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EC98-1776 Nebraska Groundwater of Aquaculture

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NEBRASKA AQUACULTURE

Published by University of Nebraska Cooperative Extension in cooperation with the Nebraska Aquaculture Board

Nebraska Groundwater for Aquaculture

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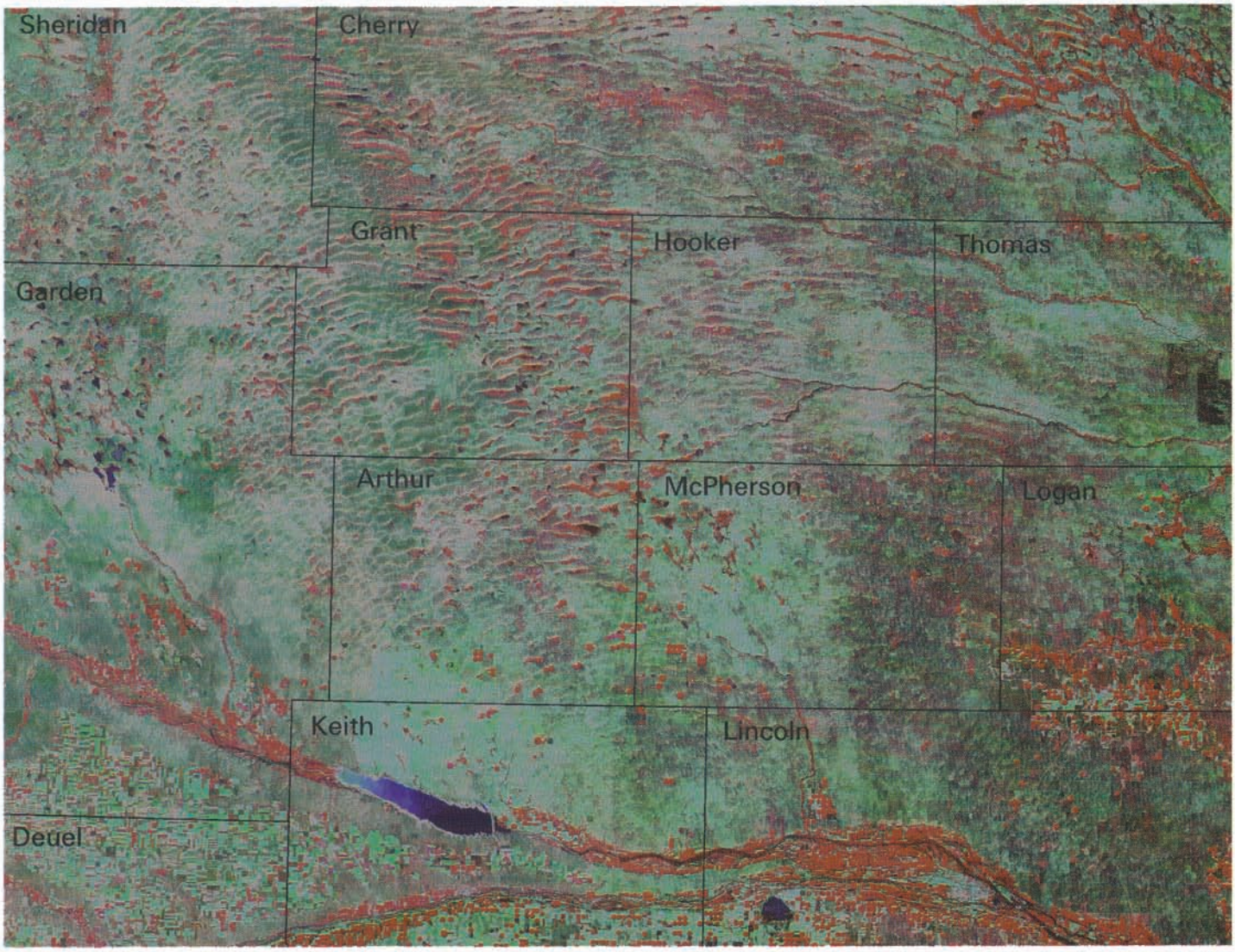


Lush vegetation growth (areas in red) in meadows between grassy dunes in the Sand Hills (above) and in the valleys of the North and South Platte Rivers (bottom) at their confluence in west-central Nebraska reflect vast stores of near-surface groundwater. County names and boundaries in black. Infrared Landsat satellite image by Michael C. Daggy, CALMIT, University of Nebraska-Lincoln.

THE NEBRASKA AQUACULTURE BOARD was established by Nebraska state law (Legislative Bill 830, approved by the Governor of Nebraska on April 13, 1993) to provide recommendations to the Nebraska State Legislature on matters related to aquaculture and commercial aquaculture development in the State of Nebraska. In addition to defining the authority and general areas of responsibility of the Board, this law charged the Board with developing a "State Aquaculture Plan to be presented to the Legislature by January 1, 1994." However, because of time constraints and the complexity of developing such a plan, the Board was unable to meet this charge, and instead, on January 25, 1994, presented the Legislature with a brief (34-page) *NEBRASKA AQUACULTURE REPORT*, which addressed some but not all of the topics and issues raised in the establishing legislation, or which are usually addressed in comprehensive state aquaculture plans.

As originally constituted, the Nebraska Aquaculture Board was comprised of two employees each from the Nebraska Department of Agriculture and the Nebraska Game and Parks Commission, the aquaculturist employed by University of Nebraska Cooperative Extension (pursuant to previously established state statute, section 85-1,104.01), and two commercial aquaculturists appointed for three-year terms by the Governor of Nebraska. In the *NEBRASKA AQUACULTURE REPORT*, the Board deferred the development of a comprehensive State Aquaculture Plan owing to "certain information constraints and a number of key issues pending at the state and national levels." This deferral, however, was not intended as an abrogation of the Board's responsibility to develop a comprehensive state plan.

Subsequent to the submission of the *NEBRASKA AQUACULTURE REPORT*, another state law (Legislative Bill 1165, approved by the Governor of Nebraska on April 19, 1994) was enacted relative to the Nebraska Aquaculture Board. This law reduced the number of representatives to the Board from the Nebraska Department of Agriculture and Nebraska Game and Parks Commission to one each, enacted into law certain recommendations made by the Board in the *NEBRASKA AQUACULTURE REPORT*, and changed "provisions relating to and to provide [assigned] duties" for the Board. As part of the Board's subsequent deliberations, it was confirmed that work should continue on the development of a comprehensive State Aquaculture Plan.

The purpose of the *NEBRASKA AQUACULTURE* series is twofold: first, to provide in detail key information to promote and help facilitate the development of a major Nebraska aquaculture industry; and second, to provide a framework for making informed policy recommendations, as part of a Nebraska State Aquaculture Plan. Accordingly, all articles comprising the *NEBRASKA AQUACULTURE* series are intended to be used as chapters in the Nebraska plan.

