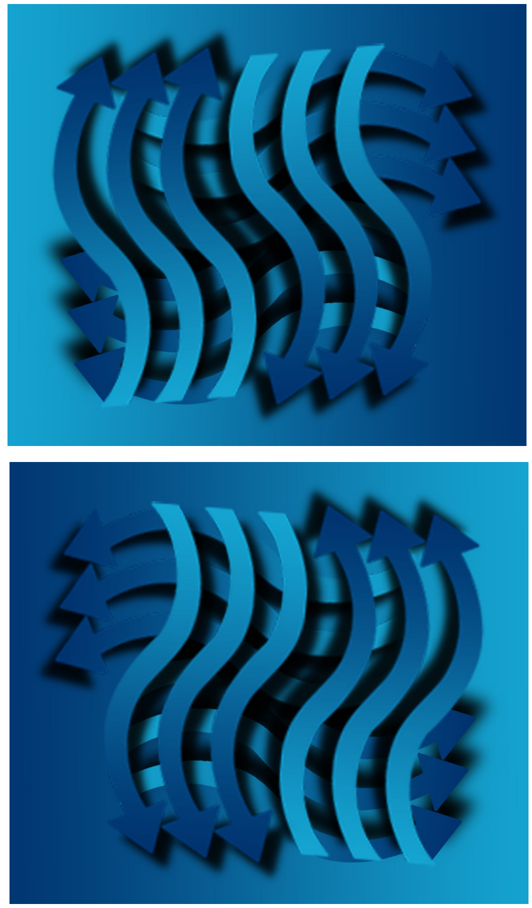


2012

Annual Evaluation of Availability of Hydrologically Connected Water Supplies

Determination of Fully Appropriated

Published by the
Nebraska Department of Natural Resources
December 21, 2011

TABLE OF CONTENTS

Page

APPENDICES

TABLES

Page

FIGURES

Page

Report Organization

This report is divided into eight 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 A. Detailed descriptions of the methodologies used in the analyses can be found in Section Four. Sections Five through Seven are the evaluations of the Big Blue River Basins, Lower Niobrara 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 groundwater 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 Eight is a summary of the basin sub-sections and the report conclusions. The appendices contain additional detailed information not found within the main body of the report.

1.0 SUMMARY

The Nebraska Department of Natural Resources (Department) has evaluated the expected long-term availability of surface water supplies and hydrologically connected groundwater supplies of the Blue River Basins, the Lower Niobrara River Basin, and the Missouri Tributaries Basins, and has concluded that none of the basins or any of the subbasins or reaches within the basins are fully appropriated at the present time. The Department did not evaluate the Lower Platte River Basin or Niobrara River Basin upstream of the Spencer Hydropower facility in this year's evaluation pursuant to Neb. Rev. Stat. § 46-713(1)(a).

The Department conducted an additional evaluation of the long-term water supplies with no additional constraints on groundwater and surface water development in the Blue River Basins, the Lower Niobrara River Basin, and the Missouri Tributaries Basins using the best available science and methods. The results of this evaluation indicated that the preliminary determination would not change based on reasonable projections of the extent and location of future development in the basins.

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 previously been determined to be fully or overappropriated or for which a status change has not occurred within the previous four-year period pursuant to Neb. Rev. Stat § 46-713(1)(a). No re-evaluations were made in this report for basins, subbasins, or reaches that have previously been determined to be fully or overappropriated.

The evaluation and preliminary conclusions of this report are grouped into three river basins: the Blue River Basins, Lower Niobrara River Basin, and Missouri Tributary Basins. This format is intended to reduce repetition; each appropriate basin, subbasin, and reach, however, was analyzed separately.

As required by statute, the report describes the nature and extent of present water uses in the basins, shows the geographic areas considered to have hydrologically connected surface water and groundwater supplies, and predicts how the Department's preliminary conclusions might change if no new legal restrictions are placed on water development in the basins. The report does not address the sufficiency of groundwater supplies that are not hydrologically connected to surface water streams. The report includes a description of the criteria and methodologies used to determine whether 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 groundwater uses on resources that are dependent on streamflow or groundwater levels but that are not protected by appropriations or regulations. Appendix B contains the notice of request for any relevant data from any interested party and all comments received.

The Department did not evaluate the Lower Platte River Basin or Niobrara River Basin upstream of the Spencer Hydropower facility in this year's evaluation pursuant to Neb. Rev. Stat. §§ 46-713(1)(a) and 46-714(12)(a). However, the natural resource districts (NRD) within these basins have developed rules limiting new irrigated acres within their respective districts and the Department will limit the permitting of new appropriations for surface water irrigation within these basins Neb. Rev. Stat. §§ 46-714 (12).

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 groundwater users, and water transfers/water banking. The forty-nine Task Force members, appointed by Governor Mike Johanns 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's recommendations. Governor 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 groundwater users. Where conflicts already exist, it established principles and timelines for resolving those conflicts. It also added more flexibility to statutes governing transfer of surface water rights to a different location of use and updated a number of individual water management statutes.

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

- 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 specify by rule and regulation, the types of scientific criteria and other information to be utilized in the analysis, 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 determined to be fully appropriated, stays on new uses of groundwater and surface water are automatically imposed. The Department and the 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 groundwater 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 planned incremental approach toward achieving a balance between water uses and water supplies.

- IMPs may rely on a number of voluntary and regulatory controls, including incentives, allocation of groundwater 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.

Shortly after the passage of LB 962, a number of basins, subbasins, or reaches were determined to be fully or overappropriated. These areas included portions of the Platte River Basin, Republican River Basin, Upper Niobrara River Basin, White River Basin, and Hat Creek Basin (figures 2-1 and 2-2). Additionally, following the status change of the Lower Platte River Basin preliminary determination in April 2009, the legislature passed LB 483 and LB 54.

Some of the key provisions of LB 483 and LB 54 that are relevant to development of this report include the following:

- The NRDs affected by a status change (reversal of preliminary determination that a basin, subbasin, or reach is fully appropriated) of a basin, subbasin, or reach must develop rules to limit the total number of new groundwater irrigated acres annually for a period of at least four years following the status change.

- The Department must approve the natural resources districts proposed number of new irrigated acres if the basin, subbasin, or reach would not be caused to be fully appropriated based on the most recent annual evaluation. Absent such approval, the natural resources districts must limit new irrigated acres to two thousand five hundred or twenty percent of the historically irrigated acres, whichever is less.

- The Department must ensure that any new appropriation granted will not cause the basin, subbasin, or reach to be fully appropriated based on the most recent annual evaluation.

- The Department must limit new natural flow surface water appropriations for irrigation within the basin, subbasin, or reach to ensure that there is not a net increase of more than 834 irrigated acres in each NRD during each calendar year of the four-year period.

- The Department is not required to perform an annual evaluation for a river basin, subbasin, or reach during the four years following a status change in such river basin, subbasin, or reach.

Areas that are currently subject to the restrictions resulting from the passage of LB 483 are illustrated in figures 2-3 and 2-4.

Previous statutorily required reports on the evaluation of hydrologically connected water supplies are available online (http://www.dnr.ne.gov/docs/studiesandresearch.html) or upon request from the Department.

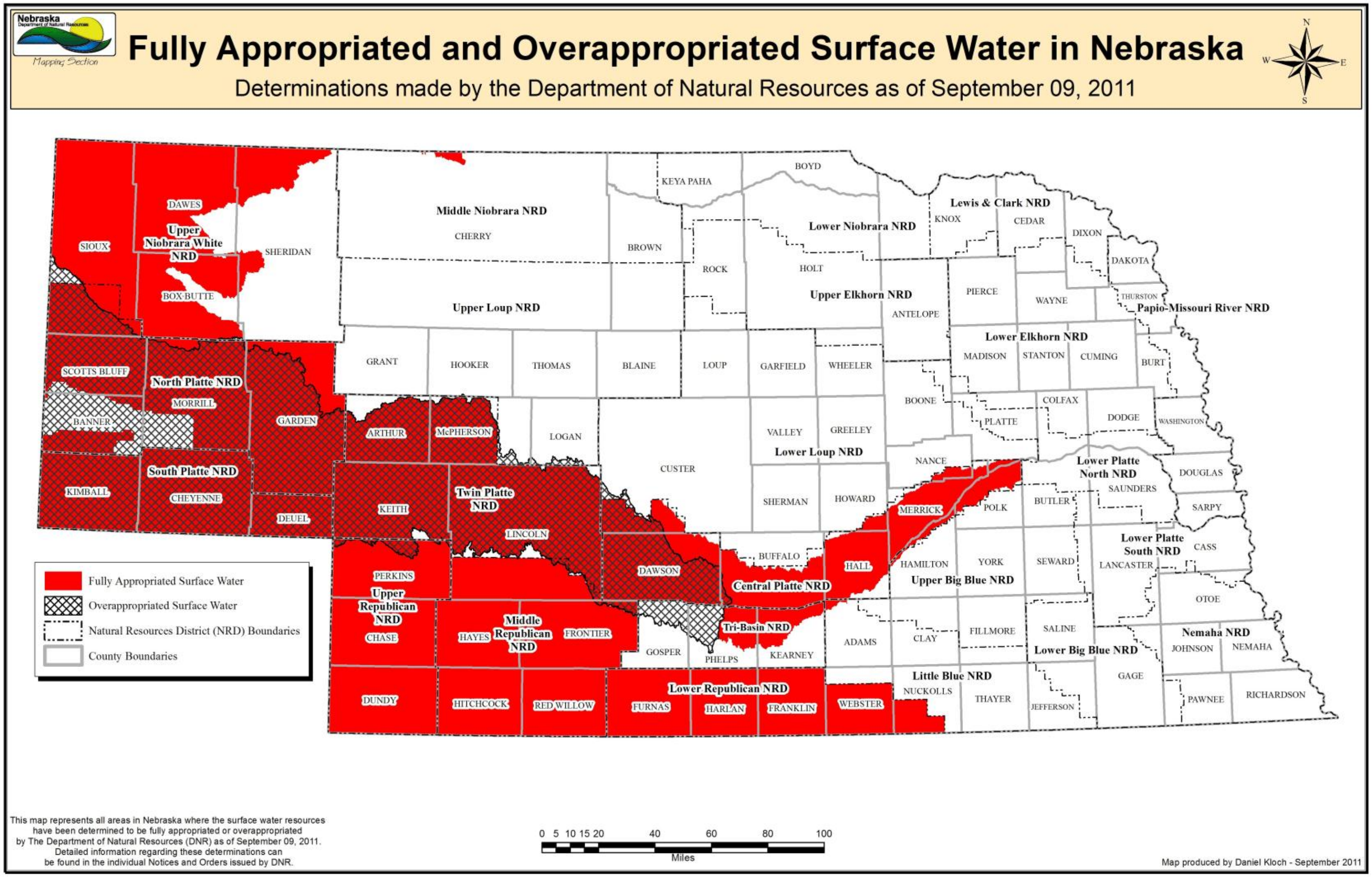


Figure 2-1. Areas designated as fully appropriated or overappropriated basins, subbasins, and reaches since the passage of LB 962.

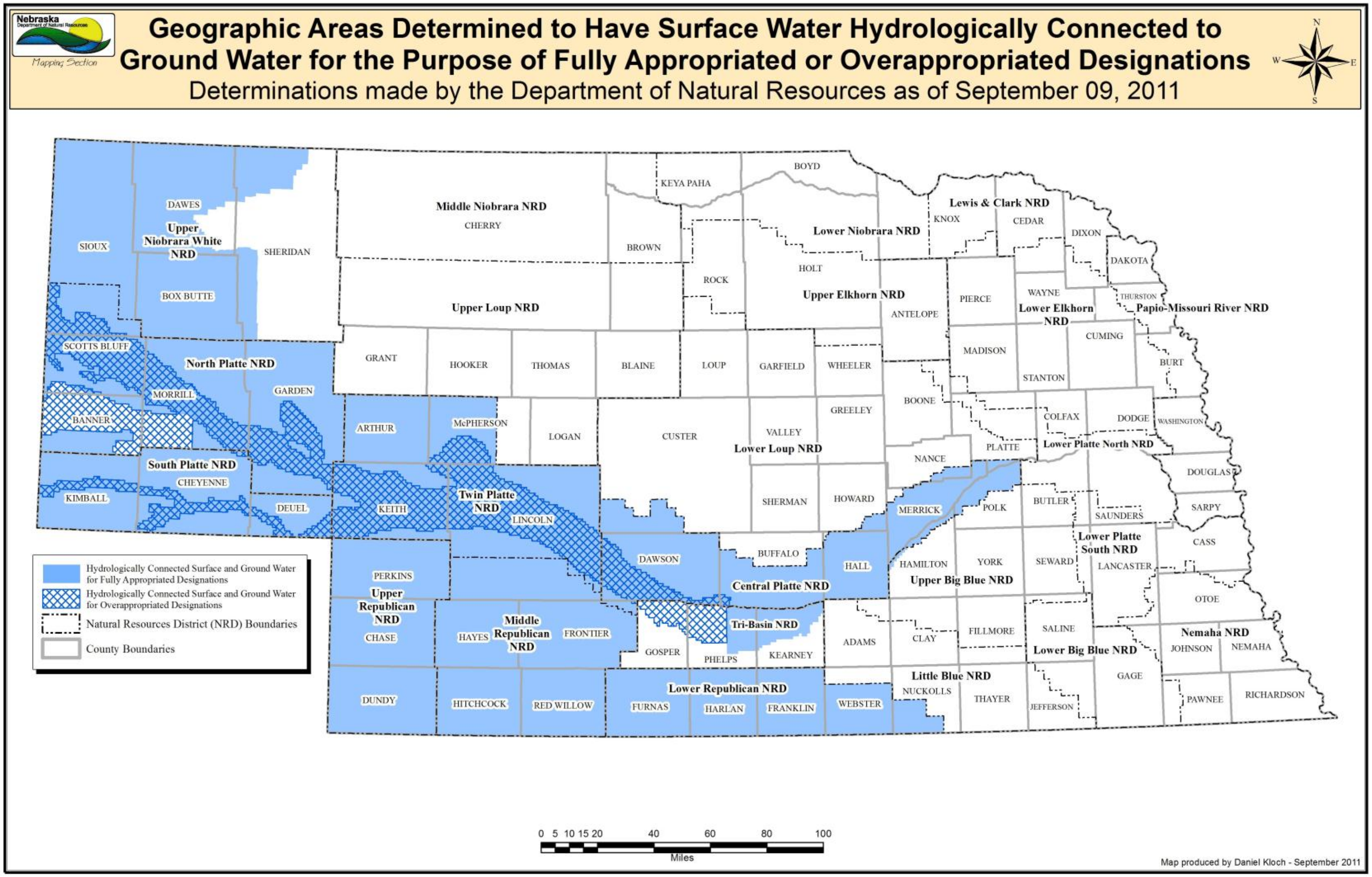


Figure 2-2. Areas designated as hydrologically connected to fully appropriated or overappropriated basins, subbasins, and reaches since the passage of LB 962.

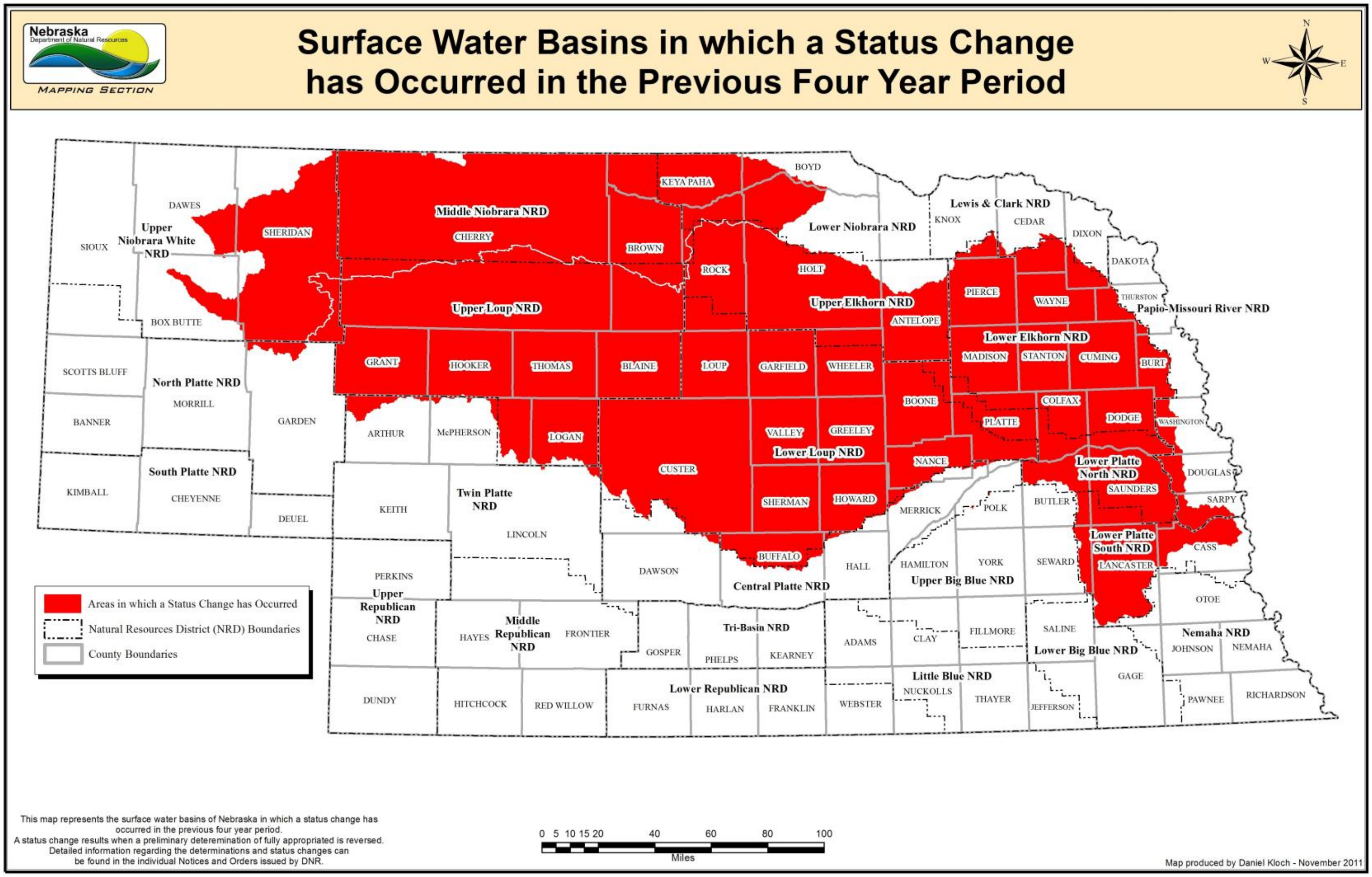


Figure 2-3. Surface water basins in which a status change has occurred in the previous four-year period.

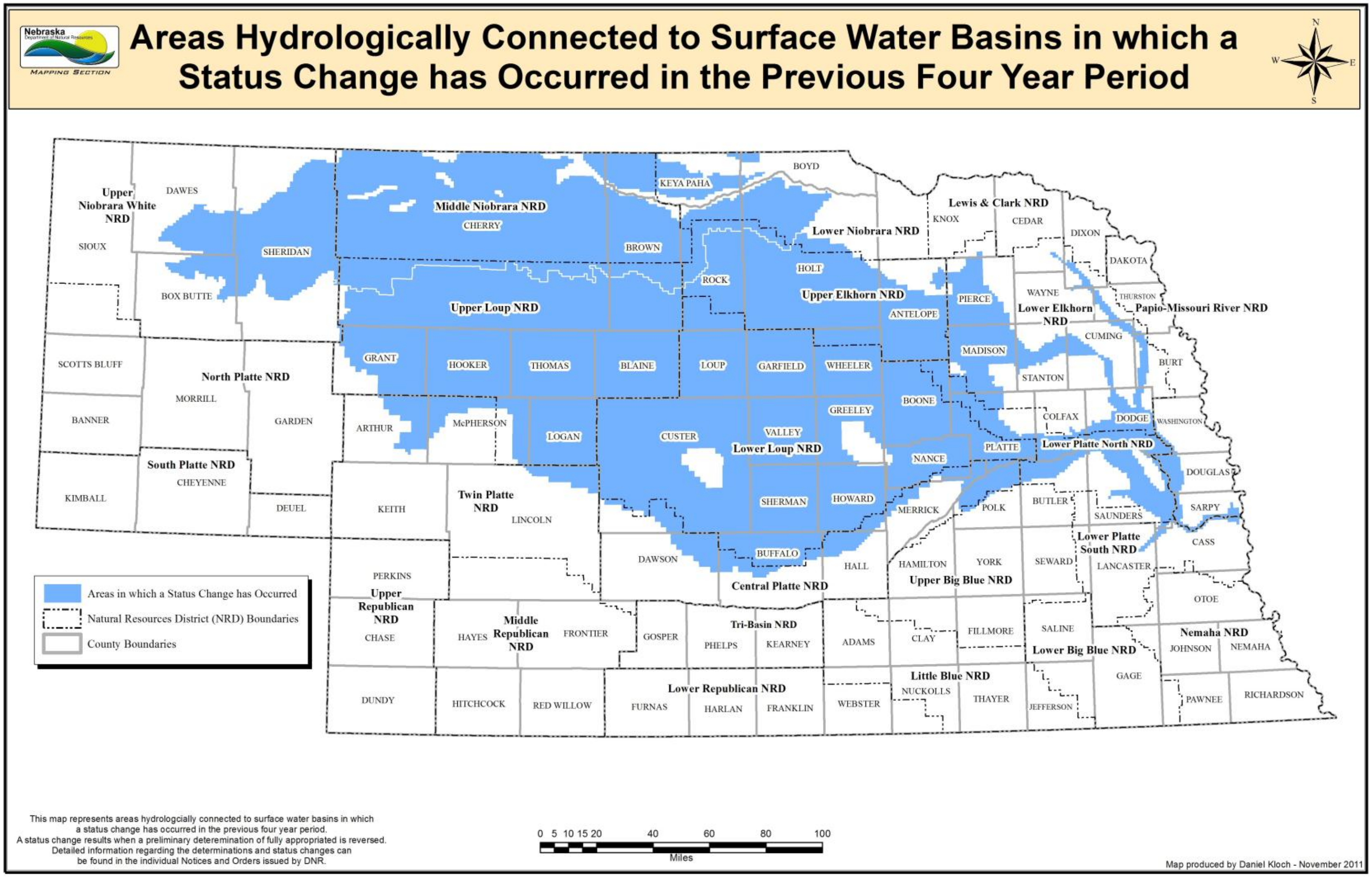


Figure 2-4. Areas hydrologically connected to surface water basins in which a status change has occurred in the previous four-year period.

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 groundwater that is in hydrologic connection with the stream. For all evaluated basins, the geographic areas of hydrologically connected surface water and groundwater, where present, are illustrated on a basin-wide map that is included in each basin sub-section of the report. On each of those maps, the surface watershed basin is shown by a solid line and the hydrologically connected groundwater 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 NAC 24.001.02, the Department considers the area within which groundwater 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 the purposes of evaluation, a river basin may be divided into two or more subbasins or reaches. Basins that have not previously been determined as overappropriated or fully appropriated or that have not experienced a status change (reversal of preliminary determination that a basin, subbasin, or reach is fully appropriated) in the previous four years are required to be evaluated.

In preparing its annual report, the Department is required by Neb. Rev. Stat. § 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 may use is found in rule 457 NAC 24.002 (Appendix A). 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 groundwater. 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 groundwater 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 (ESA), 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) or by the significant modification or degradation of designated critical habitat where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering (50 CFR § 17.3). The state Nongame and Endangered Species Conservation Act (NNESCA), Neb. Rev. Stat. §§ 37-801 *et seq.*, also prohibits the actual killing or harming of an individual member of a listed species, and the destruction or modification of designated critical habitat. It was concluded that any reductions in flow that may occur as a result of not determining a basin, subbasin, or reach to be fully appropriated will not cause noncompliance with either federal or state law at this time in any of the basins evaluated.

Prior to making a final determination that a basin is fully appropriated, 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 METHODOLOGY

This section provides an overview of the methodologies used in the Department's basin evaluations and is separated into three sub-sections.

1) The first sub-section outlines the legal requirements established in section 46-713 of the Ground Water Management and Protection Act and regulation 457 NAC 24 (Appendix A) as they relate to the analysis.
2) The second sub-section provides the overall procedure for evaluation of each basin.
3) The third sub-section discusses the specific methods implemented by the Department to calculate the extent of the 10/50 area.

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 groundwater uses in each river basin, subbasin, or reach; 2) define the geographic area within which surface water and groundwater 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 groundwater uses is based on information obtained through published reports from the University of Nebraska-Conservation and Survey Division (CSD), the U.S. Geological Survey (USGS), NRDs, 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 CSD and USGS websites, http://snr.unl.edu/csd/ and http://waterdata.usgs.gov/ne/nwis/nwis, respectively. All data utilized in this report are available at: ftp://dnrftp.dnr.ne.gov/Pub/FAB_Report/ or from the Department upon request. This data and the following methodologies are provided to allow for complete reproducibility of the results.

4.1.2 Regulation 457 NAC 24.001

The Department's evaluation of the extent to which current uses will affect available near-term and long-term water supplies considers current surface water appropriations, current well development, and the twenty-five-year lag impacts from that current well development on surface water flows. For the 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 its associated impact on surface water appropriations.

Regulation 457 NAC 24.001 generally states that a basin is fully appropriated if current uses of hydrologically connected surface water and groundwater 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 NAC 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 NAC 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 NAC 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.

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. When projecting the quantity of wells that may be added to the number of currently developed wells, the Department considers the following: 1) the availability of lands suitable for irrigation; 2) the extent of well-construction moratoriums established by NRDs; and 3) trends in well development over the previous ten-year period.

4.1.2.1 The Role of the Surface Water Administration Doctrine in Implementation of the 65/85 Rule

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 surface water is in short supply 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; 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 excess surface water is available, 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, which governs surface water administration, ensures that if sufficient water is available 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.

