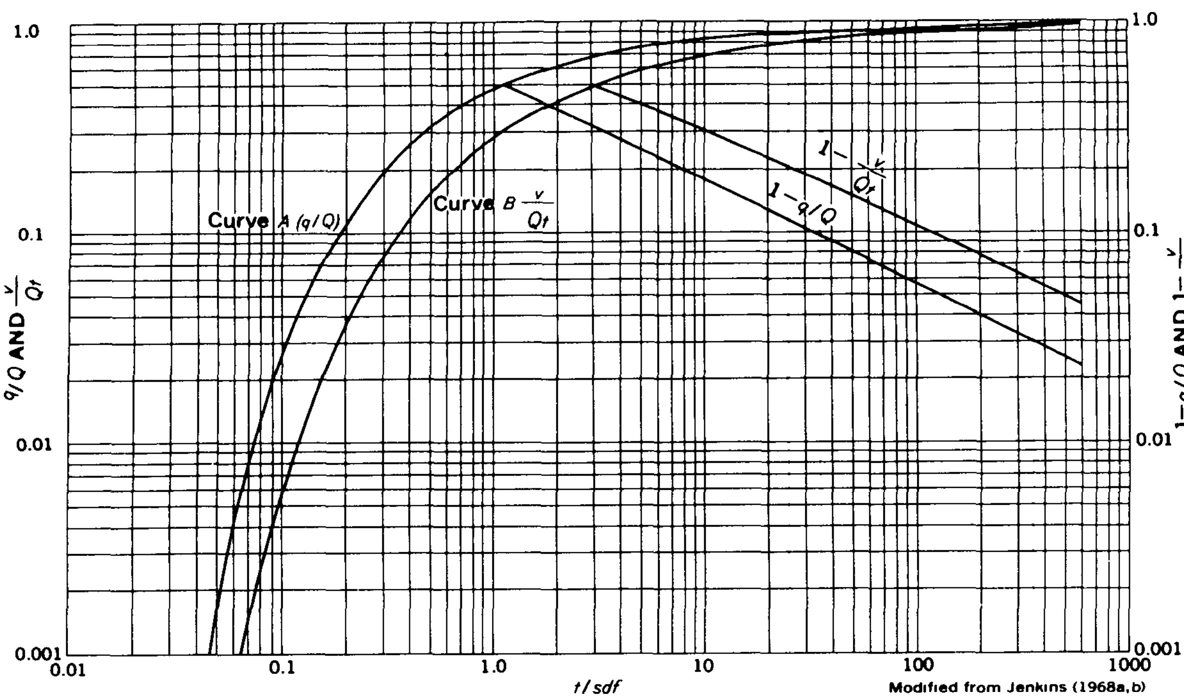


Figure 1.—Curves to determine rate and volume of stream depletion.

Residual effects

Stream depletion continues after pumping stops. As time approaches infinity, the volume of stream depletion approaches the volume pumped, if the assumption is made that the stream is the sole source of recharge. In any real case this is not true in the long term because precipitation and return flow from irrigation may represent the major portion of the recharge. To simplify the relation between well pumpage and stream depletion all other sources of water input are ignored in the following discussions. The rate and volume of depletion at any time after pumping ends can be computed by using the method of superposition, that is, by assuming that the pumping well continues to pump, and that an imaginary well at the same location is recharged continuously at the same rate the pumping well is discharging. The rate and volume of stream depletion at any time after pumping ends is equal to the differences between the rate and volume of depletion that would have occurred if pumping had continued, and the rate and volume of accretion resulting from recharge by the imaginary recharge well, starting from the time pumping ends.

Residual effects are shown in figures 2 and 3 for eight values of t_p/sdf. Problems concerned with values of t_p/sdf other than those for which curves are shown in figures 2 and 3 can be solved with an acceptable degree of accuracy by interpolation, but if the user desires a more accurate appraisal, separate computations can be made.

The computations shown in table 2, which are the basis for the curves labeled $t_p/sdf=0.35$ in figures 2 and 3 and for the curve in figure 4, will serve as an illustration of how additional curves can be constructed. As an aid to construction of curves such as those in figure 3, note that the curves are asymptotic to the ordinate $\frac{v}{Qsdf}$ $(=t_p/sdf)$.

Because Q is the same for both the pumping and recharging wells, residual q/Q can be computed directly from q/Q values in table 1. However, Qt is different for the two wells; so the ratios $\frac{v}{Qt}$ must be given a common denominator by multiplying by their respective values

Table 1.—Values of q/Q, $\frac{v}{Qt}$, and $\frac{v}{Qsdf}$ corresponding to selected values of t/sdf

$\frac{t}{sdf}$	q/Q	$\frac{v}{Qt}$	$\frac{v}{Qsdf}$
0	0	0	0
.07	.008	.001	.0001
.10	.025	.006	.0006
.15	.068	.019	.003
.20	.114	.037	.007
.25	.157	.057	.014
.30	.197	.077	.023
.35	.232	.097	.034
.40	.264	.115	.046
.45	.292	.134	.060
.50	.317	.151	.076
.55	.340	.167	.092
.60	.361	.182	.109
.65	.380	.197	.128
.70	.398	.211	.148
.75	.414	.224	.168
.80	.429	.236	.189
.85	.443	.248	.211
.90	.456	.259	.233
.95	.468	.270	.256
1.0	.480	.280	.280
1.1	.500	.299	.329
1.2	.519	.316	.379
1.3	.535	.333	.433
1.4	.550	.348	.487
1.5	.564	.362	.543
1.6	.576	.375	.600
1.7	.588	.387	.658
1.8	.598	.398	.716
1.9	.608	.409	.777
2.0	.617	.419	.838
2.2	.634	.438	.964
2.4	.648	.455	1.09
2.6	.661	.470	1.22
2.8	.673	.484	1.36
3.0	.683	.497	1.49
3.5	.705	.525	1.84
4.0	.724	.549	2.20
4.5	.739	.569	2.56
5.0	.752	.587	2.94
5.5	.763	.603	3.32
6.0	.773	.616	3.70
7	.789	.640	4.48
8	.803	.659	5.27
9	.814	.676	6.08
10	.823	.690	6.90
15	.855	.740	11.1
20	.874	.772	15.4
30	.897	.810	24.3
50	.920	.850	42.5
100	.944	.892	89.2
600	.977	.955	573

of *t/sdf*, to obtain the values given in table 1 for $\frac{v}{Qsdf}$. The "stepping" of the last six items in column 8, table 2, is the result of using linear interpolation in table 1. The errors are small and can be practically eliminated by drawing mean curves.

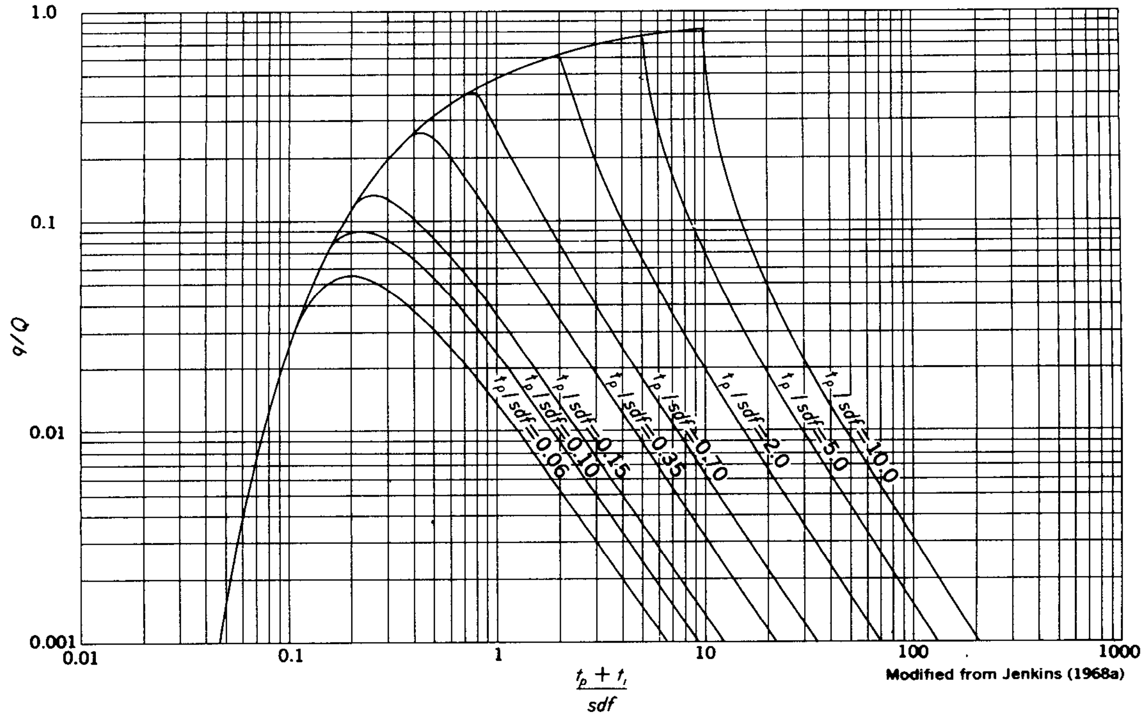
The magnitude, distribution, and extent of residual effects in a hypothetical field situation are shown in figure 4. The curve labeled *q* shows the relation between the rate of stream depletion, *q*, and time, *t*, resulting from pumping a well 3,660 feet from a stream at a rate of 10 acre-ft/day for 35 days. The ratio *T/S* is 134,000 ft ^{2}/day, which is not an unusual value for an alluvial aquifer. The *sdf* is 100 days. The pumping rate is 10 acre-ft/day; the maximum rate of stream depletion is 2.7 acre-ft/day. Pumping stops at the end of 35 days; the maximum rate of stream depletion occurs about 10 days later, and *q* still is about half the maximum rate 45 days after pumping stops.

The area in the rectangle under the line labeled *Q* represents total volume pumped; the area under the curve labeled *q* represents the volume of stream depletion. In terms of volume removed from the stream during the pumping period, the effect is small, only about 10 percent of the volume pumped. However, the effect continues, and as time approaches infinity, the volume of stream depletion approaches the volume pumped.

Consideration of such residual effects as are illustrated in figure 4 leads to the conclusion that the management of a system that uses both surface water and a connected ground-water reservoir requires a great deal of foresight. The immediate effects on streamflow of a change in pumping pattern may be very small; plans adequate for effective management of the resource generally require consideration of needs in the future—sometimes the distant future. The sample problems solved later in this report illustrate the value of long-range plans in water management.

Intermittent pumping

The curves in figure 5 illustrate the effect of one pattern of intermittent pumping. The computations are shown in table 3. Effects on the stream, both in volume removed and rate of removal are compared for two patterns of pumping of 63 acre-ft during a 42-day period. In both cases the aquifer has a ratio *T/S* of 134,000 ft ^{2}/day, and the well is 1,890 feet from the stream; thus the value for the *sdf*= 26.7 days. During steady pumping, the well is pumped at a rate of 1.5 acre-ft/day for 42 days. In the intermittent pattern, the well is pumped at a rate of 5.25 acre-ft/day for



Modified from Jenkins (1968a)

Figure 2.—Curves to determine rate of stream depletion during and after pumping.

Table 2.—Computation of residual effects of pumping

[Pumping stopped when t/sdf=0.35]

Pumped well			Recharged well			Residual	Residual
t/sdf	q/Q	$\frac{v}{Qsdf}$	t/sdf	q/Q	$\frac{v}{Qsdf}$	q/Q	$\frac{v}{Qsdf}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0. 35	0. 232	0. 034	0	0	0	0. 232	0. 034
. 42	. 275	. 052	. 07	. 008	. 0001	. 267	. 052
. 45	. 292	. 060	. 10	. 025	. 0006	. 267	. 059
. 50	. 317	. 076	. 15	. 068	. 003	. 249	. 073
. 60	. 361	. 109	. 25	. 157	. 014	. 205	. 095
. 70	. 398	. 148	. 35	. 232	. 034	. 166	. 114
1. 00	. 480	. 280	. 65	. 380	. 128	. 099	. 152
1. 50	. 564	. 543	1. 15	. 510	. 354	. 053	. 189
2. 00	. 617	. 838	1. 65	. 581	. 629	. 035	. 209
3. 00	. 683	1. 49	2. 65	. 664	1. 255	. 019	. 235
5. 00	. 752	2. 94	4. 65	. 743	2. 67	. 009	. 27
7. 00	. 789	4. 48	6. 65	. 783	4. 21	. 006	. 27
10. 00	. 823	6. 90	9. 65	. 8198	6. 61	. 0032	. 29
15. 00	. 855	11. 1	14. 65	. 8528	10. 81	. 0022	. 29
20. 00	. 872	15. 3	19. 65	. 8718	15. 00	. 0012	. 30
30. 00	. 897	24. 3	29. 65	. 8961	23. 99	. 0009	. 31

1. $\frac{t_p+t_i}{sdf}=t/sdf$ for pumped well if pumping had continued.
2. q/Q for pumped well if pumping had continued. Values from table 1 for value of t/sdf indicated in column 1.
3. $\frac{v}{Qsdf}$ for pumped well if pumping had continued. Values from table 1 for value of t/sdf indicated in column 1.
4. t/sdf for recharged well, beginning at end of pumping.
5. q/Q for recharged well, beginning at end of pumping. Values from table 1 for value of t/sdf indicated in column 4.
6. $\frac{v}{Qsdf}$ for recharged well, beginning at end of pumping. Values from table 1 for value of t/sdf indicated in column 4.
7. Column 2 minus column 5; residual q/Q.
8. Column 3 minus column 6; residual $\frac{v}{Qsdf}$.

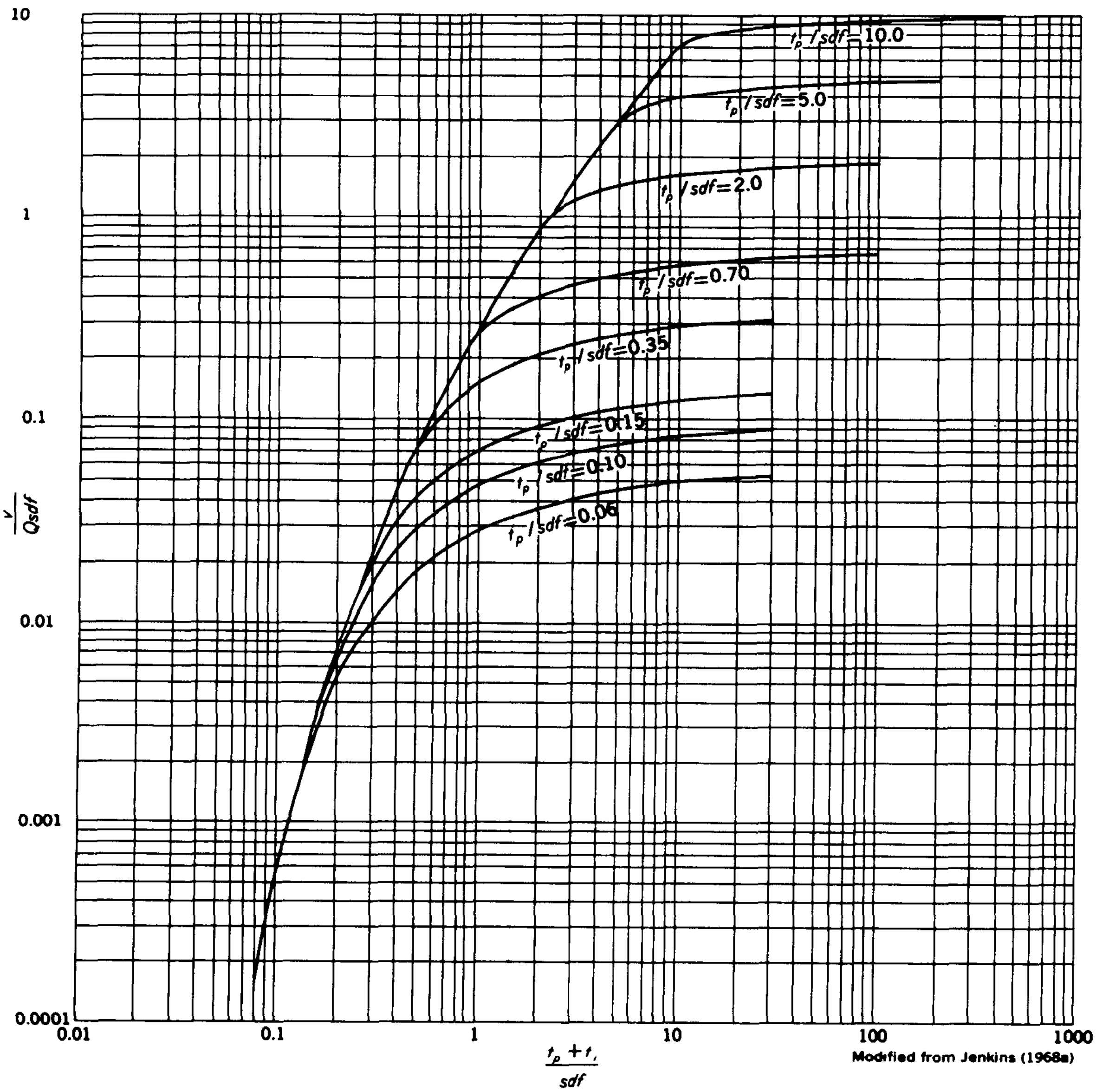


Figure 3.—Curves to determine volume of stream depletion during and after pumping.

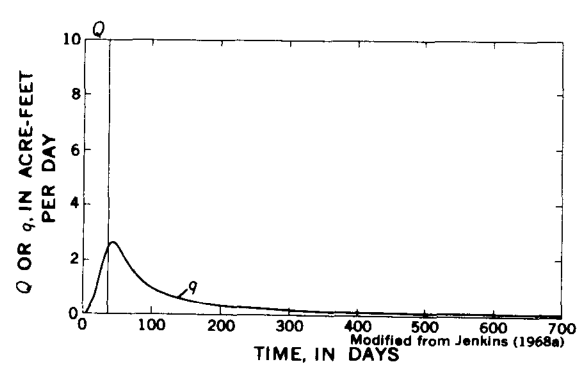


Figure 4.—Example of residual effects of well pumping 35 days.

4 days beginning 5 days after the beginning of the period, shut down 10 days, pumped 4 days, shut down 10 days, pumped 4 days, and shut down 5 days. The computed effects of the pattern of intermittent pumping are compared in figure 5 with those of the steady rate. The comparisons indicate that, within quite large ranges of intermittency, the effects of intermittent pumping are approximately the same as those of steady, continuous pumping of the same volume.

Table 3.—Computation of the effects of two selected

[a=1,890 ft, T/S=134,000 ft²/day, sdf=26.7 days. Intermittent pumping rate=5.25 acre-ft/day,

Time from beginning of period (days)	Steady pumping: Pumping period (1st–42d day inclusive)					Intermittent pumping: Pumping period (6th–9th day inclusive)			
	t/sdf	q/Q	$\frac{v}{Qsdf}$	q (acre-ft per day)	v (acre-ft)	Time (days)	t/sdf	q/Q	$\frac{v}{Qsdf}$
0	0	0	0	0	0				
5	.187	.102	.006	.15	.2	0	0	0	0
9	.337	.223	.031	.33	1.2	4	.150	.068	.003
12	.449	.291	.060	.44	2.4	7	.262	.127	.015
19	.712	.402	.153	.60	6.1	14	.524	.080	.044
23	.861	.446	.216	.67	8.7	18	.674	.061	.054
26	.974	.471	.262	.71	10.5	21	.787	.050	.061
33	1.236	.525	.398	.79	15.9	28	1.049	.034	.071
37	1.386	.548	.479	.82	19.2	32	1.199	.029	.074
42	1.573	.573	.585	.86	23.4	37	1.386	.023	.081

Sample Computations

To illustrate the use of the curves and tables, solutions are shown of problems that might arise in the conjunctive management of ground water and surface water.

Problem I

Management criteria require that pumping cease when the rate of stream depletion by pumping reaches 0.14 acre-ft/day:

1. Under this restriction how long can a well 1.58 miles from the stream be pumped at the rate of 2 acre-ft/day if T/S is 10^6 gal/day-ft, and what is the volume of stream depletion during this time?
2. If pumping this well is stopped when q=0.14 acre-ft/day, what will the rate of stream depletion be 30 days later? What will be the volume of stream depletion at that time?
3. What will be the largest rate of stream depletion and when will it occur?

Given:

q=0.14 acre-ft/day
Q=2 acre-ft/day
a=1.58 miles
$T/S=10^6$ gal/day-ft
t_i=30 days

$$sdf=a^2S/T=\frac{a^2}{T/S}=\frac{(1.58\text{ mi})^2\,(5{,}280\text{ ft/mi})^2}{(10^6\text{ gal/day-ft})\,(1\text{ ft}^3/7.48\text{ gal})}$$
$$=520\text{ days.}$$

Find:

t_p
v at t_p
q at t_p+t_i
v at t_p+t_i
q max
t of q max.

Part 1

From information given, the ratio of the rate of stream depletion to the rate of pumping is

$$q/Q=\frac{(0.14\text{ acre-ft/day})}{(2\text{ acre-ft/day})}=0.07.$$

From curve A (fig. 1)

$$t/sdf=0.15.$$

Substitute the value under "Given" for sdf, and

$$t=(0.15)(520\text{ days})=78\text{ days.}$$

The total time the well can be pumped is 78 days.