University of Nebraska Lincoln

Institute of Agriculture and Natural Resources

Nebraska Aquaculture Industry

Nebraska Department of Agriculture

Nebraska Game and Parks Commission

Introduction

Aquaculture, the cultivation or husbandry of aquatic plants and animals, is the fastest growing component of United States agriculture. Nebraska presently has an extremely small aquaculture industry, but the potential benefits of investing in the development of a large-scale industry are enormous. As discussed in detail in the *NEBRASKA AQUACULTURE* series publication *Why Aquaculture? Why Nebraska?,* the main reasons for this are:

- Fisheries products have traditionally provided over half the animal protein consumed by the human race, the population of which is rapidly expanding.
- The demand for fisheries products in the United States has been increasing for decades, making it the world's second largest importer of such products.
- According to recent estimates, 13 out of 17 of the world's major capture fisheries have either collapsed or are classified as commercially depleted.
- Projections are that to meet world fisheries products demands, aquaculture production by 2025 will have to increase sevenfold, to 168 billion pounds.
- Nebraska has the essential resources, particularly abundant high-quality water and low-cost feedstuffs, necessary to support a major aquaculture industry.

As the word implies, "*aqua*-culture" requires water in significant quantities to pursue on a commercial scale. Contrary to popular belief, most (about 75 percent) of the world's finfish aquaculture is done in freshwater, not seawater. Approximately 85 percent of all aquaculture in the United States is done in freshwater, nearly 82 percent of which is pumped groundwater. Based on known hydrogeological data, there can be little doubt that Nebraska has the water resources necessary to develop and support a large aquaculture industry.

Nebraska Groundwater Resources and Use

As described in *Why Aquaculture? Why Nebraska?*, Nebraska is one of the nation's most water-rich states. Its groundwater resources are enormous, and include the High Plains Aquifer, which ranks among the world's largest near-surface aquifers. The volume of groundwater contained in Nebraska's aquifers totals over 2.1 billion acre-feet, which is about 44 percent more than that in Lake Ontario, an amount sufficient to cover the state's 77,355 square-mile area to an average depth of over 30 feet.

Because of the volume and shallow depth to much of Nebraska's groundwater, the state ranks third in the nation in total groundwater usage and has about 80,000 active registered irrigation wells, which (based on recently published government estimates for 1995) supply about 6.5 million acre-feet (about 2.1 trillion gallons) of groundwater to about 6.4 million acres of crop- and pastureland annually, with some year-to-year variations. Depending on precipitation and other factors, irrigation accounts for between 91 and 93 percent of the state's annual use of groundwater.

Irrigation is both the United States' and Nebraska's leading "consumptive user" of water – i.e., most of the water is "lost" to seepage, evaporation, evapotranspiration by plants, and leakage during conveyance. Nationally, only about 24 percent of the water used for irrigation is recovered in "return flow." Given Nebraska's windy climatic conditions and associated water losses due to increased evaporation, the state's "return flow" from irrigation is probably less than the national average.

In contrast to irrigation, *well-managed* high-intensity aquaculture operations are "low-consumptive" users of water – i.e., they use water but do not degrade or consume it in ways that it cannot be employed for other purposes. In several of the world's leading aquaculture nations, aquaculture is often integrated with irrigated agriculture, to the benefit of both. The development of a major Nebraska aquaculture industry will probably depend on some similar approach to integrating it with land-based agriculture.

Most of the abundant near-surface groundwater in Nebraska underlies large areas of the state that have sandy soils. Because of this, future development of a major aquaculture industry in Nebraska probably lies in the use of high-intensity production technologies employing tanks and

lined ponds. Conventional pond aquaculture is best done in earthen ponds engineered and built to allow total drainage. The construction of such ponds normally requires soil with a clay content of 20 percent or higher for effective sealing. In areas of Nebraska with abundant near-surface groundwater and certain highly mineralized soils or soils containing sufficient clay to seal properly, pond aquaculture using various improved techniques could be greatly increased above present levels, depending on appropriate species selection and the development of innovative means to access existing markets or create new ones.

Water Resources and Aquaculture Siting

Most types of aquaculture require large volumes of high-quality water, and depend on appropriate siting to achieve commercial success. Surface water sources, such as lakes, streams and watershed runoff, are used for aquaculture in many parts of the world and in the United States. However, surface water sources are often only intermittently available (depending on weather and other factors), and may be contaminated by pesticides or other pollutants, as well as by wild fish, parasites or other disease agents. Given Nebraska's highly variable patterns of precipitation and history of competition for surface water, the prospects for developing a major aquaculture industry in the state are low based on its surface water resources.

(A possible exception to this projection, depending on levels of contaminants and disease agents, as well as various legal considerations, may be certain streams in Nebraska's Sand Hills Region – which is discussed in greater detail later in this publication. Stream flows in this region, which extends over approximately 19,300 square miles, are sustained by groundwater discharge at remarkably constant levels, irrespective of season or climatic conditions. In reality, most stream flow in the Sand Hills Region comes from groundwater discharge and seepage, rather than surficial runoff. So, the distinction between ground- and surface water in this region is blurred.)

For most types of intensive aquaculture, either in tanks or ponds, groundwater is usually the preferred medium because it:

- is far more likely to be free of harmful contaminants;
- typically exhibits little variation in daily or annual temperature; and
- with proper site selection, facility design and management, should be constantly available.

The ideal groundwater sources for intensive aquaculture are continuously flowing high-volume springs or artesian wells. But in Nebraska, as in most parts of the world, such high-volume groundwater sources are scarce, are already being used, or in many instances are at risk of being depleted. It is because of these factors that most United States aquaculture is done using pumped groundwater.

In the United States, including Nebraska, most groundwater resources are being monitored closely, and laws have been (and will continue to be) passed to minimize or prevent further depletion. This one fact underscores the critical nature of careful site selection for aquaculture, and the need to think in terms of sustainable use of all resources, including water. For most commercial-scale aquaculture, the importance of careful site selection cannot be overemphasized. Factors such as land form and slope, soil type (e.g., clay content) and profile, prior land use, present use of surrounding lands and water resources, and all-weather road access are all important considerations, and may very well determine not only inherent feasibility but also the type of aquaculture that can be done at a given site.

Abundant high-quality water, however, is essential to most successful types of commercial aquaculture as presently practiced in the United States. A simple rule of thumb to evaluate water quality is that if the water at a site is potable and safe for livestock, it can probably be used for most types of freshwater aquaculture. Nearly all of Nebraska's groundwater resources meet this criterion, though some notable exceptions exist in the form of isolated aquifers containing waters that are salty, highly mineralized or inordinately high in iron, manganese or zinc. Before buying land for aquaculture or investing heavily in developing an aquaculture operation at a particular site, the quality of the water should be tested both chemically and (if possible) by culturing fish in it on a small pilot scale.

Most intensive aquaculture production technologies require a continuous flow of water through production units (i.e., tanks or ponds) to maintain water quality at high rearing densities. If constant pumping is required to provide this flow, then ready access to three-phase electricity is probably also critical to siting, particularly if the water required must be pumped from wells. Such electric power is widely distributed in most parts of Nebraska and is available at commercial rates that are among the lowest in the nation (3 to 6 cents per kilowatt-hour). In the absence of spring or artesian water sources, electrically powered wells generally provide the most cost-effective means of supplying water for intensive aquaculture, if electric rates are low. Well pumps can also be powered by internal combustion engines, but their risk of breakdown, and maintenance and initial procurement costs, are normally higher than electric motors.