4.1.3 Regulation 457 NAC 24.001.002

The Department must determine the geographic area within which surface water and groundwater are hydrologically connected. Regulation 457 NAC 24.001.02 states that the geographic area within which the groundwater and surface water are hydrologically connected is determined by calculating where, in each river basin, a well would deplete a river's flow by ten percent of the amount of water the well could pump over a fifty-year period (i.e., "the 10/50 area"). The 10/50 area serves as the minimum area that would be subject to preliminary stays when a basin is determined to be fully appropriated, requirements of an IMP, or to restrictions on the development of irrigated acres following a basin status change.

4.1.4 Utilization of the Best Available Science in the Annual Evaluation

The Department must rely on the best scientific data, information, and methodologies readily available to ensure that the conclusions and results arrived at through the annual evaluation are reliable. The Department has specified by rule and regulation the types of scientific data and other information that will be considered (457 NAC 24.002) in the annual evaluation. Specific data relied upon by the Department is referenced throughout this report and is sited in the section bibliographies.

A key component of the methods used by the Department in this report is the implementation of methods to assess stream depletions by groundwater wells. There are several methods available for estimating the extent and magnitude of stream depletions. Historically, three broad categories have been used to study groundwater flow systems, including 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 groundwater flow. Limitations of each method must be considered by the user when examining the results of analyses and the appropriateness of each method for a given task. With user-friendly interfaces and high-speed computers, numerical models have become the preferred method of evaluating regional groundwater flow. One widely used numerical model developed by the USGS is MODFLOW (McDonald and Harbaugh, 1988). For the purposes of this report, if an acceptable Department peer-reviewed MODFLOW model suitable for regional analysis is available, then it will be utilized to assist in analysis.

No areas evaluated in this report are 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. At present, however, analytical methods are the best available tool for the analysis of stream depletions within these basins.

The analytical Jenkins (1968) method for calculation of stream depletion factors (SDF) (Appendix C) lends itself best to the basin-wide aspect of the task described in this report. This method is based on simplifying assumptions and was built upon previously published equations. For this report, the Jenkins method was used in the evaluation of the Lower Niobrara River Basin and portions of the 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 (Hunt, 1999 and Zlotnik, 2004). These modified methods require additional data that are generally not available for the basins in this evaluation. However, these data were available for the Blue River Basins (Bitner, 2008) and therefore utilized in the evaluation.

In some areas of the state, use of the analytical method to determine the 10/50 area or the lag impact of groundwater pumping from wells was not completed. These areas typically lack information regarding the hydrologic connection between streams and aquifers. These areas were not evaluated in the current report.

4.2 Evaluating the Status of a Basin

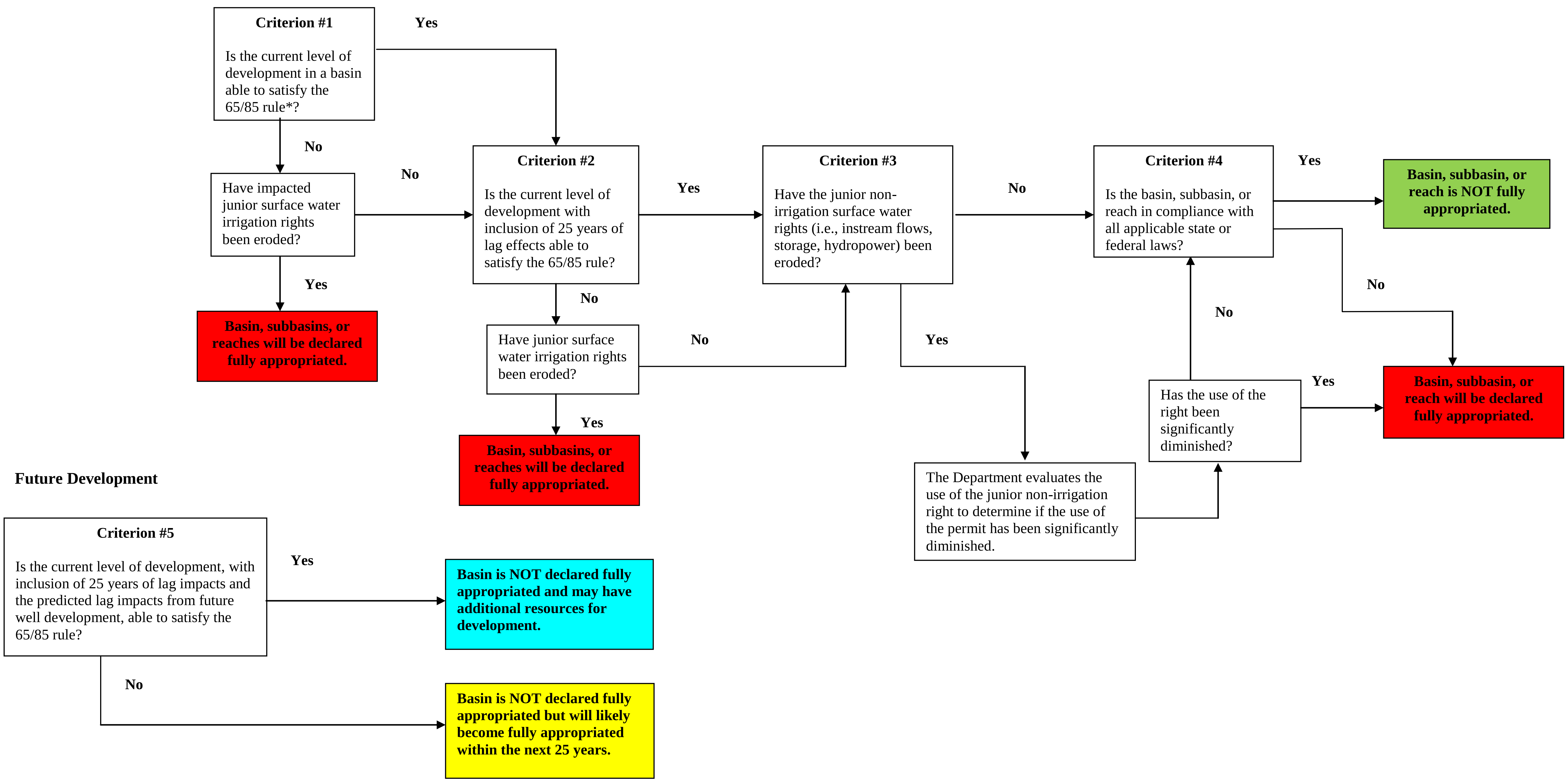
To evaluate the status of a basin, the Department must evaluate the current and future water supplies of the basin. The following provides a general overview of the process used by the Department to evaluate the current and future water supplies in each basin as well as the specific step-by-step procedures implemented by the Department.

4.2.1 The Process of Determining if a Basin is Fully Appropriated

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

If criteria one and/or two are not 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 4.2.4. Figure 4-1 illustrates the evaluation process for determining whether a basin is fully appropriated.

Evaluation of the Status of a Basin



- **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.**

Figure 4-1. Basin evaluation flow chart.

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, but such failure would indicate that future development may cause the basin to become fully appropriated if current development trends continue.

4.2.2 Evaluation of Current Water Supplies

The first criterion assessed to determine whether a basin is fully appropriated is to evaluate if the current water supply is sufficient to satisfy the 65/85 rule. The current water supply is estimated based on the most recent twenty-year period of streamflows (1991-2010). The following steps were taken to determine if current water supplies are sufficient to satisfy the 65/85 rule:

1. Determine the level of surface water administration that has occurred in each basin for the past twenty years.
2. Determine the crop irrigation requirement for junior irrigators subject to the administration.
3. Determine the number of days of diversion necessary to satisfy the 65/85 rule.
4. Compare the number of days available for diversion to the number of days necessary to satisfy the 65/85 rule.

Step 1: Determine the Level of Surface Water Administration in the Past Twenty Years

The level of surface water administration is determined based on Department records for calls for administration for the previous twenty years (1991-2010). The administration records are used to develop a twenty-year average number of days for which administration was not occurring (days available for diversion). The days available for diversion are categorized based on the months in which they are available. Days that are available for diversion during July and August are categorized as available to meet the 65% portion of the 65/85 rule and days that are available for diversion during May, June, July, August, and September are categorized as available to meet the 85% portion of the 65/85 rule.

Step 2: Determine the 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. 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 4-2). The NCCIR distribution for each basin is set out in individual basin sub-sections. The method of developing the NCCIR is described in Appendix D.

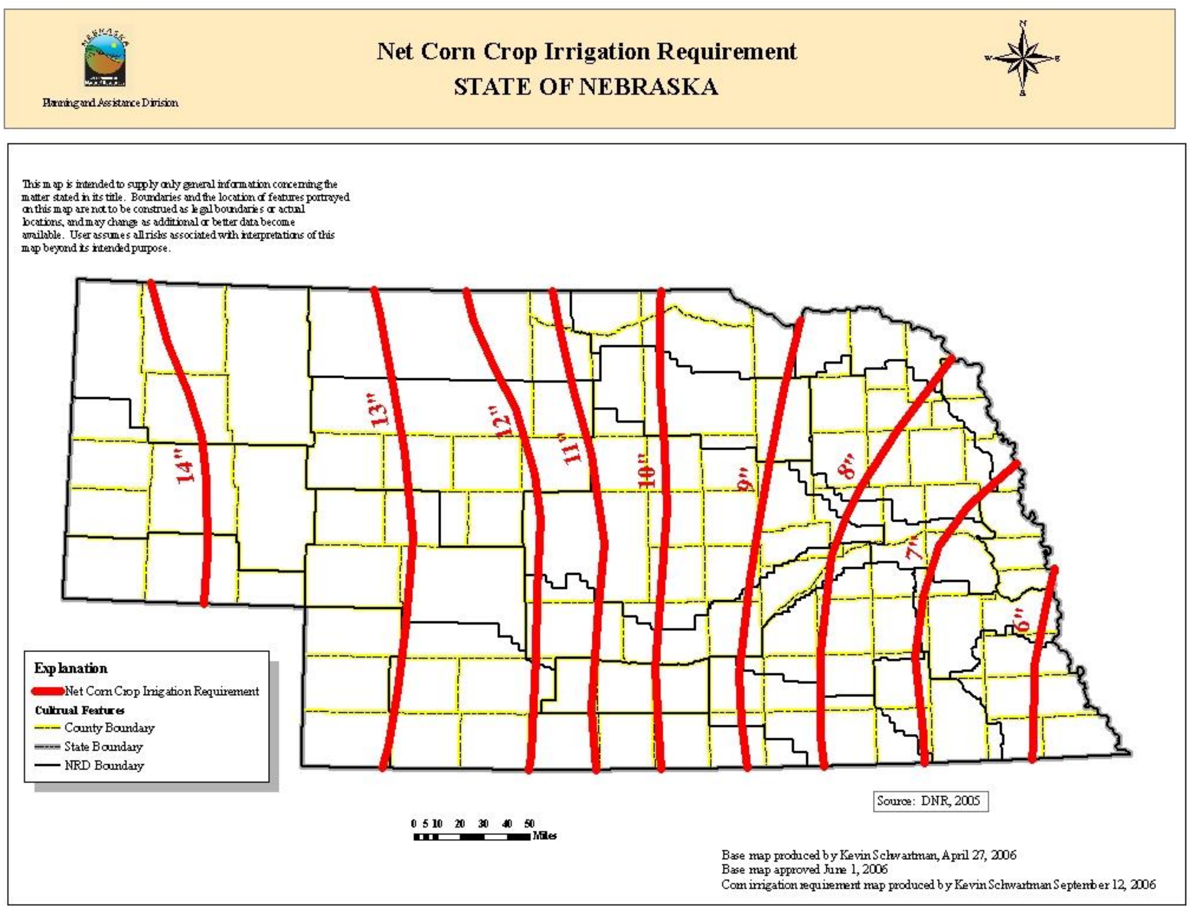


Figure 4-2. Net corn crop irrigation requirement (NCCIR).

Step 3: Determine the Number of Days Necessary for Diversion

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 one 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 junior irrigator's diversion.
2) Interpolate between the NCCIR contours to determine the specific NCCIR at the junior irrigator's diversion.
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.

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

Step 4: Compare the Number of Days Available for Diversion to the Number of Days Necessary for the Junior Irrigator to Satisfy the 65/85 Rule

The results of the calculation in Step 3 are compared to the results of Step 1, the average number of days over the previous twenty-year period (1991-2010) that surface water was available for diversion, to evaluate whether a basin is fully appropriated. If the average number of days available for diversion is less than the number of days necessary to meet either the 65% or 85% criteria, 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 4.2. If the basin satisfies this test, then the second criterion is evaluated: the addition of lag impacts from current development.

4.2.3 Evaluation of Long-Term Water Supplies with Current Levels of Development

The second criterion assessed to determine whether a basin is fully appropriated is to evaluate if the long-term water supply is sufficient to satisfy the 65/85 rule. The long-term water supply is estimated based on the most recent twenty-year period of streamflows (1991-2010) and the lag impacts from current levels of well development. In those basins for which the appropriate geologic and hydrologic data were available and no numerical models exist, the following steps were taken to compute the lag impact from current development:

1. Define the groundwater boundary for the study area.
2. Extract all high-capacity wells with completion dates prior to December 31, 2010, from the Department's database.
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.

An appropriate numerical model did not exist for calculating lag depletions in any of the basins evaluated. For areas in which the appropriate geologic and hydrologic data were available, lag depletions were calculated using the methods described in this sub-section. In those basins for which the appropriate geologic and hydrologic data were not available, the lag impacts were not calculated. 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.

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 groundwater boundary is defined by certain features that include the location of perennial baseflow streams, areas where the aquifers are present, and the location of glaciated areas.

Wells may be influenced by hydrologic boundaries (i.e., streams in other surface water basins). The methods used to account for these boundaries utilize image wells and superposition. These methods are further described in Jenkins, 1968b.

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 fifty 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 Department's water well registration 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, 2010, were used in the analysis.

Step 3: Account for Current Year (2011) 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, 2011, and December 31, 2011. The first step in estimating the number of high-capacity wells for 2011 is to average the well development rates within a basin over the previous three-year period (2008-2010) 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 forty 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, 2010, and those estimated to be developed in each basin in 2011 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 4.2.2) by the number of acres irrigated by the well. The number of acres irrigated by each well was estimated to be ninety acres for reasons documented in Appendix E (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 4-2): 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

In the Lower Niobrara River Basin and the Bazile Creek subbasin of the Missouri Tributary Basins, the Jenkins SDF methodology was 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 (2011 is the 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 4-3).

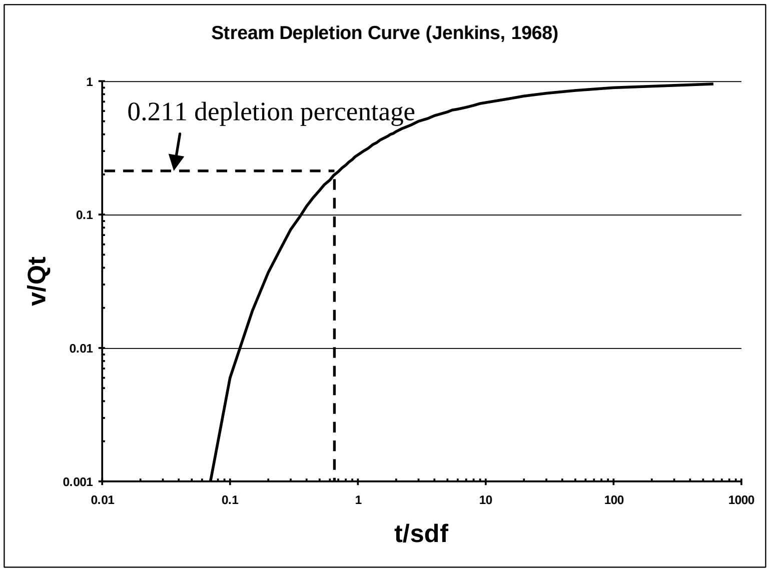


Figure 4-3. Determining depletion percentage (v/Qt) from the dimensionless term.

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 4-3.

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 depletion rate calculated for 2011 is subtracted from the depletion rate calculated for 2036 (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. The lag depletion is calculated by subtracting the rate of annual depletion in twenty-five years from the current rate of annual depletion.

Year	**Cumulative Depletion (cfs)**	**Rate of Annual Depletion**	**Lag (cfs)**
2010	100	10	20
2011	110		
2035	300	30	
2036	330		

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 value 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 for diversion to the most junior appropriator within the basin. 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.

4.2.4 Determining Erosion of Rights

If a basin has failed either the first or second criterion (described in Sections 4.2), then the next step in the Department's analysis is to apply what has been termed "the erosion rule" (457 NAC 24.001.01C). This rule takes into account the fact that appropriations may be granted even though water supplies may be insufficient 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.

In the event that the junior water right is not an irrigation right, regulation 457 NAC 24.001.01B states that 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.

The erosion rule is applied using 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., 1991-2010). 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 1991-2010 to serve as the current twenty-year period.

3. Determine the twenty-five-year lagged groundwater 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 groundwater depletions from wells existing at the end of the current twenty-year period (using methodologies described in Section 4.2.3), and subtract them from the daily streamflow record for the current twenty-year period (1991-2010).
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 (1991-2010) 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.

4.2.5 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 that would trigger condition (c). The federal Endangered Species Act (ESA), 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) or by the significant modification or degradation of designated critical habitat where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding or sheltering (50 CFR § 17.3). The state Nongame and Endangered Species Conservation Act (NNESCA), Neb. Rev. Stat. §§ 37-801 *et seq.*, also prohibits the actual killing or harming of an individual member of a listed species, and the destruction or modification of designated critical habitat. It was concluded that any reductions in flow that may occur as a result of not determining a basin, subbasin, or reach to be fully appropriated will not cause noncompliance with either federal or state law at this time in any of the basins evaluated.

4.2.6 Evaluating the Impacts of 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. The analysis does, however, 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 the steps outlined in Section 4.2.3. The specific steps necessary to conduct an analysis of the impacts of future well development on the status of a basin are as follows:

1. Gather information on lag impacts of current wells (from calculations performed in Section 4.2.3).
2. Project the rate of future well development.
3. Incorporate projected future well development into the study area.
4. Calculate the depletions of projected future well development.
5. Subtract the depletions of projected future well development from the previous twenty-year lag-adjusted flow record (1991-2010), 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 are determined as outlined in Section 4.2.3 above, and the lag-adjusted flow record developed in Step 6 of Section 4.2.3 is that discussed in this section. In using the lag-adjusted flow record, the twenty-five-year lag impacts of current well development are 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, the rate of future well development must be estimated. This estimation is completed by projecting the linear trend of current high capacity well development within a study area over the previous ten years (2001-2010). 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 forty 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 4.2.3. 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 6 of Section 4.2.3 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 6 in Section 4.2.3 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 1991-2010 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.

4.3 Development of the 10/50 Areas

The 10/50 area is defined as the geographic area within which groundwater is hydrologically connected to surface water. A well constructed in the 10/50 area would deplete river flow by at least ten percent 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 Numerical and Analytical Models Used in Development of the 10/50 Areas

The Department reviewed available numerical models to assess their validity in defining the 10/50 area. Currently no valid numerical models for defining the 10/50 area exist within the areas evaluated by the Department.

In areas where an acceptable numerical model has not been developed but where appropriate geologic data exist (i.e., the Lower Niobrara Basin, portions of the Blue River Basins, and portions of the Missouri Tributary Basins), an analytical 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 calculations to delineate the 10/50 boundary for these basins.
4. Develop the 10/50 area.

Two analytical approaches were utilized to determine the extent of the 10/50 area. The Hunt Method (Hunt,1999) was used to determine the 10/50 area and to estimate groundwater depletions in the Blue Basins. This methodology was able to be used in the Blue Basins since streambed conductance data was provided by the Upper Big Blue Natural Resources District (Bitner, 2008). The Jenkins Method was used to determine the extent of the 10/50 area in portions of the Lower Niobrara River Basin and Bazile Creek subbasin of the Missouri Tributary Basins. In all other areas, where sufficient data do not exist or where the principal aquifer is not present, the 10/50 area could not be determined at this time.

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,
- Streambed conductance (to apply the Hunt Method; only available in the Blue Basins).

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 USGS National Hydrography Dataset. The main stems of each river and of their perennial 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 that 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). Supporting evidence from other published reports may also be used in some cases to delineate the extent of hydrologic connection between aquifers and streams. This information is referenced where used.

Step 3: Perform Jenkins SDF Calculations

In the Lower Niobrara River Basin and the Bazile Creek subbasin of the Missouri Tributary Basins, the Jenkins SDF method was used. The Jenkins SDF method utilizes the following two terms, for which solutions are derived graphically using the curve shown in figure 4-4.

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.

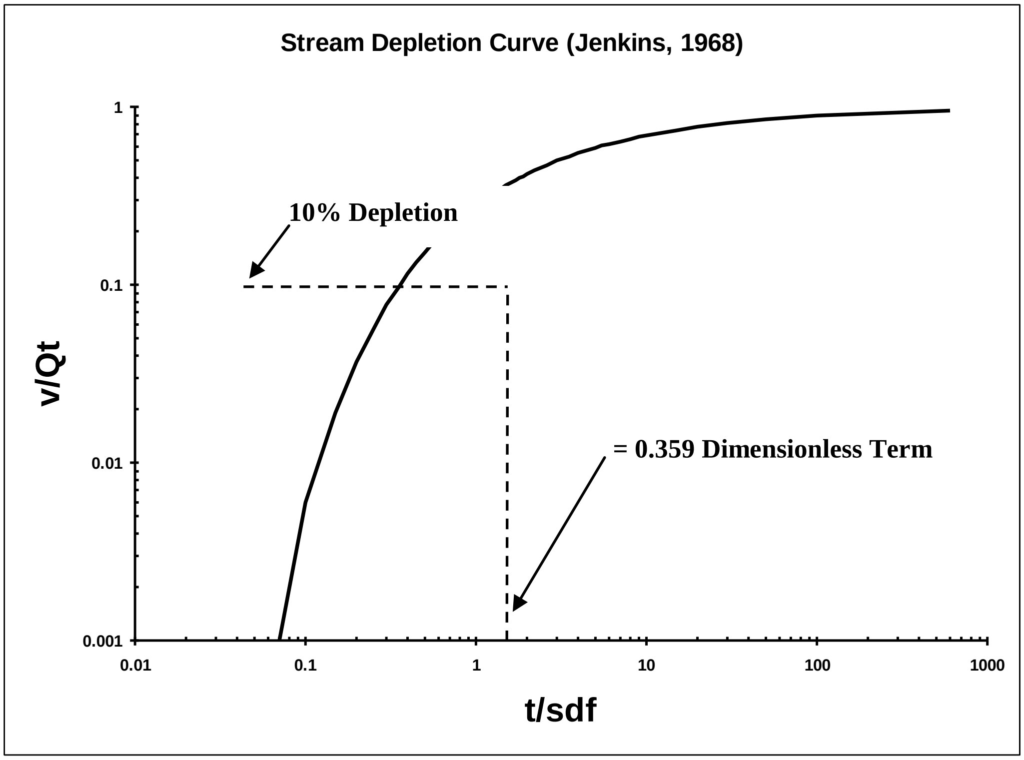


Figure 4-4. Stream depletion curve from Jenkins (1968). The dimensionless term will equal 0.359 when the depletion percentage is equal to ten percent. The aquifer properties (transmissivity and specific yield) at each grid point and the distance of each grid point from the nearest perennial stream will be utilized to calculate the dimensionless term.

Figure 4-5 illustrates an example of the data used in the determination of the dimensionless term at each point. 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.

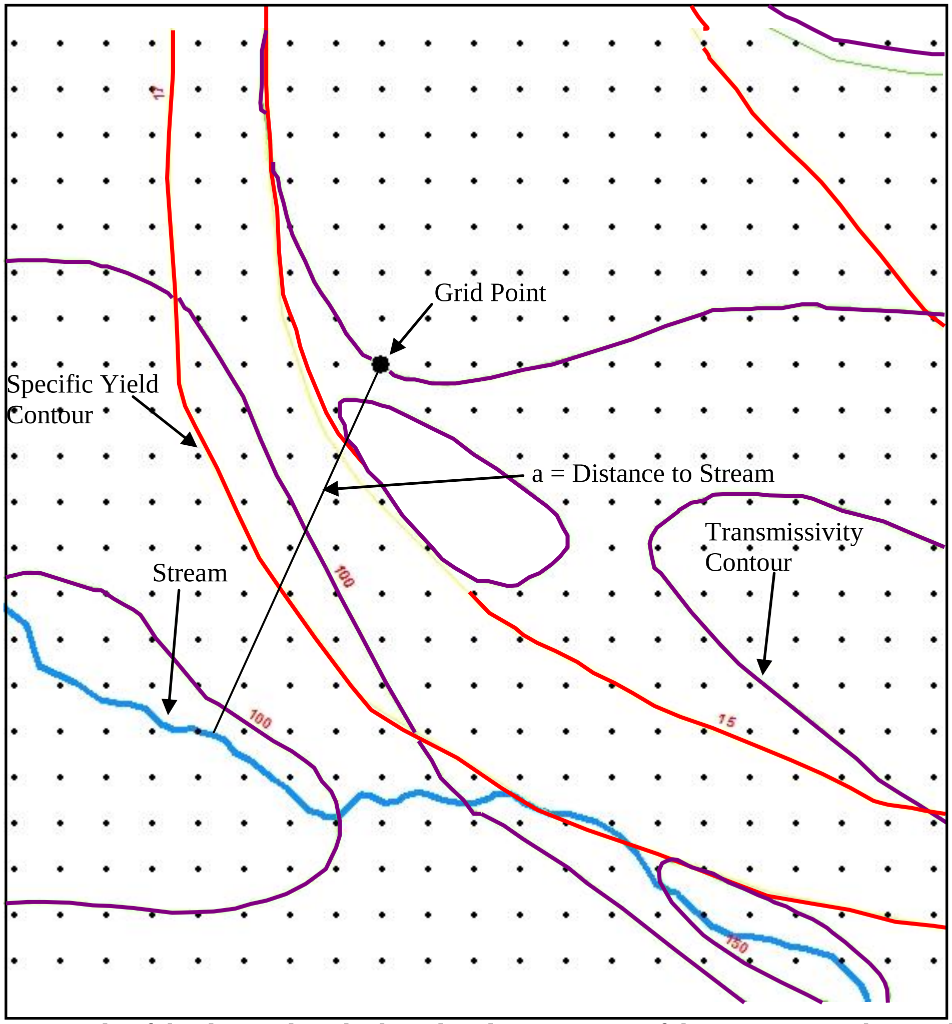


Figure 4-5. An example of the data and method used in determination of the 10/50 area. The purple and red lines are isolines (constant value along that line). Transmissivity and specific yield values for individual points are interpolated between the two nearest contour lines.