When

$$t/sdf=0.15.$$

then from curve B (fig. 1),

$$\frac{v}{Qt}=0.02.$$

Substitute the values for Q and t, and the volume of stream depletion during this time is

$$v=(0.02)(2\text{ acre-ft/day})(78\text{ days})$$
$$=3.1\text{ acre-ft.}$$

patterns of pumping on a nearby stream

t_p/sdf=0.15 (see curves in figures 2 and 3). Steady pumping rate=1.5 acre-ft/day]

Intermittent pumping—Continued											
Pumping period (20th–23d day inclusive)				Pumping period (32d–35th day inclusive)				Totals			
Time (days)	t/sdf	q/Q	$\frac{v}{Qsdf}$	Time (days)	t/sdf	q/Q	$\frac{v}{Qsdf}$	q/Q	$\frac{v}{Qsdf}$	q (acre-ft per day)	v (acre-ft)
								0	0	0	0
								.068	.003	.36	.4
								.127	.015	.67	2.1
0	0	0	0					.080	.044	.42	6.2
4	.150	.068	.003					.129	.057	.68	8.0
7	.262	.127	.015					.177	.076	.93	10.7
14	.524	.080	.044	0	0	0	0	.114	.115	.60	16.1
18	.674	.061	.054	4	.150	.068	.003	.158	.131	.83	18.4
23	.861	.044	.063	9	.337	.223	.031	.188	.169	.99	23.7

During the 78-day pumping period, 3.1 acre-ft, out of a total of 156 acre-ft pumped, is stream depletion.

Part 2

If pumping is stopped at the end of 78 days, then t_p/sdf=0.15, and 30 days later,

$$\frac{t_p+t_i}{sdf}=\frac{108\text{ days}}{520\text{ days}}=0.21.$$

From figure 2: if

$$t_p/sdf=0.15$$

and

$$\frac{t_p+t_i}{sdf}=0.21,$$

$$q/Q=0.12.$$

Thus the rate of stream depletion is

$$q=(0.12)(2\text{ acre-ft/day})$$
$$=0.24\text{ acre-ft/day, 30 days after pumping stops.}$$

From figure 3

$$\frac{v}{Qsdf}=0.008.$$

Substitute the values for Q and sdf, and the total volume of the stream depletion at the end of 30 days is

$$v=(0.008)(2\text{ acre-ft/day})(520\text{ days})$$
$$=8.3\text{ acre-ft of stream depletion during 108 days}$$

as a result of pumping 2 acre-ft/day during the first 78 days.

Part 3

If

$$t_p/sdf=0.15,$$

then from figure 2

$$\text{maximum } q/Q=0.13,$$

when

$$\frac{t_p+t_i}{sdf}=0.25.$$

Therefore

$$\text{maximum } q=(0.13)(2\text{ acre-ft/day})$$
$$=0.26\text{ acre-ft/day}$$

when

$$t_p+t_i=(0.25)(520\text{ days})$$
$$=130\text{ days, or 52 days after pumping stops.}$$

Problem II

An irrigator is restricted to a maximum withdrawal of 150 acre-ft during the 150-day growing season, provided his pumping depletes the stream less than 25 acre-ft during the season. His well is 1 mile from the stream, and T/S=134,000 ft^2/day. He will pump at the rate of 2.00 acre-ft/day, regulating his average pumping rate by shutting his pump off for the appropriate number of hours per day. Examine the effects of several possible pumping patterns: Given:

max=Qt 150 acre-ft
v max=25 acre-ft
t max=150 days
a=1 mile
T/S=134,000 ft^2/day

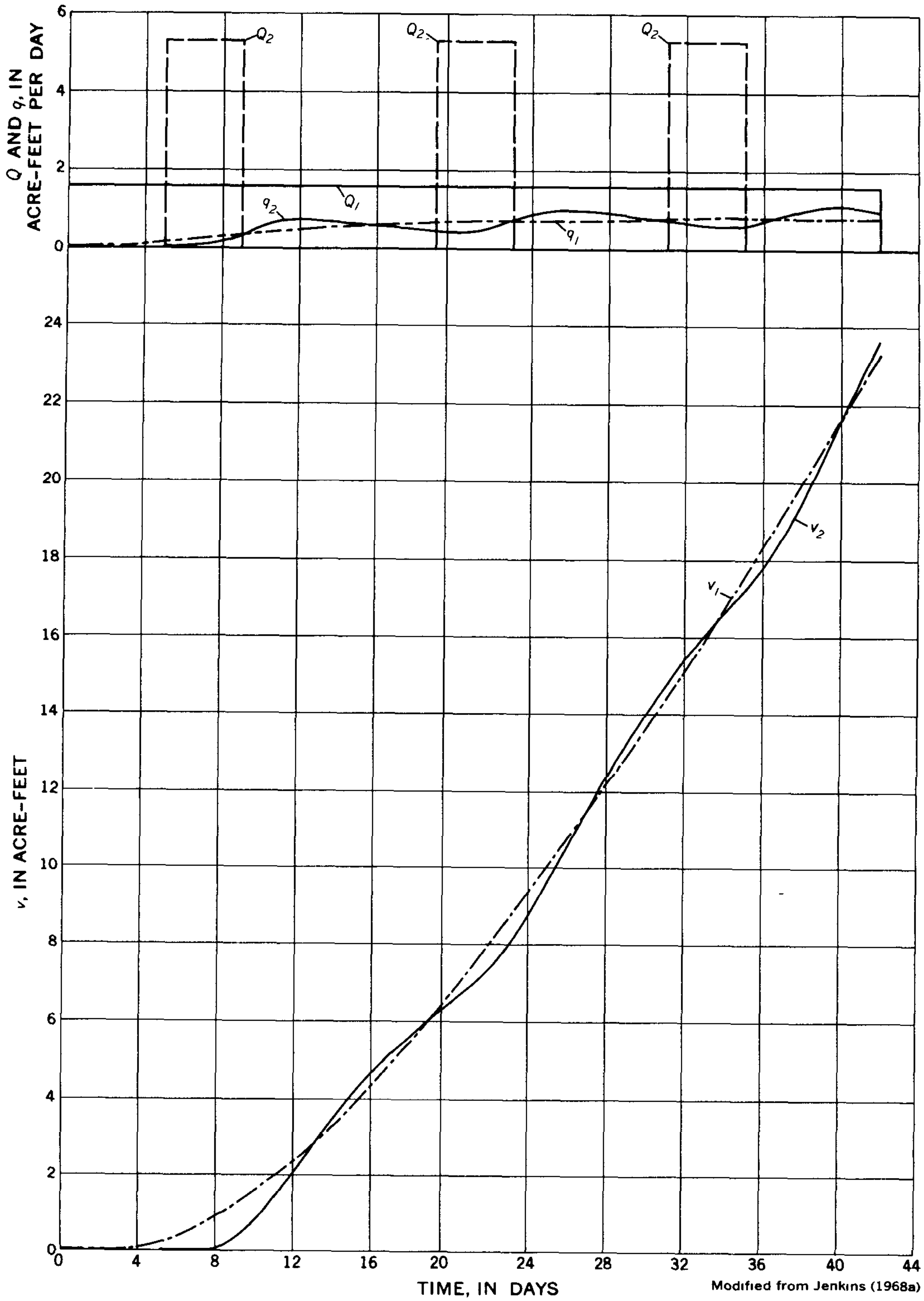


Figure 5.—Curves showing the effects of intermittent and steady pumping on a stream

$$sdf=a^2S/T=\frac{a^2}{T/S}=\frac{(5{,}280\text{ ft})^2}{134{,}000\text{ ft}^2/\text{day}}=209\text{ days.}$$

Find:

Various pumping patterns possible within the restrictions given.

Part 1

First, test to see if both restrictions apply to any combination of pumping time and rate within the 150-day period. Try ending pumping the last day of the season, beginning pumping at a time and rate such that pumping 150 acre-ft will result in a depletion of the stream of 25 acre-ft at the end of pumping.

$$Qt=150\text{ acre-ft, }v=25\text{ acre-ft; }\frac{v}{Qt}=0.167.$$

From curve *B* (fig. 1)

$$t/sdf=0.54.$$

Time will be

$$t=(0.54)\ (209\text{ days})$$
$$=113\text{ days, or 37 days after beginning of season.}$$

Pumping rate will be

$$Q=\frac{150\text{ acre-ft}}{113\text{ days}}=1.33\text{ acre-ft/day.}$$

He can pump 16 hours per day, beginning 113 days before the end of the season.

If pumping 150 acre-ft during the 113-day period at the end of the season results in 25 acre-ft of stream depletion, it follows that pumping 150 acre-ft—regardless of rate—in a shorter period at the end of the season will result in less than 25 acre-ft depletion, and the 150 acre-ft limit will apply. It also follows that pumping 150 acre-ft in the earlier periods will result in more than 25 acre-ft of stream depletion, hence the restriction on stream depletion will apply during the first part of the season.

Part 2

Begin pumping 60 days after the beginning of the season. Test reasoning that the restriction on volume pumped applies.

$$Qt=150\text{ acre-ft,}$$
$$t=90\text{ days,}$$

$$t/sdf=\frac{90\text{ days}}{209\text{ days}}=0.43.$$

From curve *B*

$$\frac{v}{Qt}=0.13.$$

The volume of stream depletion is

$$v=(0.13)\ (150\text{ acre-ft})=19.5\text{ acre-ft.}$$

The restriction on the volume of stream depletion has not been exceeded; therefore, the restriction on volume pumped does apply, and the allowable pumping rate would be

$$Q=\frac{150\text{ acre-ft}}{90\text{ days}}=1.67\text{ acre-ft/day}$$

which is the equivalent of pumping at the rate of 2.00 acre-ft/day for 20 hours per day.

Part 3

Begin pumping at the beginning of the season, pump for 73 days. Test reasoning that the restriction on stream depletion applies.

$$t_p/sdf=73\text{ days}/209\text{ days}=0.35.$$

From figure 3, for

$$t/sdf=0.35$$

and

$$\frac{t_p+t_i}{sdf}=\frac{150\text{ days}}{209\text{ days}}=0.72,$$

$$\frac{v}{Qsdf}=0.12.$$

The steady pumping rate is

$$Q=\frac{25\text{ acre-ft}}{(0.12)(209\text{ days})}=1.00\text{ acre-ft/day,}$$

and the net volume pumped is

$$Qt=(1.00\text{ acre-ft/day})\ (73\text{ days})=73\text{ acre-ft.}$$

Therefore, the restriction on volume of stream depletion does apply. He can pump 12 hours per day at a rate of 2.00 acre-ft/day during a 73-day pumping period at the beginning of the season.

Part 4

The irrigator elects to pump 6 hours per day for the first 32 days of the season. What is the highest rate he can pump during the remaining 118 days?

Try assumption that restriction on volume of stream depletion will apply.

$$t_p/sdf=\frac{32 \text{ days}}{209 \text{ days}}=0.15$$

and

$$\frac{t_p+t_i}{sdf}=\frac{150 \text{ days}}{209 \text{ days}}=0.72.$$

From figure 3

$$\frac{v_1}{Qsdf}=0.057.$$

The volume of stream depletion during the 32 days is

$$v_1=(0.057)\ (0.5 \text{ acre-ft/day})\ (209 \text{ days}) =6.0 \text{ acre-ft}.$$

The net volume pumped during this time is

$$Q_1t_1=(0.5 \text{ acre-ft/day})\ (32 \text{ days})=16 \text{ acre-ft}.$$

Subtract v_1 from the allowable volume of stream depletion

$$25 \text{ acre-ft}-6 \text{ acre-ft}=19 \text{ acre-ft}=v_2.$$

If

$$t_2/sdf=\frac{118 \text{ days}}{209 \text{ days}}=0.56,$$

then from figure 1

$$\frac{v_2}{Q_2t_2}=0.17.$$

The volume pumped during the 118 days is

$$Q_2t_2=(19 \text{ acre-ft})/0.17=112 \text{ acre-ft}.$$

The values for the two periods total

$$(112+16) \text{ acre-ft}=128 \text{ acre-ft},$$

which is less than 150 acre-ft. Therefore the assumption that restriction on volume of stream depletion applies is correct.

$$Q_2=\frac{112 \text{ acre-ft}}{118 \text{ days}}=0.95 \text{ acre-ft/day}.$$

He can pump at the steady rate of 2.00 acre-ft/day for 11.4 hours per day during the last 118 days of the season.

The irrigator elects to pump continuously at the rate of 2.00 acre-ft/day. If he plans to pump until the end of the season, how soon can he start pumping? (See Part 5.) If he plans to start pumping at the beginning of the season, how long can he pump? (See Part 6.) If he plans to start pumping 50 days after the beginning of the season, how long can he pump? (See Part 7.)

Part 5

$$Qt=150 \text{ acre-ft},$$

$$t=\frac{150 \text{ acre-ft}}{2 \text{ acre-ft/day}}=75 \text{ days}$$

$$t/sdf=\frac{75 \text{ days}}{209 \text{ days}}=0.36.$$

From curve B (fig. 1)

$$\frac{v}{Qt}=0.10.$$

The volume of stream depletion is

$$v=15.0 \text{ acre-ft}.$$

Therefore the restriction on volume pumped applies, and he can pump continuously at the rate of 2 acre-ft/day, beginning 75 days before the end of the season.

Part 6

Assume that the restriction on stream depletion applies,

$$\frac{v}{Qsdf}=\frac{25 \text{ acre-ft}}{(2 \text{ acre-ft/day})\ (209 \text{ days})}=0.060$$

and

$$\frac{t_p+t_i}{sdf}=\frac{150 \text{ days}}{209 \text{ days}}=0.72.$$

From figure 3

$$t_p/sdf \approx 0.17$$

$$t_p \approx (0.17)\ (209 \text{ days}) \approx 35 \text{ days}.$$

Therefore the irrigator can begin pumping at the beginning of the season and pump continuously at a rate of 2.00 acre-ft/day for about 35 days.

Part 7

Restriction on volume pumped limits pumping time to

$$\frac{150 \text{ acre-ft}}{2 \text{ acre-ft/day}}=75 \text{ days.}$$

Test to see if depletion restriction would be exceeded by 75 days of pumping beginning 50 days after the beginning of the season.

$$t_p+t_i=(150-50) \text{ days}=100 \text{ days.}$$

If

$$\frac{t_p+t_i}{sdf}=\frac{100 \text{ days}}{209 \text{ days}}=0.48$$

and

$$t_p/sdf=75 \text{ days}/209 \text{ days}=0.36,$$

then from figure 3

$$\frac{v}{Qsdf}=0.72.$$

The volume of stream depletion is

$$v\approx(0.72)(2 \text{ acre-ft/day})\ (209 \text{ days})$$

$$\approx 30 \text{ acre-ft,}$$

which exceeds the 25 acre-ft restriction.

Try stopping pumping after 69 days. Use values from table 1 instead of interpolation between curves in figure 3.

$$t_i=(100-69) \text{ days}=31 \text{ days.}$$

If

$$\frac{t_p+t_i}{sdf}=0.48, \text{ then } \frac{v_1}{Qsdf}=0.070,$$

and if

$$\frac{t_i}{sdf}=0.15, \text{ then } \frac{v_2}{Qsdf}=0.003.$$

The net is

$$\frac{v}{Qsdf}=0.067.$$

The volume of steam depletion is

$$v=28 \text{ acre-ft.}$$

Try $t_p=54$ days, $t_i=46$ days.

$$\frac{t_p+t_i}{sdf}=0.48, \quad \frac{v_1}{Qsdf}=0.070,$$

and

$$\frac{t_i}{sdf}=0.22, \quad \frac{v_2}{Qsdf}=0.010.$$

The net is

$$\frac{v}{Qsdf}=0.060.$$

The volume of stream depletion is

$$v=25 \text{ acre-ft.}$$

Therefore, the irrigator can pump continuously at a rate of 2 acre-ft/day during the 54-day period beginning 50 days after the season begins.

Problem III

A well 4,000 feet from the stream is shut down after pumping at a rate of 250 gal/min for 150 days; $T/S=67{,}000 \text{ ft}^2/\text{day}$.

1. What effect did pumping the well have on the stream during the pumping period?
2. What will be the effect during the next 216 days after pumping was stopped?
3. What would the effect have been if pumping had continued during the entire 366 days?

Given:

Q =250 gal/min
t_p =150 days, 366 days
t_i =216 days
a =4,000 feet
T/S=67,000 ft^2/day

$$sdf=\frac{(4000 \text{ ft})^2}{67{,}000 \text{ ft}^2/\text{day}}=239 \text{ days.}$$

Find:

q and v for $t_p=150$ days
q and v for $t_p+t_i=366$ days
q and v for $t_p=366$ days

Part 1

$$t_p/sdf=150 \text{ days}/239 \text{ days}=0.63.$$

The rate of pumping in consistent units is

$$Q=\left(\frac{250 \text{ gal}}{\text{min}}\right)\left(1{,}440\frac{\text{min}}{\text{day}}\right)\left(\frac{1 \text{ ft}^3}{7.48 \text{ gal}}\right)\left(\frac{1 \text{ acre-ft}}{43{,}560 \text{ ft}^3}\right)$$
$$=1.1 \text{ acre-ft/day.}$$

When

$$t=t_p,$$

$$t/sdf=0.63.$$

From curve A

$$q/Q=0.37.$$

From curve *B*

$$\frac{v}{Qt}=0.19.$$

At the end of 150 days,

$q=(1.1 \text{ acre-ft/day})\ (0.37)$
$=0.41 \text{ acre-ft/day},$
$v=(1.1 \text{ acre-ft/day})\ (150 \text{ days})\ (0.19)$
$=31 \text{ acre-ft}.$

Part 2

When $t_p+t_i=(150+216) \text{ days}=366 \text{ days},$

$$\frac{t_p+t_i}{sdf}=1.53.$$

From figure 2 by interpolation,

$$q/Q=0.11.$$

From figure 3 by interpolation,

$$\frac{v}{Qsdf}=0.33.$$

Thus, 216 days after pumping ceased,

$q=(0.11)\ (1.1 \text{ acre-ft/day})$
$=0.12 \text{ acre-ft/day},$
$v=(0.33)\ (1.1 \text{ acre-ft/day})\ (239 \text{ days})$
$=87 \text{ acre-ft}.$

The additional volume of stream depletion during the 216-day period would be

$$(87-31) \text{ acre-ft}=56 \text{ acre-ft}.$$

Part 3

If pumping had continued for the entire 366-day period,

$$\frac{t}{sdf}=1.53,$$

and from table 1, $q/Q=0.568$ and

$$\frac{v}{Qt}=0.366.$$

$q=(0.568)\ (1.1 \text{ acre-ft/day})$
$=0.62 \text{ acre-ft/day},$
$v=(0.366)\ (1.1 \text{ acre-ft/day})\ (366 \text{ days})$
$=147 \text{ acre-ft}.$

During the last 216 days the stream depletion would have been

$$v=(147-31) \text{ acre-ft}=116 \text{ acre-ft}.$$

Problem IV

A municipal well is to be drilled in an alluvial aquifer near a stream. Downstream water uses require that depletion of the stream be limited to no more than 5,000 cubic meters during the dry season, which commonly is about 200 days long. The well will be pumped continuously at the rate of 0.03 m^3/sec (cubic meters per second) during the dry season only. Wet season recharge is ample to replenish storage depleted by the pumping in the previous dry season, thus residual effects can be disregarded. $T=30$ cm^2/sec (square centimeters per second), $S=0.20$.

What is the minimum allowable distance between the well and the stream?

Given:

$v=5{,}000 \text{ m}^3$
$Q=0.03 \text{ m}^3/\text{sec}$
$t_p=200 \text{ days}$
$T=30 \text{ cm}^2/\text{sec}$
$S=0.20$
$Qt=(0.03 \text{ m}^3/\text{sec})\ (200 \text{ days})$
$(86{,}400 \text{ sec/day})=5.184\times10^5 \text{m}^3$

$$\frac{v}{Qt}=5{,}000 \text{ m}^3/5.184\times10^5 \text{ m}^3=0.01.$$

Find: *a*

From curve *B*

$$t/sdf=0.12=\frac{tT}{a^2S},$$

$$0.12=\frac{(200 \text{ days})\ (86{,}400 \text{ sec/day})\ (30 \text{ cm}^2/\text{sec})}{a^2(0.20)},$$

$$a^2=\frac{(200)\ (86{,}400)\ (30) \text{ cm}^2}{(0.12)\ (0.20)}=2.16\times10^{10} \text{ cm}^2,$$

$$a=1.47\times10^5 \text{ cm}=1{,}470 \text{ meters}.$$

Problem V

A water company wants to install a well near a stream and pump it 90 days during the summer to supplement reservoir supplies. Downstream residents have protested that the well might dry up the stream. Natural streamflow at the lower end of the reach that would be affected by pumping is not expected to go below 2.0 ft^3/sec in most years, and the downstream users have agreed that the well can be installed if depletion of the stream is limited to a maximum of 1.5 ft^3/sec. The well would be 500 feet from the the stream and would pump 1,000 gpm. $T=50{,}000$ gpd/ft, and $S=0.20$.