In siting an intensive aquaculture operation that will require continuous groundwater pumping, the following considerations are critical:

- pump, power-plant, well installation and electric power costs;
- groundwater abundance, water-table depth and aquifer permeability, (all three will determine sustained pumping depth); and
- sustained pumping depth, which in turn will directly affect power consumption.

To minimize the effects of electrical outages and well failures, backup power sources are essential, and the installation of three or more medium-size wells in the long run is preferable to the installation of one large well of similar total pumping capacity. To minimize power costs, wells for aquaculture should be sited to minimize sustained pumping depth.

Regardless of size, the decision to develop an aquaculture operation should be guided by the ready availability of high-quality water at minimum cost, which in Nebraska means gaining a basic general understanding of the state's hydrogeology as it relates to aquaculture. This is true because, when necessary, well water pumping usually constitutes a significant part of total operating costs. Over time, even small differences in pumping costs between sites may make the difference between financial success or failure. The main controlling factors for any given size of operation are sustained pumping depth and power costs. The economics of scale are such that large aquaculture operations, at a given electric rate, can afford to pump water from greater depths than small operations.

Nebraska Hydrogeology and Aquaculture

Irrespective of production methods or the species being cultured, freshwater aquaculture is most often done in river valleys or headwaters, in areas where springs or high-yield near-surface alluvial aquifers are present. Because much of Nebraska's agricultural economy is directly or indirectly dependent on irrigation, considerable technical information has been compiled regarding the state's hydrogeology by the Conservation and Survey Division of the Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. All the hydrogeological information presented in the remainder of this publication was drawn from technical literature available from the Division, or was derived from data in the Division's computer files.

As previously indicated, the collective groundwater resources of Nebraska are enormous. However, the distribution of those resources and their utility for commercial aquaculture development vary widely in different parts of the state. To evaluate and illustrate these variations, existing data sets on the hydrogeology and groundwater resources of Nebraska were combined, analyzed and mapped using computer-based Geographic Information Systems (GIS) technology. The maps generated *(Figures 1-9)* provide insights on the potential for aquaculture development in various parts of the state based on the following hydrogeological factors:

- ***Saturated thickness of the principal groundwater reservoir*** *(Figure 1)* – the estimated thickness of the saturated unconsolidated sediments and rock that underlie the state's 13 groundwater regions.

- ***Depth to the regional water table*** *(Figure 2)* – the estimated distance between the land surface and water table at drilled test holes and observation wells (that are not being pumped) at sites in all of the state's groundwater regions.

- ***Transmissivity*** *(Figures 3-8)*, as described in the Division's 1986 publication *The Groundwater Atlas of Nebraska* – "a measure of the volume of groundwater that will flow through a given width of an aquifer under a specified slope of the water table" in a given period of time. (Note: An updated second edition of *The Groundwater Atlas of Nebraska* [1998] has recently been published and is now available from the Division.)

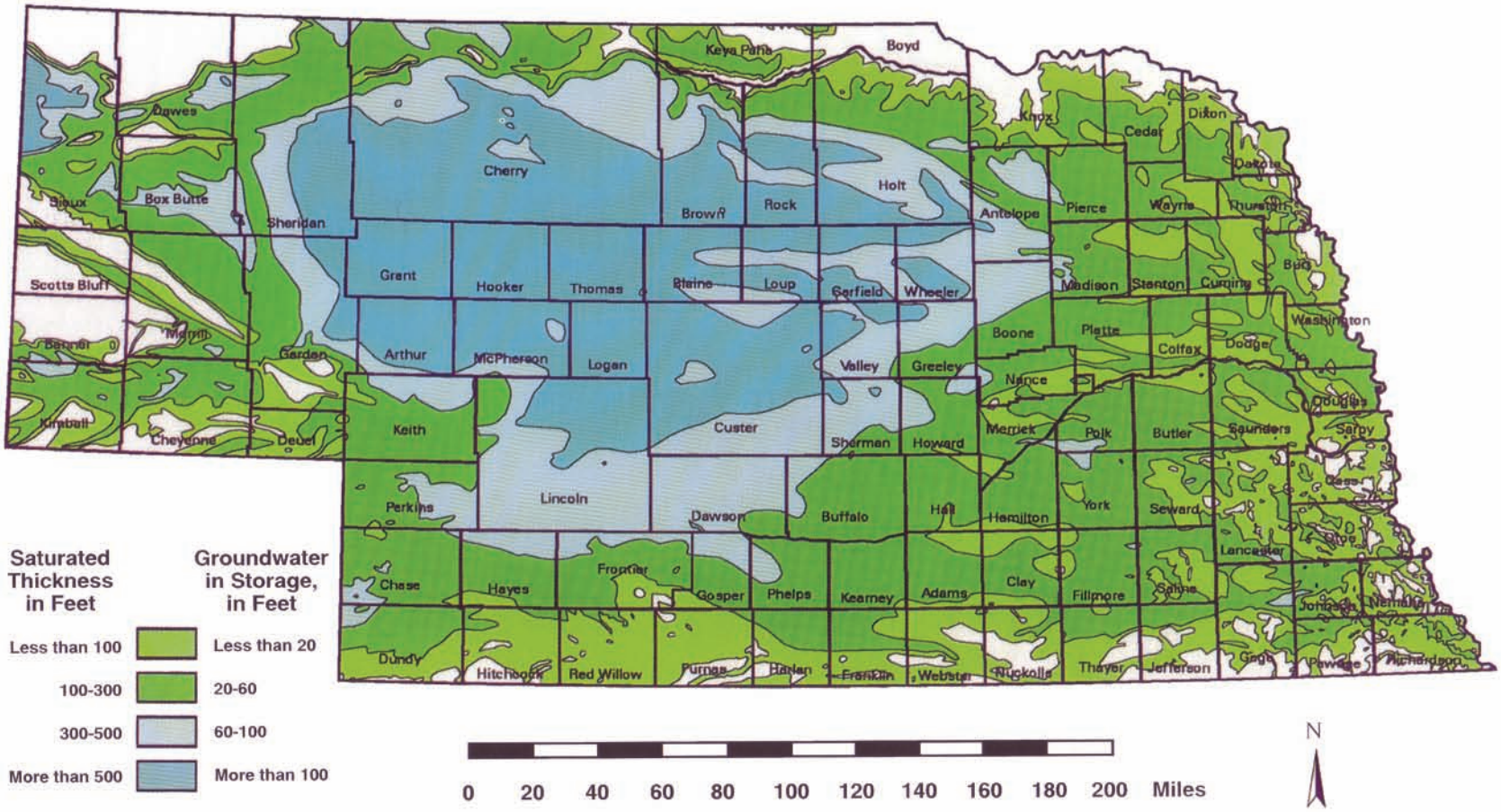
- ***Groundwater-level changes in Nebraska, predevelopment to spring 1994*** *(Figure 9)* – the estimated changes in groundwater level in various parts of the state since predevelopment, due primarily to the development of water resources that have resulted in declines or increases in the water table.