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.

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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. The Department has also determined that, based on current information, if no additional legal constraints are imposed on future development of hydrologically connected surface water and groundwater and reasonable projections are made about the extent and location of future development, this preliminary conclusion would not change to a conclusion that the basin is fully appropriated.

The analysis of lag effects of current development for areas in the western portion of the Big Blue River Basin indicates a reduction in streamflows by 23 cfs in twenty-five years. The analysis of lag effects of current development for areas in the western portion of the Little Blue River Basin indicates a reduction in streamflows by 25 cfs in twenty-five years. It was not possible to calculate lag effects of current development for areas in the eastern portions of the basins at this time due to the glaciated nature of the area and the fact that the principal aquifer is absent or very thin (CSD, 2005).

The analysis of the impacts of potential future development in the western portion of the Big Blue River Basin, based on current development trends, indicates an additional reduction in streamflows of 4 cfs in twenty-five years. The analysis of the impacts of potential future development in the western portion of the Little Blue River Basin, based on current development trends, indicates an additional reduction in streamflows of 13 cfs in twenty-five years. The potential impacts of future development in the eastern portions of the basins were not evaluated at this time due to the glaciated nature of the area and the fact that the principal aquifer is absent or very thin (CSD, 2005).

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. NRDs with significant area in the basins are the Little Blue, the Lower Big Blue, the Upper Big Blue, and the Tri-Basin NRDs. The basins are the subject to an interstate compact between Kansas and Nebraska that sets state line target flows.

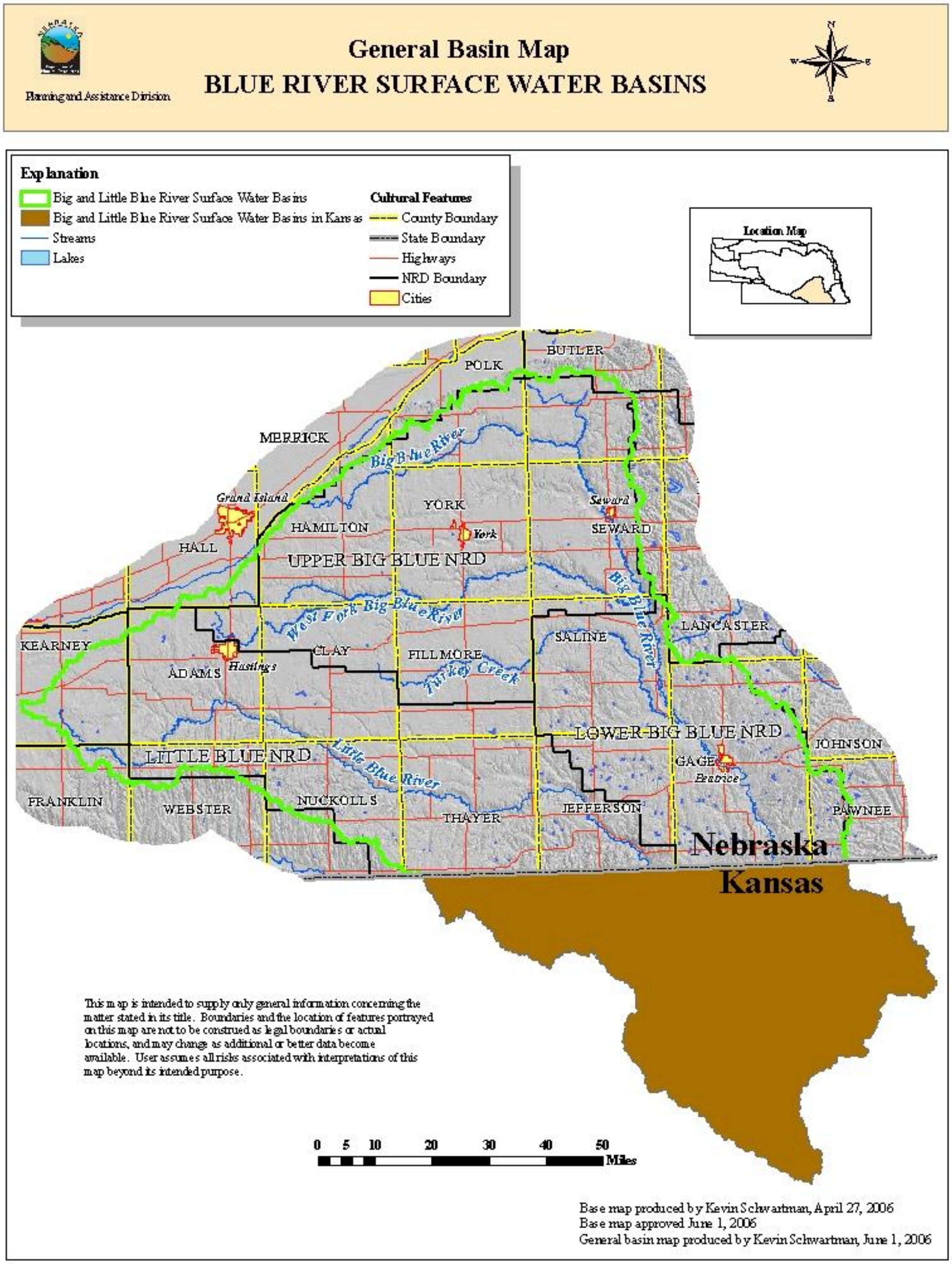

Figure 5-1. General basin map, Blue River Basins.

5.3 Nature and Extent of Water Use

5.3.1 Groundwater

Groundwater in the basins is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 25,808 groundwater wells had been registered within the basins as of December 31, 2010 (Department registered groundwater wells database) (figure 5-2). The locations of all active groundwater wells are shown in figure 5-3.

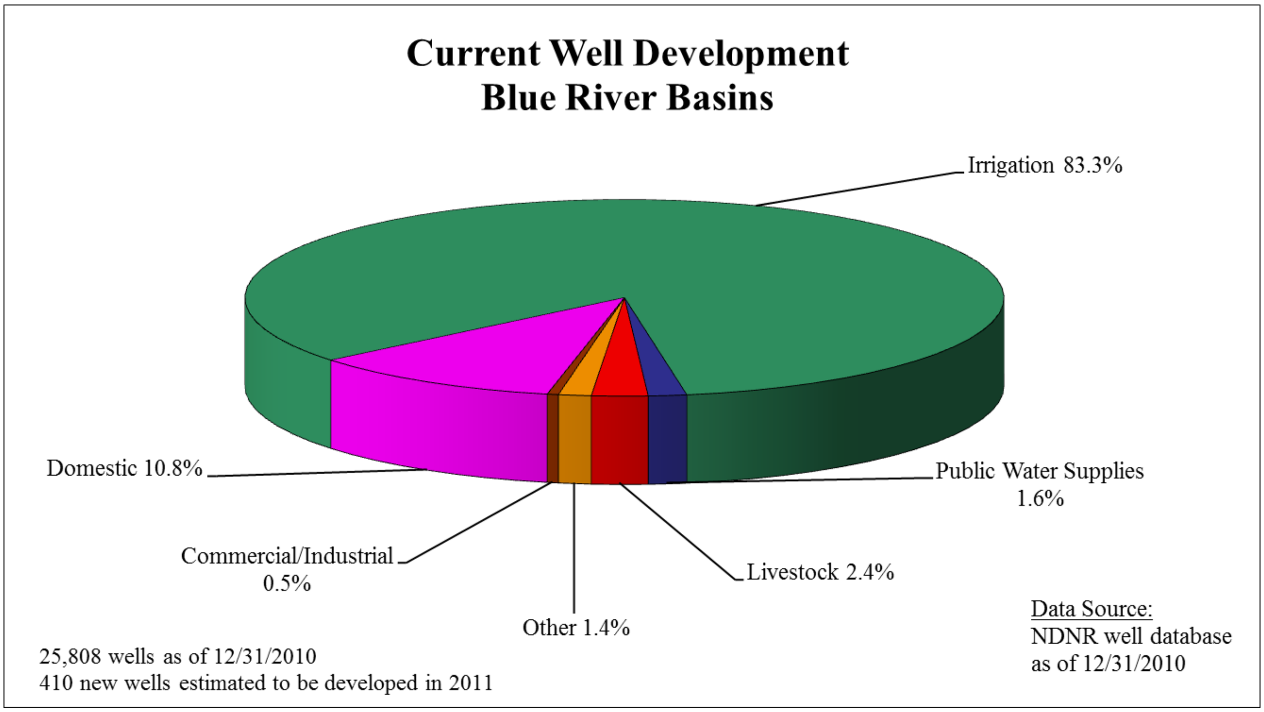

Figure 5-2. Current well development by number of registered wells, Blue River Basins.

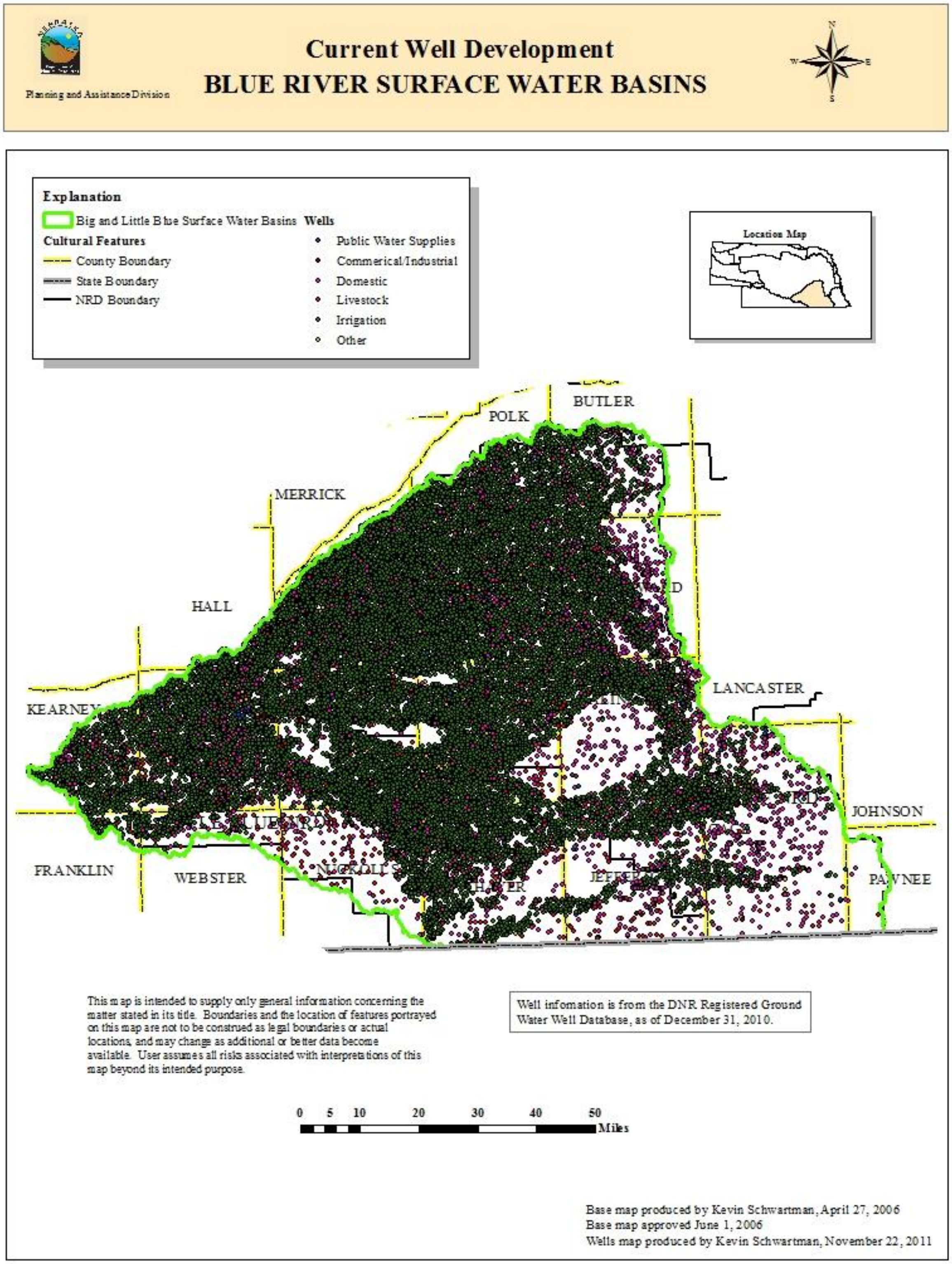

Figure 5-3. Current well locations, Blue River Basins.

5.3.2 Surface Water

As of December 31, 2010, 2,326 active surface water appropriations were held in the basins, issued for a variety of uses (figure 5-4). Most of the surface water appropriations are irrigation and storage uses that 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.

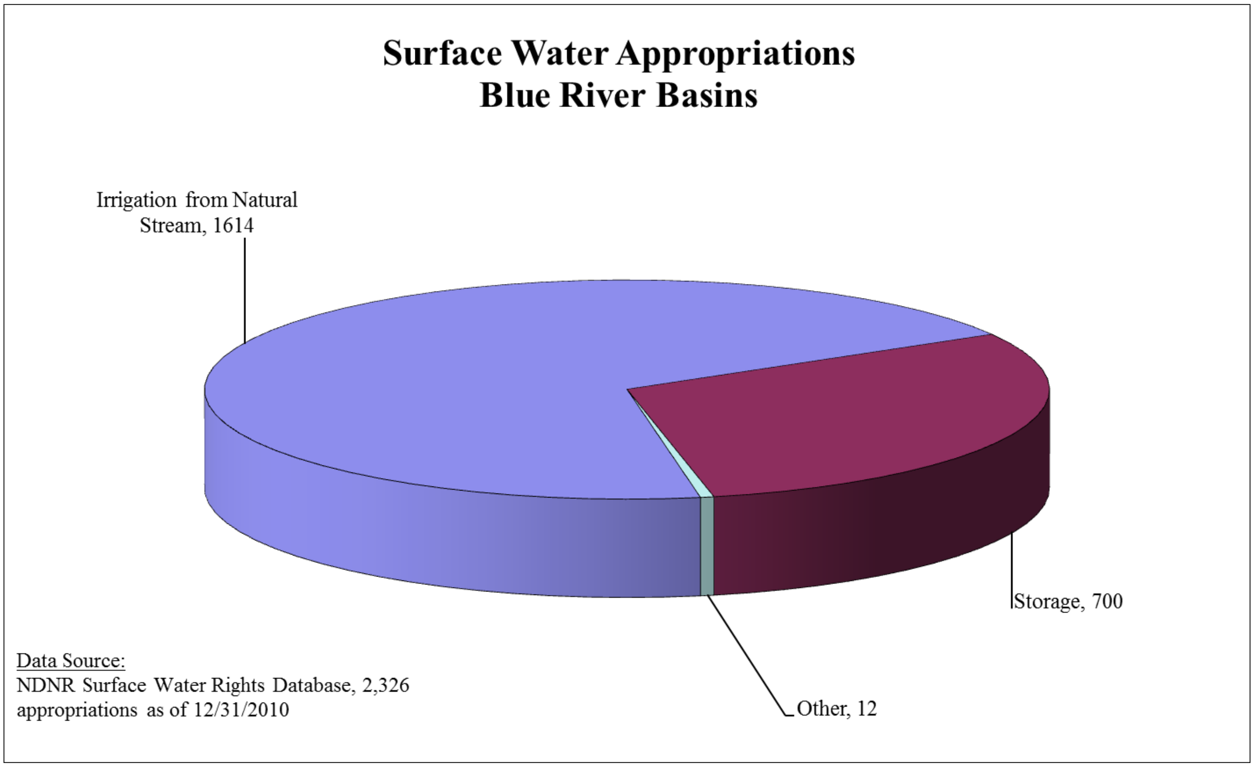

Figure 5-4. Surface water appropriations by number of diversion points, Blue River Basins.

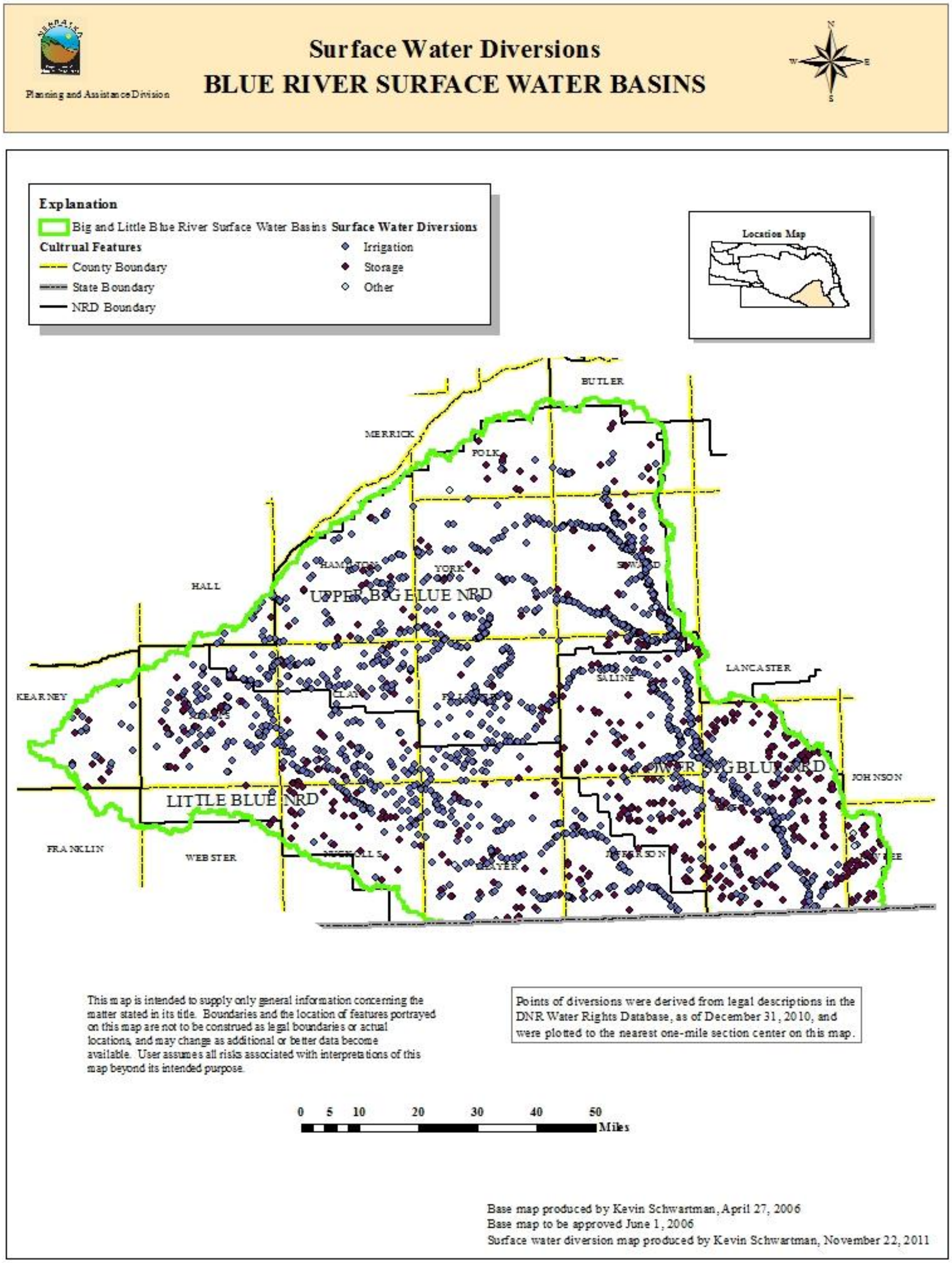

Figure 5-5. Surface water appropriation diversion locations, Blue River Basins.

5.4 Hydrologically Connected Area

The Blue River Basins can be divided into two distinct areas based on the presence or absence of glacial deposits. At the present time, the Department only has sufficient data to determine the 10/50 area for the Big Blue River and Little Blue River Basins in the western (non-glaciated) portion of the basins. No valid numeric groundwater model is available in the Blue River Basins at this time to determine the 10/50 area. Therefore, the 10/50 area was determined using the Hunt methodology (Hunt, 1999). Figure 5-6 specifies the extent of the 10/50 area for the western portion of the basin.

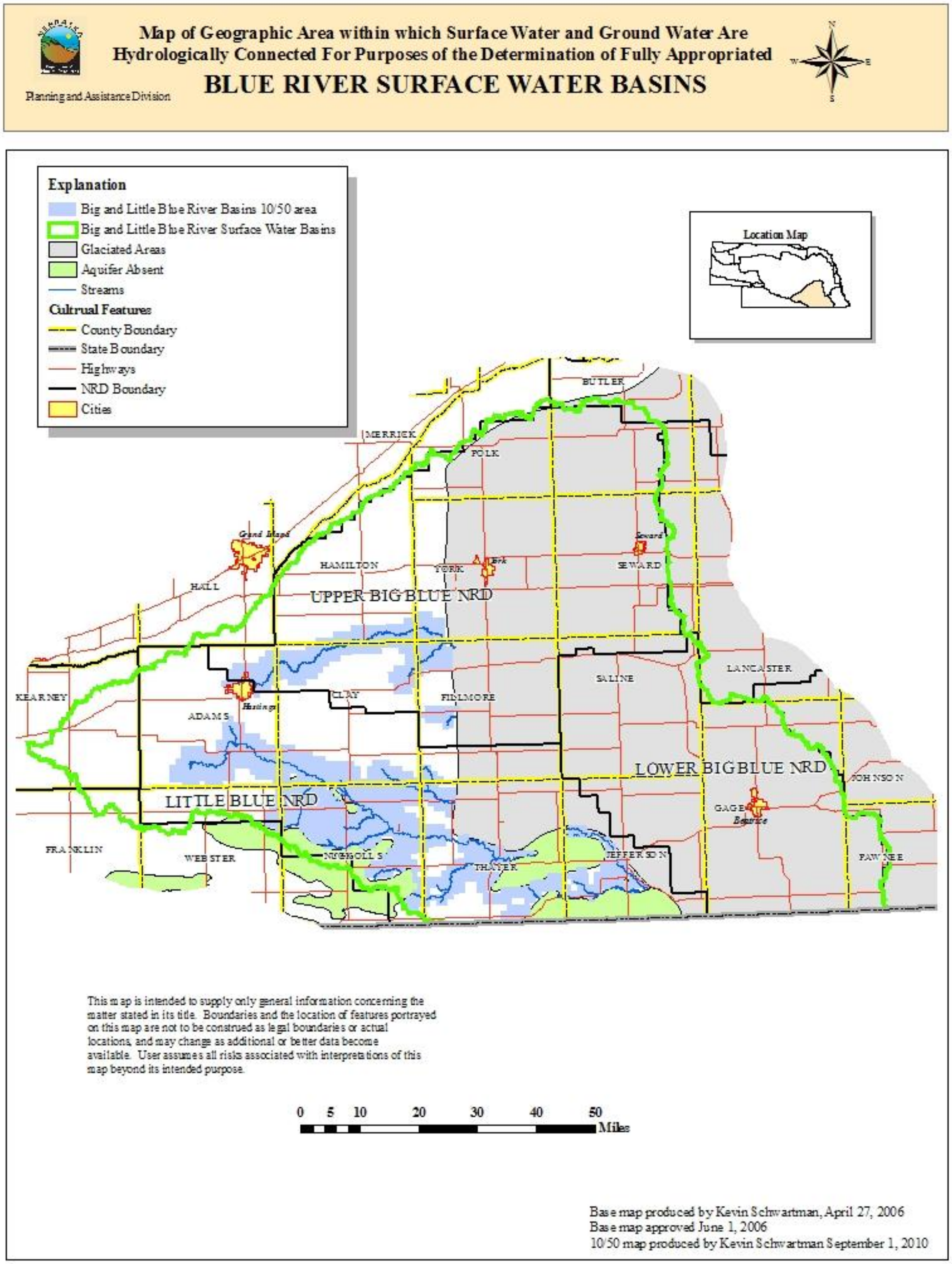

Figure 5-6. 10/50 area for the Blue River Basins.

5.5 Net Corn Crop Irrigation Requirement

Figure 5-7 is a map of the net corn crop irrigation requirement (NCCIR) 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 for diversion, a surface water diversion rate equal to 1 cfs per 70 acres, a downtime of ten percent, and an irrigation efficiency of 80% were assumed. Based on these assumptions, the junior surface water appropriation in the Big Blue River Basin would need 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.