1. Will the rate of stream depletion exceed 1.5 ft^3/sec during the first season or any following season?
2. If so, when will the rate of stream depletion exceed 1.5 ft^3/sec?
3. At what rate could the well be pumped in order not to exceed 1.5 ft^3/sec of stream depletion?

Given:

q max allowable$=1.5$ ft^3/sec
$a=500$ feet
$T=50{,}000$ gal/day-ft
$S=0.20$
$Q=1{,}000$ gal/min

$$sdf=\frac{(500\text{ ft})^2(0.20)(7.48\text{ gal/ft}^3)}{50{,}000\text{ gal/day-ft}}=7.5\text{ days}$$

Find:

q max
t for $q=1.5$ ft^3/sec
Q for $q=1.5$ ft^3/sec

Part 1

$$t_p=90\text{ days.}$$

$$t_p/sdf=12.$$

From figure 1,

$$1-q/Q=0.155.$$

Therefore

$$q/Q=0.845,$$

$$q=\frac{(0.845)(1{,}000\text{ gal/min})(1{,}440\text{ min/day})}{7.48\text{ gal/ft}^3}$$

$$=1.63\times10^5\text{ ft}^3\text{/day}$$

$$=1.88\text{ ft}^3\text{/sec.}$$

Therefore by the end of the first pumping period, the rate of stream depletion would have exceeded the allowable depletion of 1.5 ft^3/sec.

Part 2

$$q=1.5\text{ ft}^3\text{/sec}=(1.5\text{ ft}^3\text{/sec})\ (86{,}400\text{ sec/day})$$
$$=1.30\times10^5\text{ ft}^3\text{/day}$$

$$Q=1{,}000\text{ gal/min}$$
$$=\frac{(1{,}000\text{ gal/min})(1{,}440\text{ min day})}{7.48\text{ gal/ft}^3}$$
$$=1.93\times10^5\text{ ft}^3\text{/day}$$

$$q/Q=1.30\times10^5/1.93\times10^5=0.67$$

$$1-q/Q=1.00-0.67=0.33.$$

From figure 1, curve $1-q/Q$

$$t/sdf=2.7,$$

$$t=(2.7)\ (7.5)=20\text{ days.}$$

Therefore, the rate of stream depletion will exceed 1.5 ft^3/sec after 20 days pumping at 1,000 gal/min.

Part 3

From "Part 1," $q/Q=0.845$.

$$Q=q/0.845$$
$$=(1.30\times10^5\text{ ft}^3\text{/day})/0.845$$
$$=1.54\times10^5\text{ ft}^3\text{/day}$$
$$=800\text{ gal/min.}$$

Therefore, if pumping were reduced to 800 gal/min, the rate of stream depletion would not exceed 1.5 ft^3/sec during the first 90-day period of pumping.

However, the residual effects of this pumping would carry over through the next pumping period.

The residual effect of the first pumping period on rate of stream depletion at the end of the second period, assuming no pumping during the second period, is as follows:

$$t_p+t_i=90\text{ days}+365\text{ days}=455\text{ days.}$$

$$\frac{t_p+t_i}{sdf}=61,\ t_i/sdf=49.$$

From figure 1,

$$(1-q/Q)_{p+i}=0.073,$$

$$(1-q/Q)_i=0.081,$$

and

$$q/Q=0.008.$$

Thus the rate of depletion is

$$q=(0.008)\ (1.54\times10^5\ \text{ft}^3/\text{day})$$
$$=1{,}230\ \text{ft}^3/\text{day}$$
$$=0.014\ \text{ft}^3/\text{sec}.$$

The effects are very slight. Pumping 800 gal/min during the second pumping period would exceed the allowable stream depletion rate by only 0.014 ft^3/sec. Reduction of the pumping rate to about 750 gal/min would keep rate of stream depletion below 1.5 ft^3/sec during several successive pumping seasons.

Mathematical Bases for Curves and Tables

The literature concerning the effect of a pumping well on a nearby stream contains several equations and charts that, although superficially greatly different, yield identical results. The basic curves and table (Curves *A* and *B*, and table 1) of this report can be derived from any of the published expressions. A cursory review of some of the pertinent equations may be useful to those interested in the mathematics.

Definitions

The notation that has been used in the literature is even more diverse than the published equations; consequently, definitions of only selected terms are given below. Complete definitions of all terms used are in the indicated references.

erf x=the error function of x

$$=\frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt=1-\text{erfc}\,x$$

erfc x=the complementary error function of x

$$=\frac{2}{\sqrt{\pi}}\int_x^\infty e^{-t^2}dt$$

i^2erfc x=the second repeated integral of the error function.

The line source integral (Maasland and Bittinger, 1963, p. 84)

$$=\sqrt{\pi}\int_{x/\sqrt{4h^2t}}^\infty \frac{e^{-u^2}du}{u^2}$$

In the notation used in the main body of this report,

$$x/\sqrt{4h^2t}=\sqrt{\frac{sdf}{4t}}$$

Definitions and tabular values of erf x ,erfc x, and i^2erfc x are shown by Gautschi (1964, p. 297, 310–311, 316–317). Tabular values of the line source integral are shown by Maasland and Bittinger (1963, p. 84) and by Glover (1964, p. 45–53).

Mathematical base for curve A

Curve *A* and its coordinates in table 1 can be computed from Theis (1941), Conover (1954), and Theis and Conover (1963)

$$P=\frac{2}{\pi}\int_0^{\pi/2} e^{-k\sec^2 u}du \tag{1}$$

from Glover and Balmer (1954)

$$q/Q=1-P(x_1/\sqrt{4\alpha t}) \tag{2}$$

from Glover (1960)

$$q_1/Q=1-\frac{2}{\sqrt{\pi}}\int_0^{x_1/\sqrt{4\alpha t}} e^{-u^2}du \tag{3}$$

and from Hantush (1964, 1965)

$$Q_r=Q\text{erfc}\ (U) \tag{4}$$

Theis transformed his basic integral into equation 1 because the basic integral is laborious to evaluate, but in the form of equation 1, is amenable to either numerical or graphical solution. Equations 2, 3, and 4 are identical, and in the notation used in this paper are

$$q/Q=\text{erfc}\left(\sqrt{\frac{sdf}{4t}}\right)=1-\text{erf}\left(\sqrt{\frac{sdf}{4t}}\right). \tag{5}$$

Mathematical base for curve B

Curve B and its coordinates in table 1 can be computed either by integration of curve A or of the equations that are the base of curve A. Analytical integration of equations 2 and 3 is shown by Glover (1960) as

$$\int_0^t \frac{q_r}{Q}\,dt = 1 - \frac{2}{\sqrt{\pi}}\int_0^{x_1/\sqrt{4\alpha t}} e^{-u^2}du - \frac{2}{\pi}\left(\frac{x_1^2}{4\alpha t}\right)\sqrt{\pi}\int_{x_1/\sqrt{4\alpha t}}^{\infty}\frac{e^{-u^2}}{u^2}\,du \quad (6)$$

and equation 4 is integrated by Hantush (1964, 1965)

$$v_r = \int_0^{t_0} Q_r\,dt = 4Qt_0 \mathrm{i}^2\,\mathrm{erfc}\,(U_0) \quad (7)$$

In the notation used in this paper, equation 6 is

$$\frac{v}{Qt} = 1 - \mathrm{erf}\left(\sqrt{\frac{sdf}{4t}}\right) - \frac{2}{\pi}\left(\frac{sdf}{4t}\right)\sqrt{\pi}\int_{\sqrt{\frac{sdf}{4t}}}^{\infty}\frac{e^{-u^2}}{u^2}\,du \quad (8)$$

and equation 7 is

$$\frac{v}{Qt} = 4\mathrm{i}^2\,\mathrm{erfc}\left(\sqrt{\frac{sdf}{4t}}\right). \quad (9)$$

Equations 8 and 9 both can be expressed in terms extensively tabulated in Gautschi (1964, p. 310–311) as

$$\frac{v}{Qt} = \left(\frac{sdf}{2t}+1\right)\mathrm{erfc}\left(\sqrt{\frac{sdf}{4t}}\right) - \left(\sqrt{\frac{sdf}{4t}}\right)\frac{2}{\sqrt{\pi}}\exp\left(-\frac{sdf}{4t}\right) \quad (10)$$

Before discovering equations 6 and 7, the writer integrated curve A both numerically and graphically. The results were identical, within the limitations of the methods, to those obtained from equation 10.

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☆ U.S. Government Printing Office: 1977—240-961/125

Appendix D

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Nebraska Water Science Center
5231 South 19 Street
Lincoln, NE 68512-1271

November 2, 2005

Ann S. Bleed, Acting Director
Nebraska Department of Natural Resources
P.O. Box 94676
Lincoln, NE 68509-4676

Dear Ann:

The U.S. Geological Survey Nebraska Water Science Center (NWSC) acknowledges the State of Nebraska Department of Natural Resources (NDNR) request for review of "Stream Depletion Line Calculations for Determination of Fully Appropriated Basins for the State of Nebraska". We were pleased to perform this task for NDNR. I assigned this review to Richard Luckey, Gregory Steele, and Steve Peterson, who are NWSC hydrologists experienced with the development of numerical models that describe ground water/surface water interactions.

The NWSC reviewers found the document to be technically sound, but have made suggestions to improve the final product. Copies of the reviewers notes and list of their recommendations are enclosed. Please feel free to contact me directly at (402) 328-4110 if we can be of further assistance.

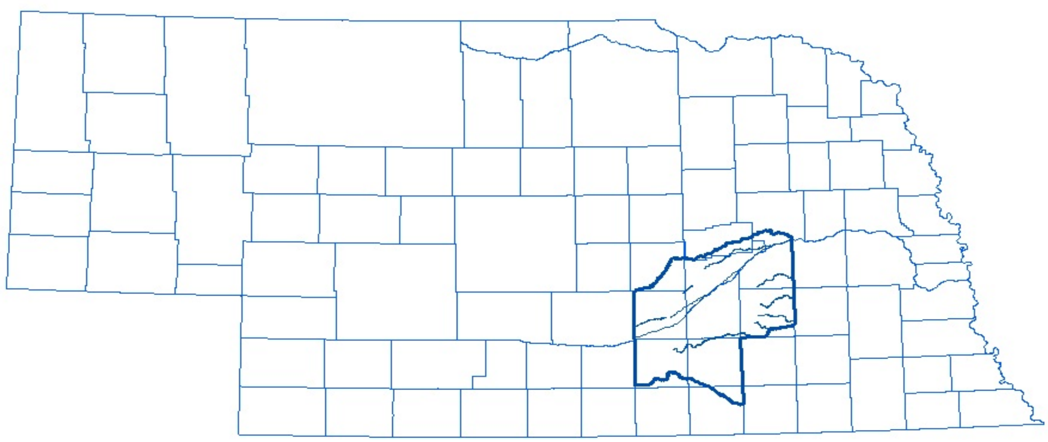
Sincerely,

Robert B. Swanson
Director

Enclosure

Appendix E

A GROUNDWATER MODEL TO DETERMINE THE AREA WITHIN THE UPPER BIG BLUE NATURAL RESOURCES DISTRICT WHERE GROUNDWATER PUMPING HAS THE POTENTIAL TO INCREASE FLOW FROM THE PLATTE RIVER TO THE UNDERLYING AQUIFER BY AT LEAST 10 PERCENT OF THE VOLUME PUMPED OVER A 50-YEAR PERIOD



Prepared By
R.J. Bitner, P.E.
Upper Big Blue Natural Resources District

September 2005

ACKNOWLEDGMENTS

The following persons provided assistance with inputs and reviews that were incorporated into the model and final report:

Courtney Hemenway, P.E., Hemenway Groundwater Engineering, Inc., provided a peer review of the model development, model inputs, model application, and report to ensure that these components are developed in accordance with acceptable standards.

Duane Woodward, Hydrologist, Central Platte Natural Resources District, reviewed the model and inputs for consistency with COHYST standards. Duane also assisted with evaluating recent river bed conductance data that was incorporated into the model.

Steve Peterson, Hydrologist, U.S. Geological Survey, assisted with implementation of the EMSI[1] GMS[2] modeling techniques.

Jim Cannia, Nebraska Department of Natural Resources, reviewed the model and model inputs regarding suitability for determining hydrologic connectivity of streams with the aquifer.

Marie Krausnick, Upper Big Blue Natural Resources District, provided assistance with GIS mapping.

Xun Hong Chen, Ph.D. and *Mark Burhach, Ph.D.*, University of Nebraska Conservation and Survey Division, provided Geoprobe electric logging, permeameter testing, and pump tests to estimate aquifer hydraulic conductivity and river bed conductance on the Platte River and Big Blue River.

Larry Cast, Geologist, reviewed test hole and irrigation well drilling logs to determine geologic and hydrologic properties of the layers used to define the aquifer.

Rich Kern, P.E., Hydrologist / Programmer, Nebraska Department of Natural Resources, provided computer programming of utilities to assist with database management, grouping geologic layer parameters, retrieving data from the DNR databases, and analysis of GMS - MODFLOW outputs.

COHYST Modelers[3], developed the COHYST Eastern Regional groundwater model from which this sub-regional model is derived.

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[1] EMSI is an acronym for “Environmental Modeling Systems, Inc.”

[2] GMS is an acronym for “Groundwater Modeling System”.

[3] COHYST is an acronym for “ Cooperative Hydrology Study”.

AUTHORIZATION

The groundwater model discussed in this report was commissioned by the Upper Big Blue Natural Resources District for the purpose of estimating the location of areas within the Natural Resources District that have the potential to be hydrologically connected to base-flow streams. The groundwater model and modeling results, shown in this report, have been presented to the Natural Resources District Board, and have been approved for submittal to the Nebraska Department of Natural Resources.

HGE
Hemenway Groundwater Engineering, Inc.

September 29, 2005

NE-0010-05

Mr. Jay Bitner
District Engineer
Upper Big Blue Natural Resources District
105 Lincoln Avenue
York, NE 68467

Dear Jay:

Subject: Groundwater Model Review for the Upper Big Blue Natural Resources District (UBBNRD)

As you requested, Hemenway Groundwater Engineering, Inc. (HGE) is pleased to submit this letter documenting the consulting services provided for the UBBNRD regarding your ongoing groundwater model development. HGE's Scope of Work (SOW) for consulting services was related to the review of the current groundwater computer model for the UBBNRD. The model is a sub-regional model of the area covered by the Eastern Model Unit (EMU) developed by the Nebraska Cooperative Hydrology Study (COHYST). The model utilizes the Groundwater Modeling System (GMS) pre- and post-processor modeling system and the United States Geological Survey (USGS) finite difference model MODFLOW 2000. The grids in the model are 1,320 feet by 1,320 feet or 40 acres per model grid, which is a refinement of the COHYST EMU model grid size of 2,640 feet by 2,640 feet. The focus of the UBBNRD model is to determine the depletion to the Platte River from wells, which represents 10 percent flow from the river after 50 years of well pumping. To determine the depletions, a baseline transient model was run without any wells pumping. Following the baseline run, the model was run numerous times with one well pumping at a new location at each model run. The depletions were calculated after each model run as a function of the distance of the well from the Platte River, and the 10 percent depletion line was mapped.

The services provided by HGE included reviewing the current UBBNRD groundwater model for "fatal flaws" and providing recommendations for improving and modifying the model to meet the intended purposes by the UBBNRD. HGE's recommendations were accepted and implemented by UBBNRD in the current groundwater model. The UBBNRD provided additional studies and information, model refinements, and improvements to the current COHYST EMU groundwater model. With these revisions and improvements, the current UBBNRD groundwater model meets the industry standards for groundwater modeling practices.

17011 Lincoln Avenue, PMB 416
Parker, Colorado 80134
Phone: 303-805-1750
Fax: 303-805-1850
EMAIL: CHEMENWA@SNI.NET

HGE looks forward to the opportunity to work with you and the UBBNRD in the future. If you have any questions regarding this letter or HGE's review of the UBBNRD groundwater model, please do not hesitate to contact me.

Sincerely,

Hemenway Groundwater Engineering, Inc.

Courtney Hemenway
President

HGE/UBBNRDGWMODELREVLET

TABLE OF CONTENTS

INTRODUCTION

This report discusses development and application of a groundwater model for a region that lies within the boundary of the Cooperative Hydrology Study (COHYST) eastern regional groundwater model[4] in Nebraska. The geographic area modeled is shown on Figure 1 and includes all, or portions of, Platte, Polk, York, Nance, Merrick, Hamilton, Clay, Nuckolls, Howard, Hall, and Adams Counties. The modeled area overlays portions of the Upper Big Blue, Central Platte, and Little Blue Natural Resources Districts. The total land surface within the model boundary is approximately 7,520 square miles (4.8 million acres).

PURPOSE

The purpose of this model is to provide a method for calculating the potential increase in the rate of flow from the Platte River to the underlying aquifer due to groundwater pumping near the Platte River within the Upper Big Blue Natural Resources District. The model is used to define a boundary encompassing the area within which a well pumping groundwater could increase flow from the Platte River to the underlying aquifer by an amount equal to, or greater than, 10 percent of the volume pumped over a period of 50 years. For purposes of determining whether or not a river basin is *fully appropriated* [5], the Nebraska Department of Natural Resources considers that wells within the 10 percent / 50-year boundary are hydrologically connected to the river.

CONCEPTUAL MODEL

The model boundaries are defined with a series of *fixed flow* arcs that specify flow into or out of the model, depending upon the direction and slope of the groundwater gradient at the boundary. The Platte River is defined with a series of *river* arcs which specify the river bed conductance, river bed thickness, and river stage. The model cells intersected by the river arcs are defined by the model as a series of point source river cells, each with its own conductance value. The model cells intersected by the fixed flow boundary arcs are defined by the model as a series of wells that are either source (injection) or sink (withdrawal), depending on whether the

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4 S. M. Peterson, *Groundwater Flow Model of the Eastern Model Unit of the Nebraska Cooperative Hydrology Study (COHYST) Area*, 2005.

5 Nebraska Department of Natural Resources, Proposed Rule pursuant to Neb. Rev. Stat. §46-713.

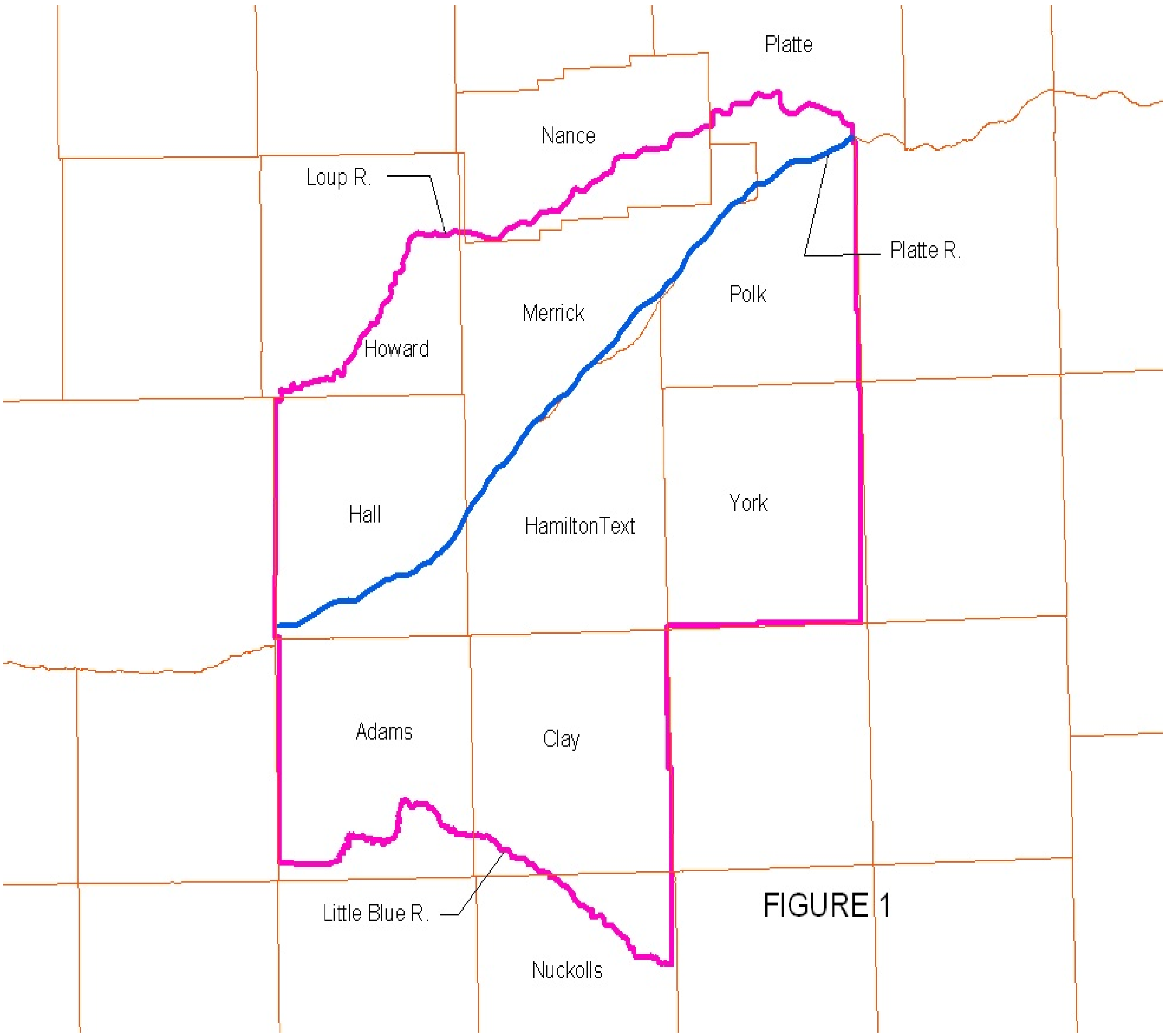
Platte
Nance
Loup R.
Platte R.
Polk
Merrick
Howard
Hall
HamiltonText
York
Adams
Clay
Little Blue R.
Nuckolls

FIGURE 1

boundary flow is into or out of the model at that point. The amount of river to aquifer flow induced by pumping is tested with a single well, which is moved from cell to cell parallel to the Platte River, at varying distances from the river. Other streams within the model boundary, such as the Big Blue River and its tributaries, including the West Fork Big Blue River, Lincoln Creek, and Beaver Creek, are not included in the model. The bed conductances of these rivers and streams are very low, approximately 0.0079 ft^2/day, and have minimal connectivity to the underlying aquifer[6] and the Platte River. Areal sources and sinks included in this model are recharge from precipitation, and evapotranspiration from rooted plants located in wet meadows near the Platte River. The model geology is represented by five unconfined layers. The numerical flow model is based on the following basic assumptions:

- At the scale in which this model is constructed, flow in the aquifer obeys Darcy's Law and mass and energy are conserved.
- Since the modeled fluid is groundwater, having a temperature in the range of 50 degrees Fahrenheit, the density and viscosity of water are constant over time and space.
- Parameters are uniform within each cell, and represent an estimate of their average value within the cell.
- The interchange of water between the aquifer and Platte River can be adequately simulated as one-dimensional flow through a discrete streambed layer. This conceptualization is appropriate over the scale at which this model is constructed.
- Hydraulic conductivity in the horizontal plane is isotropic; however, hydraulic conductivity in the vertical direction is not equal to hydraulic conductivity in the horizontal direction. The horizontal to vertical anisotropic ratio is assigned a value of 10 (i.e. horizontal hydraulic conductivity is ten times greater than vertical hydraulic conductivity), unless otherwise noted.