Figures 3 through *8* show the results of combining and analyzing data on aquifer saturated thickness and transmissivity, and water-table depth in relation to the potential of various parts of the state for aquaculture development based on their hydrogeology. According to *The Groundwater Atlas of Nebraska* (1998), transmissivity in practical terms "provides a measure of the ability of an aquifer to supply water to wells," and "is dependent on a combination of the [total] saturated thickness and the permeability of the aquifer."

Thus "thick aquifers of highly permeable materials have the highest transmissivity . . . . Where transmissivity values exceed 100,000 gallons per day per foot, high-capacity wells of more than 1,000 gallons per minute can [usually] be developed." Where transmissivity values are between 20,000 and 100,000 gallons per foot per day, wells of intermediate capacity up to about 1,000 gallons per day can potentially be used to develop small to intermediate-size aquaculture operations, depending on actual transmissivity values at any given site and in the surrounding area.

Figure 1

Saturated Thickness of the Principal Groundwater Reservoir

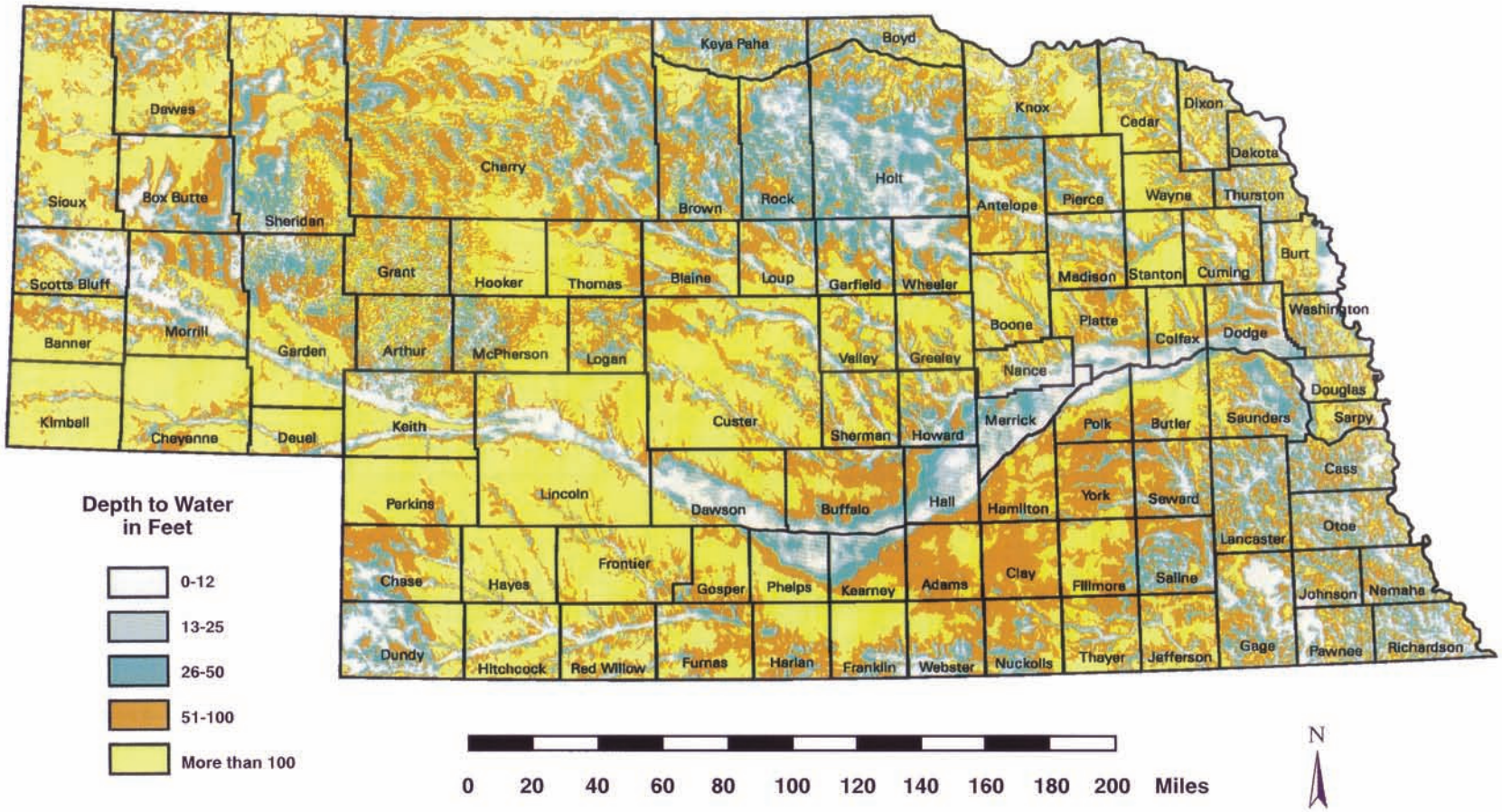


White areas indicate aquifer is very thin or absent.

Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 2

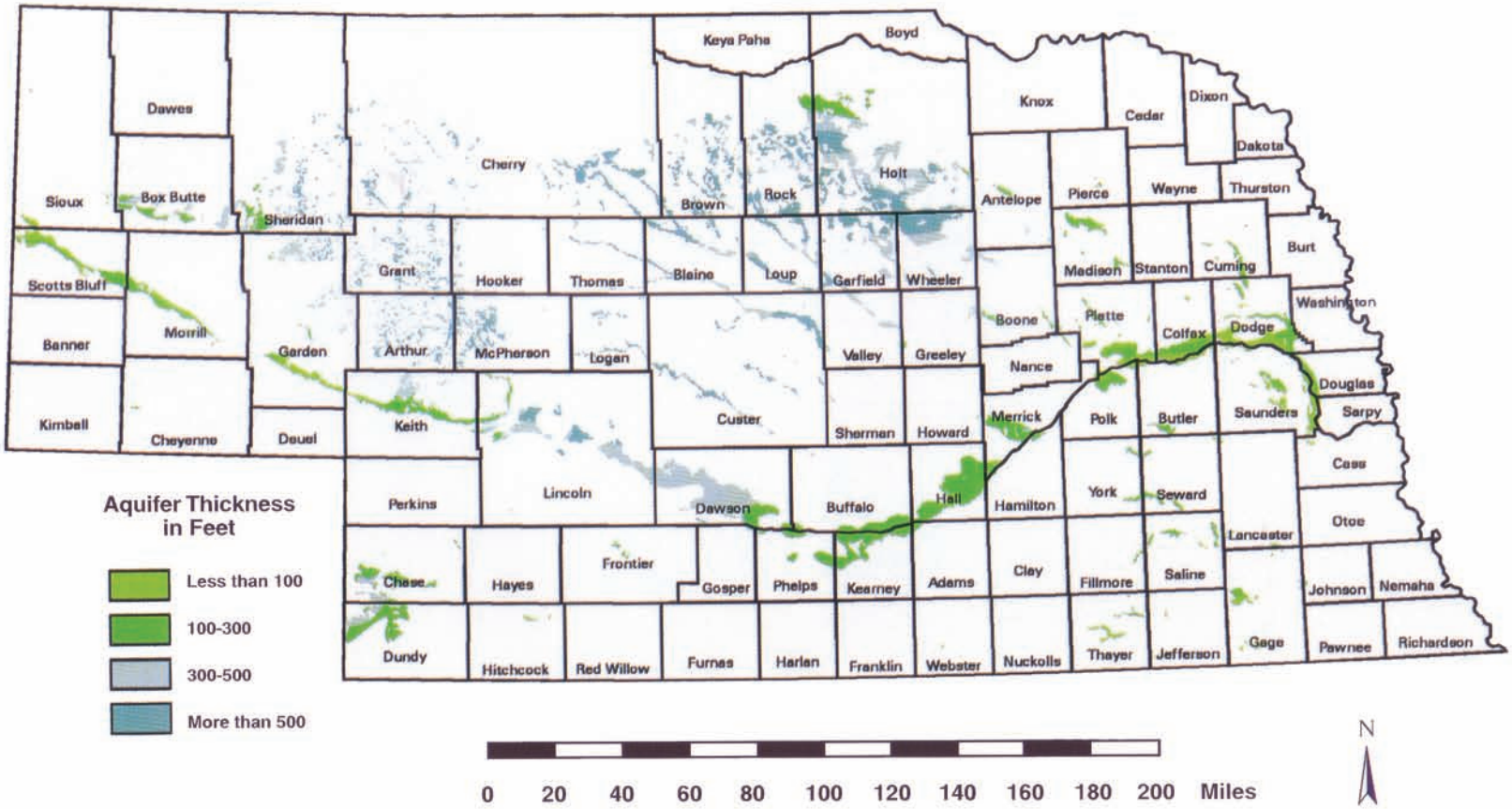
Depth to the Regional Water Table



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 3

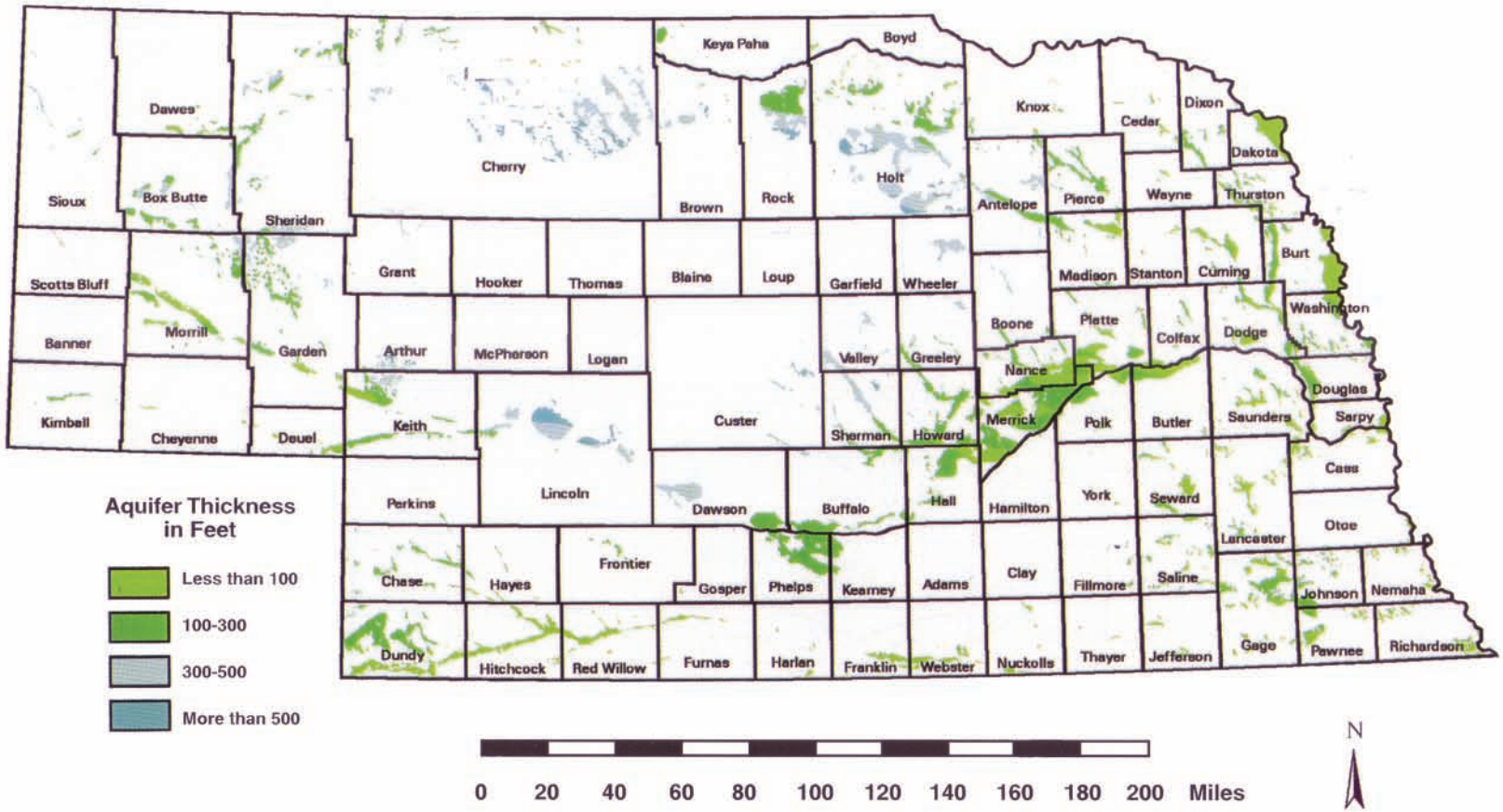
Aquifer Thickness for Areas with a Depth to Water of from 0 to 25 Feet and a Transmissivity Greater than 100,000 Gallons per Day per Foot



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 4

Aquifer Thickness for Areas with a Depth to Water of from 0 to 25 Feet and a Transmissivity between 20,000 and 100,000 Gallons per Day per Foot



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 5

Aquifer Thickness for Areas with a Depth to Water of from 0 to 50 Feet and a Transmissivity Greater than 100,000 Gallons per Day per Foot