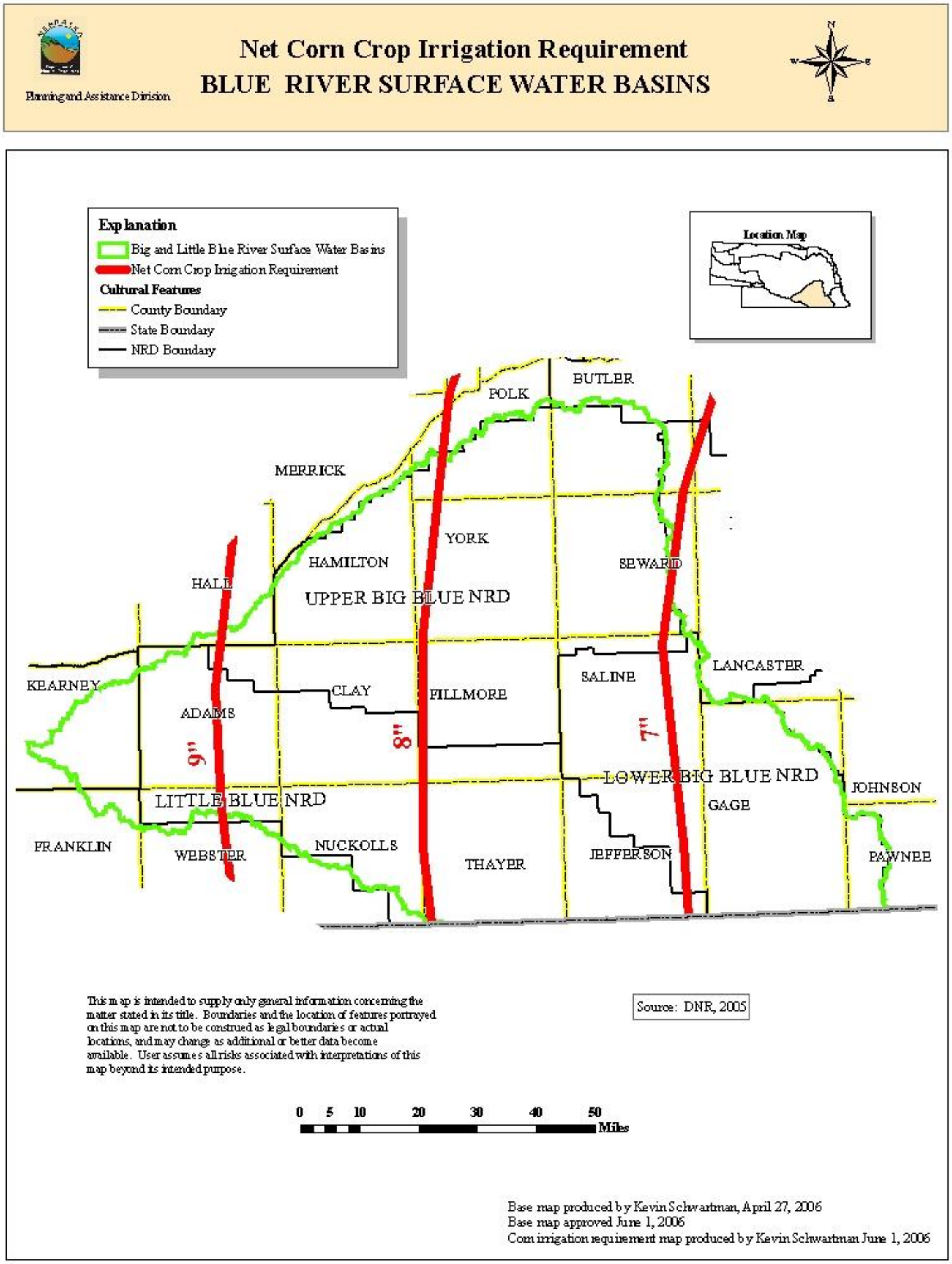

Figure 5-7. Net corn crop irrigation requirement (NCCIR), Blue River Basins.

5.6 Surface Water Closing Records

Tables 5-1 and 5-2 record all surface water administration that has occurred in the basins between 1991 and 2010.

Table 5-1. Surface water administration in the Big Blue River Basin, 1991-2010.

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, 1991-2010.

Year	Water Body	Days	Closing Date	Opening Date
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
2009	Little Blue River Basin	14	Aug 13	Aug 27

5.7 Evaluation of Current Development

5.7.1 Current Water Supply

The current water supply is estimated by using the previous twenty years (1991-2010) of surface water administration. The results of the analyses conducted for the Big Blue River Basin and Little Blue River Basin, respectively, are shown in tables 5-3 and 5-4. The results indicate that the current surface water supply in the Big Blue River Basin provides an average of at least 54.5 days available for diversion between July 1 and August 31 and 145.3 days available for diversion between May 1 and September 30 (table 5-5). The current surface water supply in the Little Blue River Basin provides an average of at least 54.7 days available for diversion between July 1 and August 31 and 143.2 days available for diversion between May 1 and September 30 (table 5-6).

Table 5-3. Estimate of the current number of days surface water is available for diversion in the Big Blue River Basin.

Year	July 1 through 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
1991	62	153
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	60	151
2001	61	152
2002	36	127
2003	16	104
2004	46	137
2005	37	128
2006	27	118
2007	62	153
2008	62	153
2009	62	153
2010	62	153
Average	54.5	145.3

Table 5-4. Estimate of the current number of days surface water is available for diversion in the Little Blue River Basin.

Year	July 1 through 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
1991	0	59
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	38	122
2003	62	153
2004	62	143
2005	40	131
2006	37	128
2007	62	153
2008	62	153
2009	48	139
2009	62	153
Average	54.7	143.2

Table 5-5. Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is currently 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	**Average Number of Days Available for Diversion with Current Development**
July 1 – August 31 (65% Requirement)	23.9	54.5 (30.6 days above the requirement)
May 1 – September 30 (85% Requirement)	31.3	145.3 (114.0 days above the requirement)

Table 5-6. Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is currently 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	**Average Number of Days Available for Diversion with Current Development**
July 1 – August 31 (65% Requirement)	25.7	54.7 or greater (29.0 days above the requirement)
May 1 – September 30 (85% Requirement)	33.6	143.2 (109.6 days above the requirement)

5.7.2 Long-Term 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 groundwater 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 sixty years (figure 5-8). Data do not exist to test whether trends in groundwater movement into the basin have changed. Therefore, using the previous twenty years of streamflow data as the best estimate of the future surface water supply is reasonable.

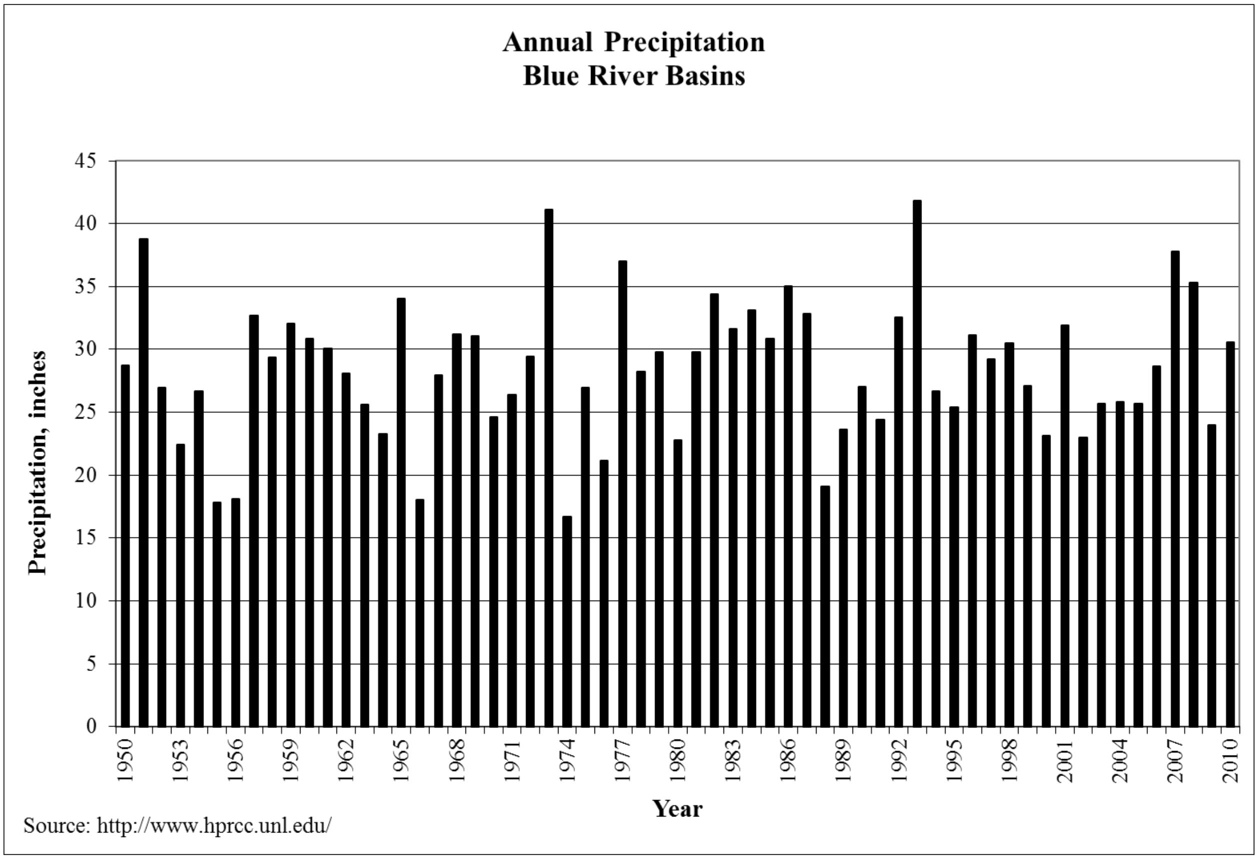

Figure 5-8. Annual precipitation, Blue River Basins.

5.7.3 Depletions Analysis

The future depletions due to current well development that could be expected to affect streamflow were estimated for the western portions of the Big Blue and Little Blue River Basins using Hunt methodology. The results estimate the future streamflow in the Big Blue River Basin to be depleted by 23 cfs in twenty-five years and flows in the Little Blue River Basin to be depleted by 25 cfs in twenty-five years.

5.7.4 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 state line compact target flows. The results of the analyses are shown in tables 5-7 and 5-8 and are compared to the numbers of days surface water is required to be available to divert 65% and 85% of the NCCIR in tables 5-9 and 5-10. In all cases, the estimated long-term surface water supply, given current levels of development, is sufficient to satisfy the 65/85 rule.

Table 5-7. Estimate of days surface water is available for diversion in the Big Blue River Basin with current development and twenty-five-year lag impacts.

Year	July 1 through 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	59	138
2	62	153
3	62	153
4	62	153
5	62	153
6	62	153
7	62	153
8	62	153
9	62	153
10	56	147
11	61	152
12	23	114
13	0	88
14	44	135
15	27	118
16	25	116
17	62	153
18	62	153
19	60	151
20	62	153
Average	51.9	142.1

Table 5-8. Estimate of days surface water is available for diversion in the Little Blue River Basin with current development and twenty-five year lag impacts.

Year	July 1 through 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	0	47
2	61	152
3	62	153
4	62	153
5	62	153
6	62	153
7	62	153
8	62	153
9	62	153
10	58	134
11	61	152
12	24	101
13	58	142
14	54	122
15	36	118
16	28	117
17	62	153
18	62	153
19	34	124
20	62	153
Average	51.7	137.0

Table 5-9. 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 in the Big Blue River Basin 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)	23.9	51.9 (28.0 days above the requirement)
May 1 – September 30 (85% Requirement)	31.3	142.1 (110.8 days above the requirement)

Table 5-10. 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 in the Little Blue River Basin 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)	25.7	51.7 (26.0 days above the requirement)
May 1 – September 30 (85% Requirement)	33.6	137.0 (103.4 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 (figures 5-9 and 5-10). The present-day rate of development is based on the linear trend of the previous ten years of development in the basins. Based on the analysis of the past ten years of development, the rate of increase in high-capacity wells is estimated to be 73 wells per year in the Big Blue River Basin and 114 wells per year in the Little Blue River Basin.

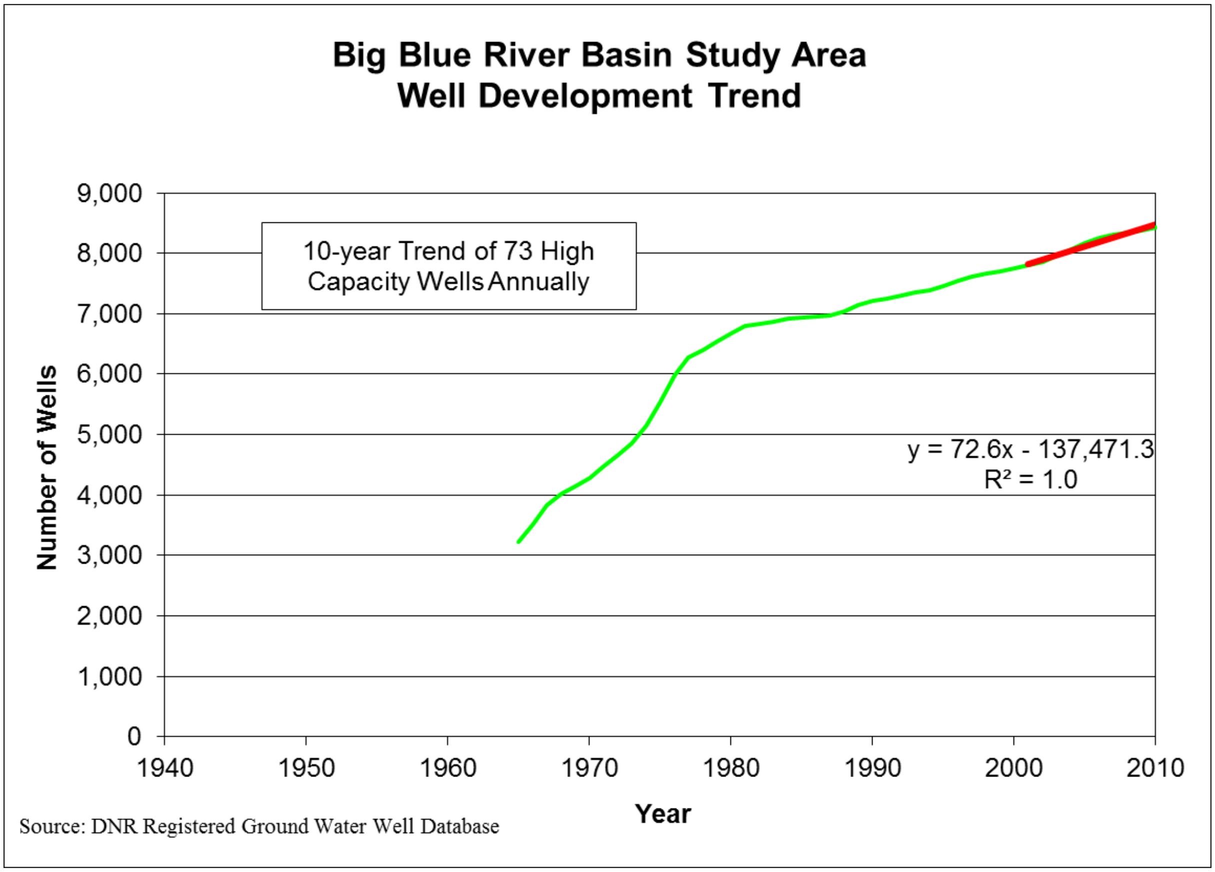

Figure 5-9. High capacity well development, western portion of Big Blue River Basin.

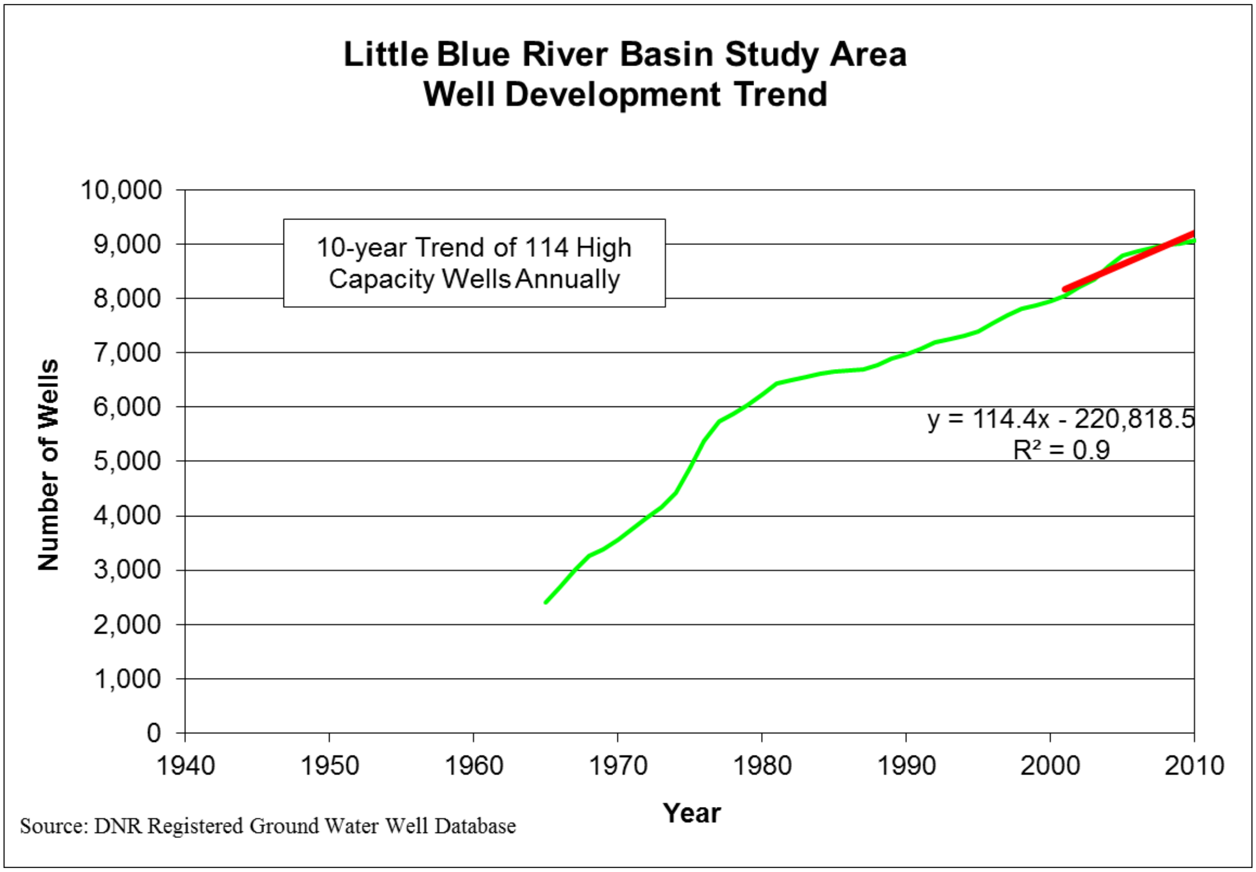

Figure 5-10. High capacity well development, western portion of Little Blue River Basin.

The future depletions due to current and future well development that could be expected to affect streamflow in the basin were estimated using an analytical methodology (Hunt, 1999). The results estimate the streamflow in the Big Blue River Basin will be depleted by an additional 1 cfs in ten years, 1cfs in fifteen years, 2 cfs in twenty years, and 4 cfs in twenty-five years due to potential future development. The results estimate the future streamflow in the Little Blue River Basin will be depleted by 3 cfs in ten years, 6 cfs in fifteen years, 9 cfs in twenty years, and 13 cfs in twenty-five years due to potential future development.

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 state line compact flow targets. The results of the analyses are shown in tables 5-11 and 5-12 and are compared to the numbers of days surface water is required to be available to divert 65% and 85% of the NCCIR in tables 5-13 and 5-14. The results indicate that, based on current information, the Department's conclusion that the basin is not fully appropriated would not change if no additional constraints are placed on future development of surface water and groundwater in the basin.

Table 5-11. Estimated number of days surface water is available for diversion in the Big Blue River Basin with current and predicted future development.

Year	July 1 through 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	58	137
2	62	153
3	62	153
4	62	153
5	62	153
6	62	153
7	62	153
8	62	153
9	62	153
10	55	146
11	61	152
12	21	112
13	0	85
14	43	134
15	25	111
16	23	114
17	61	152
18	62	153
19	59	150
20	62	153
Average	51.3	141.2

Table 5-12. Estimated number of days surface water is available for diversion in the Little Blue River Basin with current and predicted future development.

Year	July 1 through 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	0	40
2	58	149
3	62	153
4	62	153
5	62	153
6	62	153
7	62	153
8	62	153
9	62	153
10	53	115
11	59	149
12	22	98
13	55	139
14	51	118
15	33	111
16	26	112
17	59	150
18	62	153
19	27	114
20	61	152
Average	50.0	133.6

Table 5-13. 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 in the Big Blue River Basin 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)	23.9	51.3 (27.4 days above the requirement)
May 1 – September 30 (85% Requirement)	31.3	141.2 (109.9 days above the requirement)

Table 5-14. 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 in the Little Blue River Basin 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)	25.7	50.0 (24.3 days above the requirement)
May 1 – September 30 (85% Requirement)	33.6	133.6 (100.0 days above the requirement)

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 (cfs) are shown in table 5-15. If the flow targets are not met, then 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 the Compact Administration determines 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 wells with the area describe in number four above will not yield measurable increases in flow at the state line.

Table 5-15. State line flow targets for the Blue River Basins.

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 groundwater 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. Decreased streamflows could, however, 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 Groundwater 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 as explained in Appendix F.

5.11 Current Studies being Conducted to Assist with Future Analysis

The Department is initiating work to develop a numeric groundwater model that would cover the extent of the Big Blue and Little Blue River Basins. The Department will continue to coordinate with the natural resources districts in the basin as the model is developed. When completed, this model will be utilized in future evaluations conducted by the Department.

5.12 Relevant Data Provided by Interested Parties

The Department published a request for relevant data from interested parties for this year's evaluation on August 19, 2011 (see Appendix B for affidavit). The Department did not receive any such information.

5.13 Conclusions

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. The Department has also determined that, based on current information, if no additional legal constraints are imposed on future development of hydrologically connected surface water and groundwater and reasonable projections are made about the extent and location of future development, this preliminary conclusion would not change to a conclusion that the basin is fully appropriated.

The analysis of lag effects of current development for areas in the western portion of the Big Blue River Basin indicates a reduction in streamflows of 23 cfs in twenty-five years. The analysis of lag effects of current development for areas in the western portion of the Little Blue River Basin indicates a reduction in streamflows of 25 cfs in twenty-five years. It was not possible to calculate the lag effects of current development for areas in the eastern portions of the basins due to the glaciated nature of the area and the fact that the principal aquifer is absent or very thin (CSD, 2005).

The analysis of the impacts of potential future development in the western portion of the Big Blue River Basin based on current development trends indicates an additional reduction in streamflows of 4 cfs in twenty-five years. The analysis of the impacts of potential future development in the western portion of the Little Blue River Basin based on current development trends indicates an additional reduction in streamflows of 13 cfs in twenty-five years. The potential impacts of future development in the eastern portions of the basins were not evaluated at this time due to the glaciated nature of the area and the fact that the principal aquifer is absent or very thin (CSD, 2005).

Bibliography of Hydrogeologic References for Big and Little Blue River Basins

Bitner, R.J. 2008. *A groundwater study of the Blue River Basin in Nebraska to estimate potential stream baseflow depletions resulting from groundwater pumping near streams.* 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.

Hunt, B. 1999. Unsteady Stream Depletion from Ground Water Pumping, *Ground Water*, 37 (1): 98-102.

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Wen, F.J. and X.H. Chen, 2006. Evaluation of the impact of groundwater irrigation on streamflow depletion in Nebraska.. *Journal of Hydrology* 327: 603-617.

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 not fully appropriated. The analysis of lag effects of current development for the Lower Niobrara Basin indicates a reduction in streamflows of 9 cfs in twenty-five years. The analysis of the impacts of future development on the Lower Niobrara Basin based on current development trends indicates an additional reduction in streamflows of 106 cfs in twenty-five years. The future number of days available to junior irrigators was not estimated because only minimal surface water administration has occurred on the Niobrara River in the past twenty years. Even though the future number of days available to junior irrigators was 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 net corn crop irrigation requirement (NCCIR).

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 that have not previously been determined to be fully appropriated. This general basin area extends from the Spencer Hydropower facility 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 Lower Niobrara River Basin evaluated in this year’s report is approximately 1,200 square miles. The Lower Niobrara and the Upper Elkhorn NRDs are the only NRDs with significant area in the Lower Niobrara River Basin.

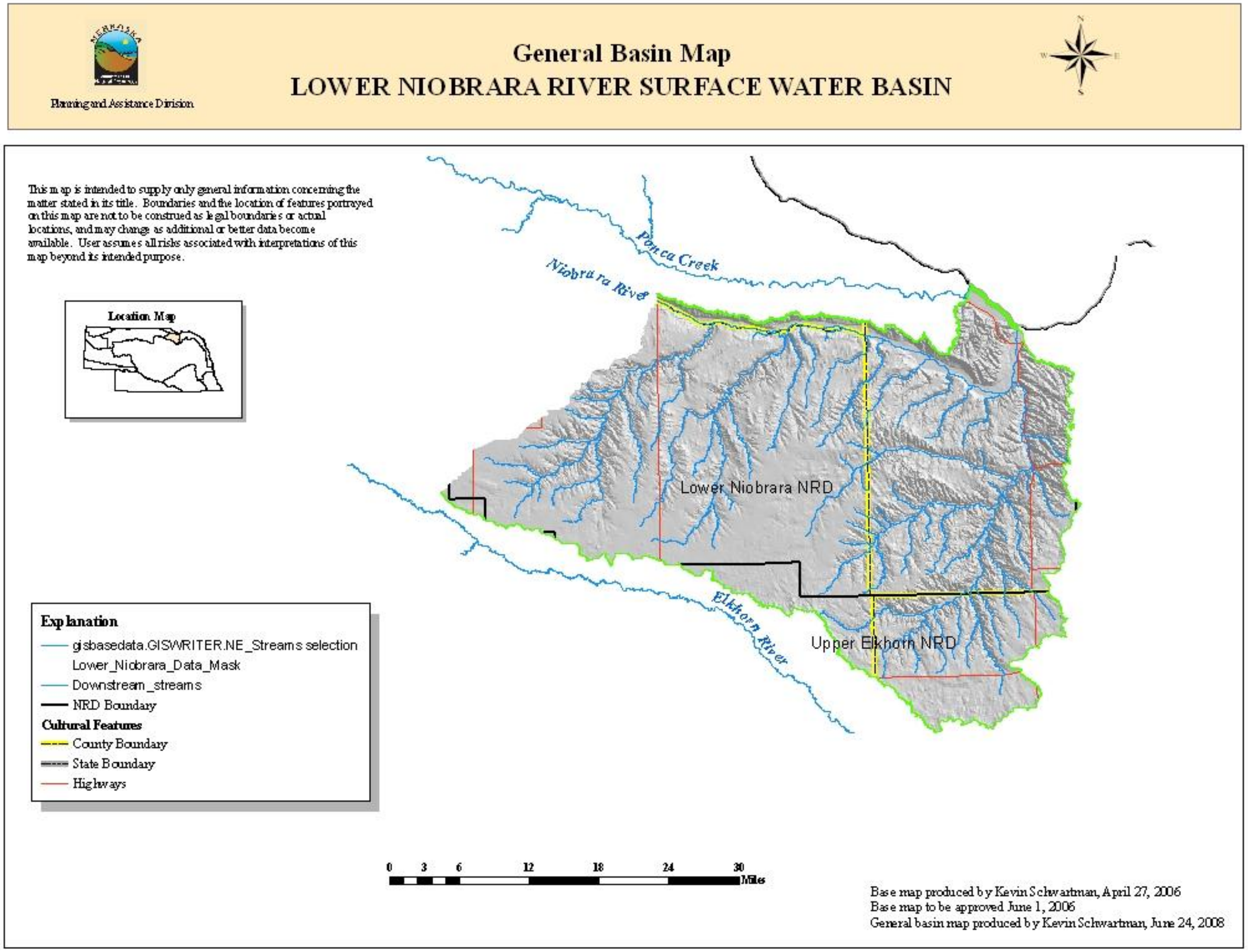

Figure 6-1. General basin map, Lower Niobrara River Basin.