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6 Xun Hong Chen, *River Bed Conductance Studies - West Fork Big Blue River and Platte River in Nebraska*, University of Nebraska Conservation and Survey Division, 2005.

GEOLOGIC AND HYDROSTRATIGRAPHIC UNITS

The model has five unconfined geologic layers. The layer definitions are consistent with those documented in the COHYST aquifer characterization report[7]. The model layers consist primarily of Quaternary deposits of Pleistocene alluvium, Pleistocene and Holocene loess, Holocene dune sand, and Holocene valley fill. Valley fill deposits are found along the Platte River and consist of gravel, sand, and silt. Alluvial deposits, which typically support high capacity wells, are found throughout the model area. In topographic bedrock highs these deposits are generally thinner, and produce lower yielding wells. Loess deposits are found throughout the model area, and the thickest deposits are located along the Platte River bluffs. The deposits become thinner as they approach the Platte River north of the loess bluffs. The Platte River bed contains a low permeability loess layer at about 10 to 20 feet below the current streambed surface[8]. The bedrock formation at the bottom of Layer 5 consists of shale, chalk, limestone, siltstone, and sandstone of Cretaceous age. These bedrock materials transmit very little water, and for modeling purposes are considered to be impermeable.

The model layers are numbered 1 through 5. Unit 1 is the top layer, and Unit 5 is the bottom layer. The layers used in this model are described as follows:

- Layer 1 — Top layer consisting of upper Quaternary age silt and clay with some sand and gravel
- Layer 2 — Middle Quaternary age sand and gravel
- Layer 3 — Lower Quaternary age silt and clay with some sand and gravel
- Layer 4 — Upper Tertiary age silt and clay with some sand and gravel
- Layer 5 — Middle Tertiary age sand and gravel underlain with bedrock materials consisting of shale, chalk, limestone, siltstone, and sandstone

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7 J. C. Cannia, D. Woodward, L. Cast, and R. L. Luckey, Cooperative Hydrology Study COHYST Hydrostratigraphic Units and Aquifer Characterization Report, November 2004.

8 See geoprobe electric logs shown in Appendix B

MODEL DESCRIPTION

The groundwater model is a three-dimensional finite difference computer model developed around the MODFLOW[9], Version 2000, groundwater modeling software enclosed within EMSI GMS[10], Version 5.1. The GMS software includes a pre-processor to read input data and place it in the model according to MODFLOW format requirements. GMS also does some post-processing of output in both graphical and numerical forms. The units of measure used in this model include feet for linear measure, days for time, feet per day for velocity, cubic feet for volume, and cubic feet per day for flow rate.

Model Grid

The model grid has 120,330 cells per layer. Each cell measures 1,320 feet per side, and covers an area of approximately 40 acres. Model feature locations are geo-referenced in the horizontal plane to the Nebraska State Plane Coordinate System, NAD 83 - feet. Top and bottom elevations of each layer are referenced to USGS mean sea level datum.

Modules

The MODFLOW software is modular in the sense that various modules (packages) can be activated for any particular modeling situation. The modules used in this model include river, well, recharge, and evapotranspiration.

River Module

The Platte River is simulated in this model as a series of arcs, connected at their upstream and downstream ends at nodes, with a combined length of 87.8 miles. Attributes associated with the arcs and nodes specify the river bed conductance, bottom of river bed elevation, and river stage. The hydrologic properties (K, S_y) of model cells identified as river cells (cells crossed by river arcs), and located in Layer 1, are adjusted to match the hydrologic properties of the underlying cell in Layer 2. In this way there is a direct connection of the Platte River bed to the aquifer, and the only limitation on inter-connectivity between the river bed and underlying

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9 M. G. McDonald and A.W. Harbaugh, *Modular Three-Dimensional Finite-Difference Groundwater Flow Model*, U.S. Geological Survey, 1984.

10 *Groundwater Modeling System (GMS)*, Environmental Modeling Systems, Inc. (EMSI), Park City, Utah.

aquifer is river bed conductance. River bed conductance is a function of river bed length, width, bed thickness, and hydraulic conductivity. MODFLOW uses the following equation[11] to calculate bed conductance:

EQ. 1 $$C = (k \times L \times W) / M$$

For each river arc "n":

C_n = streambed conductance ($ft^2/d/ft$)

k_{vn} = vertical hydraulic conductivity of the streambed (ft/d)

L_n = length of the streambed (ft)

W_n = width of streambed (ft)

M_n = thickness of streambed (ft)

For this model, the value of river bed conductance at each river arc is set at the same value as used in the COHYST Eastern Regional Model, except where detailed testing indicates the value should be different. The values established by testing were determined based on geoprobe and permeameter tests conducted by the University of Nebraska Conservation and Survey Division. Geoprobe electric logs, hydraulic conductivities, and bed conductance calculations are shown in Appendix B of this report. Platte River bed conductances used in this model are set at 11 $ft^2/d/ft$ in reaches where testing is completed. River bed conductances in the remaining reaches vary from 20 $ft^2/d/ft$ to 30 $ft^2/d/ft$.

Well Module

The potential increase in induced flow from the Platte River to the underlying aquifer, due to groundwater pumping near the Platte River, is tested with this model by placing a simulated pumping well at alternate cell locations, operating the model for a 50-year period at each location, and calculating the change in the water budget when compared with the baseline condition. The initial baseline condition is simulated with no pumping well.

For these simulations, pumping is assumed to be from Layer 2, the volume of water

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11 *Documentation of a Computer Program to Simulate Stream-Aquifer Relations Using a Modular, Finite Difference, Groundwater Flow Model*, U.S. Geological Survey, Open-File Report 88-729, 1989.

pumped is set at 160 acre-feet per year, and the pumping rate is set to be continuous at 19,094.79 cubic feet per day. This volume of groundwater is approximately the average amount of water pumped in one year to irrigate a quarter section of crop. A gravity irrigated system would pump slightly more volume on average, and a pivot irrigated system would pump slightly less volume on average, based on the District's records of irrigation water use. Although irrigation systems typically operate at a higher pumping rate, are operated on an intermittent pumping schedule, and only operate for a few months per year, a continuous lower pumping rate is used to simplify the modeling process. The volume of water pumped per year would be the same with either continuous or transient pumping schedules. The continuous pumping schedule is not expected to give significantly different results than a transient pumping schedule would yield. Some comparisons of continuous and transient pumping were made to confirm this conclusion.

Recharge Module

Recharge is modeled as an areal source of inflow to the aquifer, and includes the amount of precipitation that percolates from the surface through Layer 1 into Layer 2. The recharge rate used in this model, in feet per day, is interpolated from the COHYST Eastern Model, pre-development period, scatter point data set. The scatter point file is derived from the COHYST EMU model and interpolated to this model's 2-dimensional grid. The 2D data set is imported to the MODFLOW model recharge array. The recharge point of application option is set to the highest active layer at each grid cell. For this model, the minimum recharge rate is 0.000222 feet per day (0.97 inches per year), and the maximum rate is 0.000557 feet per day (2.44 inches per year). The mean rate is 0.000222 feet per day (0.972 inches per year). The recharge rate is held constant throughout the modeled time period, and does not vary from stress period to stress period.

Evapotranspiration Module

Evapotranspiration (ET) is modeled as the amount of groundwater extracted from the aquifer by rooted vegetation, and then evaporated from the plant canopy to the atmosphere external from the model. For this model ET is considered to be an areal sink; i.e., outflow from the model space. The ET rate data set used in this model is interpolated from the COHYST Eastern Model pre-development data set. A scatter point file is produced from the COHYST

EMU model and interpolated to this model's 2-dimensional grid. The 2D data set is then imported to the MODFLOW model ET array. The point of ET withdrawal is the top of Layer 1, and the extinction depth is set at a specified depth (nominally 7 feet) below the top of Layer 1. For this sub-regional model, the minimum ET rate is 0.00 feet per day, and the maximum rate is 0.002993 feet per day (13.1 inches per year). The rate of evapotranspiration is held constant throughout the modeled time period, and does not vary from stress period to stress period.

Wetland areas, mostly located near the Platte River, are treated as groundwater sinks, where groundwater can be removed from the model space by plant evapotranspiration. The evapotranspiration rate, extinction depth, and active ET layer are interpolated to the model 2D grid from COHYST EMU scatter point data sets. Areas that have potential for significant evapotranspiration are selected using 1997 land use mapping data for wetlands (Dappen and Tooze, 2001), and also by defining areas where the depth to groundwater is on average 7 feet or less below land surface, according to USGS long-term depth to water data (U.S. Geological Survey National Water Information System, 1999).

Boundary Conditions

The model is bounded vertically by land surface at the top of Layer 1 and bedrock at the bottom of Layer 5. The model is bounded horizontally by fixed flow boundaries. A fixed flow boundary is a boundary where the flow is specified prior to the simulation and held constant throughout the simulation (McDonald and Harbaugh, 1988). At fixed flow boundaries the simulated water level can change, but flow across the boundary does not change. The northern model boundary is aligned with the Loup River and the southern boundary is aligned with the Little Blue River and southern boundary of Adams County. The eastern model boundary is aligned with the eastern boundaries of York and Polk Counties, and the western boundary is aligned with the western boundaries of Hall and Adams Counties, as shown on Figure 1. The rate of flow through each model boundary, in cubic feet per day, is calculated using the Darcy Equation.

EQ. 2 $$Q_n = k_n \times i_n \times A_n$$

For each boundary arc "n"

Q_n = fixed rate of flow through the boundary, ft^3/d

k_n = weighted horizontal hydraulic conductivity, ft/d

i_n = gradient of the 1950 groundwater surface perpendicular to the boundary flow plane, ft/ft

A_n = cross sectional area of the flow plane at the boundary, ft^2

Each layer's thickness determines the relative weight given to each layer's hydraulic conductivity for this calculation. The calculated boundary flow is distributed evenly over the saturated thickness between the groundwater level and the base of the aquifer at each boundary arc. Appendix A contains calculations and supporting documents used to compute boundary fixed flows. A boundary flow is not computed for Layer 1, since it is a silty clay layer generally representing the unsaturated zone which overlays the saturated zone.

Model Flow Simulation

The MODFLOW software has several packages (BCF, LPF, and HUF) available for calculating conductance coefficients and groundwater storage parameters to be used in the finite-difference equations that calculate flow between cells. The Layer Property Flow (LPF) package is selected as the internal flow calculation methodology for this model. The LPF package reads input data for hydraulic conductivity and global top and bottom elevation data for each cell (layer). Transmissivity is calculated for each cell at the beginning of each iteration of the flow equation matrix solution process. The LPF package calculates leakance between layers using the vertical hydraulic conductivity, based on estimated anisotropic ratio K_x/K_z, and distance between nodes obtained from global elevation data.

Flow Equation Solver

The MODFLOW software has several linear differential equation "solver" packages (SIP1, PCG2, SCR1, and GMG) available. For this model, the pre-conditioned conjugate-gradient[12] (PCG2) package is selected to solve the linear finite difference equation matrix. For a transient groundwater model, the solution matrix is expressed as shown in EQ. 3, where [A] is the coefficient matrix, [x] is a vector of hydraulic heads, and [b] is a vector of defined flows, associated with head-dependent boundary conditions and storage terms at each grid cell.

EQ. 3 $$[A] \bullet [\vec{x}] = [\vec{b}]$$

The matrix is solved iteratively until both head-change and residual convergence criteria are met. The convergence criteria are too large if the global groundwater flow budget discrepancy is unacceptably large. In general, a global budget discrepancy less than one percent is considered acceptable. Convergence criteria for this model, specified in the input options for the PCG2 module, are 0.5 foot for heads and 10.0 ft^3/d for flow residual. The iteration parameters are not specified, but rather are calculated internally.

Aquifer Characteristics

Aquifer properties are input for each layer, including horizontal hydraulic conductivity (K_x), vertical anisotropic ratio (K_x/K_z) or vertical hydraulic conductivity K_z, horizontal anisotropic ratio (K_x/K_y), Specific Storage (S_s), and specific yield (S_y). The procedures used to estimate parameter values for each layer are described in the COHYST hydrostratigraphic Units Characterization Report[13].

Hydraulic Conductivity K_x

Test well logs, interpreted by Reed and Piskin[14], are the basis for horizontal hydraulic conductivity values used in this groundwater model and the COHYST eastern regional model. The interpreted values for each layer are weighted according to layer thickness, and the weighted average value of K_x is then determined for each model layer at each test well location. The

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12 P. Concus, G. H. Golub, and D. P. O'Leary, A Generalized Conjugate Gradient for the Numerical Solution of Elliptical Partial Differential Equations, Academic Press, 1976.

13 J. C. Cannia, D. Woodward, L. Cast, and R. L. Luckey, *Cooperative Hydrology Study COHYST Hydrostratigraphic Units and Aquifer Characterization Report*, November 2004.

14 E. C. Reed and R. Piskin, unpublished report, University of Nebraska Conservation and Survey Division.

process used to weight the values is written in a computer code called *Geoparm*[15]. A 2D data set is then created by interpolating the computed values. The 2D data set is then used to set the MODFLOW array of values for each layer.

Anisotropic Ratios

As described previously in this report, the vertical anisotropic ratio, K_x/K_z , is estimated to be 10.0 for all layers at each grid cell, unless pump testing indicates a different ratio, and the horizontal anisotropic ratio, K_x/K_y, is estimated to be 1.0.

Specific Yield S_y

Data compiled by USGS, and summarized by Reed and Piskin, is the basis for specific yield values used in this groundwater model and the COHYST eastern regional model. As discussed in the Hydrostratigraphic Units Report, specific yield values are interpreted for each layer material classification. The interpreted values are then weighted using the Geoparm program to establish specific yield for each model layer at each test well location. The computed values are then interpolated to the model's 2D grid for each model layer. The 2D data sets are then used to set the MODFLOW array values for each layer.

Specific Storage Ss

All layers in this model are considered to be unconfined; however, the LPF simulation options available in MODFLOW are either confined or convertible. The convertible option is selected for all layers, and the specific storage for all layers, except Layer 1, is set to $2.1e^{-3}$; this value is based on discussions with UNL Conservation and Survey[16] and takes into account low potential for changes in aquifer storage due to height of overburden or changes in hydraulic head. The specific storage for Layer 1 is set to 0.16, the estimated specific yield, since this layer is always unconfined, and cannot be converted to confined.

Specific storage is the volume of water per unit volume of *confined* saturated aquifer that is absorbed, or expelled, due to changes in pressure within the aquifer. Overburden tends to

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15 R. Kern, *Nebraska Cooperative Hydrology Study Computer Program Documentation GeoParam - Hydraulic Conductivity from Well Logs*, Nebraska Department of Natural Resources.

16 Personal communication with Xun Hong Chen, University of Nebraska, Conservation and Survey Division.

consolidate the aquifer (reduce storage volume), and hydraulic pressure head tends to offset consolidation (increase storage volume).

Storativity for a *confined* layer is equal to the product of specific storage and layer thickness. Storativity for an *unconfined* layer is equal to the specific yield plus the product of groundwater depth and specific storage.

PRE-DEVELOPMENT PERIOD

Geologic and hydrogeologic layer parameters used in this model are derived from calibrated COHYST eastern regional model (EMU) data. The EMU was calibrated for the pre-groundwater development period by varying and adjusting evapotranspiration, recharge, hydraulic conductivity, properties at horizontal flow boundaries, and streambed conductances. For this model the evapotranspiration, recharge and horizontal hydraulic conductivity are interpolated from EMU scatter point files. Streambed conductances and vertical hydraulic conductivities are adjusted at some locations based on recent testing conducted by the University of Nebraska Conservation and Survey. Fixed flows at boundaries are computed for each boundary arc as previously described. Observed water levels, measured between 1946 and 1955, are used to establish the starting head values.

Observed water levels used to establish starting heads are from a period of relatively stable conditions. Observation points were selected as being representative of pre-groundwater development, and only the most reliable data within 4-mile by 4-mile grid cells were selected (by COHYST modelers) for EMU calibration. This selection process prevents a cluster of closely spaced observation wells from dominating the calibration process. After screening values in all of the 4 by 4-mile cells, a few points that appeared to have large errors in location or land-surface elevation were excluded from the calibration data set. The starting heads file for this model is based on a sub-set of the EMU calibration data set that contains 209 of the observation points.

The ability of this model to represent a 50-year period of pre-groundwater development conditions is evaluated by comparing the percent discrepancy in global groundwater flow budget, as well as the mean difference, mean absolute difference, and root mean square of the differences between observed pre-development groundwater levels at the beginning and end of a 50-year computer run without well development.

Mean Difference

The mean difference (MD) of observed and simulated water levels is defined in EQ.4. The variable h_0 is the observed water level and h_s is the simulated water level at each of the n observation points. The mean difference is used here as a measure of overall bias in calibration, and as such should be close to zero at calibration.

EQ.4 $$MD = \frac{1}{n}\sum_{i=1}^{n}\left(h_0 - h_s\right)_i$$

Mean Absolute Difference

The mean absolute difference (MAD) of observed and simulated water levels is defined in EQ.5. The MAD is used here to evaluate the overall model calibration, since positive and negative differences do not cancel each other. All differences are given an equal weight, so a few measurements with large differences will not dominate the result.

EQ.5 $$MAD = \frac{1}{n}\sum_{i=1}^{n}\left|h_0 - h_s\right|_i$$

MODFLOW calculates the water level changes as draw-downs, therefore positive changes are declines and negative changes are rises.

Root Mean Square Difference

The root mean square difference (RMSD), also referred to as the quadratic mean, is defined in EQ. 6. This statistic is the standard deviation of the differences between observed groundwater levels and groundwater levels produced by the model, for the pre-development period. Assuming that the differences between observed and modeled water levels are normally distributed about the mean difference, the standard deviation gives a measure for determining the range within which the differences can be expected to occur. Statistically, 68.27% of the differences are expected to occur within MD ± RMSD, and 95.45% of the differences are expected to occur within MD ± (2)(RMSD).

EQ. 6 $$RMSD = \left[\frac{1}{n}\sum_{1}^{n}\left(h_s - h_0\right)_i^2\right]^{0.5}$$

PRE-DEVELOPMENT MODEL - WITHOUT PUMPING

Starting heads for the pre-development model are obtained by interpolating the observed pre-development water levels to the model 2D grid, which is then imported to the MODFLOW model starting head data set. The observation data points are also imported to the model so that heads computed by the model can be compared to the starting heads for the purpose of evaluating groundwater level changes over the 50-year period. Figures 2 and 3 show the locations of water level observation points, water level contours, and statistical variation at each observation point for the starting heads and 50-year model run. Statistical variations are shown in 10 feet increments; green indicates variation from 0 to 10 feet, yellow indicates variation from 10 to 20 feet, and red indicates variation from 20 to 30 feet. If the indicator is above the line, the computed water level is higher than observed, and if the indicator is below the line the computed water level is lower than observed at that observation point. The mean difference between observed and interpolated water levels, for both starting heads and 50-year model run, is 0.240 feet, the mean absolute difference is 1.376 feet, and the root mean square difference is 2.235 feet. Statistically it can be expected that approximately 95% of the differences between observed and computed water levels will occur within ± 2.235 feet of the mean difference.