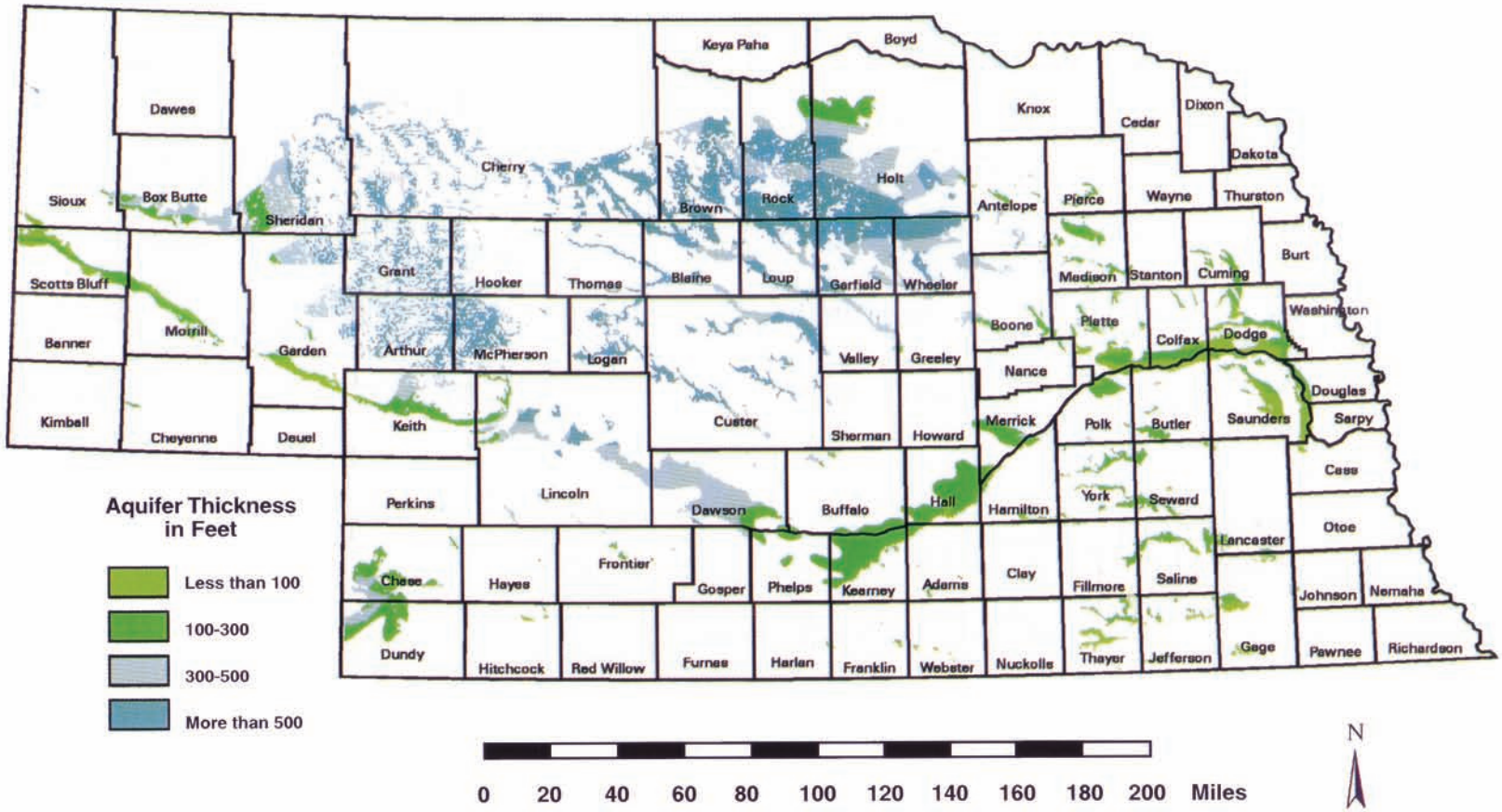


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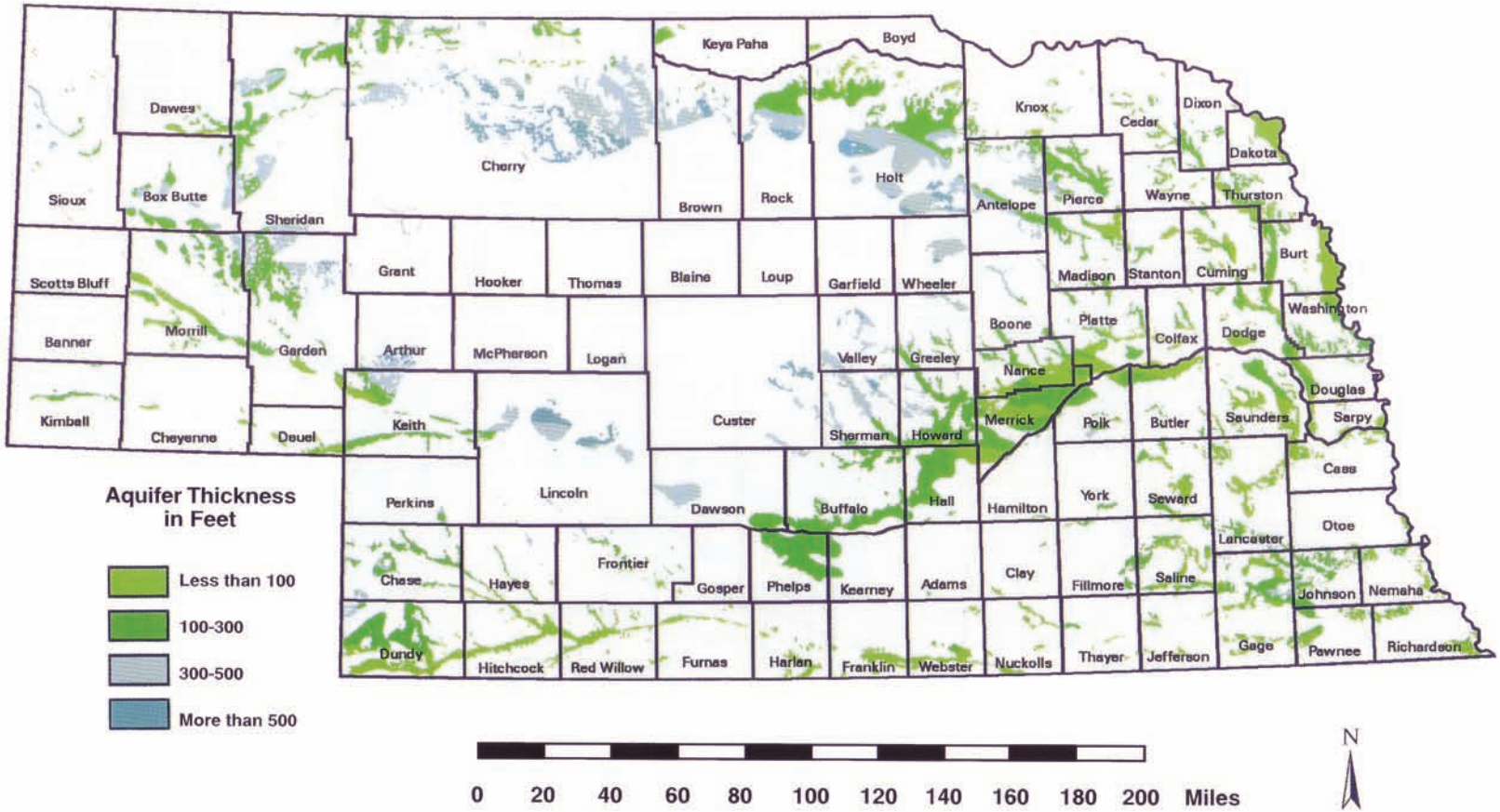
Figure 6