6.3 Nature and Extent of Water Use

6.3.1 Groundwater

Groundwater in the basin is used for a variety of purposes: domestic, industrial, livestock, irrigation, and other uses. A total of 2,540 groundwater wells had been registered within the basin as of December 31, 2010 (Department registered groundwater wells database) (figure 6-2). The locations of all active groundwater wells can be seen in figure 6-3.

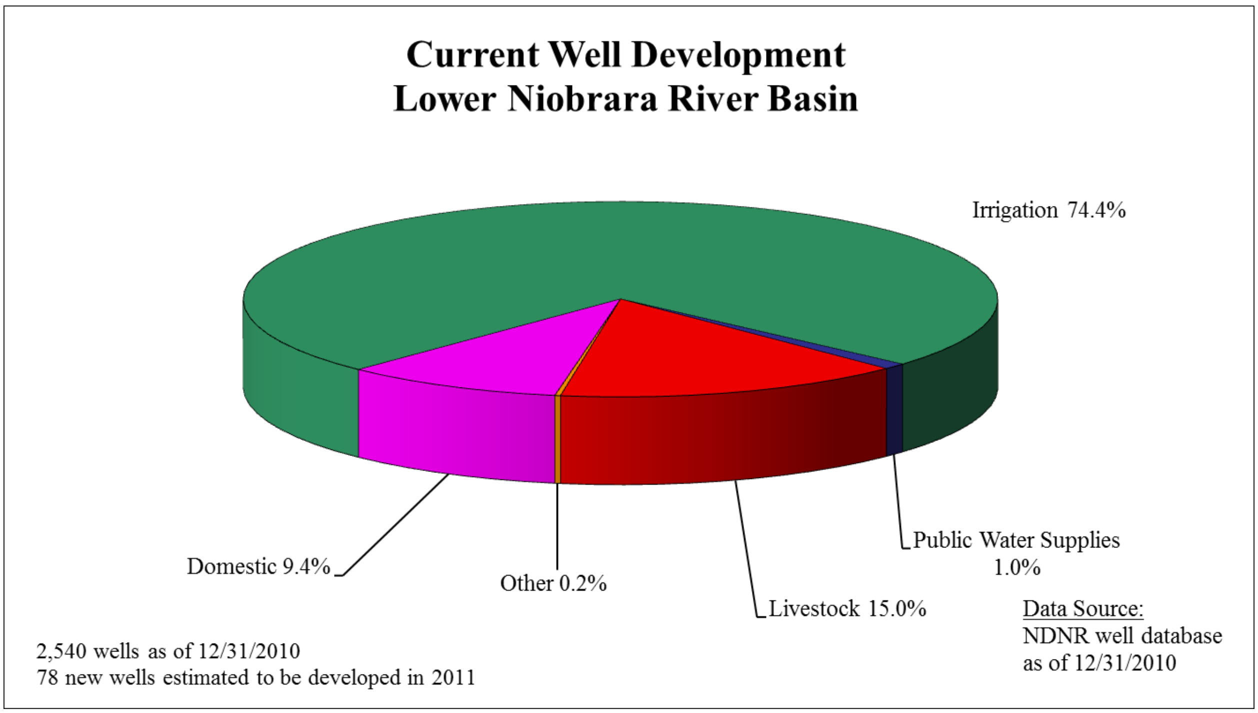

Figure 6-2. Current well development by number of registered wells, Lower Niobrara River Basin.

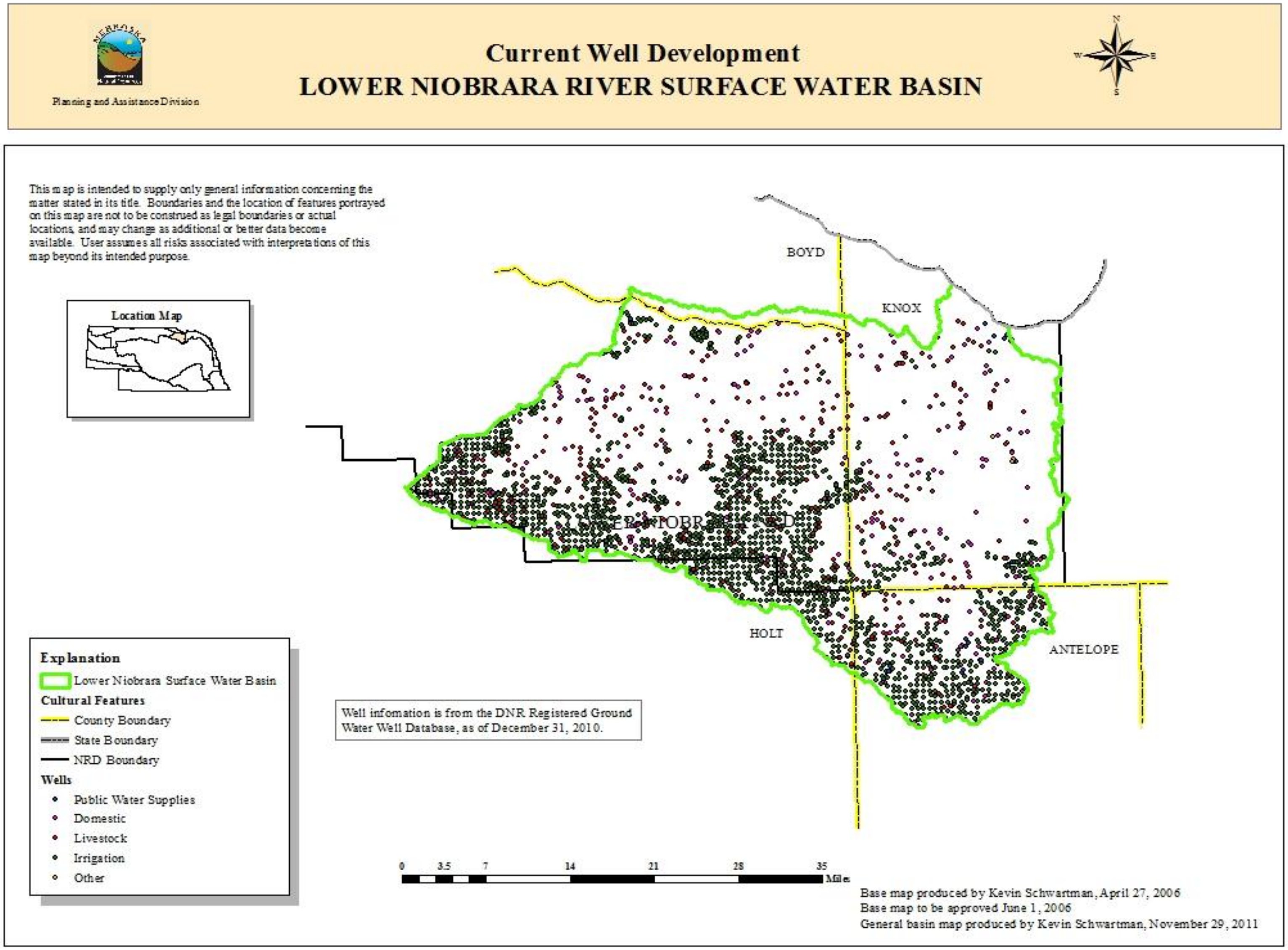

Figure 6-3. Current well locations, Lower Niobrara River Basin.

6.3.2 Surface Water

As of December 31, 2010, 264 active surface water appropriations were held 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. 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.

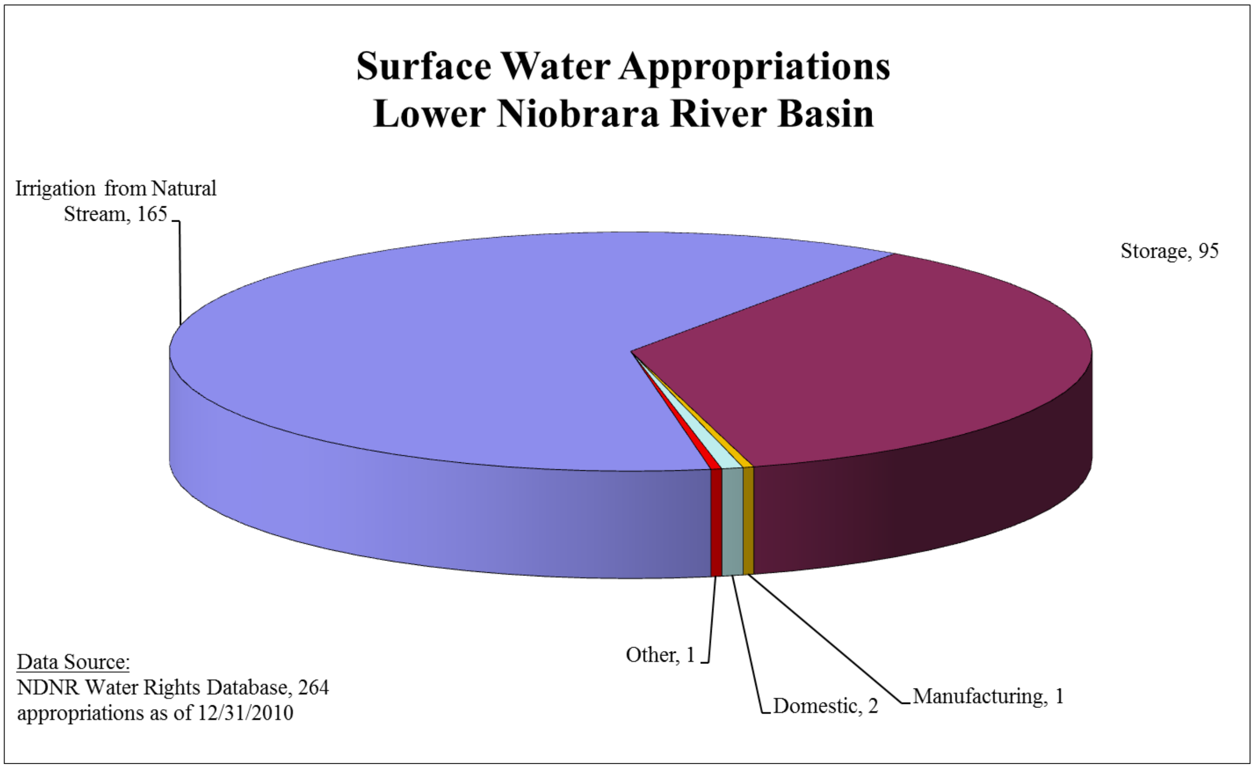

Figure 6-4. Surface water appropriations by number of diversion points, Lower Niobrara River Basin.

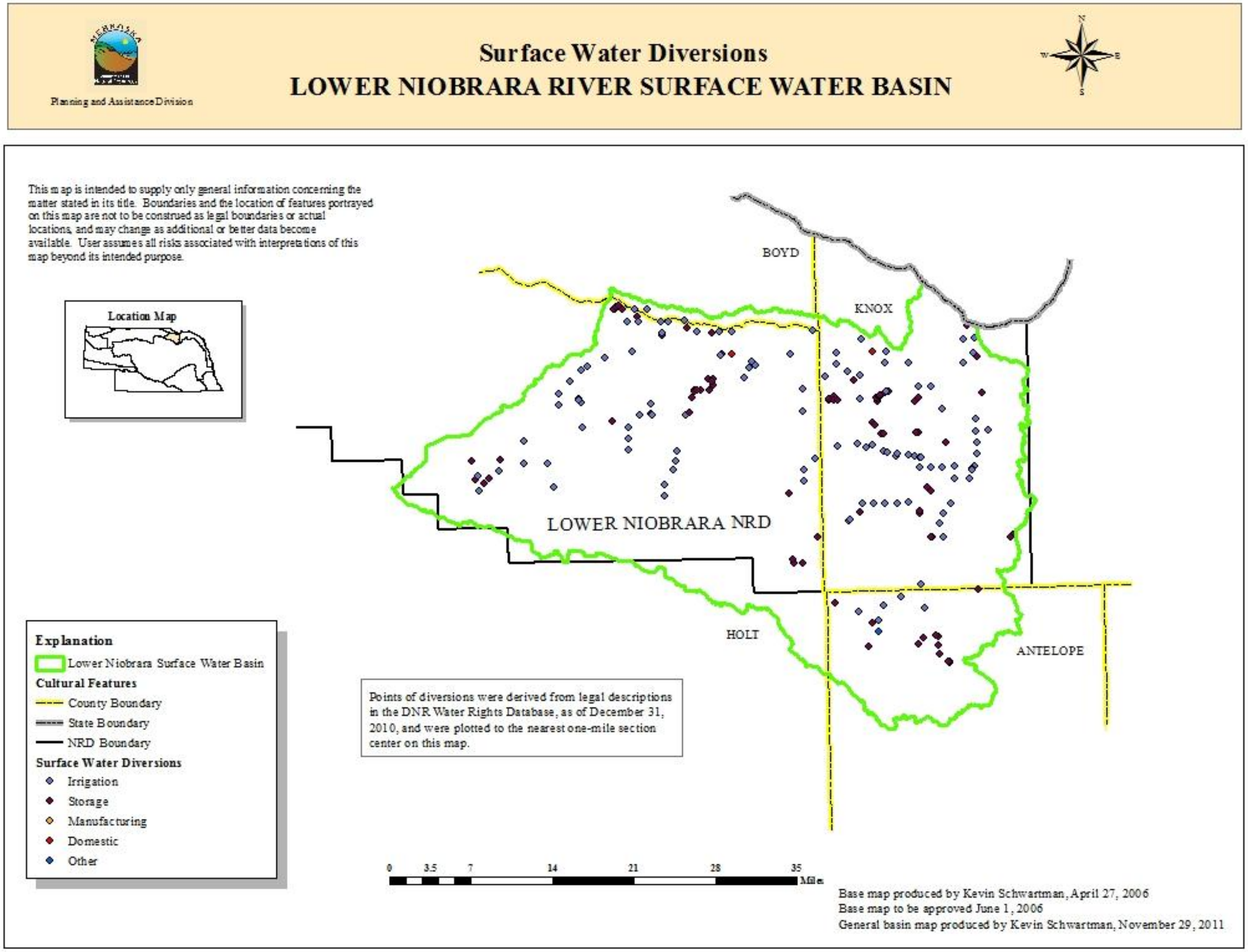

Figure 6-5. Surface water appropriation diversion locations, Lower Niobrara River Basin.

6.4 Hydrologically Connected Area

No sufficient numeric groundwater 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. The SDF methodology used is described in the “Methodology” section of this report.

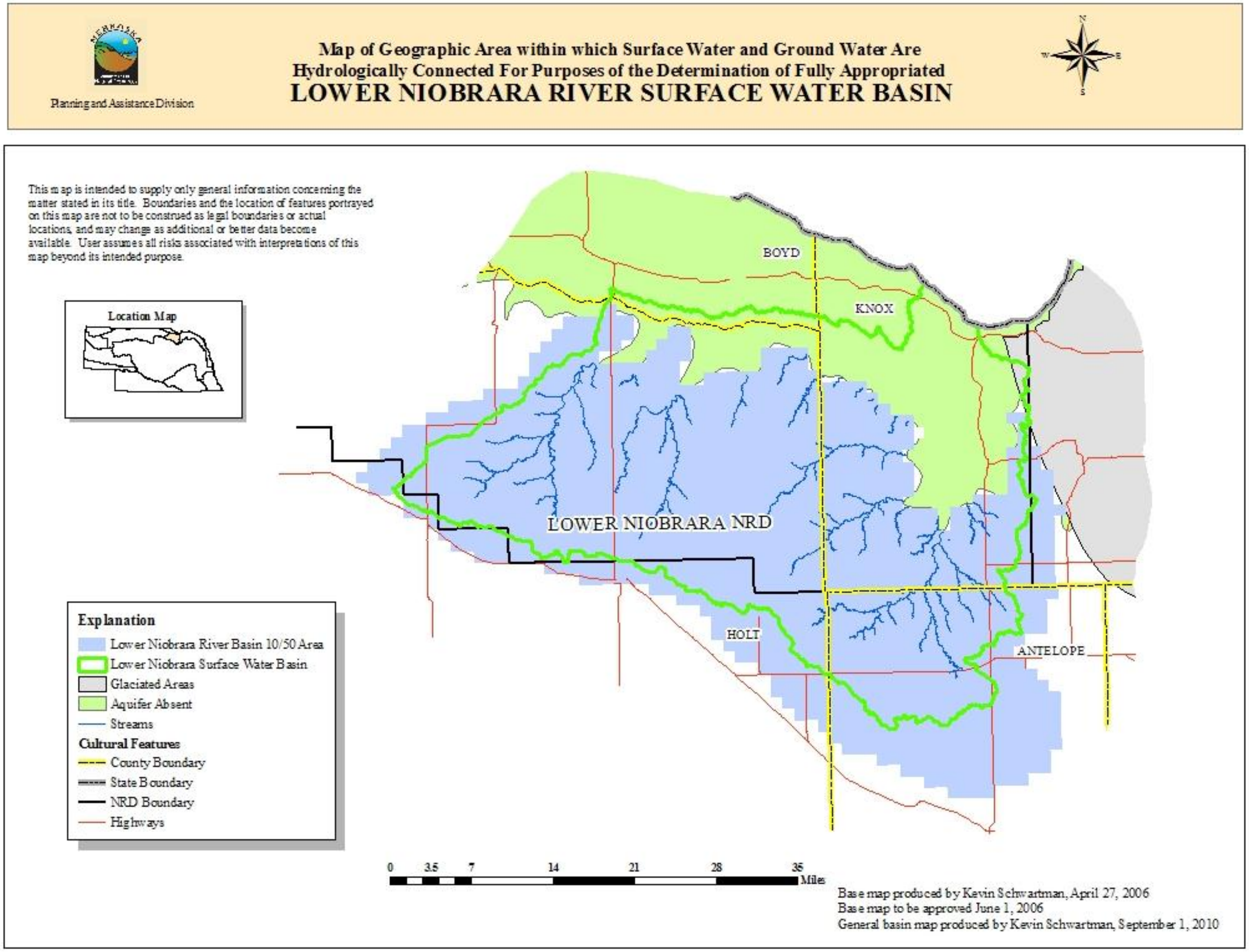

Figure 6-6. 10/50 area, Lower Niobrara River Basin.

6.5 Net Corn Crop Irrigation Requirement

Figure 6-7 is a map of the net corn crop irrigation requirement (NCCIR) for the basin (DNR, 2005). The NCCIR in the basin ranges from 8.9 to 9.6 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 ten percent, and an irrigation efficiency of 80% were assumed. Based on these assumptions, a junior surface water appropriation in the Lower Niobrara River Basin will require between 23.6 and 25.5 days annually to divert 65% of the NCCIR and between 30.9 and 33.3 days to divert 85% of the NCCIR.

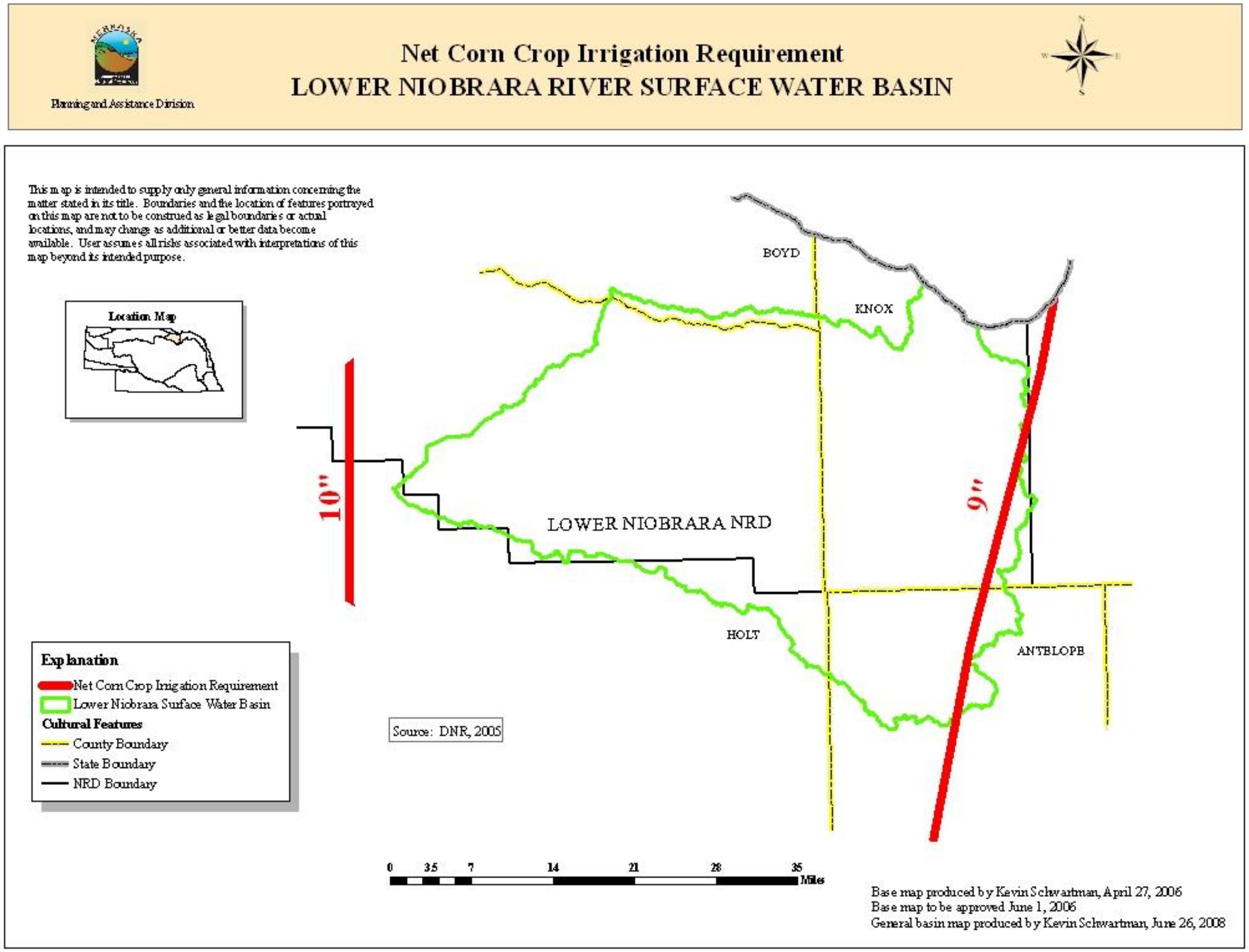

Figure 6-7. Net corn crop irrigation requirement (NCCIR), Lower Niobrara River Basin.

6.6 Surface Water Closing Records

Table 6-1 contains records of all surface water administration that has occurred in the basin between 1991 and 2010.

Table 6-1. Surface water administration in the Lower Niobrara River Basin, 1991-2010.

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

6.7 Evaluation of Current Development

6.7.1 Current Water Supply

The current water supply is estimated by using the previous twenty years (1991-2010) of flows available for junior irrigation rights. The results of the analysis conducted for the Lower Niobrara River Basin are shown in table 6-2. The results indicate that the current surface water supply in the Lower Niobrara River Basin provides an average of 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 (table 6-3).

Table 6-2. Estimate of the current number of days surface water is available for diversion in the Lower Niobrara River Basin.

Year	July 1 through 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
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
2007	62	153
2008	62	153
2009	62	153
2010	62	153
Average	61.9	152.9

Table 6-3. Comparison between the number of days required to meet the net corn crop irrigation requirement and the current number of days surface water is available for diversion in the Lower Niobrara River Basin.

	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)	23.6 to 25.5	61.9 (at least 36.4 days above the requirement)
May 1 – September 30 (85% Requirement)	30.9 to 33.4	152.9 (at least 119.5 days above the requirement)

6.7.2 Long-Term 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; groundwater movement into the basin, which discharges as baseflow; and streamflow from the middle 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 sixty years (figure 6-8). 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 groundwater wells.