The global groundwater inflow and outflow budgets, without well development, are shown in Tables 1 and 2 for the 50-year model run.

TABLE 1

MODEL INFLOW VOLUMETRIC BUDGET

Inflow From	Inflow Volume (KAF)	Inflow Rate (KAF / Yr.)	Percent of Inflow (%)
Storage	19,088	382	52.1
Fixed Flow Boundary	2,324	46	6.4
Platte River	4,388	88	12.0
Recharge	10,781	216	29.5
Total Inflow	36,580	732	100

TABLE 2

MODEL OUTFLOW VOLUMETRIC BUDGET

Outflow From	Outflow Volume (KAF)	Outflow Rate (KAF / Yr.)	Percent of Outflow (%)
Storage	22,196	444	60.7
Fixed Flow Boundary	5,599	112	15.3
Platte River	106	2	0.3
Evapotranspiration	8,681	174	23.7
Total Outflow	36,582	732	100

For the 50-year no well development scenario, the model calculates flow from the Platte River to the underlying aquifer at an average rate of 86 acre-feet per year within the model boundaries. This river to aquifer flow, without pumping, is the baseline for computing induced river to aquifer flow due to groundwater pumping. The global groundwater flow budget discrepancy is less than 0.01 percent.

HYDROLOGICALLY CONNECTED AREA

The portion of the Upper Big Blue Natural Resources District that is considered to be "hydrologically connected" to the Platte River, is that area contained between the Platte River, the Upper Big Blue NRD boundary, and the 10% / 50 year line. Groundwater pumping wells contained within this area are determined by the model to have the potential for inducing additional flow from the Platte River to the underlying aquifer by an amount of at least 10 percent of the volume pumped over a 50-year period. The increase in flow from the river to the aquifer is presented in terms of the "global" model volumetric budget; i.e., the water pumped from the well causes an increase in the mass of water moving from the river to the aquifer, but does not address the transport issues, such as source path or age of water pumped.

A baseline model run, without a pumping well, establishes the volume of water moving from the river to the aquifer due to non-pumping gradients. Independent model runs are then made for each new location of the single pumping well. The well is placed at the center of a grid

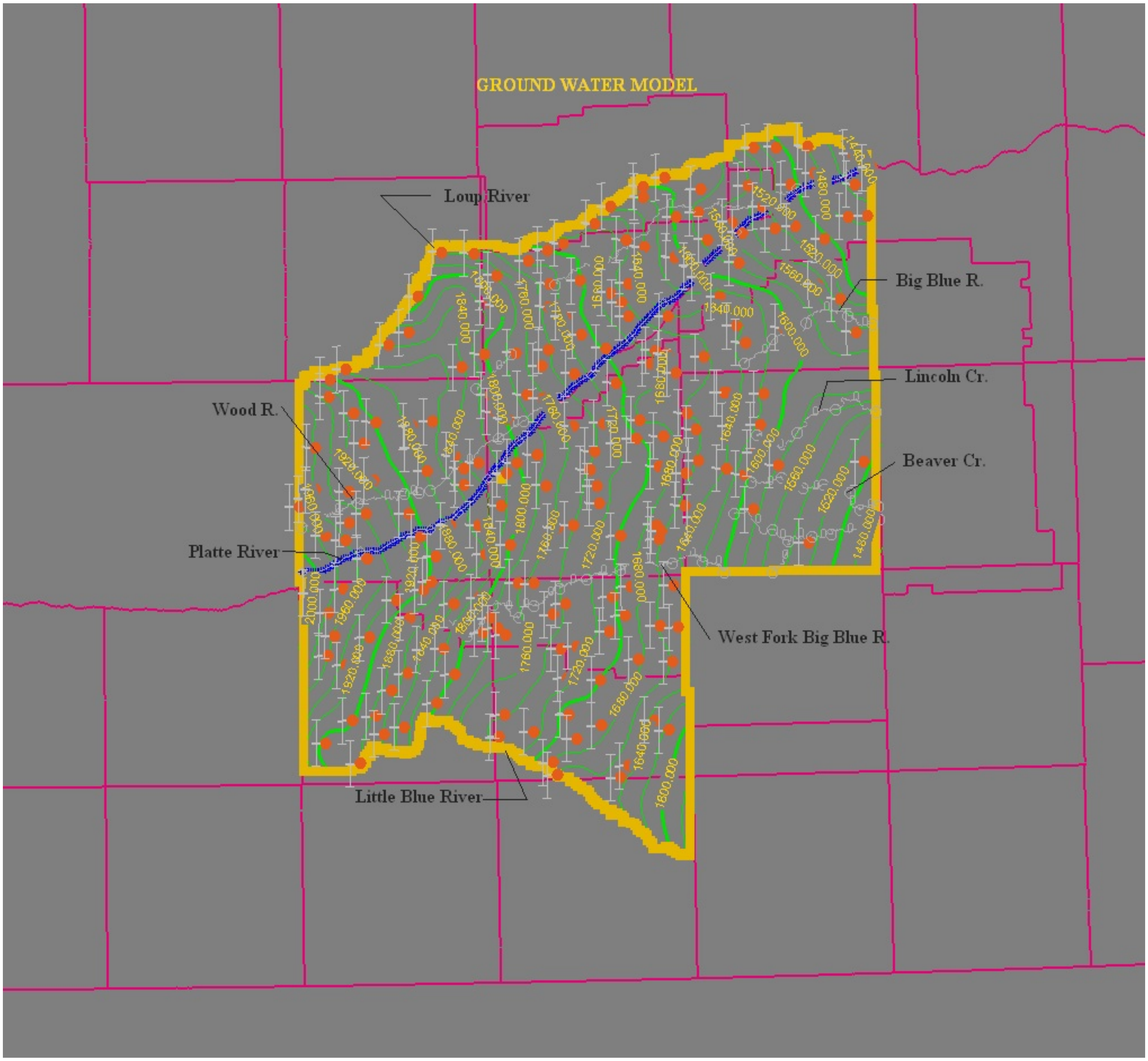


FIGURE 2

PRE-DEVELOPMENT G.W. LEVELS

STARTING HEADS

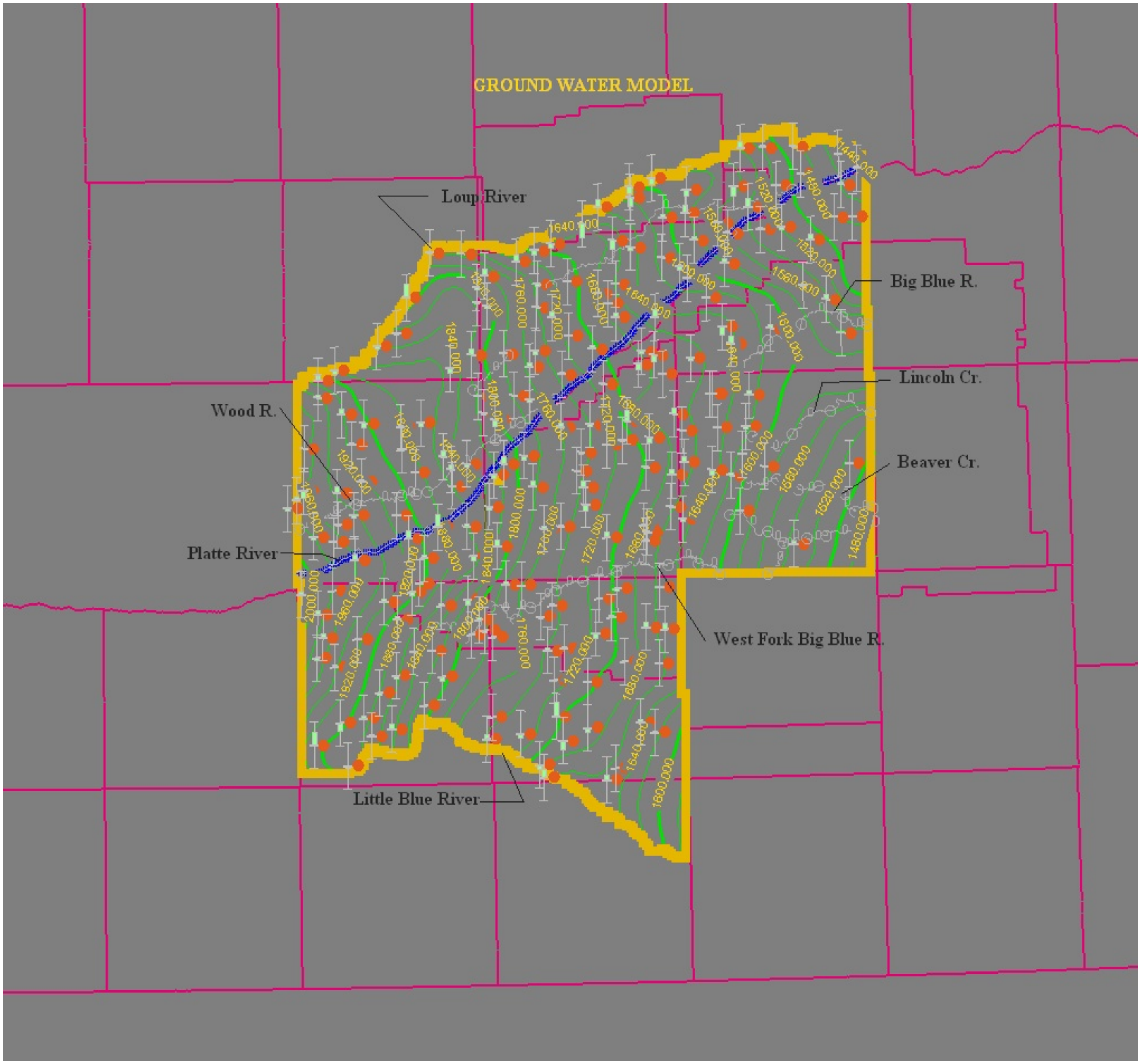


FIGURE 3

FIFTY YEAR MODEL G.W. LEVELS

CHANGES AT OBSERVATION WELLS

cell, and the well screen is assumed to be in Layer 2 for each run. The global volumetric budgets at the end of the 50th stress period are compared with and without pumping, and the difference in river flow into the model is used to determine the volume of water induced from the river to the aquifer due to pumping.

10% / 50-Year Boundary Determination

The 10% / 50-year boundary is determined by evaluating groundwater pumping along transects, spaced approximately 1 mile apart and perpendicular to the Platte River. Transect cells that lie on either side of the boundary line are interpolated linearly to determine the actual coordinates[17] of the boundary line on each transect. Table 3 is a summary of coordinates used to establish the 10 / 50 boundary line within the Upper Big Blue NRD. Figures 4 and 5 are graphical representations of the 10% / 50-year boundary line location.

TABLE 3

10% / 50-YEAR BOUNDARY WITHIN THE UPPER BIG BLUE NRD

STATE PLANE COORDINATES

Easting	Northing
2115914.5307	368243.7495
2119524.3678	373861.1446
2122067.5150	377912.3125
2124670.4467	383220.1545
2128158.4452	387639.9242
2132229.2680	391476.8695
2135624.8026	395989.1030
2139012.1417	400512.5376
2140957.5416	402519.5190
2145105.3989	406279.4298
2149493.4078	411118.6532
2153212.8089	415307.0203

17 Coordinate system is North American Datum, 1983, Nebraska State Plane, Feet.

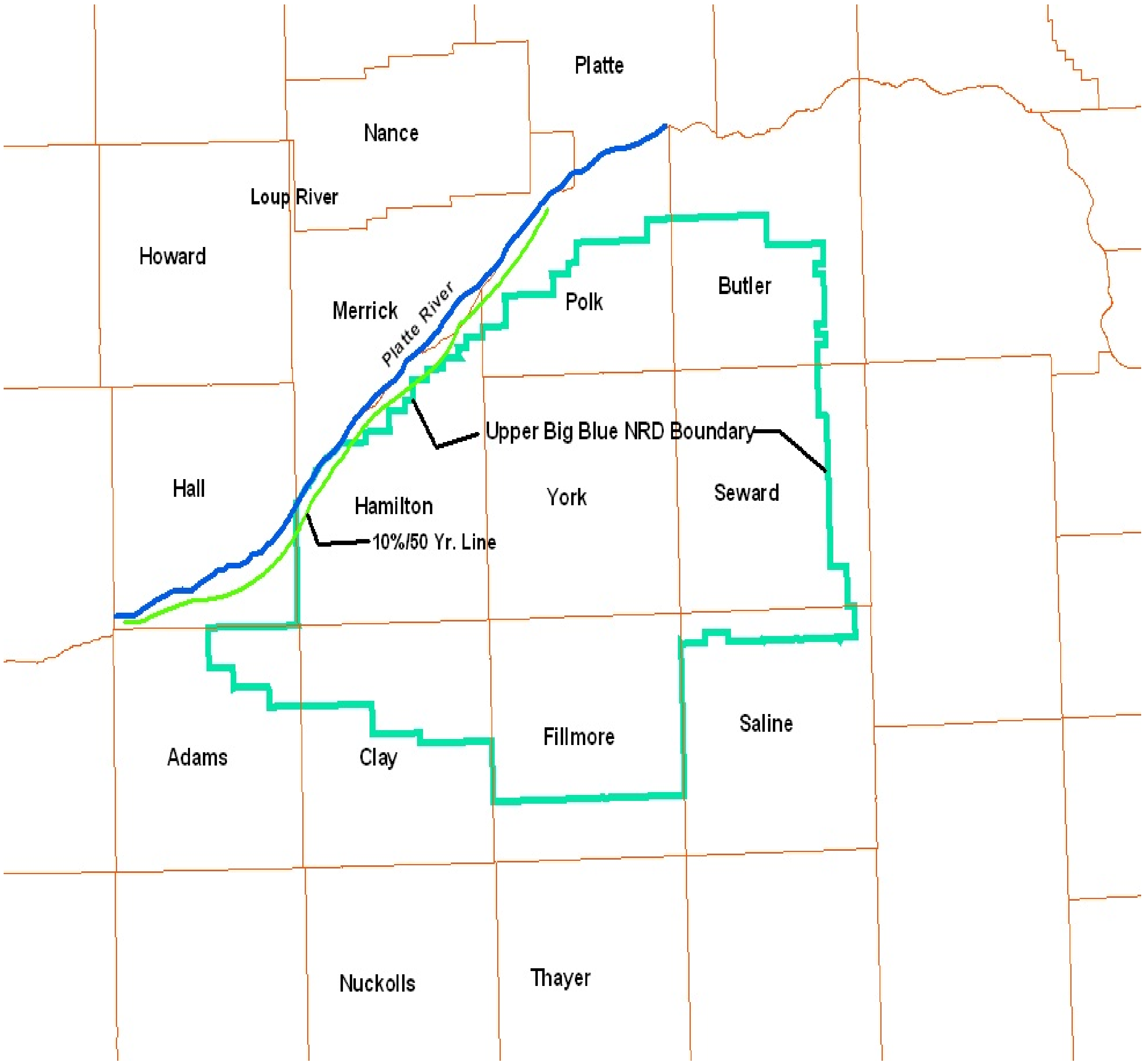


FIGURE 4

10% / 50-YEAR LINE PLATTE RIVER

HALL, HAMILTON AND POLK COUNTIES

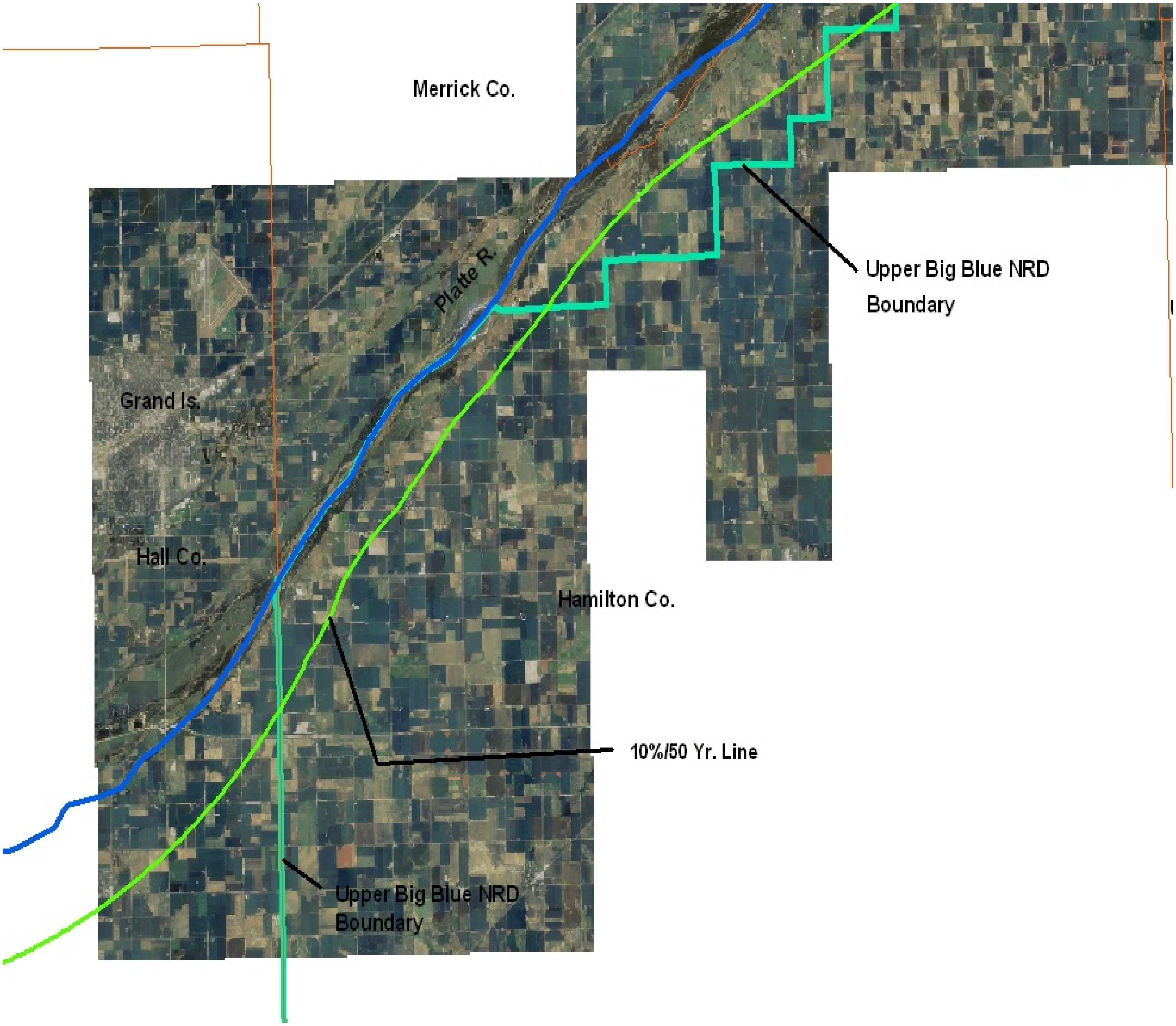


FIGURE 5

10% / 50-YEAR LINE PLATTE RIVER

WITHIN THE UPPER BIG BLUE NRD BOUNDARY

APPENDIX A

MODEL BOUNDARY

FIXED FLOW CALCULATIONS

Ground Water Model
Fixed Flow Boundary Estimates
Southern Boundary
1950 G.W. Level - Layer 5
Updated 07/18/05

Boundary Arc No.	Gradient Crossing Boundary (ft./ft.)	Gradient Angle At Boundary (deg)	Gradient Perpendicular To Boundary (ft./ft.)	Weighted Hyd. Cond. At Boundary (ft./d)	Weighted G.W. Velocity At Boundary (ft./d)	1950 Groundwater Elevation (ft.>msl)	Bottom Layer 5 Elevation (ft.>msl)	Saturated Thickness At Boundary (ft.)	Boundary Arc Length (ft.)	Boundary Flow Area (ft.2)	Boundary Flow (ft.3/d)
80	-0.000869	90	0.000000	44.3	0.000	1880.0	1660.4	219.6	46,017	10,105,333	0
38	-0.00208	90	0.000000	69.6	0.000	1833.0	1589.0	244.0	28,340	6,914,960	0
39	-0.00208	0	-0.002080	54.4	-0.113	1805.0	1557.6	247.4	27,847	6,889,348	-779,543
82	-0.00129	90	0.000000	59.8	0.000	1775.0	1551.3	223.7	41,096	9,193,175	0
23	-0.00089	90	0.000000	109.5	0.000	1740.0	1587.2	152.8	16,903	2,582,778	0
40	-0.000968	90	0.000000	84.0	0.000	1728.0	1600.4	127.6	30,987	3,953,941	0
41	-0.002924	72	-0.000904	144.8	-0.131	1680.0	1575.0	105.0	24,486	2,571,030	-336,384
1	-0.002000	35	-0.001638	192.1	-0.315	1650.0	1566.5	83.5	24,920	2,080,820	-654,872
42	0.001481	24	0.001353	93.3	0.126	1660.0	1562.9	97.1	35,838	3,479,870	439,268
43	0.002000	33	0.001677	82.0	0.138	1632.0	1467.0	165.0	35,201	5,808,165	798,866
36	0.002105	67	0.000822	94.2	0.077	1600.0	1410.6	189.4	31,263	5,921,212	458,766