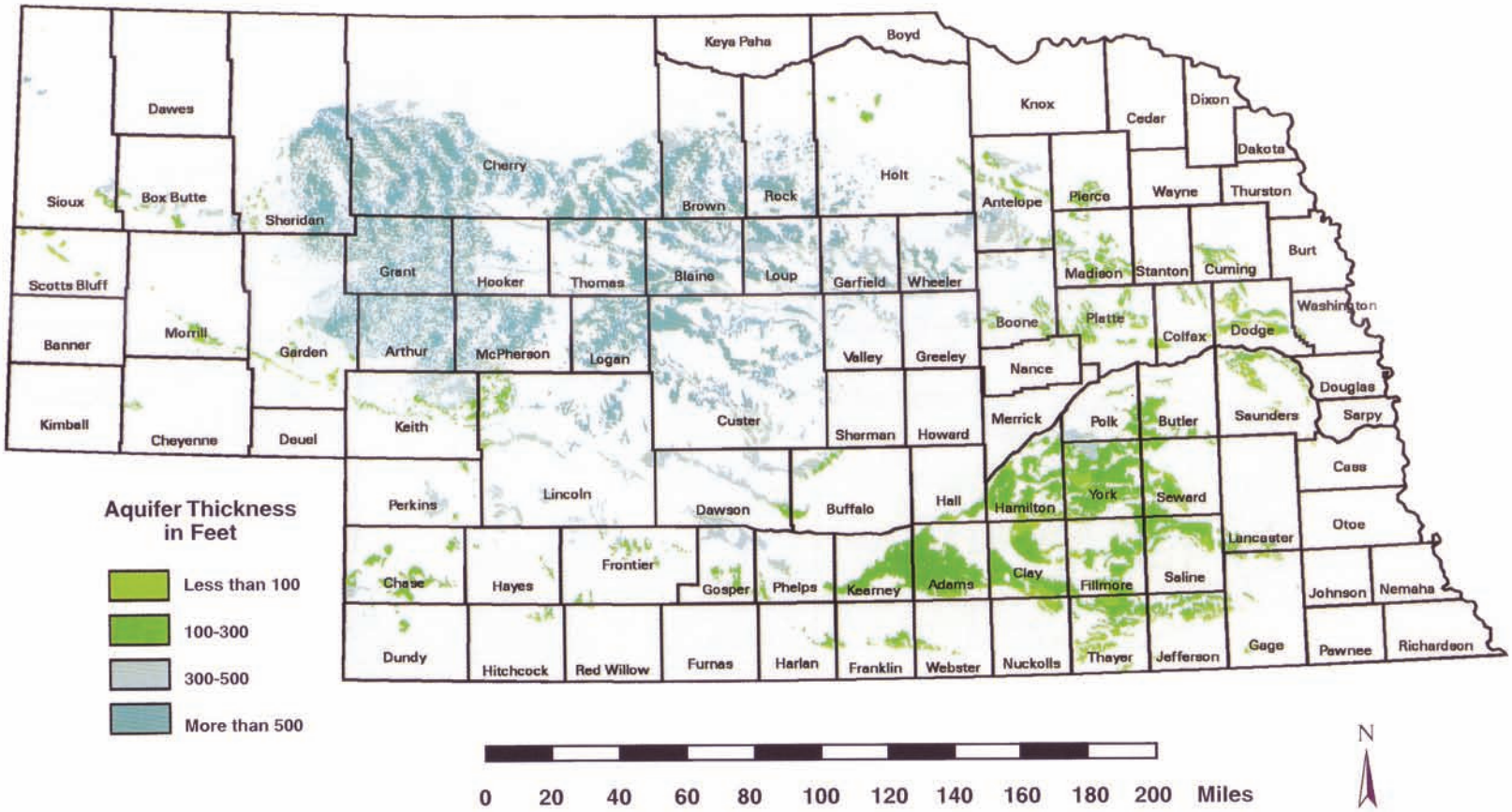
Aquifer Thickness for Areas with a Depth to Water of from 0 to 50 Feet and a Transmissivity between 20,000 and 100,000 Gallons per Day per Foot



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 7

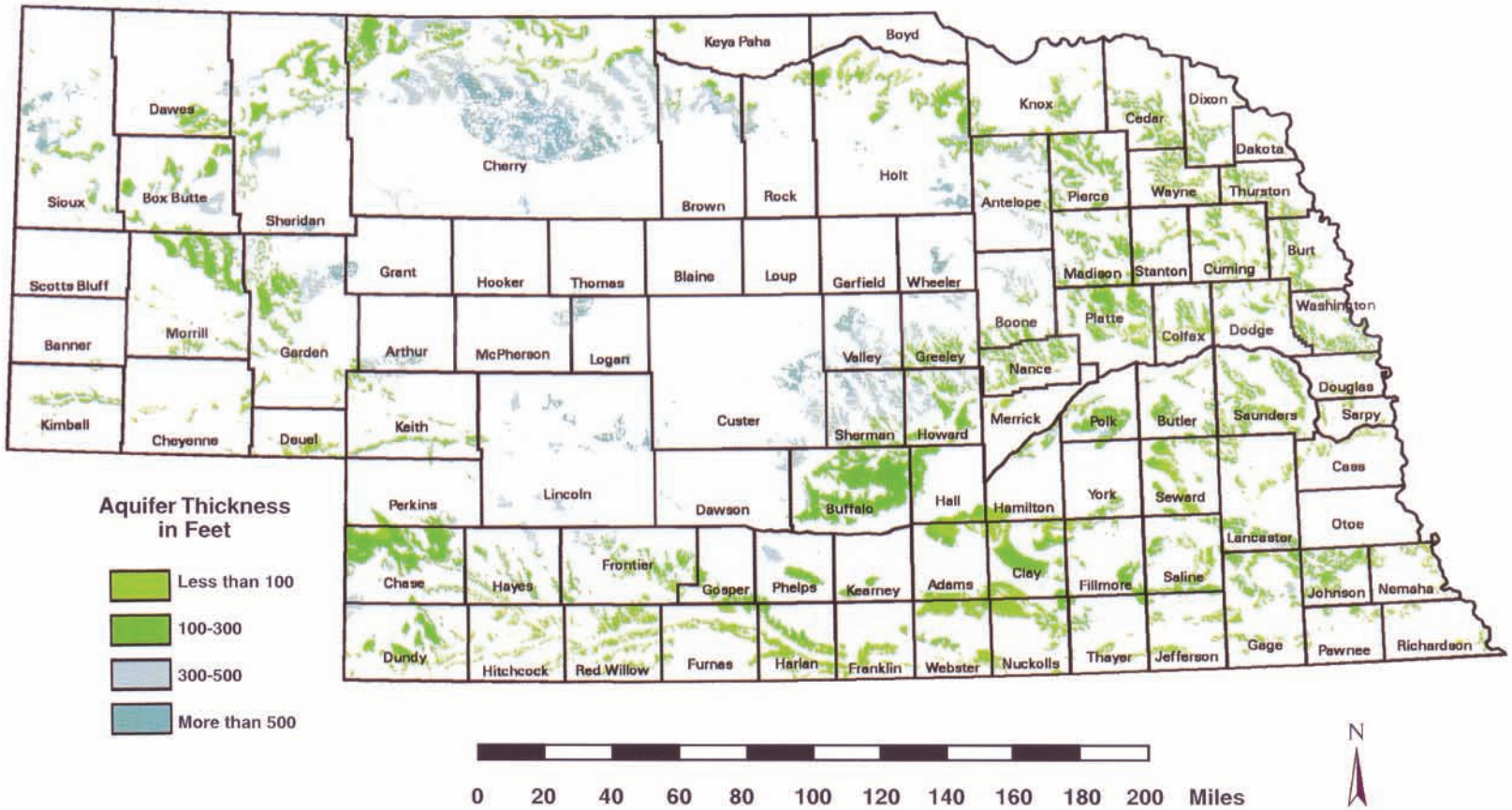
Aquifer Thickness for Areas with a Depth to Water of from 51 to 100 Feet and a Transmissivity Greater than 100,000 Gallons per Day per Foot