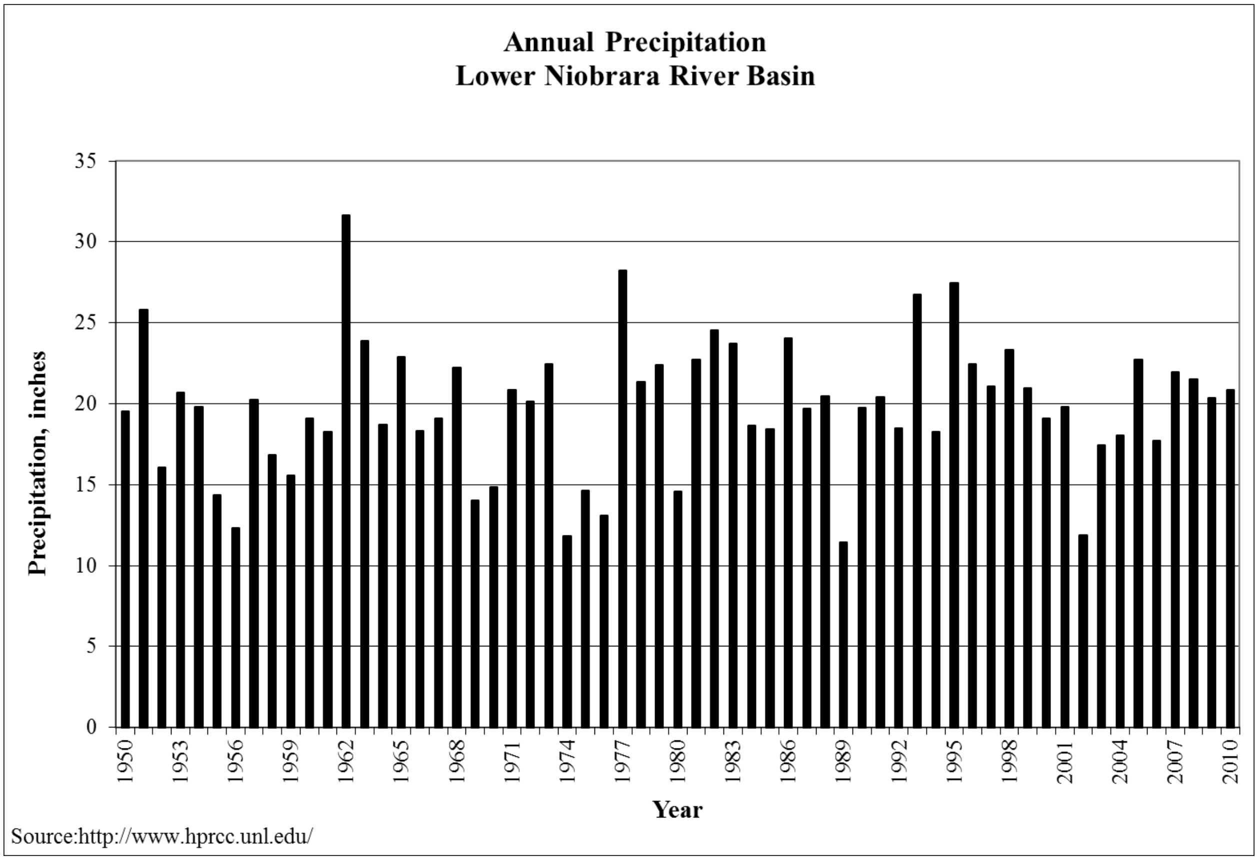

Figure 6-8. Annual precipitation, Lower Niobrara River Basin.

6.7.3 Depletions Analysis

The future depletions due to current well development that could be expected to affect streamflow in the basin were estimated using the SDF methodology. The results estimate the future streamflows in the Lower Niobrara River Basin to be depleted by 9 cfs in twenty-five years.

6.7.4 Evaluation of Current Levels of Development against Future Water Supplies

The estimates of the twenty-year average number of days available for diversion were not estimated for the Lower Niobrara Basin because only minimal surface water administration has previously occurred in the basin, and the threshold flows necessary to satisfy senior appropriations could not be estimated. 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 65/85 rule.

6.8 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 6-9). 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 estimated to be 62 wells per year in the basin.

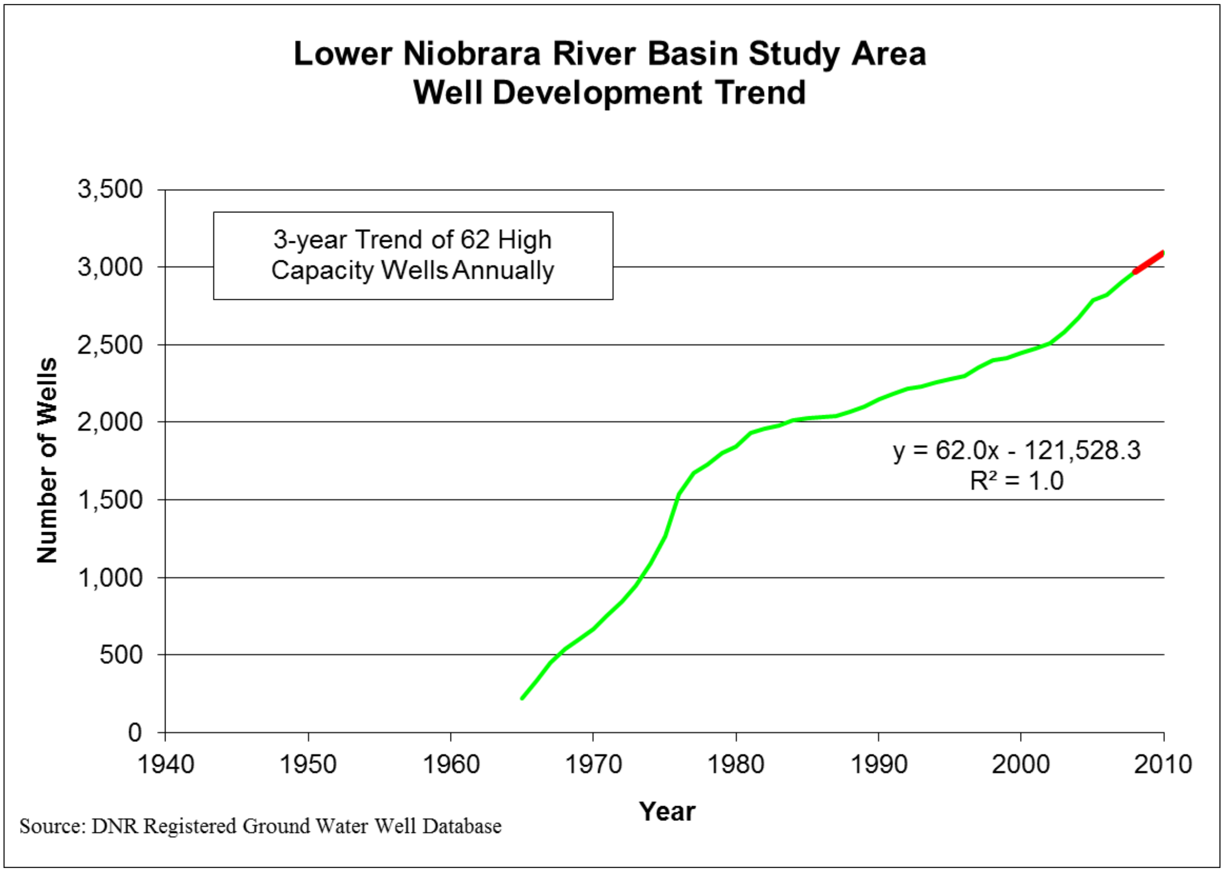

Figure 6-9. High capacity well development, Lower Niobrara River Basin.

The future depletions due to current and future well development that could be expected to affect streamflow in the basin were estimated using the SDF methodology. The results estimate the future streamflow to be depleted by an additional 37 cfs in ten years, 59 cfs in fifteen years, 82 cfs in twenty years, and 106 cfs in twenty-five years.

The estimate of the twenty-year average number of days surface water is available for diversion was not calculated because minimal surface water administration has previously occurred and the threshold flows necessary to satisfy senior appropriations could not be estimated. 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 65/85 rule.

6.9 Sufficiency to Avoid Noncompliance

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

6.10 Groundwater 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 as explained in Appendix F.

6.11 Current Studies being Conducted to Assist with Future Analysis

The Department applied for and received funding from the Bureau of Reclamation to develop modeling tools that may assist in completing future evaluations. The project began in April 2011 with an anticipated completion date of March 2013.

6.12 Relevant Data Provided by Interested Parties

The Department published a request for relevant data for this year’s evaluation from interested parties on August 19, 2011 (see Appendix B for affidavit). The Department did not receive any such information.

6.13 Conclusions

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 not fully appropriated. The analysis of lag effects of current development for the Lower Niobrara Basin indicates a reduction in streamflows by 9 cfs in twenty-five years. The analysis of the impacts of future development on the Lower Niobrara Basin based on current development trends indicates an additional reduction in streamflows of 106 cfs in twenty-five years. The future number of days available to junior irrigators was not estimated because only minimal surface water administration has occurred on the Niobrara River in the past twenty years. Even though the future number of days available to junior irrigators was 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 net corn crop irrigation requirement (NCCIR).

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, 2006. Evaluation of the impact of groundwater irrigation on streamflow depletion in Nebraska.. *Journal of Hydrology* 327: 603-617.

7.0 MISSOURI TRIBUTARY BASINS

7.1 Summary

Based on the analysis of the sufficiency of the long-term surface water supply in the Missouri River Tributary Basins, the Department has reached a preliminary conclusion that the basins are not fully appropriated. The use of the SDF methodology to determine lag effects of current development requires sufficient data and appropriate hydrogeologic conditions. Those data and conditions exist only in the Bazile Creek subbasin at this time. Therefore, lag effects of current development and potential future development were estimated only for in the Bazile Creek subbasin.

The analysis of lag effects of current development for the Bazile Creek subbasin indicates a reduction in streamflows by 14 cfs in twenty-five years. The analysis of the impacts of future development on the Bazile Creek subbasin based on current development trends indicates an additional reduction in streamflows of 19 cfs in twenty-five years. The future number of days available to junior irrigators was not estimated because no surface water administration has occurred in the Bazile Creek subbasin in the past twenty years. Even though the future number of days available to junior irrigators was 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 net corn crop irrigation requirement (NCCIR).

7.2 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 in the basins (figure 7-1). Major 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. NRDs with significant area in the basins are the Lower Niobrara, the Lewis and Clark, the Papio-Missouri River, and the Nemaha NRDs.

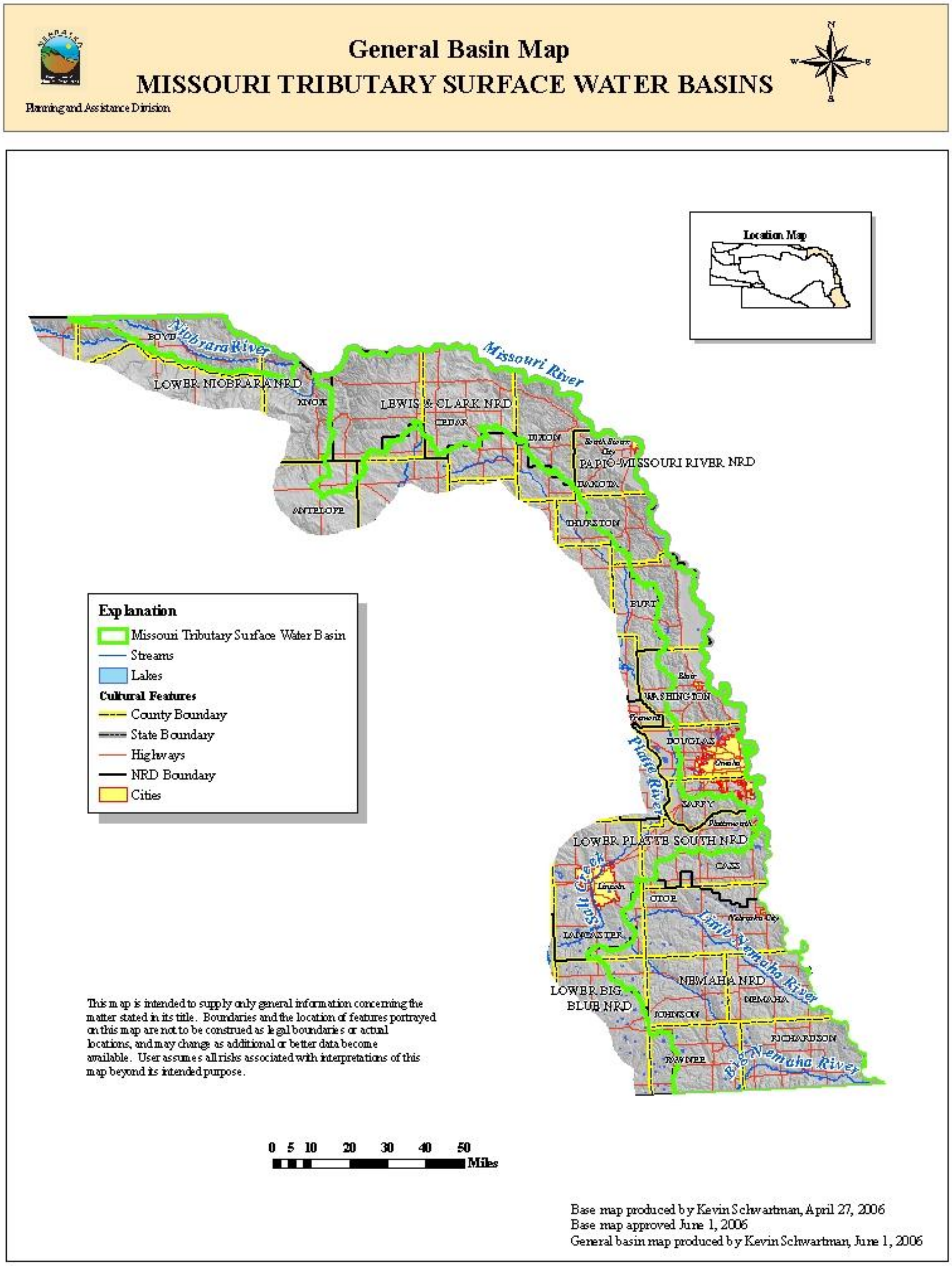

Figure 7-1. General basin map, Missouri Tributary Basins.

7.3 Nature and Extent of Water Use

7.3.1 Groundwater

Groundwater in the basins is used for a variety of purposes including domestic, industrial, livestock, irrigation, and other uses. A total of 6,677 groundwater wells had been registered within the basins as of December 31, 2010 (Department registered groundwater wells database) (figure 7-2). The locations of all active groundwater wells can be seen in figure 7-3.

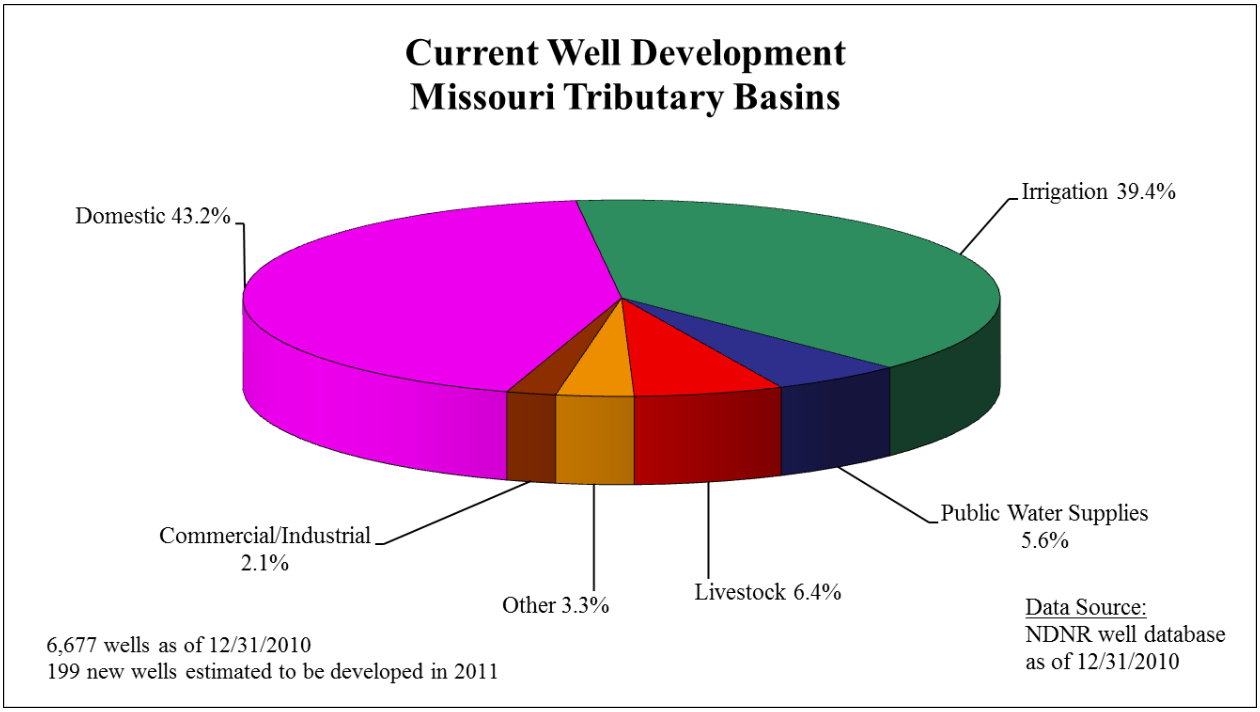

Figure 7-2. Current well development by number of registered wells, Missouri Tributary Basins.

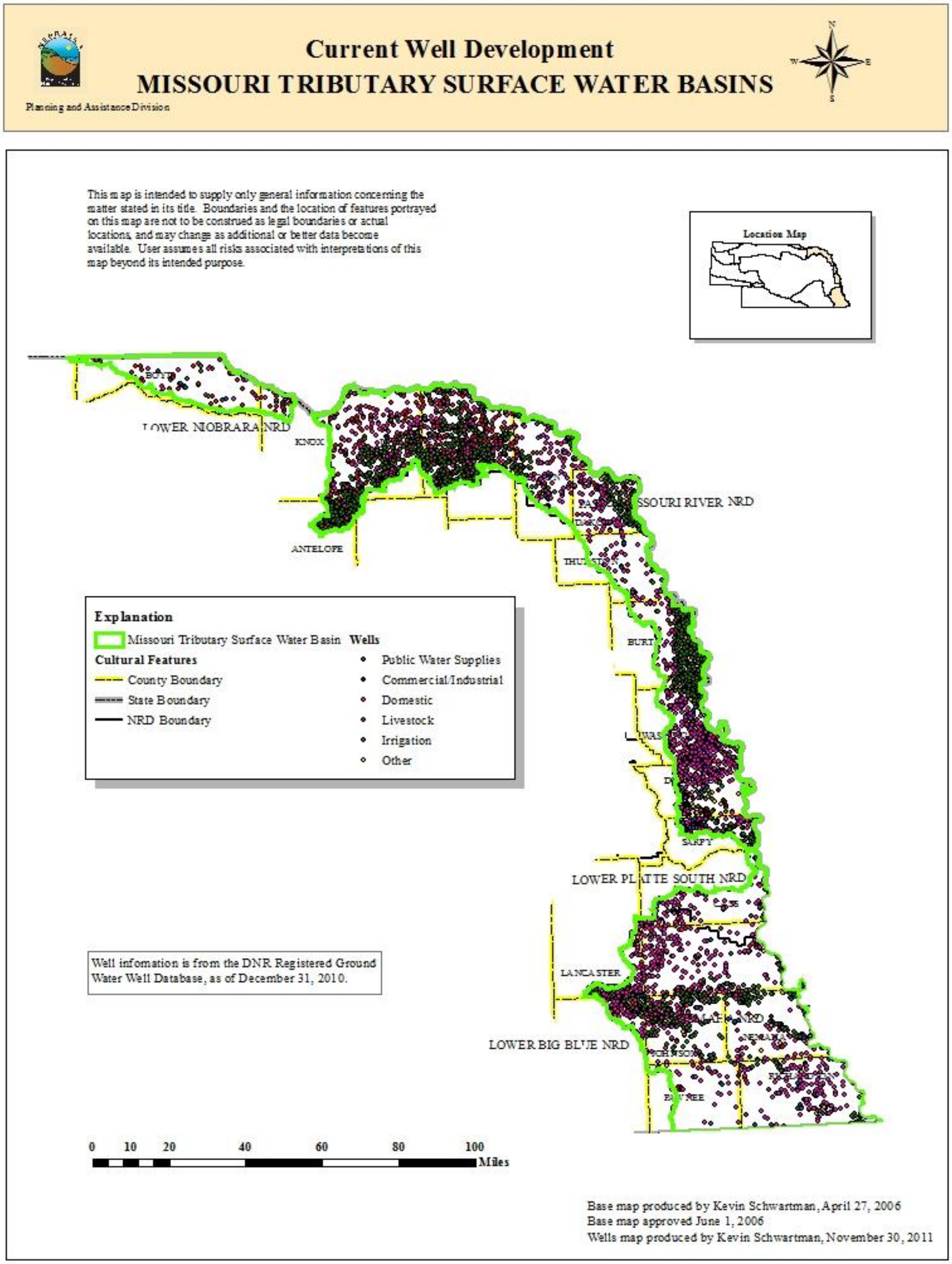

Figure 7-3. Current well locations, Missouri Tributary Basins.

7.3.2 Surface Water

As of December 31, 2010, 1,269 active surface water appropriations were held in the basins, issued for a variety of uses (figure 7-4). 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 7-5.

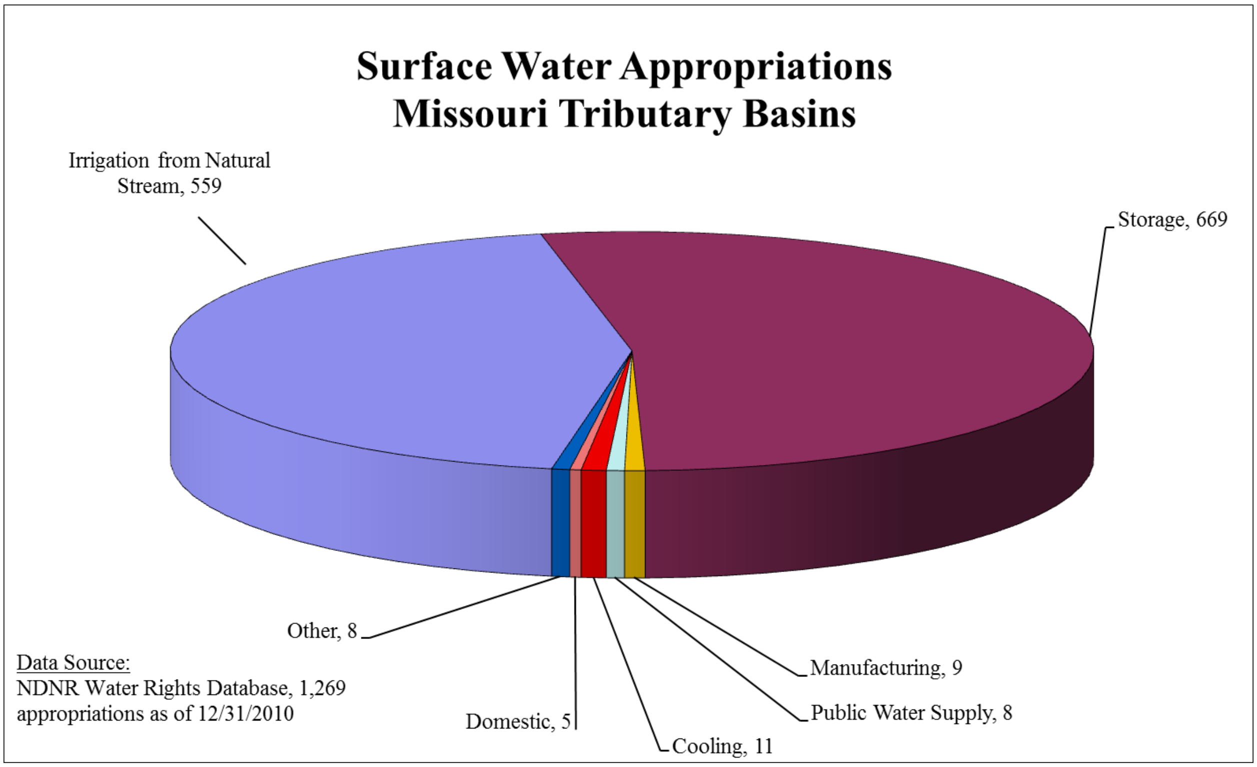

Figure 7-4. Surface water appropriations by number of diversion points, Missouri Tributary Basins.

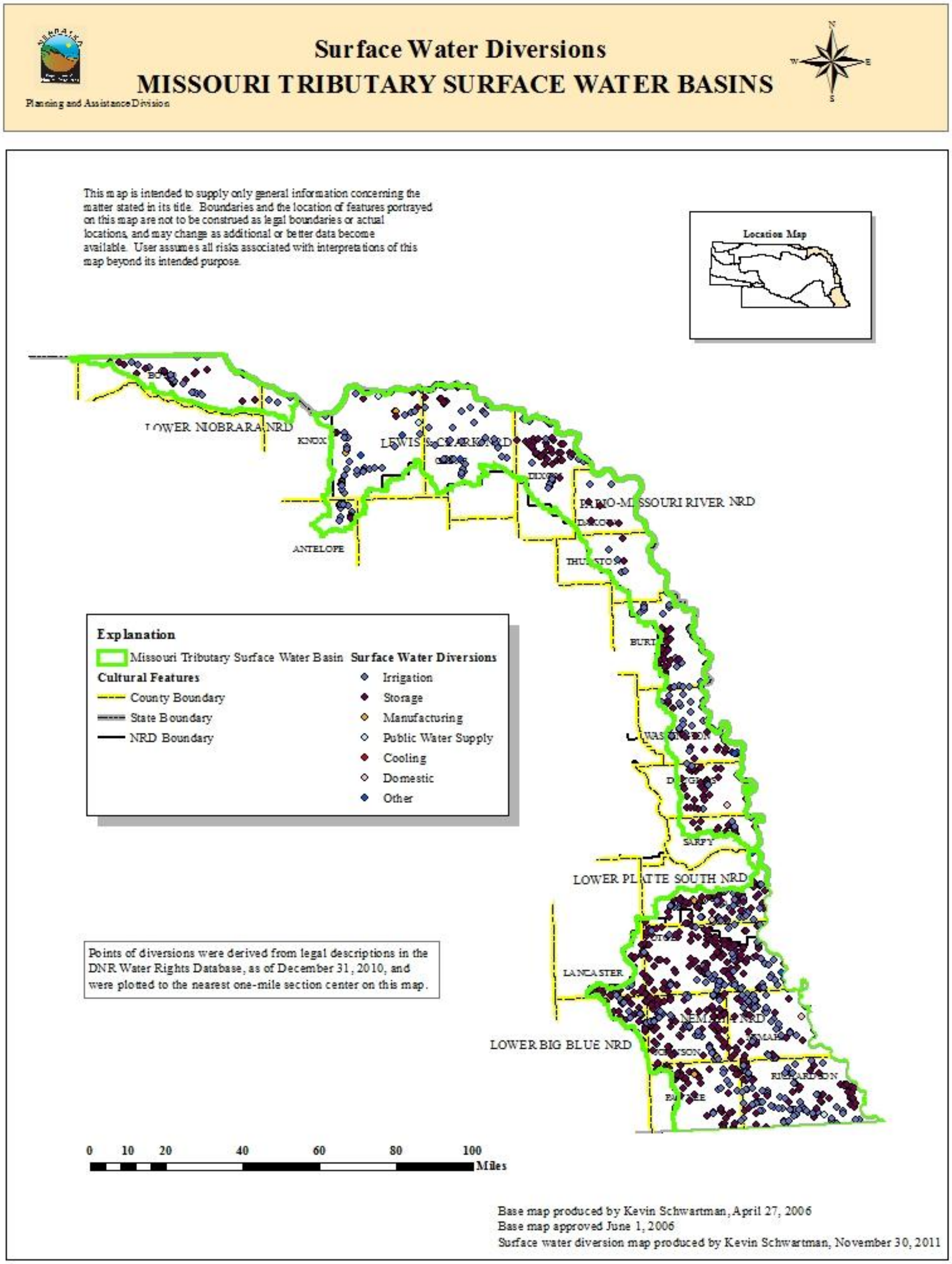

Figure 7-5. Surface water appropriation diversion locations, Missouri Tributary Basins.