Total Estimated 1950 Boundary Flow = -73,898

Ground Water Model
Fixed Flow Boundary Estimates
Northern Boundary
1950 G.W. Level - Layer 5
Updated 07/18/05

Boundary Arc No.	Gradient Crossing Boundary (ft./ft.)	Gradient Angle At Boundary (deg)	Gradient Perpendicular To Boundary (ft./ft.)	Weighted Hyd. Cond. At Boundary (ft./d)	Weighted G.W. Velocity At Boundary (ft./d)	1950 Groundwater Elevation (ft.>msl)	Bottom Layer 5 Elevation (ft.>msl)	Saturated Thickness At Boundary (ft.)	Boundary Arc Length (ft.)	Boundary Flow Area (ft.2)	Boundary Flow (ft.3/d)
79	-0.002609	54	-0.001534	34.9	-0.054	1910.0	1698.3	211.7	64,788	13,715,620	-734,063
66	-0.001696	49	-0.001113	178.6	-0.199	1735.0	1687.3	47.7	30,975	1,477,508	-293,616
67	-0.001885	70	-0.000645	54.3	-0.035	1790.0	1635.3	154.7	46,543	7,200,202	-252,062
78	-0.002924	0	0.000000	36.2	0.000	1775.0	1608.3	166.7	9,834	1,639,328	0
49	-0.002924	0	0.000000	19.3	0.000	1765.0	1611.0	154.0	10,939	1,684,606	0
50	-0.002924	26	-0.002628	11.1	-0.029	1750.0	1605.0	145.0	18,572	2,692,940	-78,557
75	-0.002924	26	-0.002628	18.7	-0.049	1730.0	1598.7	131.3	14,537	1,908,708	-93,803
68	-0.002924	26	-0.002628	35.5	-0.093	1715.0	1593.3	121.7	37,939	4,617,176	-430,767
69	-0.002827	29	-0.002473	69.4	-0.172	1670.0	1596.3	73.7	33,140	2,442,418	-419,107
70	-0.002827	29	-0.002473	121.3	-0.300	1630.0	1544.3	85.7	37,584	3,220,949	-966,028
71	-0.002827	29	-0.002473	175.5	-0.434	1595.0	1505.0	90.0	36,660	3,299,400	-1,431,717
77	-0.002310	63	-0.001049	121.7	-0.128	1585.0	1468.7	116.3	51,693	6,011,896	-767,292
72	-0.002310	63	-0.001049	53.8	-0.056	1505.0	1430.3	74.7	40,925	3,057,098	-172,485
37	-0.002310	63	-0.001049	17.7	-0.019	1480.0	1417.5	62.5	3,374	210,875	-3,914
74	-0.001571	51	-0.000989	21.5	-0.021	1475.0	1409.0	66.0	31,526	2,080,716	-44,228
73	-0.001571	51	-0.000989	18.9	-0.019	1445.0	1365.7	79.3	27,643	2,192,090	-40,961

Total Estimated 1950 Boundary Flow = -5,728,601

Ground Water Model
Fixed Flow Boundary Estimates
Eastern Boundary
1950 G.W. Level - Layer 5
Updated 07/18/05

Boundary Arc No.	Gradient Crossing Boundary (ft./ft.)	Gradient Angle At Boundary (deg)	Gradient Perpendicular To Boundary (ft./ft.)	Weighted Hyd. Cond. At Boundary (ft./d)	Weighted G.W. Velocity At Boundary (ft./d)	1950 Groundwater Elevation (ft.>msl)	Bottom Layer 5 Elevation (ft.>msl)	Saturated Thickness At Boundary (ft.)	Boundary Arc Length (ft.)	Boundary Flow Area (ft.2)	Boundary Flow (ft.3/d)
27	-0.001333	34	-0.001105	13.3	-0.015	1440.0	1323.2	116.8	11,533	1,347,054	-19,799
1	-0.001097	59	-0.000565	23.8	-0.013	1443.0	1318.4	124.6	9,800	1,220,753	-16,415
5	-0.001296	81	-0.000203	22.8	-0.005	1455.0	1304.0	151.0	15,820	2,388,820	-11,042
2	-0.001296	81	-0.000203	14.0	-0.003	1480.0	1298.4	181.6	23,550	4,276,680	-12,139
3	-0.002455	41	-0.001853	12.8	-0.024	1487.0	1302.1	184.9	26,940	4,981,206	-118,134
4	0.002261	0	0.000000	20.7	0.000	1555.0	1260.0	295.0	51,610	15,224,950	0
6	-0.002665	75	-0.000690	21.4	-0.015	1570.0	1207.1	362.9	33,086	12,006,909	-177,230
19	-0.001964	50	-0.001262	31.6	-0.040	1505.0	1206.0	299.0	26,280	7,857,720	-313,468
18	-0.001399	29	-0.001224	35.8	-0.044	1485.0	1210.9	274.1	34,070	9,338,587	-409,073
17	-0.001399	29	-0.001224	52.3	-0.064	1473.0	1191.8	281.2	8,860	2,491,432	-159,436
25	-0.001399	29	-0.001224	32.8	-0.040	1465.0	1267.9	197.1	24,300	4,789,530	-192,222
16	-0.001565	74	-0.000431	24.3	-0.010	1472.0	1318.6	153.4	18,560	2,847,104	-29,844
15	-0.001565	74	-0.000431	62.0	-0.027	1500.0	1318.3	181.7	19,950	3,624,915	-96,949
14	-0.001565	74	-0.000431	124.9	-0.054	1520.0	1310.1	209.9	13,430	2,818,957	-151,881
13	-0.001565	74	-0.000431	131.8	-0.057	1540.0	1308.8	231.2	12,850	2,970,920	-168,911
12	-0.001565	74	-0.000431	138.2	-0.060	1552.0	1328.8	223.2	10,080	2,249,856	-134,127
11	-0.001565	74	-0.000431	100.4	-0.043	1570.0	1371.8	198.2	13,820	2,739,124	-118,631
10	-0.001565	74	-0.000431	52.5	-0.023	1590.0	1409.6	180.4	8,470	1,527,988	-34,604
9	-0.001565	90	0.000000	45.2	0.000	1600.0	1425.0	175.0	5,450	953,750	0
8	-0.001565	90	0.000000	35.1	0.000	1615.0	1449.2	165.8	12,070	2,001,206	0
7	-0.001565	90	0.000000	22.4	0.000	1630.0	1489.1	140.9	9,460	1,332,914	0
26	-0.001399	90	-0.001399	23.4	-0.033	1638.0	1512.3	125.7	18,456	2,319,919	-75,946
20	-0.001399	90	-0.001399	72.3	-0.101	1640.0	1471.9	168.1	28,943	4,865,318	-492,116
21	-0.001399	90	-0.001399	30.0	-0.042	1647.0	1506.0	141	30,370	4,282,170	-179,723
22	-0.001794	41	-0.001354	77.2	-0.105	1595.0	1388.6	206.4	52,830	10,904,112	-1,139,751
23	-0.001696	22	-0.001573	117.6	-0.185	1577.0	1314.5	262.5	14,429	3,787,613	-700,430
24	-0.001555	7	-0.001543	109.1	-0.168	1575.0	1364.0	211	35,841	7,562,451	-1,273,411

Total Estimated 1950 Boundary Flow = -6,025,283

Ground Water Model
Fixed Flow Boundary Estimates
Western Boundary
1950 G.W. Level - Layer 5
Updated 07/18/05

Boundary Arc No.	Gradient Crossing Boundary (ft./ft.)	Gradient Angle At Boundary (deg)	Gradient Perpendicular To Boundary (ft./ft.)	Weighted Hyd. Cond. At Boundary (ft./d)	Weighted G.W. Velocity At Boundary (ft./d)	1950 Groundwater Elevation (ft.>msl)	Bottom Layer 5 Elevation (ft.>msl)	Saturated Thickness At Boundary (ft.)	Boundary Arc Length (ft.)	Boundary Flow Area (ft.2)	Boundary Flow (ft.3/d)
1	0.000891	0	0.000891	29.5	0.026	1902.0	1745.3	156.7	10,227	1,602,571	42,123
2	0.001382	45	0.000977	56.5	0.055	1903.0	1782.5	120.5	12,141	1,462,991	80,776
4	0.003388	26.5	0.003032	50.5	0.153	1920.0	1812.4	107.6	9,090	978,084	149,762
12	0.002875	18.4	0.002728	45.0	0.123	1932.0	1811.7	120.3	12,930	1,555,479	190,952
3	0.002964	26.5	0.002653	48.5	0.129	1930.0	1784.8	145.2	13,060	1,896,312	243,961
13	0.002341	34.5	0.001929	54.1	0.104	1955.0	1720.3	234.7	26,130	6,132,711	640,096
5	0.002145	19.3	0.002024	51.6	0.104	1985.0	1694.7	290.3	25,910	7,521,673	785,727
6	0.001969	17.6	0.001877	50.0	0.094	2008.0	1768.2	239.8	40,530	9,719,094	912,056
7	0.001607	45	0.001136	40.7	0.046	2003.0	1818.3	184.7	35,491	6,555,188	303,166
14	0.001786	45	0.001263	31.9	0.040	1982.0	1797.9	184.1	11,750	2,163,175	87,146
8	0.001684	0	0.001684	17.6	0.030	1972.0	1759.4	212.6	34,700	7,377,220	218,649
9	0.001684	0	0.001684	10.0	0.017	1978.0	1731.2	246.8	14,990	3,699,532	62,300
10	0.001752	27.6	0.001553	9.2	0.014	1978.0	1722.8	255.2	10,340	2,638,768	37,693
11	0.001906	56.9	0.001041	19.2	0.020	1960.0	1713.6	246.4	19,299	4,755,274	95,033

Total Estimated 1950 Boundary Flow = 3,849,440

APPENDIX B

RIVER BED CONDUCTANCE

PLATTE RIVER

Platte River
Average Bed Conductance
Between Hwy. 34 And Chapman Bridges
Based On Permeameter Tests and Geoprobe Borings
UNL Conservation and Survey - August 2005

Transect	Site	K_{v1} (ft/d)	K_{v2} (ft/d)	Ecbase (mS/m)	M_1 (ft)	M_2 (ft)	K_v (ft/d)	L (ft)	W (ft)	M (ft)	C (ft^2/d/ft)
A1	NC	78.7	0.056	35	13.8	6.8	0.169	1	1	20.6	0.0082
A2	MC	78.7	0.056	35	15.9	6.9	0.185	1	1	22.8	0.0081
A3	SC	78.7	0.056	35	12.4	13.3	0.108	1	1	25.7	0.0042
B1	NC	109.7	0.056	35	21.6	1.7	0.763	1	1	23.3	0.0327
B2	MC	109.7	0.056	35	10.8	9.5	0.120	1	1	20.3	0.0059
B3	SC	109.7	0.056	35	8.5	8.1	0.115	1	1	16.6	0.0069

Average Unit C = 0.0110 ft^2/d per foot of river reach per foot of river width
Total Conductance C 11.0 ft^2/d per foot of river reach (using a river bed with of 1,000 ft.)

NOTES:
1. NC = North Channel
2. MC = Middle Channel
3. SC = South Channel
4. Site A is located in Sec 29, Twp 11N, Rng 8W, and is upstream from the BNSF railroad bridge over the Platte River near Grand Island
5. Site B is located in the NW^4 Sec 11, Twp 11N, Rng 8W, and is near the upstream from the Chapman Bridge near the intersection of 5^{th} and B Streets
6. K_{v1} = vertical hydraulic conductivity of river bed material with EC log < 35 mS/m
7. K_{v2} = vertical hydraulic conductivity of river bed material with EC log >= 35 mS/m
8. K_v = wighted vertical hydraulic conductivity for total river bed thickness M
9. L = river reach length (use 1.0 ft. for this calculation)
10. W = river bed width (use 1.0 ft. to compute the unit condutance.
Apply total river bed width of 1,000 ft. to determine total bed conductance per linear foot of river reach between Hwy. 34 bridge and Chapman bridge
11. M1 = thickness of the river bed material with EC log < 35 mS/m)
(based on CSD geoprobe resistivity log)
12. M2 = thickness of the river bed material with EC log >= 35 mS/m)
(based on CSD geoprobe resistivity log)
13. M = total river bed thickness ($M_1 + M_2$)
14. Equation for computing river bed conductance

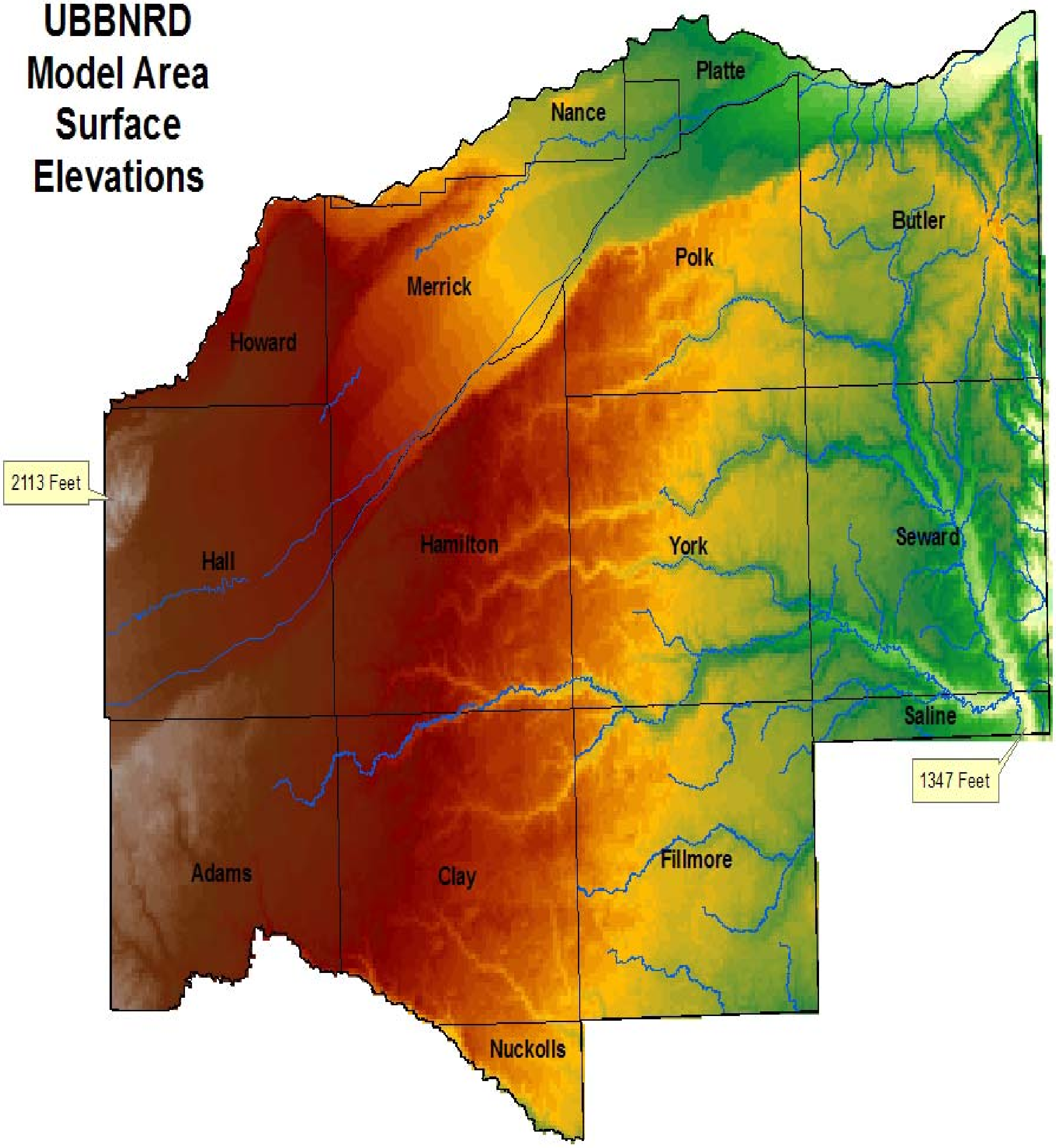
$$C = \frac{K_v \times L \times W}{M}$$

15. Equation for weighting vertical hydraulic conductivity:

$$Kv = \frac{M}{(M_1/K_{v1}) + (M_2/K_{v2})}$$

APPENDIX C
GROUNDWATER LEVEL MAPS
DEPTH TO GROUNDWATER

UBBNRD Model Area Surface Elevations



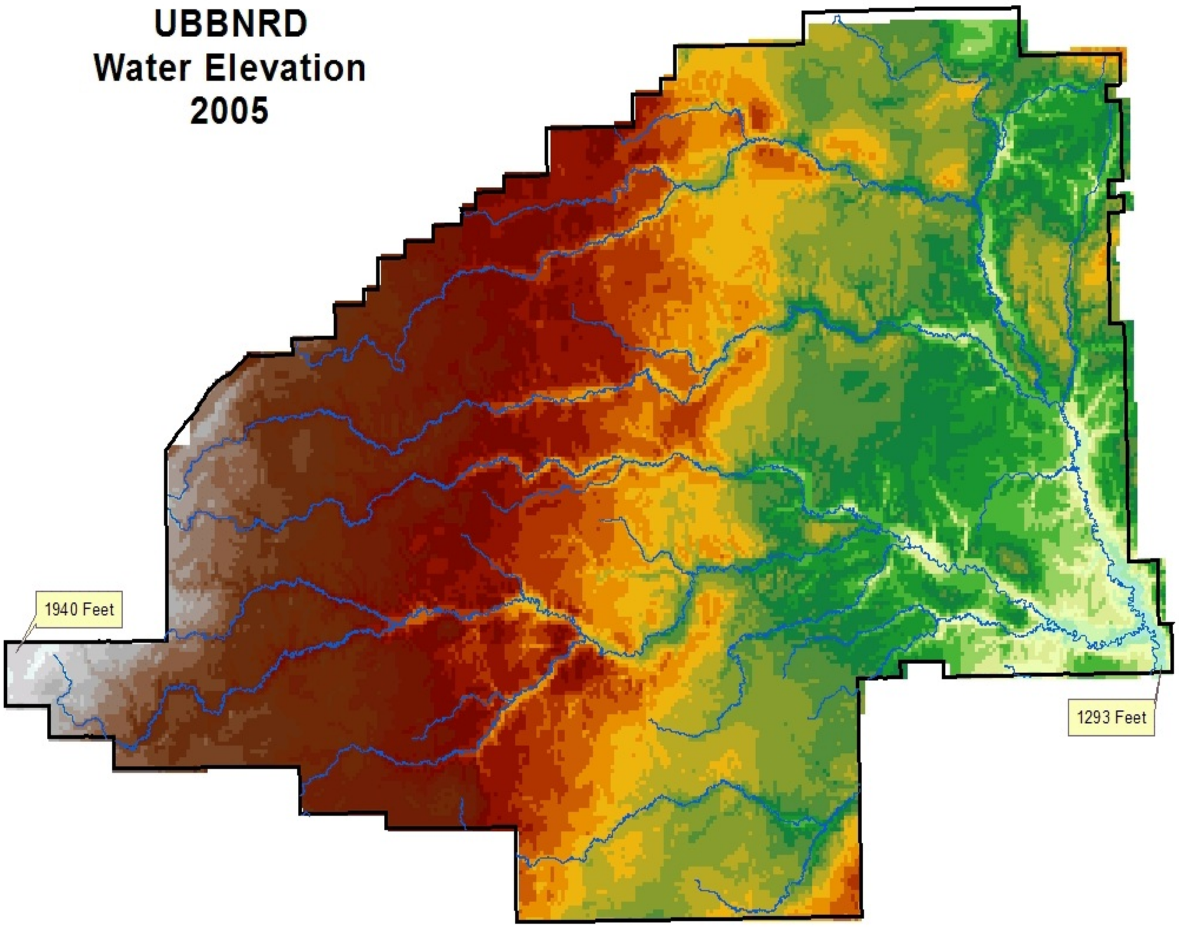


FIGURE 7

GENERAL GROUNDWATER ELEVATION MODEL

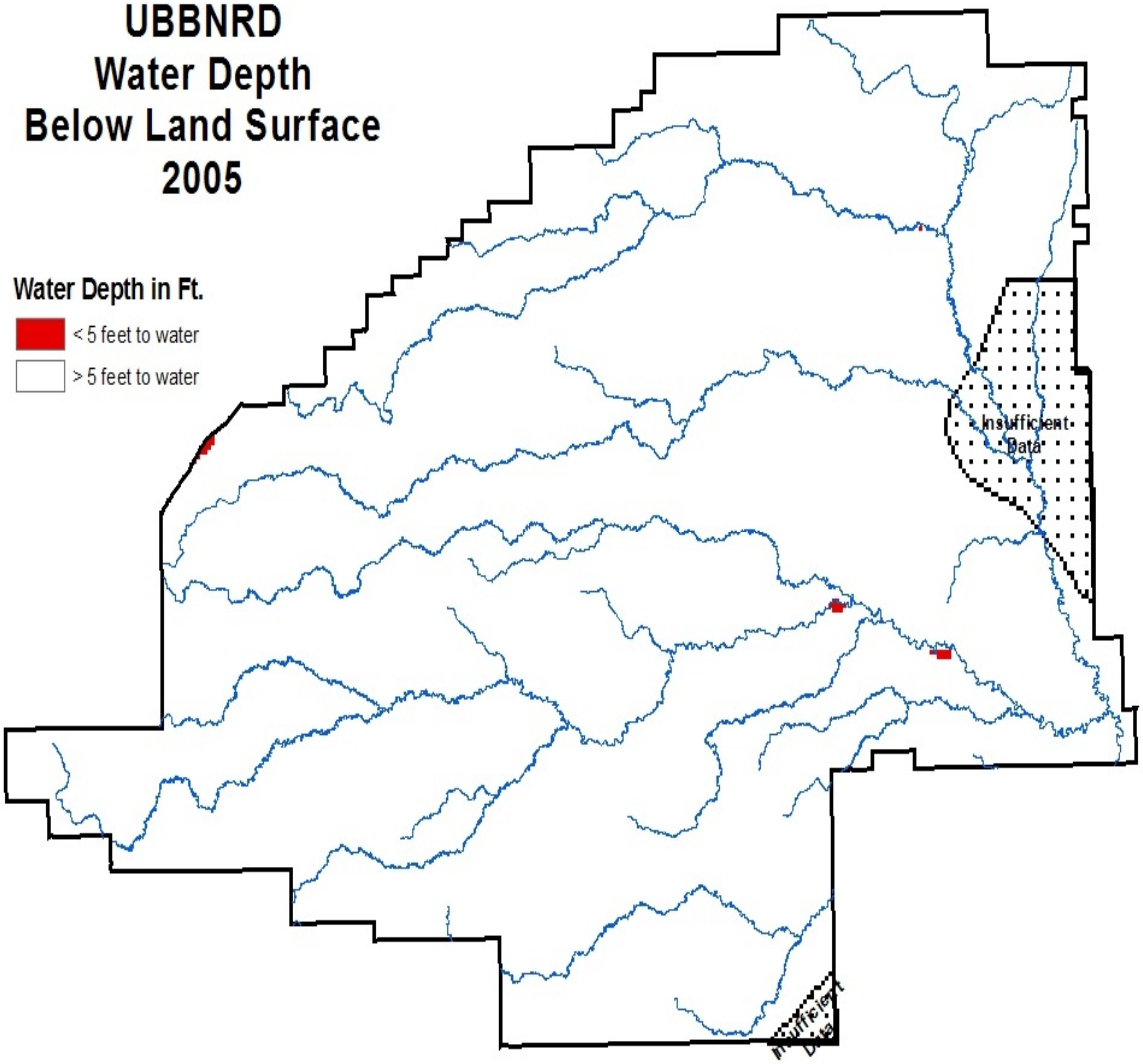


FIGURE 8

GENERAL DEPTH OF GROUNDWATER BELOW LAND SURFACE

Appendix F

Net Irrigation Requirement[1]

Background

The net irrigation water requirement (INET) is the net amount of water that must be applied by irrigation to supplement stored soil water and precipitation and supply the water required for the full yield of an irrigated crop. INET does not include irrigation water that is not available for crop water use such as irrigation water that percolates through the crop root zone or that runs off of the irrigated field. INET as used in this application is the annual amount of water and is expressed in units of acre-inches of water per acre of irrigated land for a year. Since corn is the most widely irrigated crop in Nebraska, the net irrigation requirement was simulated for corn grown on fine sandy loam soil. The soil used in the simulations holds about 1.75 inches of available water per foot of soil depth. The soil used for the simulations represents an average condition of soils across Nebraska.

Procedure

The net irrigation requirement can be computed using several methods. Early methods relied on the difference between the evapotranspiration (ET) required for full crop yields minus the amount of precipitation during the irrigation season that is estimated to be effective in meeting crop water requirements. This method was generally applied on a monthly basis and did not consider precipitation or soil water rewetting during the portion of the year when crops were not growing, or the effects of individual precipitation events. This method has given way to daily calculations of the soil water balance of irrigated crops.

A computer simulation model (CROPSIM) developed at the University of Nebraska-Lincoln by Dr. Derrel Martin was used to compute the daily water balance for irrigated corn and INET for an array of weather stations across the state. Computations with the CROPSIM program for data from selected weather stations were used to generate the map of net irrigation water requirements for corn grown on a fine sandy loam soil.

The CROPSIM model maintains a daily soil water balance including the following terms:

$$D_i = D_{i-1} + ET_c + DP + RO - P - I_{net}$$

where D_i is the available soil water depletion on day i, inches
D_{i-1} is the depletion on the previous day, inches
ET_c is the daily evapotranspiration rate, inches/day
DP is the daily deep percolation from the root zone, inches/day
RO is the daily run off from the irrigated land due to rainfall, inches/day
P is the daily precipitation, inches/day
I_{net} is the net irrigation that is applied on day i, inches/day.

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[1] Prepared by Derrel Martin, Professor of Irrigation and Water Resources Engineering, Department of Biological Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE. 68583-0726.

The daily soil water depletion is maintained in the model. Irrigations are applied on days when the depletion reaches a specified amount for the crop root zone. Irrigations were applied when more than half of the available water in the top four feet of the root zone was depleted. This is a common management practice used to schedule irrigation. The net irrigation applied each irrigation resembles practices typical of center pivot irrigation. This involved applying a gross irrigation of one inch each application which equaled a net irrigation of 0.85 inches per irrigation. Irrigations did not begin until the corn crop had begun vegetative growth. Irrigations were continued for the year until the corn crop had reached a growth stage where water stress has minimal affects on yield. This stage generally matches a hard-dent growth stage for corn.

The CROPSIM program depends on evapotranspiration (ET) to compute the soil water depletion and determine dates for irrigation. The ET for corn was computed in the model using a reference crop evapotranspiration (ETr) that represents the amount of energy available from the environment to evaporate water. The reference crop evapotranspiration is multiplied by a crop coefficient (Kc) to compute the water use of corn:

$$ETc = Kc\ ETr$$

A tall reference crop often considered to be alfalfa about 20 inches in height was used for the reference crop evapotranspiration. The Standardized Penman-Monteith method developed by the ASCE-EWRI[2] task force was used as the basis for computing ETr. Since climatic data needed for the Penman-Monteith method are not available dating back to 1950, the Hargreaves[3] method was calibrated to the Penman-Monteith method for a period of about 20 years for selected weather stations that are part of the Automated Weather Data Network operated by the High Plains Climate Center at the University of Nebraska-Lincoln. The calibrated Hargreaves method provides daily estimates of reference crop ET for the CROPSIM model to simulate corn ET and net irrigation requirements for the period from 1950 through 2004. The fifty-five year period was used to include climatic variations that are expected in the Great Plains. The Hargreaves method was calibrated for each month using the ASCE Hourly method for an alfalfa (tall) reference crop. Data were used from the 23 automated weather data network stations listed in Table 1. The automated weather stations were selected to provide statewide coverage and a period long enough to represent climatic variations across the state. The location of the automated weather data network (AWDN) stations are shown in Figure 1. The map shows that the AWDN stations are well distributed across the state.

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[2] ASCE-EWRI. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Environmental and Water Resources Institute of the American Society of Civil Engineers, Standardization of Reference Evapotranspiration Task Committee. ASCE. Reston, NY.

[3] Hargreaves, G.H. and R,G. Allen. 2003. History and evaluation of Hargreaves evapotranspiration equation. Journal of Irrigation and Drainage Engineering. ASCE. 129(1): 53-63.

Table 1. Automated weather data network stations used to calibrate the Hargreaves method to the sum-of-hourly for daily reference ET for a tall reference crop (i.e., alfalfa). The date the system first became operational and the latitude, longitude and elevation of the stations are also listed.

Station	**Latitude degrees North**	**Longitude, degrees west**	**Elevation, meters**	**Month**	**Day**	**Year**
AINSWORTH	42.550	-99.817	765	6	4	1984
ALLIANCEWEST	42.017	-103.133	1213	5	29	1988
BEATRICE	40.300	-96.933	376	1	1	1990
CENTRALCITY	41.150	-97.967	517	9	4	1986
CHAMPION	40.400	-101.717	1029	5	20	1981
CLAY CENTER(SC)	40.567	-98.133	552	7	14	1982
CONCORD(NE)	42.383	-96.950	445	7	16	1982
DICKENS	40.950	-100.967	945	5	21	1981
ELGIN	41.933	-98.183	619	1	1	1988
GORDON	42.733	-102.167	1109	10	18	1984
GUDMUNDSENS	42.067	-101.433	1049	10	5	1982
HOLDREGE	40.333	-99.367	707	5	29	1988
LEXINGTON	40.767	-99.733	728	8	5	1986
MCCOOK	40.233	-100.583	792	5	21	1981
MEADTURFFARM	41.167	-96.467	366	7	29	1986
MITCHELL FARMS	41.933	-103.700	1098	7	11	1996
NEBRASKA CITY	40.533	-95.800	328	6	29	1998
ONEILL	42.467	-98.750	625	7	17	1985
ORD	41.617	-98.933	625	7	10	1983
SCOTTSBLUFF	41.883	-103.667	1208	1	1	1991
SIDNEY	41.217	-103.017	1317	12	1	1982
WESTPOINT	41.850	-96.733	442	5	15	1982
YORK	40.867	-97.617	490	4	22	1996

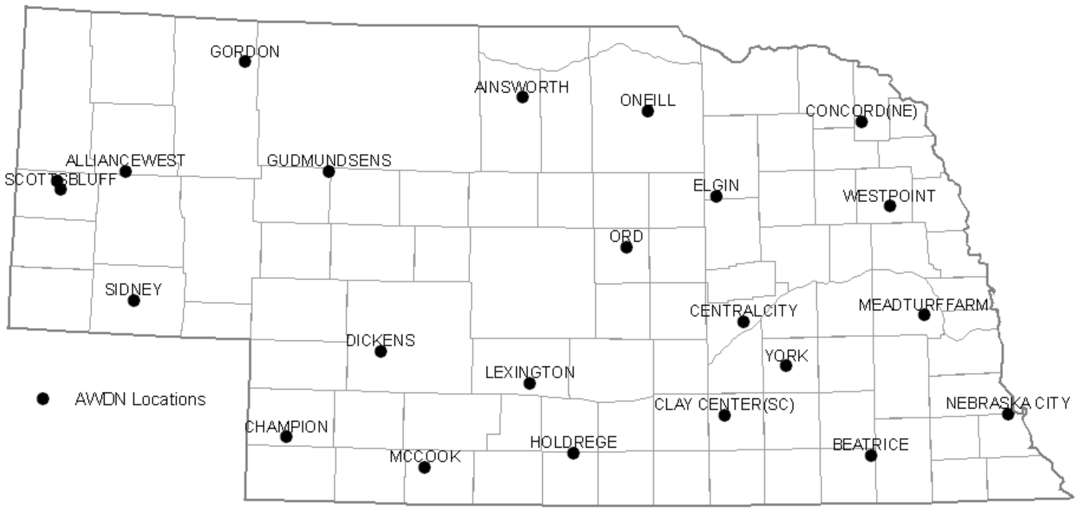

Figure 1. Location of automated weather stations used to calibrate the Hargreaves method.

The daily reference crop ET for alfalfa was calibrated using the following equation:

$$ETr = \left[a + b\ Long^2\right] Hg^c$$

where ETr is daily reference crop ET for alfalfa as computed with the ASCE method, and
Long is the longitude, degrees
Hg is the Hargreaves factor,
and a, b and c are empirical coefficients.

The Hargreaves factor is computed as:

$$Hg = \frac{(Ta + 17.8)\sqrt{T\max - T\min}\ \ Ra}{\lambda}$$

where Ta is the average daily temperature, °C,
Tmax is the maximum daily temperature, °C,
Tmin is the minimum daily temperature, °C,
Ra is the extraterrestrial radiation, $MJ/m^2/day$,
8 is the heat of vaporization = 2.45 MJ/Kg of water.

Daily data from the AWDN stations were used to compute daily ETr values with the Penman-Monteith method. The Hargreaves factor was compute for each day as well. The results of the computations were separated by month and the coefficients for the calibrated Hargreaves method (*i.e.*, a, b and c) were computed from the regression analysis for all 23 AWDN stations. The results of the calibration are listed in Table 2. The coefficients of determination (r^2) for the monthly values are reasonably good for all months.

Table 2. Parameters and coefficient of determination for calibration of Hargreaves method to Sum-of-Hourly calculations for ASCE Penman-Monteith.

Month	a	b	c	r^2
January	-2.97117E-03	6.68252E-07	1.0400	0.68
February	-2.10020E-03	4.71103E-07	1.0746	0.74
March	-1.99470E-04	1.60011E-07	1.1419	0.76
April	3.42244E-04	2.06925E-08	1.2499	0.76
May	1.48641E-04	1.16248E-08	1.3282	0.65
June	1.13210E-04	8.14170E-10	1.4143	0.66
July	6.58766E-05	5.44612E-09	1.4072	0.66
August	4.65366E-05	2.19358E-08	1.3122	0.62
September	3.90011E-04	7.01456E-08	1.1518	0.62
October	9.59964E-04	1.20508E-07	1.0839	0.65
November	-1.08578E-03	3.78426E-07	1.0814	0.68
December	-4.57939E-03	8.95039E-07	1.0180	0.66

Simulation of crop water use for the period from 1950 through 2004 required a different set of weather stations since AWDN data are not available before 1980. Sixty-two cooperator or National Weather Service stations were selected for the simulation. Stations that were selected included measurements for at least the maximum daily air temperature, the minimum daily air temperature and daily precipitation (rain and snow). Some stations also included evaporation measurements from evaporation pans. These data were not used in the simulation. Weather stations were selected to represent the state as indicated by the climate zones shown in Figure 2. Only stations that included daily weather data starting before 1949 were selected for analysis. The High Plains Climate Center has developed data management routines to estimate values for days when data are missing or appear to be incorrect. Therefore, none of the stations have missing data and no procedures were developed to correct these data which are referred to as National Weather Station (NWS) stations in this report.

The CROPSIM model uses a set of parameters to describe how corn develops during the year and to represent typical management practices for a region. To simulate corn growth the state wad divided into four management zones as shown in Figure 3. The management zones in Figure 3 generally align with the Climate Zones in Figure 2 except for the North Central Climate Zone. This zone was divided approximately in half to represent management practices for that region. Some important parameters for the management zones are included in Table 3. The data show that the amount of growing degree days required for crop development increases as one progresses from management zone 1 east to management zone 4. Planting is also generally delayed as one progresses west from zone 3. A slightly later planting date was used for management zone 4 since this region receives more rain in the spring that can delay planting compared to zone 3. Other parameters used to simulate crop growth and management are listed in Table 2. These values were held constant across all four management zones.

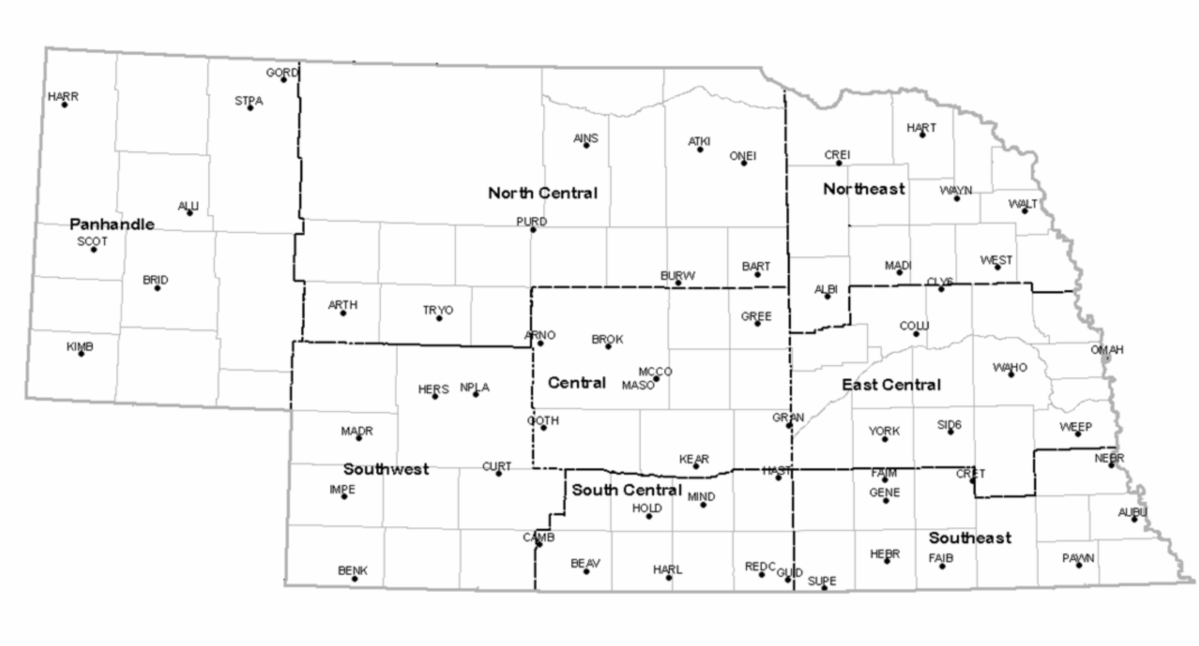

Figure 2. Location of National Weather Service stations used in simulations and Climatic Zones for Nebraska. Specific information for the NWS stations is included in Table 4.

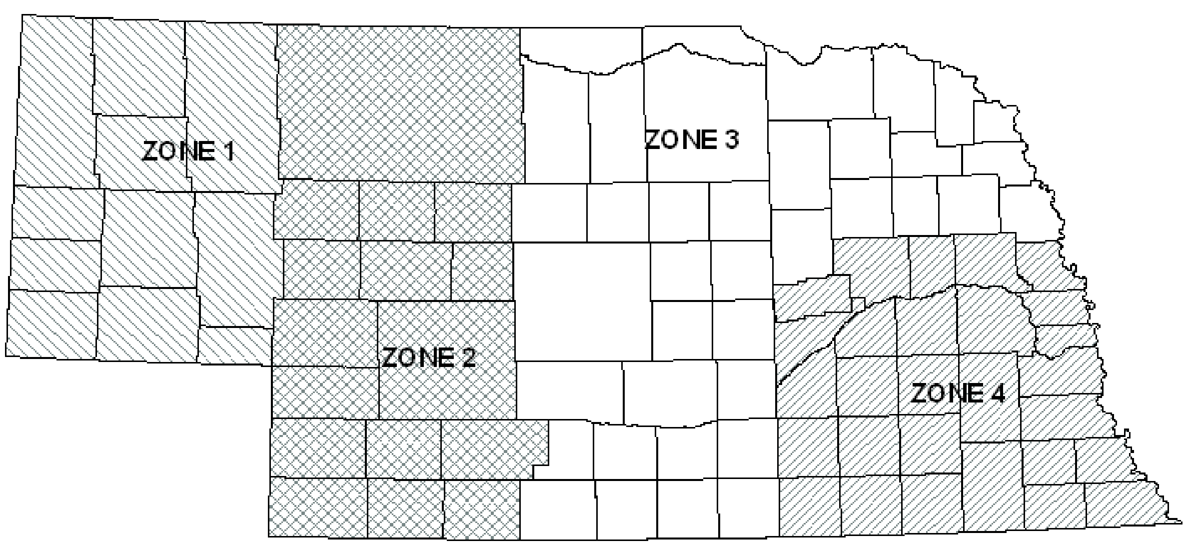

Figure 3. Location of management zones for the CROPSIM model.

Table 3. Parameters used in simulation of crop growth with the CROPSIM model.

Management Zone	Growing Degree Days for Specific Growth Stages					
	Planting Date	Begin of Flowering	Begin of Ripening	Yield Formation	Effective Cover	Physiological Maturity
Zone 1	5/5	1200	1700	2160	1050	2400
Zone 2	5/1	1300	1800	2500	1200	2750
Zone 3	4/25	1350	1850	2600	1250	2850
Zone 4	5/1	1400	1850	2700	1300	2950
Minimum Depth of Crop Root Zone, inches					6	
Maximum Depth of Crop Root Zone, inches					72	
Growing Degree Days for Start of Root Growth					200	
Growing Degree Days for Start of Vegetative Growth					450	
Depth of Soil Profile Used for Irrigation Management, inches					48	

Runoff was simulated using the curve number method originally developed by the USDA Natural Resources Conservation Service. The method was modified to adjust curve numbers based on the soil water content at the time of precipitation. The soil water content adjustment of curve numbers, and melting and infiltration of snow was based on routines in the SWAT[4] model. The fine sandy loam soil has been characterized as being in hydrologic group B in the curve number method.

Results

The net irrigation requirement and the amount of evapotranspiration for fully irrigated corn and non-irrigated corn grown on fine sandy loam was simulated at sixty-two NWS stations across Nebraska for the period from 1949 through 2004. Data for 1949 were not included in the analysis as there is usually a stabilization period following the initial conditions used for the soil water content for the first year of simulation for a site. The difference in the evapotranspiration for fully irrigated corn and non-irrigated corn is the consumptive irrigation requirement (CIR). The CIR is the amount of consumptive use of water due to irrigating for full crop yield. Results of the simulations for the NWS stations are summarized in Table 4. The net irrigation requirement was used to develop contour lines for the net irrigation map across the state (Figure 4). The results generally show that irrigation requirements increase in a southeast-northwest pattern.