7.4 Hydrologically Connected Area

No sufficient numeric groundwater 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 lack of sufficient data and appropriate hydrogeologic conditions does not allow for the use of the existing methodologies. 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 groundwater 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. Consequently, this is the only portion of the study area in which the 10/50 area was calculated (figure 7-6).

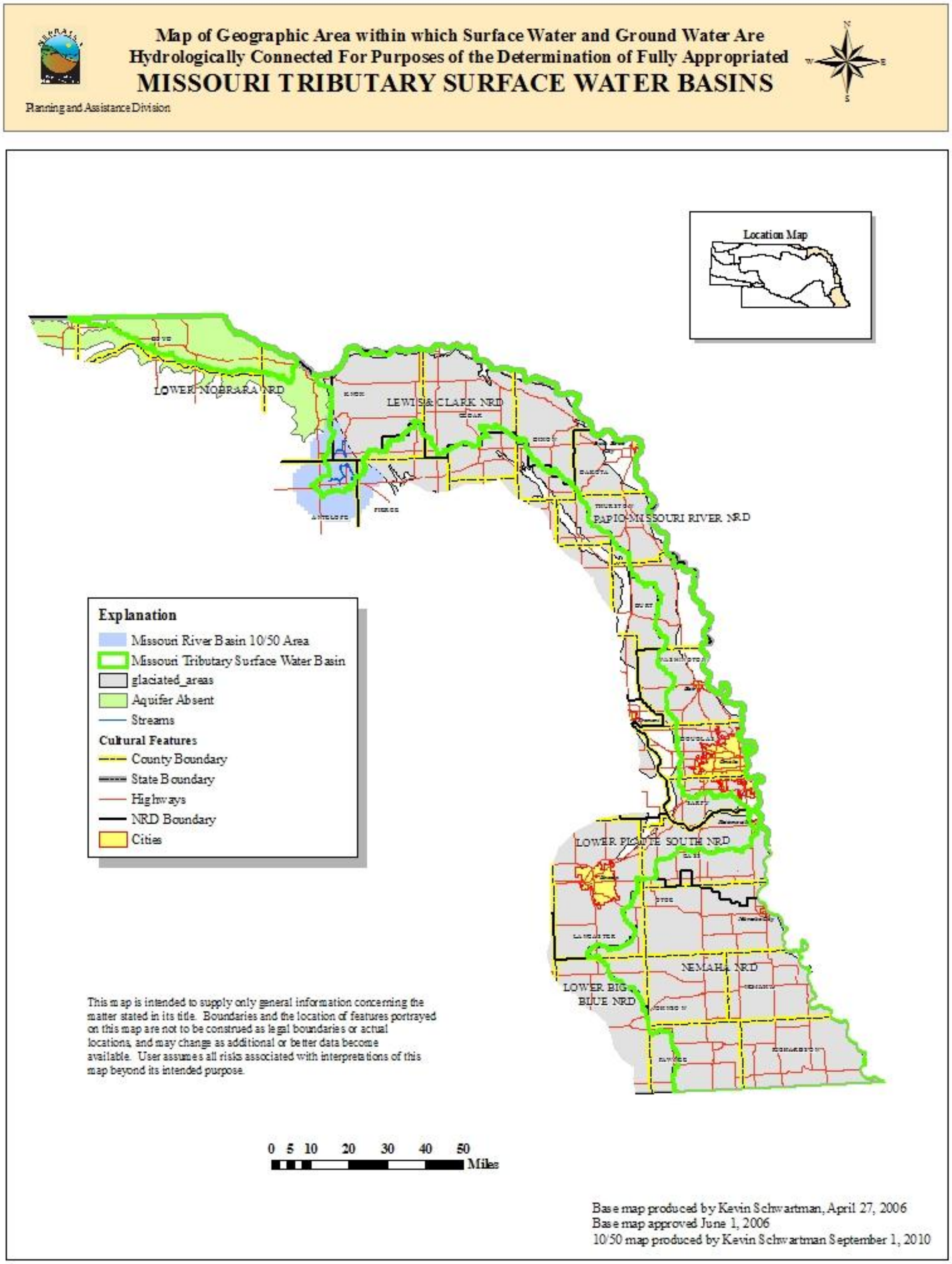

Figure 7-6. 10/50 area, Missouri Tributary Basins.

7.5 Net Corn Crop Irrigation Requirement

Figure 7-7 is a map of the net corn crop irrigation requirement (NCCIR) 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 ten percent, 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.

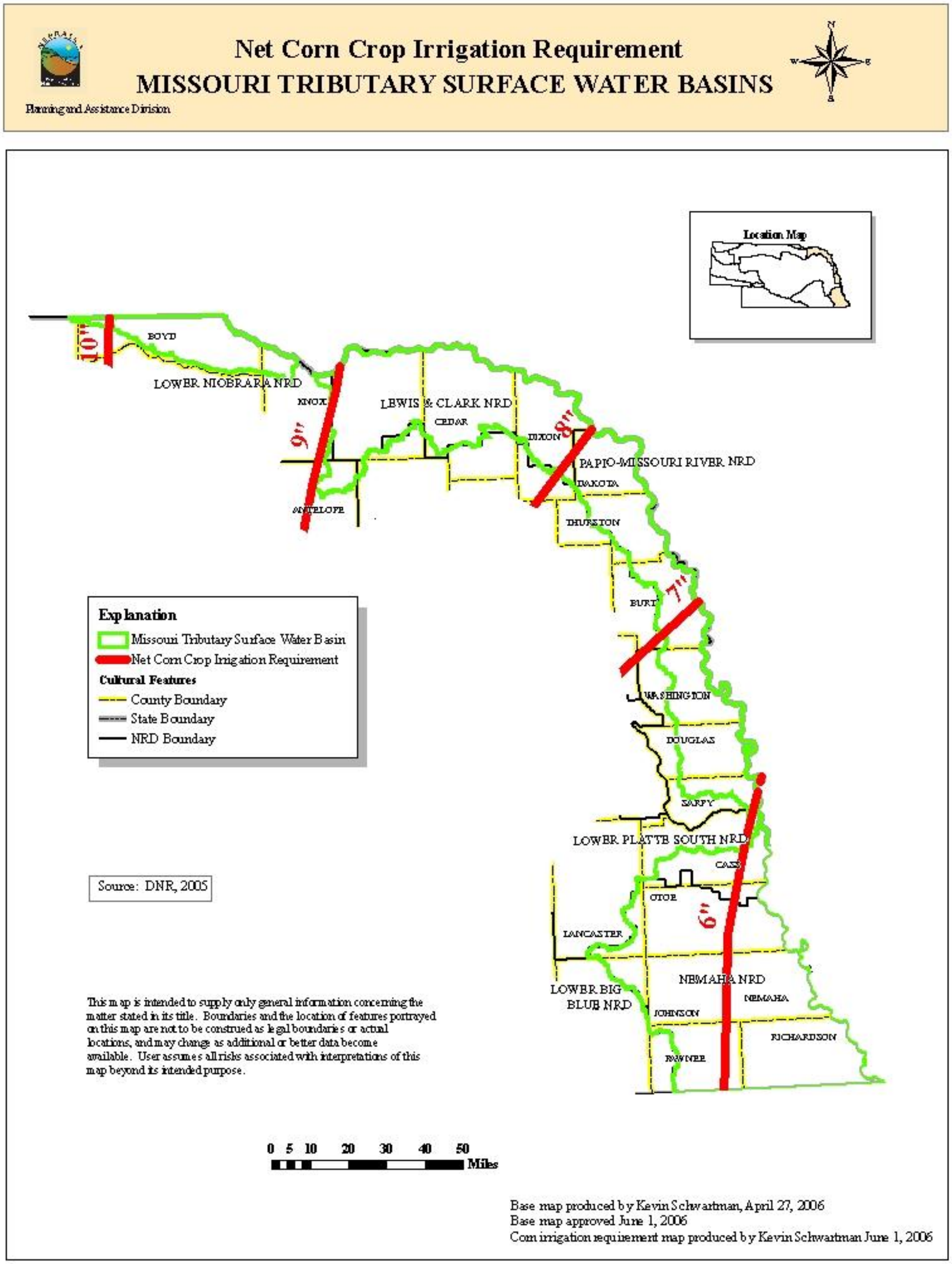

Figure 7-7. Net corn crop irrigation requirement, Missouri Tributary Basins.

7.6 Surface Water Closing Records

Table 7-1 records all surface water administration that has occurred in the basins between 1991 and 2010.

Table 7-1. Surface water administration in the Missouri Tributary Basins, 1991-2010.

Year	Water Body	Days	Closing Date	Opening Date
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

7.7 Evaluation of Current Development

7.7.1 Current Water Supply

The current water supply is estimated by using the previous twenty years (1991-2010) of surface water administration. The results of the analyses conducted for the Missouri Tributary Basins are shown in table 7-2. The results indicate that the current surface water supply in the Missouri Tributary Basins provides an average of at least 60.7 days available for diversion between July 1 and August 31 and 151.7 days available for diversion between May 1 and September 30 (table 7-3).

Table 7-2. Estimate of the current number of days surface water is available for diversion in the Missouri Tributary Basins.

Year	July 1 through 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
1991	62	153
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	41	132
2003	62	153
2004	59	150
2005	59	150
2006	62	153
2007	62	153
2008	62	153
2009	62	153
2010	62	153
Average	60.7	151.7

Table 7-3. Comparison between the number of days required to meet the net corn crop irrigation requirement and number of days surface water is currently available for diversion in the Missouri Tributary Basins.

	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)	14.1 to 26.6	60.7 or greater (at least 34.1 days above the requirement)
May 1 – September 30 (85% Requirement)	18.4 to 34.7	151.7 or greater (at least 117.0 days above the requirement)

7.7.2 Long-Term 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 groundwater 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 sixty years (figure 7-8). Data do not exist to test whether trends in groundwater movement into the basin have changed. 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 groundwater wells.

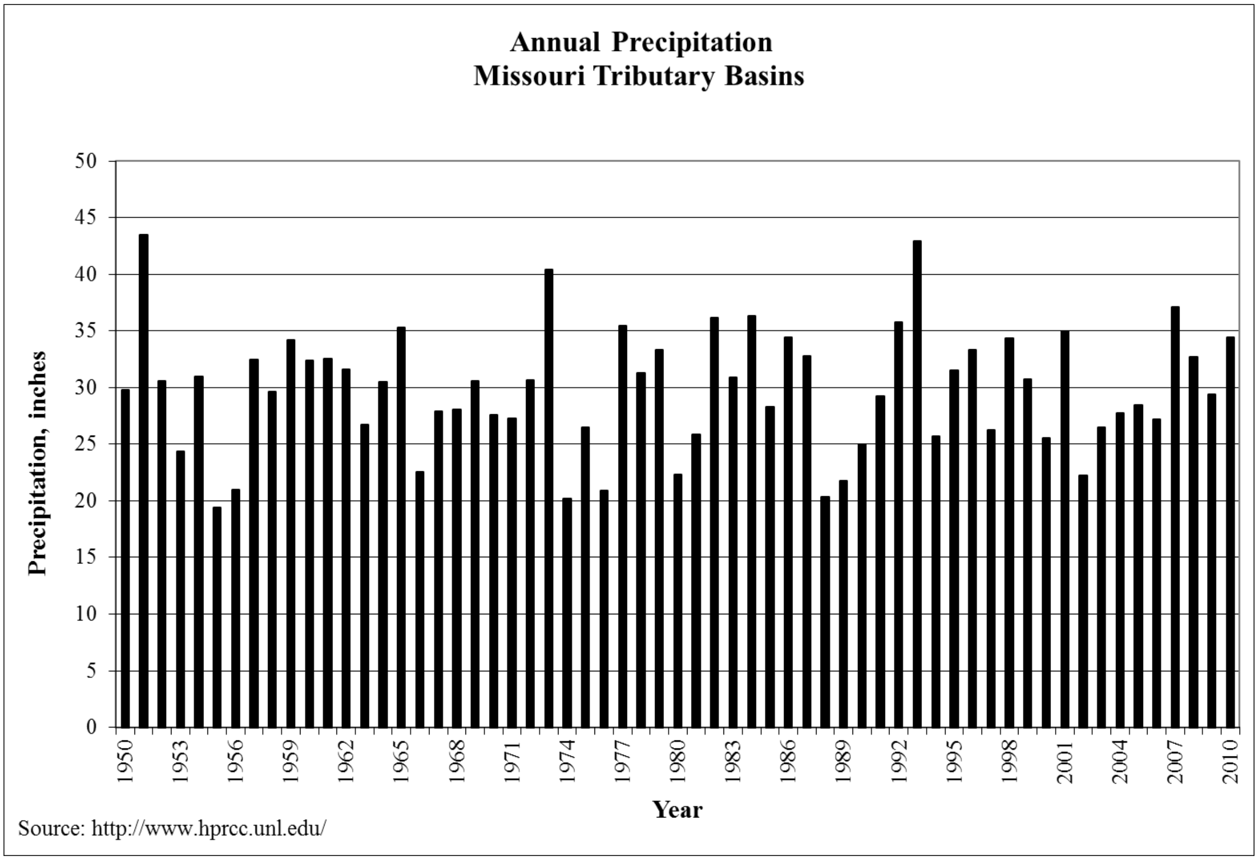

Figure 7-8. Annual precipitation, Missouri Tributary Basins.

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 the SDF methodology. The results estimate the future streamflows in the Bazile Creek subbasin to be depleted by 14 cfs in twenty-five years. For all other Missouri Tributary Basins, a lack of sufficient data and appropriate hydrogeologic conditions prohibited the use of the SDF methodology at this time.

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 were not estimated for any of the Missouri Tributary Basins including the Bazile Creek subbasin because only minimal surface water administration has previously occurred in the basin, and the threshold flows necessary to satisfy senior appropriations could not be estimated. 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 65/85 rule.

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 7-9). 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 estimated to be 35 wells per year in the basin.

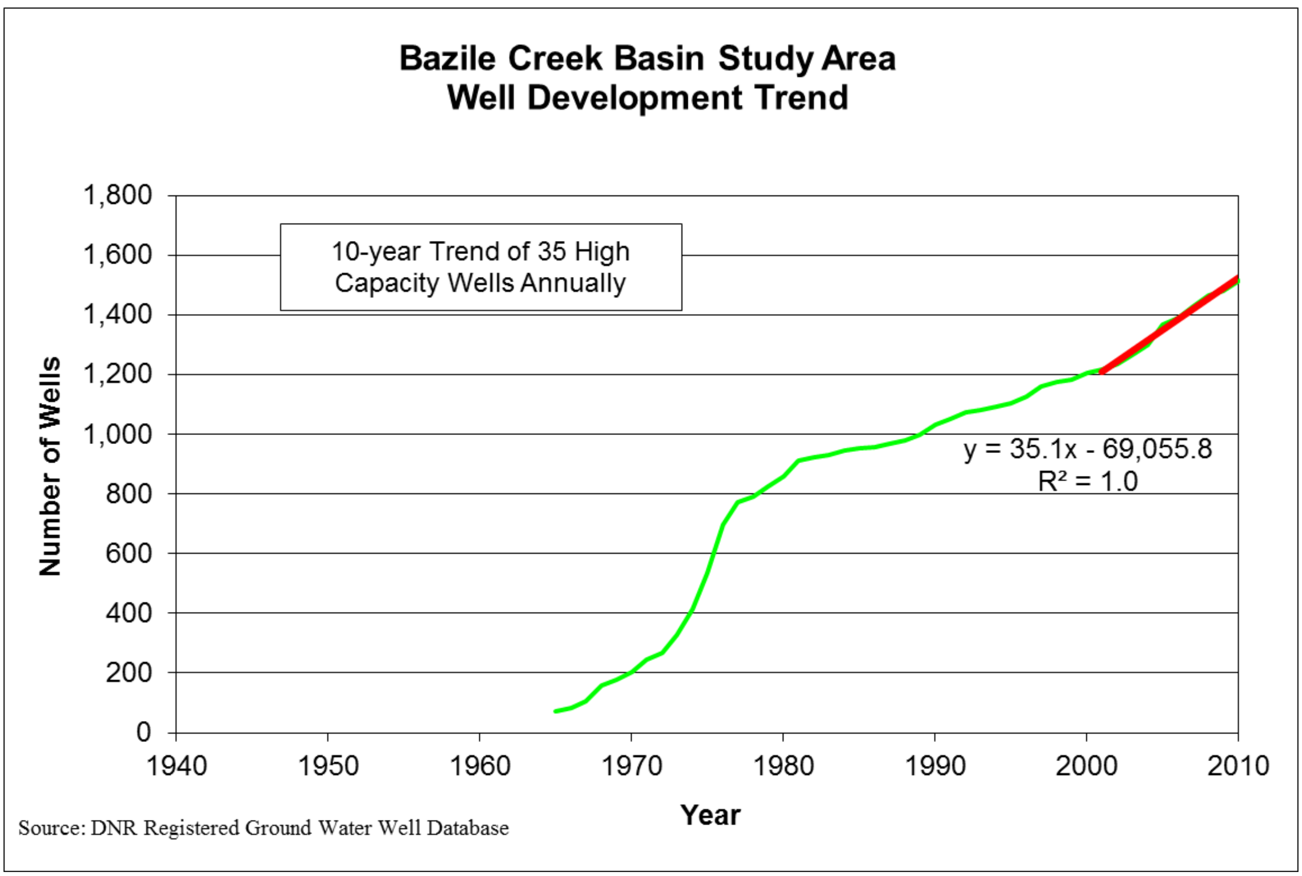

Figure 7-9. High capacity well development, Missouri Tributary Basins.

The future depletions due to potential future well development that could be expected to affect streamflow in the Bazile Creek subbasin were estimated using the SDF methodology. The results estimate the future streamflow to be depleted by an additional 5 cfs in ten years, 9 cfs in fifteen years, 14 cfs in twenty years, and 19 cfs in twenty-five years. Future depletions due to potential future well development were not estimated for all other Missouri Tributary Basins at this time due to a lack sufficient data and appropriate hydrogeologic conditions

The estimate of the twenty-year average number of days surface water is available for diversion was not calculated because minimal surface water administration has previously occurred and the threshold flows necessary to satisfy senior appropriations could not be estimated. 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 65/85 rule.

7.9 Sufficiency to Avoid Noncompliance

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

7.10 Groundwater 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 F).

7.11 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 continuing. This body of work will be reviewed by the Department to evaluate potential methods that may be developed to assess hydrologically connected areas and potential impacts of current and future development. The Department will continue to coordinate with the natural resources districts in the basin as this review is being conducted.

7.12 Relevant Data Provided by Interested Parties

The Department published a request for relevant data for this year's evaluation from interested parties on August 19, 2011 (see Appendix B for affidavit). The Department did not receive any such information.

7.13 Conclusions

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. The use of the SDF methodology to determine lag effects of current development requires sufficient data and appropriate hydrogeologic conditions. Those data and those conditions exist only in the Bazile Creek subbasin at this time. Therefore, lag effects of current development and potential future development were estimated only in the Bazile Creek subbasin.

The analysis of lag effects of current development for the Bazile Creek subbasin indicates a reduction in streamflow of 14 cfs in twenty-five years. The analysis of the impacts of future development on the Bazile Creek subbasin based on current development trends indicates an additional reduction in streamflow of 19 cfs in twenty-five years. The future number of days available to junior irrigators was not estimated because no surface water administration has occurred on the Bazile Creek subbasin in the past twenty years. Even though the future number of days available to junior irrigators was 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 net corn crop irrigation requirement (NCCIR).

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, 2006. Evaluation of the impact of groundwater irrigation on streamflow depletion in Nebraska. *Journal of Hydrology* 327: 603-617.

8.0 BASIN SUMMARIES AND RESULTS

8.1 Blue River Basins

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

The basins can be divided into two distinct areas based on the presence or absence of glacial deposits (CSD, 2005). No sufficient numerical groundwater model is available in the Blue River Basins at this time. Therefore, the Hunt methodology was used to determine the 10/50 area and lag impacts due to current and projected future well development. The Hunt methodology was applied to the western portion of the basins to determine the 10/50 area and to estimate lag impacts due to current and projected future well development. At the present time, the Department cannot determine the 10/50 area or the lag effects due to current and projected future well development for the eastern portions of the Big Blue River and Little Blue River Basins because of the glaciated nature of the area and because the principal aquifer is absent or very thin (CSD, 2005).

The Department has reached a preliminary conclusion that no portion of the basins is currently fully appropriated. The Department determined that the near-term and long-term availability of surface water for diversion for each basin 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 has also determined that based on current information, if no additional legal constraints are imposed on future development of hydrologically connected surface water and groundwater and reasonable projections are made about the extent and location of future development, this preliminary conclusion would not change to a conclusion that the basin is fully appropriated.

8.2 Lower Niobrara Basin

The Lower Niobrara River Basin is located in the northeast portion of Nebraska and consists of all of the surface areas that drain into the Niobrara River and that have not previously been determined to be fully appropriated, from the Spencer hydropower facility downstream 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 groundwater model is available in the Lower Niobrara River Basin. Therefore, the stream depletion factor (SDF) methodology was used to determine the 10/50 area and lag depletions due to current and projected future well development. The analysis of lag depletions of current development for the Lower Niobrara Basin indicates a reduction in streamflow of 9 cfs in twenty-five years. The analysis of the impacts of future development on the Lower Niobrara Basin based on current development trends indicates an additional reduction in streamflow of 106 cfs in twenty-five years.

The Department has reached a preliminary conclusion that no portion of the basin is fully appropriated. Estimates of future water supplies for junior irrigators could not be estimated due to minimal surface water administration during the past twenty years. 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 65/85 rule.

8.3 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 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 groundwater 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 lack of sufficient data and appropriate hydrogeologic conditions does not allow for the use of the 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; therefore, the 10/50 area was delineated using the SDF methodology for that portion of the Missouri Tributary Basins only.

The analysis of lag effects of current and potential future development was only conducted in the Bazile Creek subbasin due to a lack of sufficient data or appropriate hydrogeologic conditions in all other areas. The analysis of the Bazile Creek subbasin indicates a reduction in streamflow by 14 cfs in twenty-five years. The analysis of the impacts of future development on the Bazile Creek subbasin based on current development trends indicates an additional reduction in streamflow of 19 cfs in twenty-five years.

The Department has reached a preliminary conclusion that no portion of the Missouri River Tributary Basins is fully appropriated. The near-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. Estimates of future water supplies for junior irrigators in the Bazile Creek subbasin could not be estimated due to minimal surface water administration during the past twenty years. For all other subbasins, the inability to calculate the lag effects of existing and future groundwater development prohibited a determination of future water supplies for junior irrigators at this time. Even though the long-term 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 65/85 rule.

8.4 Results of Analyses

Tables 8-1 and 8-2 summarize the results of the analysis for sufficiency of water availability for irrigation in each basin.

Table 8-1. 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	54.5	51.9	51.3
Little Blue River Basin	25.7	54.7	51.7	50.0
Lower Niobrara River Basin	23.6 – 25.5	61.9	Not Calculated[1]	Not Calculated[1]
Missouri Tributary Basins	14.1 – 26.6	60.7	Not Calculated[1]	Not Calculated[1]

[1] This number could not be calculated due to a lack of geologic data, hydrologic data, or surface water administration.

Table 8-2. 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	145.3	142.1	141.2
Little Blue River Basin	33.6	143.2	137.0	133.6
Lower Niobrara River Basin	30.9 – 33.4	152.9	Not Calculated[1]	Not Calculated[1]
Missouri Tributary Basins	18.4 – 34.7	151.7	Not Calculated[1]	Not Calculated[1]

[1] This number could not be calculated due to a lack of geologic data, hydrologic data, or surface water administration.

Appendix A

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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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 B

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 2012, 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 October 1, 2011, 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, 2012, 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.

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 2012, 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 groundwater uses on resources that are dependent on streamflow or groundwater levels but are not protected by appropriations or regulations. Anyone wishing to provide relevant data must submit such relevant data by October 1, 2011, 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.

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

Proof of publication

AFFIDAVIT

State of Nebraska, County of Douglas, ss:

April Christenson, 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 19th and August, 2011, 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 153,944 Daily and 188,810 Sunday, in 2011.

(Signed) ______________ Title: Account Executive

Subscribed in my presence and sworn to before me this 19th day of August, 2011.