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4 Arnold, J.G. and N. Fohrer. 2005. SWAT2000: current capabilities and research opportunities in applied watershed modeling. Hydrol. Process. 19(3):563-572.

Table. 4. Results of simulations for ET, CIR and net irrigation for NWS weather stations used in the analysis.

Site	ET Full Yield, Inches/Year	ET Non Irrigated, Inches/Year	CIR, Inches /Year	Net Irrigation, Inches/Year	Latitude, Degrees	Longitude, Degrees	Elevation, Meter	Climate Division	Station Code	Station Name
AINS	29.86	20.48	9.38	10.45	42.55	-99.85	765	2	c250050	AINSWORTH
ALBI	29.65	23.03	6.63	8.41	41.68	-98.00	546	3	c250070	ALBION
ALLI	28.81	15.65	13.15	13.97	42.10	-102.88	1217	1	c250130	ALLIANCE 1 WNW
ARNO	32.07	19.75	12.32	13.09	41.42	-100.18	838	4	c250355	ARNOLD
ARTH	30.12	17.93	12.19	13.21	41.57	-101.68	1067	2	c250365	ARTHUR
ATKI	29.28	20.88	8.40	9.67	42.53	-98.97	643	2	c250420	ATKINSON
AUBU	28.70	24.84	3.86	6.00	40.37	-95.73	283	8	c250435	AUBURN 5 ESE
BART	30.14	22.11	8.03	9.58	41.82	-98.53	652	2	c250525	BARTLETT 4 S
BEAV	33.37	21.01	12.36	13.21	40.12	-99.82	658	7	c250640	BEAVER CITY
BENK	31.25	17.78	13.47	14.37	40.05	-101.53	922	6	c250760	BENKELMAN
BRID	30.01	15.67	14.34	14.85	41.67	-103.10	1117	1	c251145	BRIDGEPORT
BROK	30.75	20.51	10.23	11.30	41.40	-99.67	762	4	c251200	BROKEN BOW 2 W
BURW	30.67	20.59	10.08	11.16	41.77	-99.13	663	2	c251345	BURWELL 4 SE
CAMB	31.23	19.77	11.46	12.16	40.27	-100.17	689	7	c251415	CAMBRIDGE
CLY6	29.59	22.88	6.71	8.07	40.50	-97.93	530	8	c251680	CLAY CENTER 6 ESE
COLU	28.05	22.67	5.38	7.11	41.47	-97.33	442	5	c251825	COLUMBUS 3 NE
CREI	29.63	22.06	7.58	9.16	42.45	-97.90	497	3	c251990	CREIGHTON
CRET	28.67	23.78	4.89	6.80	40.62	-96.93	437	8	c252020	CRETE
CURT	31.22	19.38	11.84	13.15	40.67	-100.48	829	6	c252100	CURTIS 3 NNE
FAIB	29.92	24.67	5.25	7.09	40.13	-97.17	415	8	c252820	FAIRBURY
FAIM	29.64	22.83	6.81	8.30	40.63	-97.58	500	8	c252840	FAIRMONT
GENE	28.27	23.16	5.11	6.91	40.52	-97.58	497	8	c253175	GENEVA
GORD	28.79	16.89	11.90	13.20	42.88	-102.20	1128	1	c253355	GORDON 6 N

GOTH	30.89	20.18	10.70	11.39	40.93	-100.15	788	4	c253365	GOTHENBURG
GRAN	28.70	21.27	7.43	8.89	40.95	-98.30	561	4	c253395	GRAND ISLAND WSO AP
GREE	30.87	22.15	8.73	10.20	41.53	-98.53	616	4	c253425	GREELEY
GUID	29.48	22.43	7.05	8.72	40.07	-98.32	498	7	c253485	GUIDE ROCK
HARL	30.17	20.70	9.47	10.35	40.08	-99.20	610	7	c253595	HARLAN COUNTY LAKE
HARR	28.11	16.25	11.87	13.85	42.68	-103.88	1478	1	c253615	HARRISON
HART	28.72	22.05	6.67	8.35	42.60	-97.25	418	3	c253630	HARTINGTON
HAST	29.93	23.08	6.85	8.55	40.65	-98.38	591	7	c253660	HASTINGS 4 N
HEBR	29.51	23.75	5.77	7.46	40.17	-97.58	451	8	c253735	HEBRON
HERS	30.51	18.47	12.04	13.21	41.10	-100.97	900	6	c253810	HERSHEY 5 SSE
HOLD	30.09	22.02	8.07	9.41	40.43	-99.35	707	7	c253910	HOLDREGE
IMPE	29.85	18.30	11.56	12.67	40.52	-101.63	999	6	c254110	IMPERIAL
KEAR	29.72	21.70	8.03	9.37	40.72	-99.00	649	4	c254335	KEARNEY 4 NE
KIMB	30.38	16.60	13.78	14.51	41.27	-103.65	1451	1	c254440	KIMBALL
MADI	29.19	22.81	6.39	8.27	41.82	-97.45	511	3	c255080	MADISON 2 W
MADR	31.45	18.73	12.72	13.77	40.85	-101.53	975	6	c255090	MADRID
MASO	30.30	21.65	8.65	9.83	41.22	-99.30	689	4	c255250	MASON CITY
MCCO	29.05	19.31	9.74	11.14	40.20	-100.62	771	6	c255310	MCCOOK
MIND	29.60	21.79	7.80	9.20	40.50	-98.95	658	7	c255565	MINDEN
NEBR	28.48	24.88	3.60	5.61	40.68	-95.88	329	8	c255810	NEBRASKA CITY
NPLA	29.45	18.64	10.81	12.13	41.12	-100.67	847	6	c256065	NORTH PLATTE WSO ARP
OMAH	27.31	23.98	3.33	5.39	41.30	-95.88	304	5	c256255	OMAHA EPPLEY AIRFIEL
ONEI	30.20	21.30	8.90	10.15	42.45	-98.63	607	2	c256290	ONEILL
PAWN	29.13	24.66	4.48	6.63	40.12	-96.15	369	8	c256570	PAWNEE CITY
PURD	31.79	19.67	12.12	12.98	42.07	-100.25	820	2	c256970	PURDUM
REDC	31.29	22.46	8.83	10.35	40.10	-98.52	524	7	c257070	RED CLOUD
SCOT	29.43	14.72	14.72	15.36	41.87	-103.60	1202	1	c257665	SCOTTSBLUFF AP

SID6	29.43	15.99	13.44	14.14	41.20	-103.02	1317	1	c257830	SIDNEY 6 NNW
STPA	28.30	21.10	7.20	8.64	41.27	-98.47	541	4	c257515	ST PAUL 4 N
SUPE	29.68	23.05	6.63	8.27	40.02	-98.05	482	8	c258320	SUPERIOR
TRYO	30.53	18.30	12.23	13.34	41.55	-100.95	990	2	c258650	TRYON
WAHO	29.47	25.01	4.47	6.68	41.22	-96.62	387	5	c258905	WAHOO
WALT	29.22	23.18	6.05	7.93	42.15	-96.48	372	3	c258935	WALTHILL
WAYN	28.91	22.50	6.41	8.05	42.23	-97.00	445	3	c259045	WAYNE
WEEP	28.49	24.41	4.08	6.17	40.87	-96.13	335	5	c259090	WEEPING WATER
WEST	28.30	23.30	5.00	7.09	41.83	-96.70	399	3	c259200	WEST POINT
YORK	28.78	23.19	5.59	7.31	40.87	-97.58	491	5	c259510	YORK

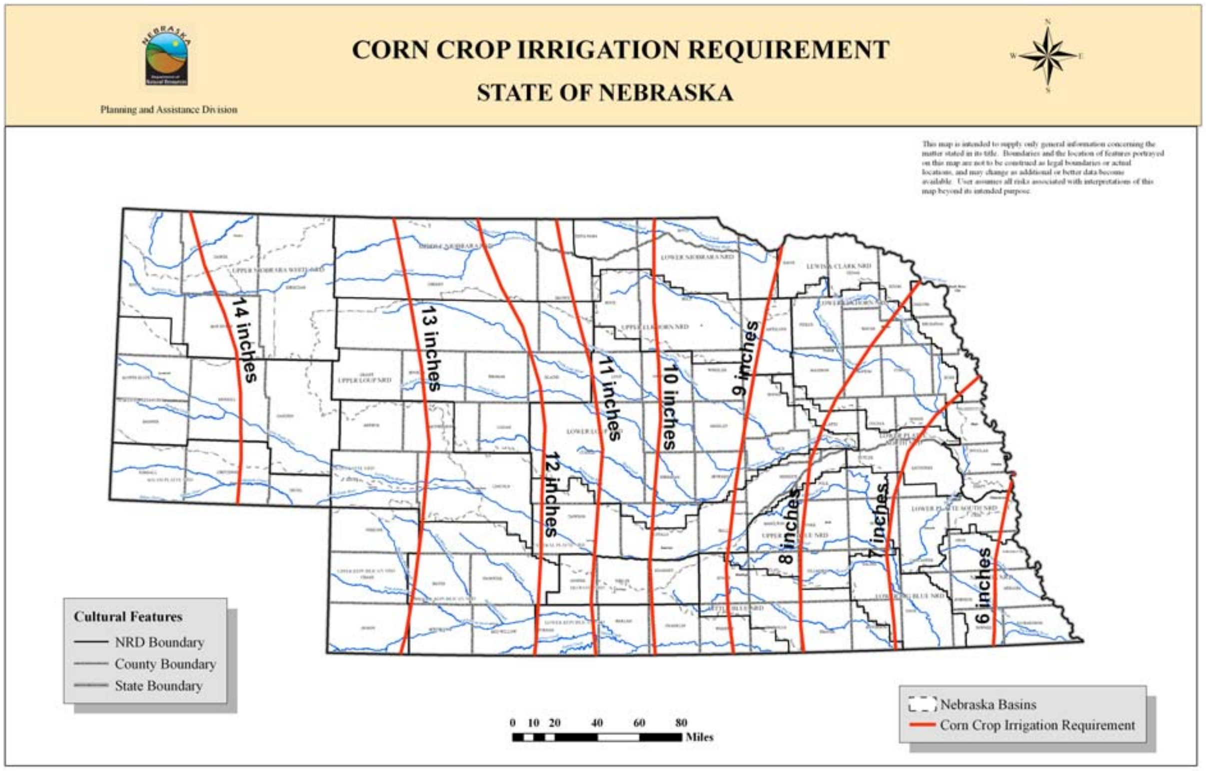

Figure 4. Map of net irrigation requirements (inches/year) for corn grown on fine sandy loam.

Appendix G

Appendix G

Development of Ground Water Irrigated Acres per Well

Estimation of the number of acres irrigated per ground water well was determined by evaluating three methodologies:

Method 1: Average Method

All active irrigation wells in the Nebraska Department of Natural Resources Ground Water Well database were queried and geographically located within the nine study basins. The average registered acres per well was computed for each basin. The ground water well database acreage value was obtained from the applicant when the well is originally registered. An examination in the Republican River Basin showed that number was, on average, 25% to 33% higher than the actual measured number of irrigated acres. Therefore, three alternate variations for Method 1 have been produced, decreasing the acres per well by 25, 30, and 35%.

Method 2: 1995 Study Ground Water Irrigated Acres

Based on the number of ground water irrigated acres for each county in the U.S. Geological Survey / Nebraska Natural Resources Commission 1995 Water Use Study Report and the number of active irrigation wells for each county in 1995 from Nebraska Department of Natural Resources Ground Water Well database, the average number of acres per well for each county was computed. After attributing each irrigation well and its associated average number of irrigated acres into one of the nine study basins, the average irrigated acres per well for each basin was computed by dividing the total irrigated acres in the basin by the total number of irrigation wells in the basin.

Method 3: Combination of 1995 Report Results and 2002 Agriculture Census Data

The total number of irrigated acres and ground water irrigated acres by county in the 1995 Water Use Study Report, total irrigated acres by county from the 2002 U.S. Agriculture Census, and the number of active irrigation wells in 2002 from Nebraska Department of Natural Resources Well Database were used to estimate the number of irrigated acres per well in 2002.

By assuming that ground water acres accounted for 95% of the increase in irrigated acres between 1995 and 2002, ground water irrigated acres per county in 2002 were estimated as the 1995 ground water irrigated acres plus 95% of the change in irrigated acres between 2002 and 1995. Then, using the estimated ground water irrigated acres for each county in 2002 and the number of irrigation wells in 2002 from the DNR well database, an average number of acres per well for each county was computed.

All irrigation wells with their average acres per well by county were assigned to their corresponding basins using GIS analysis. Then the total number of acres and wells for each basin were totaled. An average number of acres per well by basin in 2002 was developed by dividing the total acres by the number of wells in each basin. The results obtained with the three methodologies are shown in Table H-1.

Table H-1. Number of Ground Water Irrigated Acres per Well.

Basin	Method 1				Method 2	Method 3
	Average	1A (75%)	1B (70%)	1C (65%)		
Big Blue	120	90	84	78	91.7	89.7
Elkhorn River	131	98.3	91.7	85.2	99.2	95.9
Little Blue	126	94.5	88.2	81.9	96.3	92.6
Loup River	126	94.5	88.2	81.9	85.6	80.7
Lower Platte	106	79.5	74.2	68.9	85.7	84.4
Missouri Tributaries					116.2	103.9
Nemaha	138	103.5	96.6	89.7	54.6	63.8
Niobrara	130	97.5	91	84.5	83.7	78.4
Tri-Basin					100.1	99.6

Examination of the results produced by the three methods indicates that the estimated acres are fairly similar. Method 1 was eliminated because selection of the correct percentage reduction for each basin would be purely an educated guess until such time as actual data is collected to substantiate the numbers. Method 2 produces defensible numbers but is limited by its use of 1995 data. Method 3 is the procedure with the best available data.

Method 3 was selected as the preferred alternative. This process utilizes the information from a very detailed study done in 1995, and calibrates it to actual survey data collected in the 2002 Census of Agriculture. This procedure offers the additional advantage that it can be re-calibrated when the 2007 Census of Agriculture becomes available to see how the average number of acres per well in each basin has changed over time. Between census years, the number of acres irrigated can be estimated using the current number of registered wells in each basin times the number of acres per well.

There are a total of 89,695 active irrigation wells in Nebraska as of October 2005. Registration information shows that 37,519 of these are not in the area included in the nine basins evaluated. A breakdown of the location of the remaining 52,176 irrigation wells is shown in Table H-2.

Table H-2. Number of Irrigation Wells by Basin.

Basin	Number of Irrigation Wells
Big Blue	14,169
Elkhorn River	8,350
Little Blue	6,720
Loup River	9,953
Lower Platte	5,375
Missouri Tributaries	1,642
Nemaha	411
Niobrara	4,030
Tri-Basin	1,526
Nine Basin Total	52,176

There are an additional 3,539 high capacity, non-irrigation wells registered in Nebraska. Of these, 1,220 are not in the nine basins evaluated.   The remaining 2,319 wells are registered for a variety of uses: Aquaculture, Commercial/Industrial, Domestic, Livestock, Public Water Supplier, and Other. The distribution of these wells in the nine basins is shown in Table H-3.

Table H-3. Number of Non-Irrigation Wells by Use by Basin.

	Aquaculture	Commercial/ Industrial	Domestic	Livestock	Public Water Supply	Other	Total
Big Blue	4	58	19	12	244	12	349
Elkhorn River	2	88	18	79	230	31	448
Little Blue	1	21	15	9	114	10	170
Loup River	10	40	25	63	166	7	311
Lower Platte	3	108	51	8	292	29	491
Missouri Tributaries	5	72	18	20	137	14	266
Nemaha		16	2	1	135	4	158
Niobrara	3	3	5	17	72	4	104
Tri-Basin		11	2	1	8		22

The U.S. Environmental Protection Agency reports that consumptive use of water varies by use category (EPA, 2005). They estimated that the rate of water consumption is highest for livestock at 67%, followed by irrigation at 56%. Domestic use consumes 23%, while industrial/ mining and commercial uses consume 16% and 11% respectively. Thermoelectric use consumes only 3% while public uses and losses are not even quantified as consumptive use by the EPA.

Because these 2,319 wells are such a small portion of the total number of high capacity wells in the state (2%), and no data exists in the registration database to indicate the annual pumpage of these wells, no additional efforts were made to identify the pumpage and calculate consumptive use at this time.

Appendix H

Basic Assumptions Used in the Development of the Department of Natural Resources Proposed Method to Determine Whether a Stream and the Hydrologically Connected Ground Water Aquifers Are Fully Appropriated

Nebraska Revised Statutes § 46-713(3) states that a river basin subbasin or reach shall be deemed fully appropriated if the department determines that then-current uses of hydrologically connected surface water and ground water in the river basin, subbasin, or reach cause or will in the reasonably foreseeable future cause: (a) the surface water supply to be insufficient to sustain over the long term the beneficial or useful purposes for which existing natural flow or storage appropriations and the beneficial or useful purposes for which, at the time of approval, any existing instream appropriation was granted, (b) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the river or stream involved and (c) reduction in the flow of a river or stream sufficient to cause noncompliance by Nebraska with an interstate compact or decree, or other formal state contract or agreement, or applicable state off federal laws. This memo will address the assumptions relied upon to develop the method the Department proposes to use to address sections a and b of the statute.

In essence, if streamflow is sufficient enough to supply surface water appropriators, it is also sufficient to supply recharge for ground water wells dependent on the streamflow. This is true because any ground water aquifer that is hydrologically connected to a fully appropriated stream is also fully appropriated because the surface water and hydrologically connected ground water are both part of one interconnected system. A depletion in one component of this system depletes the other component. If there is an additional well and consumptive use of water in the ground water aquifers connected to the stream, the new well will either intercept and consume water that otherwise would have flowed to the stream or cause more water to flow from the stream to the aquifer. Eventually this additional consumption will cause not only additional depletions to the aquifer, but also additional depletions to the stream. In essence, the test of looking at the sufficiency of streamflow to satisfy a junior surface water right is like a canary in the coal mine; the junior water rights act as an alarm system signaling that the stream and the hydrologically connected ground water aquifers are both fully appropriated.

The nature of the connection between the stream and the aquifer determines how much and how fast water will flow between the stream and the aquifer. Water flows from a hydrologically connected aquifer to a stream, or vice versa, in response to the difference in the hydraulic head between the stream and the aquifer. Water flows down the hydraulic head gradient from areas of higher hydraulic head to areas of lower hydrologic head. Hydraulic head in ground water is a function of the combination of both the elevation and the pressure of the water. Water flows downhill in response to gravity and uphill in response to pressure from the weight of overlying aquifer materials and water.

In the case of a gaining stream, the water in the aquifer has a higher hydraulic head than the stream and water flows down gradient from the aquifer to the stream. In this situation, the addition of a pumping ground water well that removes water from the aquifer will lower the hydraulic head of the ground water in the aquifer and decrease the gradient between the higher hydraulic head in the aquifer and the lower hydraulic head in the stream. The decrease in the hydraulic gradient results in less water flowing from the aquifer to the stream.

In the case of a losing stream the water in the stream is at a higher hydraulic head than the ground water and water flows down gradient from the stream to the aquifer. As before, the addition of a pumping ground water well that removes water from the aquifer will lower the hydraulic head of the ground water in the aquifer. In this case the well will increase the hydraulic gradient between the higher head of the stream and the lower head in the aquifer and more water will flow from the stream to the aquifer, further depleting the stream. In either case, if the stream itself is already determined to be fully appropriated, than the whole integrated system must be fully appropriated.

One must also ask, is it possible for a stream itself to have sufficient water for all surface water rights but not have sufficient ground water to recharge wells dependent on streamflow? In this case, all the demands of the surface water rights would have to be satisfied, but the water in the ground water aquifer would be insufficient for the existing wells. Such a system could not happen on a gaining stream because if the ground water were insufficient to sustain the wells, there would be little or no water in the stream for the surface water users. According to Bentall and Shafer (1979) most streams in the State of Nebraska are gaining streams[1].

The remaining case would be a losing stream on which the major water supply to the stream and the hydrologically connected aquifers was from surface water runoff to the stream. Furthermore, this runoff would have to be sufficient to satisfy the junior surface water rights, or it would be determined to be fully appropriated under criteria (a) of the statute, but not sufficient enough to satisfy ground water wells for which the stream flow was a critical component of the supply. In areas on the White and Hat Creeks in western Nebraska, where isolated fractures in the Brule Formation are in close hydrologic connection to the stream but not to a surrounding ground water aquifer, there could be small stock and domestic wells that depend primarily on streamflow as their sole source of water. However, these streams have already been declared fully appropriated because the demands of the existing surface water rights are not met. There may also be such

[1] Availability and Use of Water in Nebraska 1975. 1979. Nebraska Water Survey Paper Number 48. Conservation and Survey Division Institute of Agriculture and Natural Resources, University of Nebraska Lincoln.

isolated physical systems in other parts of the state such as in the glacial till area of the eastern part of the state and along the Missouri River, but like the White River and Hat Creek, if the demands of the hydrologically wells are not being met, it is unlikely that the demands of any existing surface water rights would be met.