GENERAL NOTARY - State of Nebraska
MARCIA A. GUSTAFSON
My Comm. Exp. June 30, 2012

Marcia A. Gustafson
Notary Public

Printer's Fee $ ______________
Affidavit ______________
Paid By ______________

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AUG 22 2011
DEPARTMENT OF NATURAL RESOURCES

No information was provided by interested parties regarding relevant data 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 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, $[\mathrm{L}^2/\mathrm{T}]$;
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, $[\mathrm{L}^3/\mathrm{T}]$; the steady pumping rate less the rate at which pumped water returns to the aquifer;
q= the rate of depletion of the stream, $[\mathrm{L}^3/\mathrm{T}]$;
Qt= the net volume pumped during time t, $[\mathrm{L}^3]$;
Qt_p= the net volume pumped, $[\mathrm{L}^3]$;
v= the volume of stream depletion during time t, t_p, or t_p+t_i, $[\mathrm{L}^3]$;
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.

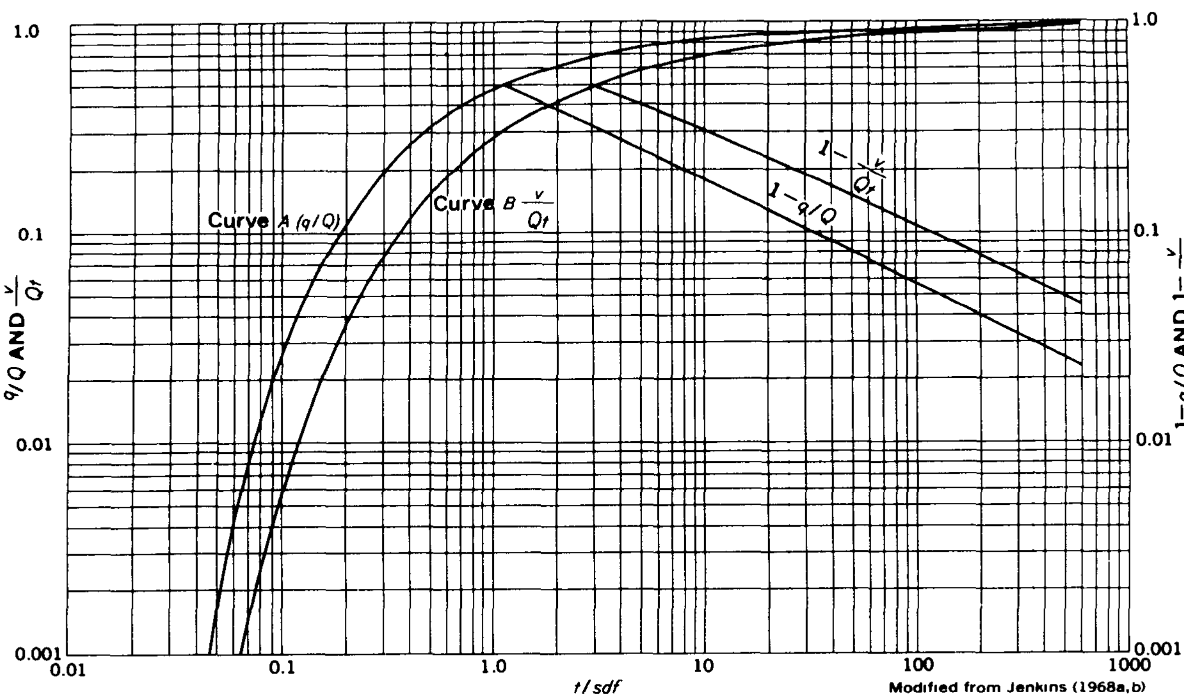

Figure 1.—Curves to determine rate and volume of stream depletion.

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

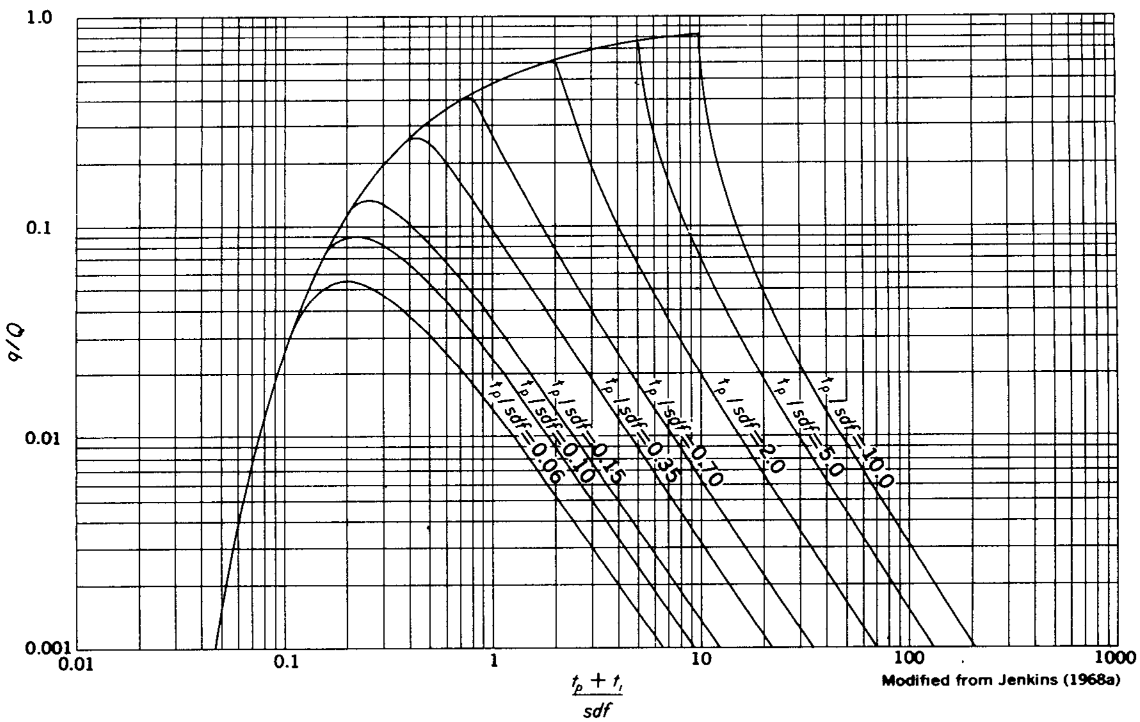

Figure 2.—Curves to determine rate of stream depletion during and after pumping.

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 $\frac{v}{Qsdf}$.

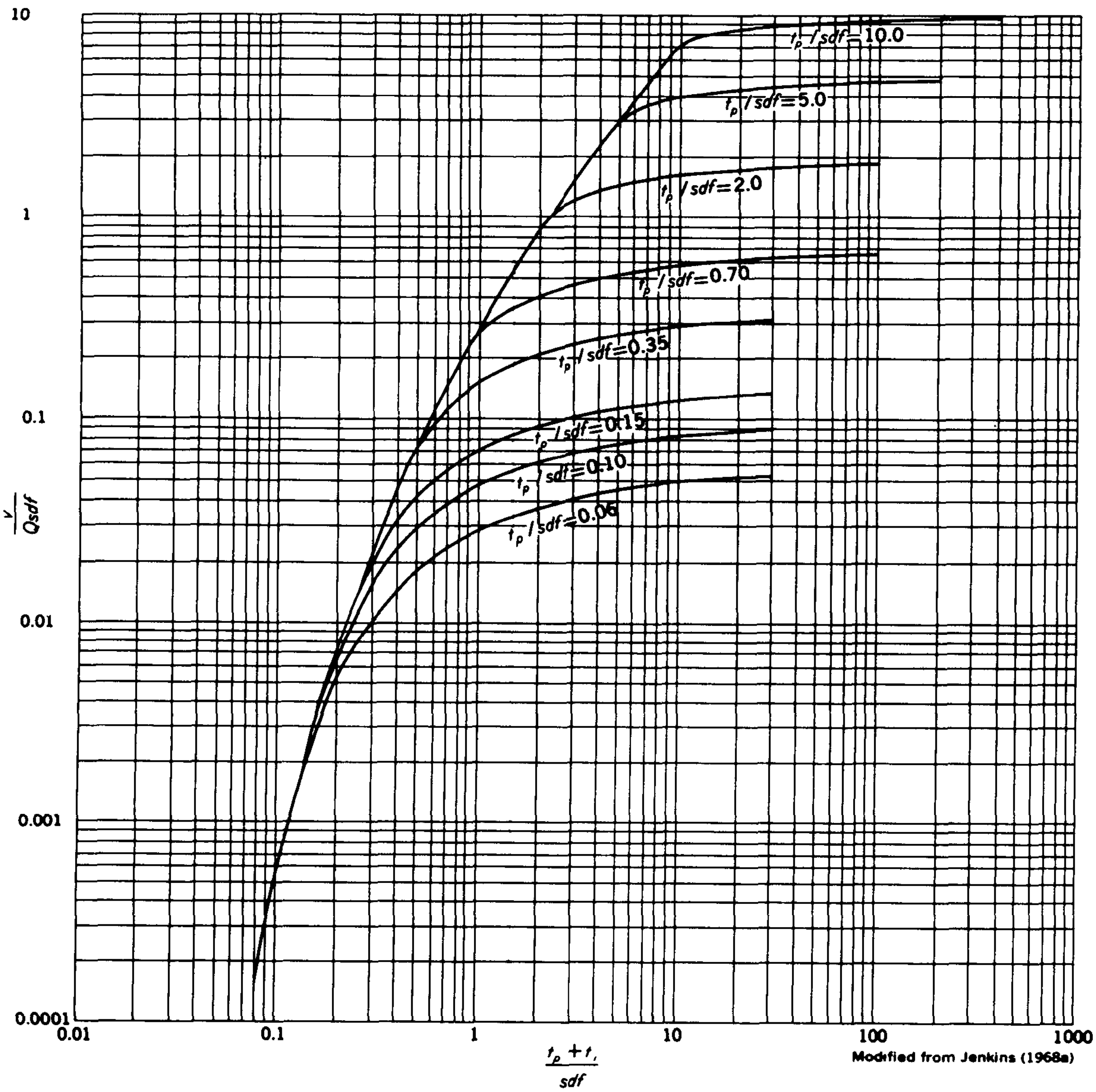

Figure 3.—Curves to determine volume of stream depletion during and after pumping.

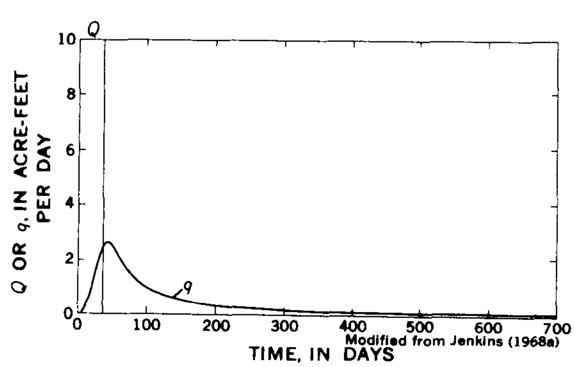

Figure 4.—Example of residual effects of well pumping 35 days.

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

$q=(0.12)(2 \text{ acre-ft/day})$
$=0.24$ 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

$v=(0.008)(2 \text{ acre-ft/day})(520 \text{ days})$
$=8.3$ 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

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

when

$t_p+t_i=(0.25)(520 \text{ days})$
$=130$ 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 $T/S=134{,}000$ ft²/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

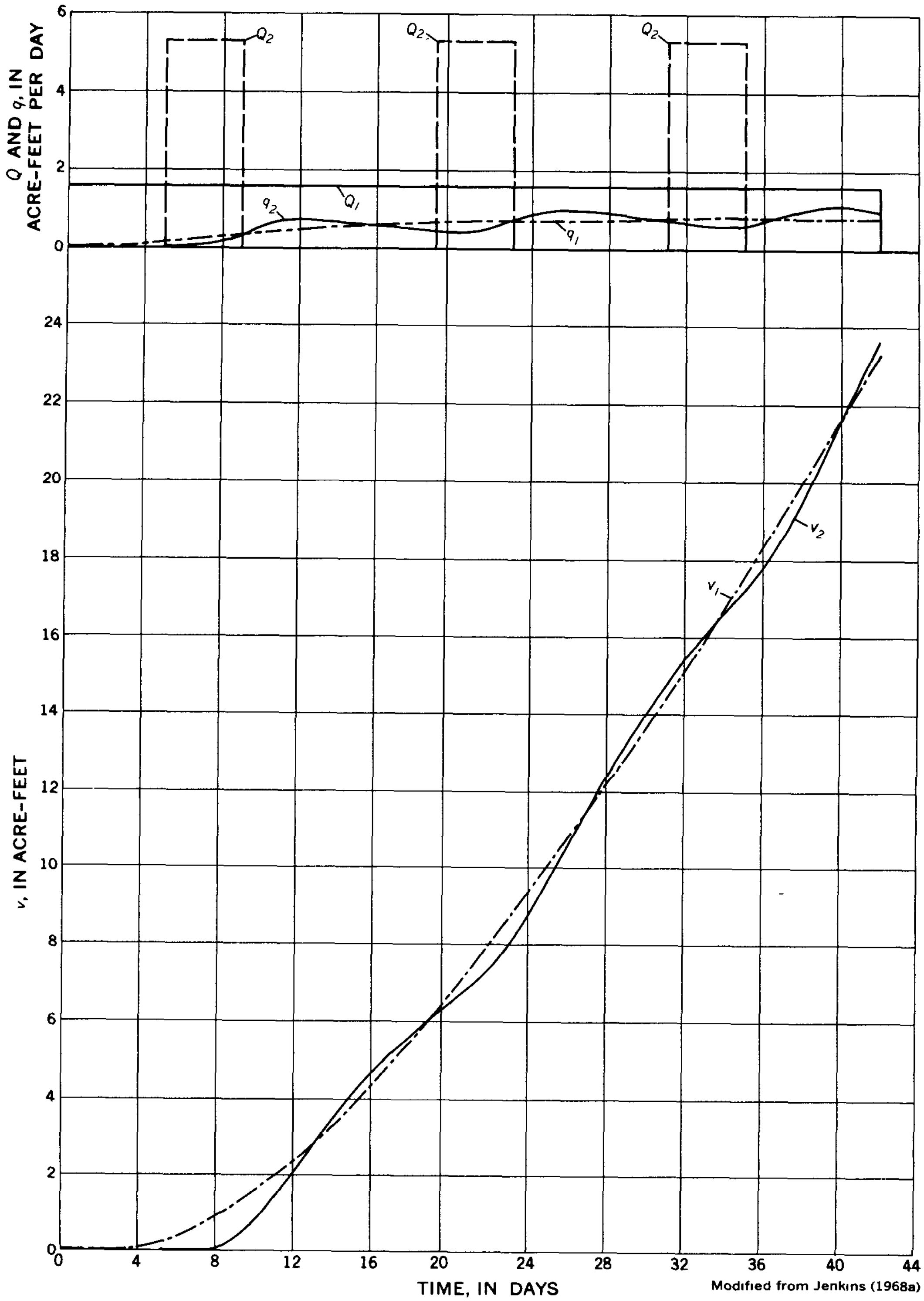

Figure 5.—Curves showing the effects of intermittent and steady pumping on a stream

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

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
$T/S=67{,}000 \text{ ft}^2/\text{day}$

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

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,

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

Part 2

When $t_p+t_i=(150+216)$ days$=366$ 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,

$q=(0.11)$ $(1.1$ acre-ft/day$)$
$=0.12$ acre-ft/day,
$v=(0.33)$ $(1.1$ acre-ft/day$)$ $(239$ days$)$
$=87$ 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

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

$q=(0.568)$ $(1.1$ acre-ft/day$)$
$=0.62$ acre-ft/day,
$v=(0.366)$ $(1.1$ acre-ft/day$)$ $(366$ days$)$
$=147$ 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:
$v=5{,}000$ m^3
$Q=0.03$ m^3/sec
$t_p=200$ days
$T=30$ cm^2/sec
$S=0.20$
$Qt=(0.03$ m^3/sec$)$ $(200$ days$)$ $(86{,}400$ sec/day$)=5.184\times10^5 m^3$

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

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 ft³/sec. Reduction of the pumping rate to about 750 gal/min would keep rate of stream depletion below 1.5 ft³/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)

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

from Glover and Balmer (1954)

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

from Glover (1960)

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

and from Hantush (1964, 1965)

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

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

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

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)

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

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

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

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

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.

[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

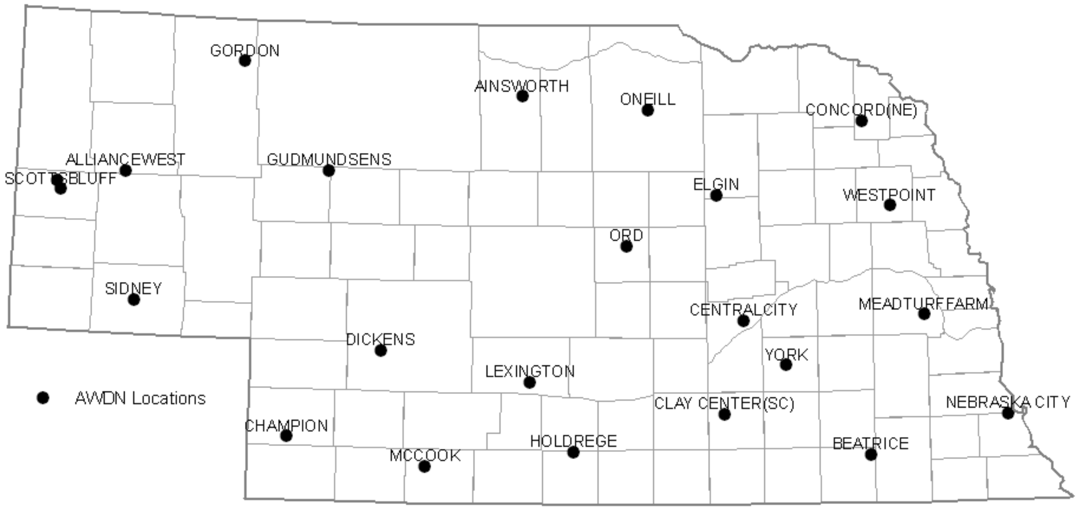

Figure 1. Location of automated weather stations used to calibrate the Hargreaves method.

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.

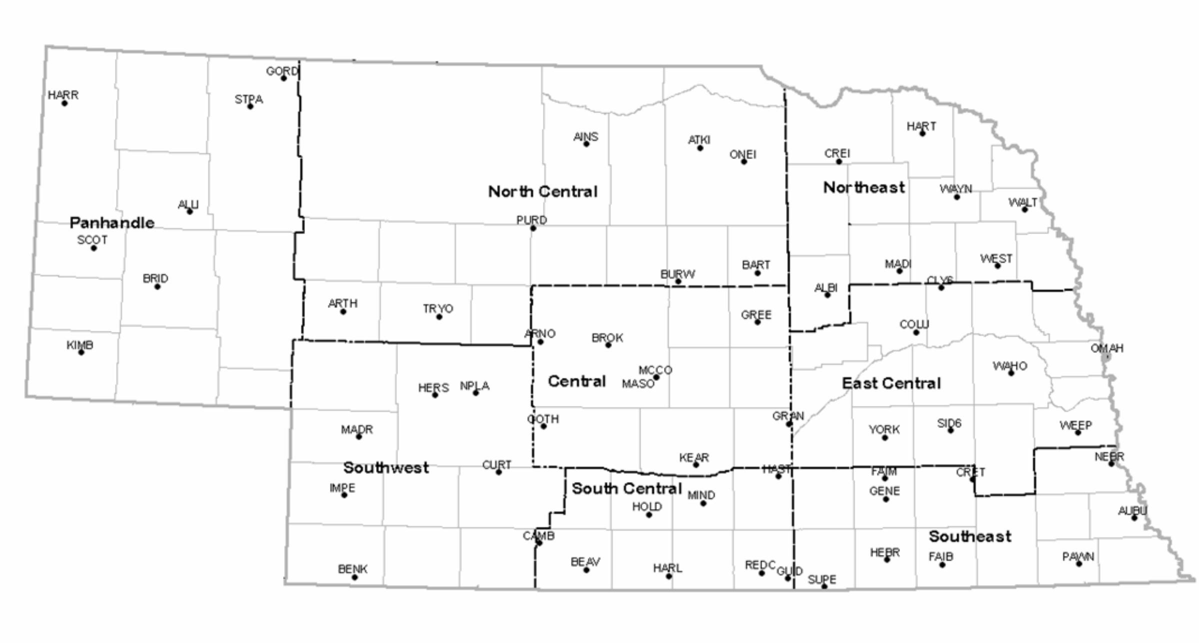

Figure 2. Location of National Weather Service stations used in simulations and Climatic Zones for Nebraska. Specific information for the NWS stations is included in Table 4.

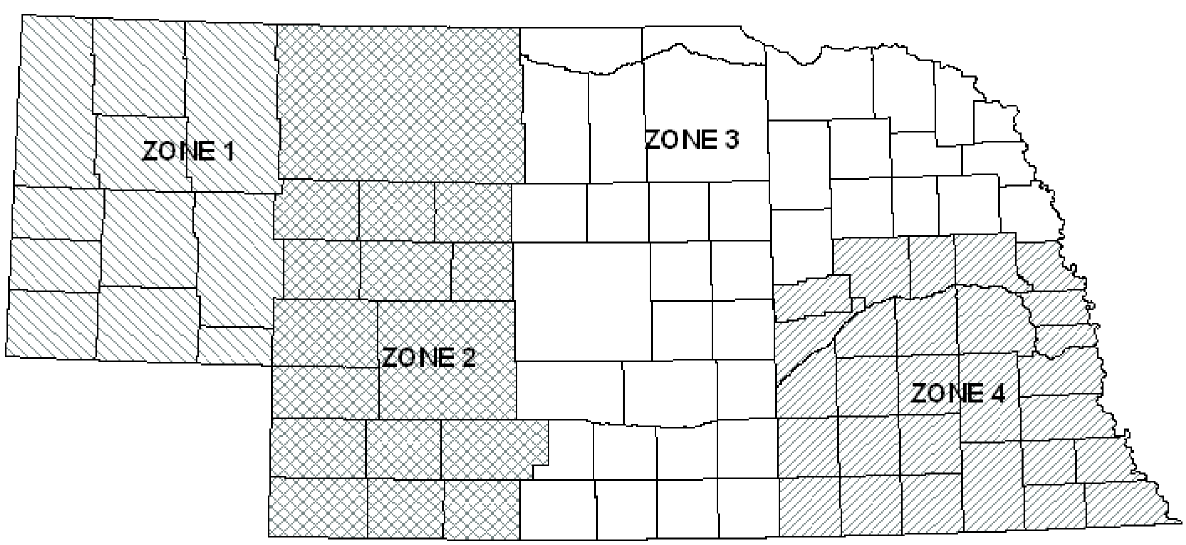

Figure 3. Location of management zones for the CROPSIM model.

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.

[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

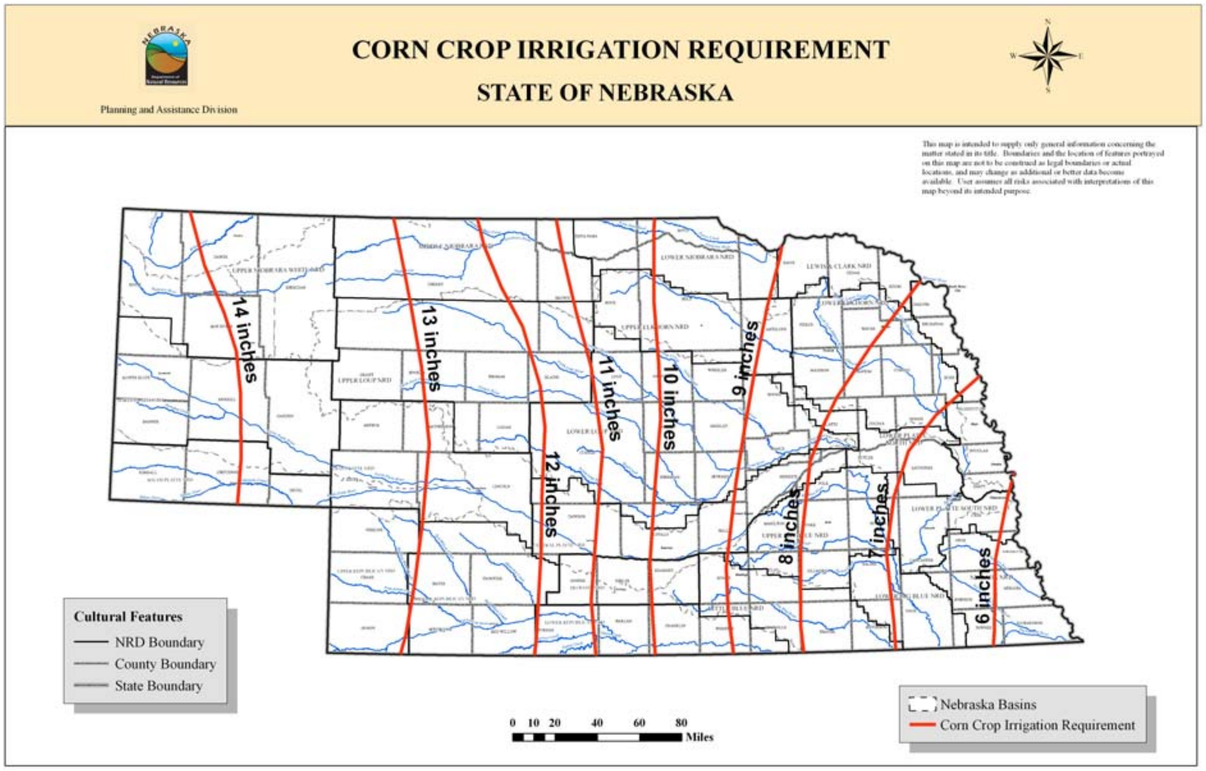

Figure 4. Map of net irrigation requirements (inches/year) for corn grown on fine sandy loam.

Appendix E

Appendix E

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 F

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.