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 8

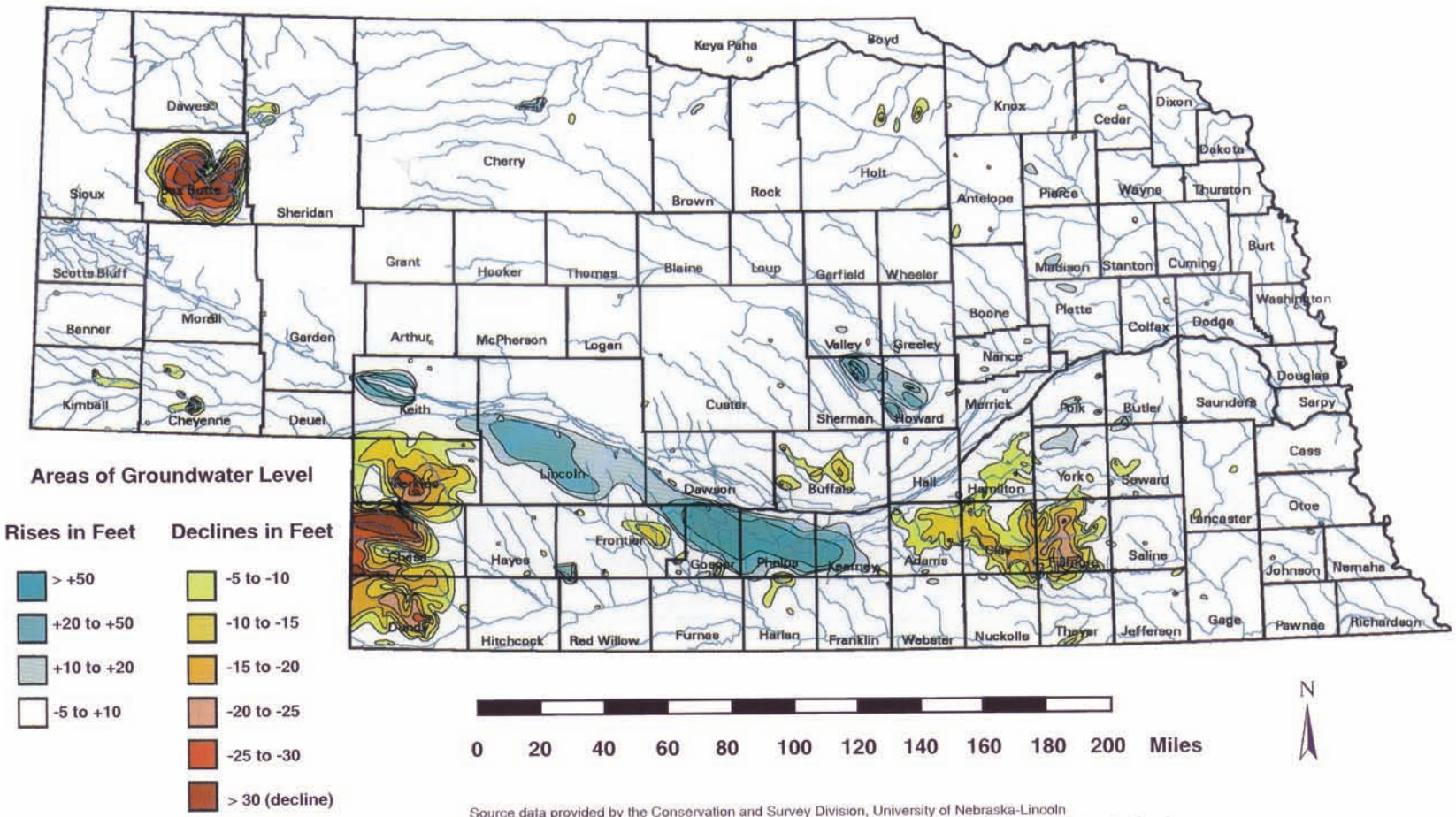
Aquifer Thickness for Areas with a Depth to Water of from 51 to 100 Feet and a Transmissivity between 20,000 and 100,000 Gallons per Day per Foot



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Figure 9

Groundwater Level Changes in Nebraska, Predevelopment to Spring 1994



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

The groundwater level changes shown in *Figure 9* reflect measurable declines in the water table of certain areas in the state caused primarily by heavy irrigation, and rises in the water table of other areas resulting from aquifer recharge due largely to the impoundment, transport and intensive application of surface water for irrigation. Nearly all the latter areas are in the vicinity of reservoirs built over the past several decades, or large canal systems that either connect those reservoirs or distribute water from them to irrigated lands. The highly variable patterns of precipitation that occur in Nebraska, both within and between years, can at any given time affect water tables significantly (e.g., by 2 to 6 feet), especially in heavily irrigated areas.

Over time, two seemingly contradictory factors have contributed to long-term historical water-table rises in those areas where they have occurred: (1) heavy surface-water irrigation, particularly during periods of drought; and (2) the retention and subsequent seepage of water from reservoirs and canals during wet or cold periods (when little or no irrigation is being done). In areas characterized by historical water-table declines, irrigation is based almost entirely on the use of groundwater. These declines in the eastern half of the state have been exacerbated by the fact that large numbers of wells are pumping water from aquifers that in most places are highly porous but have saturated thicknesses of less than 300 feet *(Figure 1)*.

Cautionary Notes on Site Evaluation

Under no circumstances should the Figures or related discussion presented in this publication be used as the sole or final source of hydrogeological or other information in making definitive decisions about site selection or the feasibility of developing an aquaculture operation at any given site. The data used to develop *Figures 1* through *9*, for example, came from drilled test holes and observation wells throughout Nebraska that were, in many instances, miles apart and highly variable in distribution and distances separating them. So the scale of these Figures is large, and their resolution is variable and in many areas quite low.

Consequently, hydrogeological features that are small in size but critical to the evaluation of a particular site may not show in the Figures. The purpose of the Figures is to help identify areas within the state that have (or clearly do not have) potential for aquaculture development and provide a comparison of their potential based on known hydrogeological data. Serious investors in aquaculture who are considering a particular site should evaluate it thoroughly and objectively on its own merits, examining all pertinent resource, regulatory and operational issues.

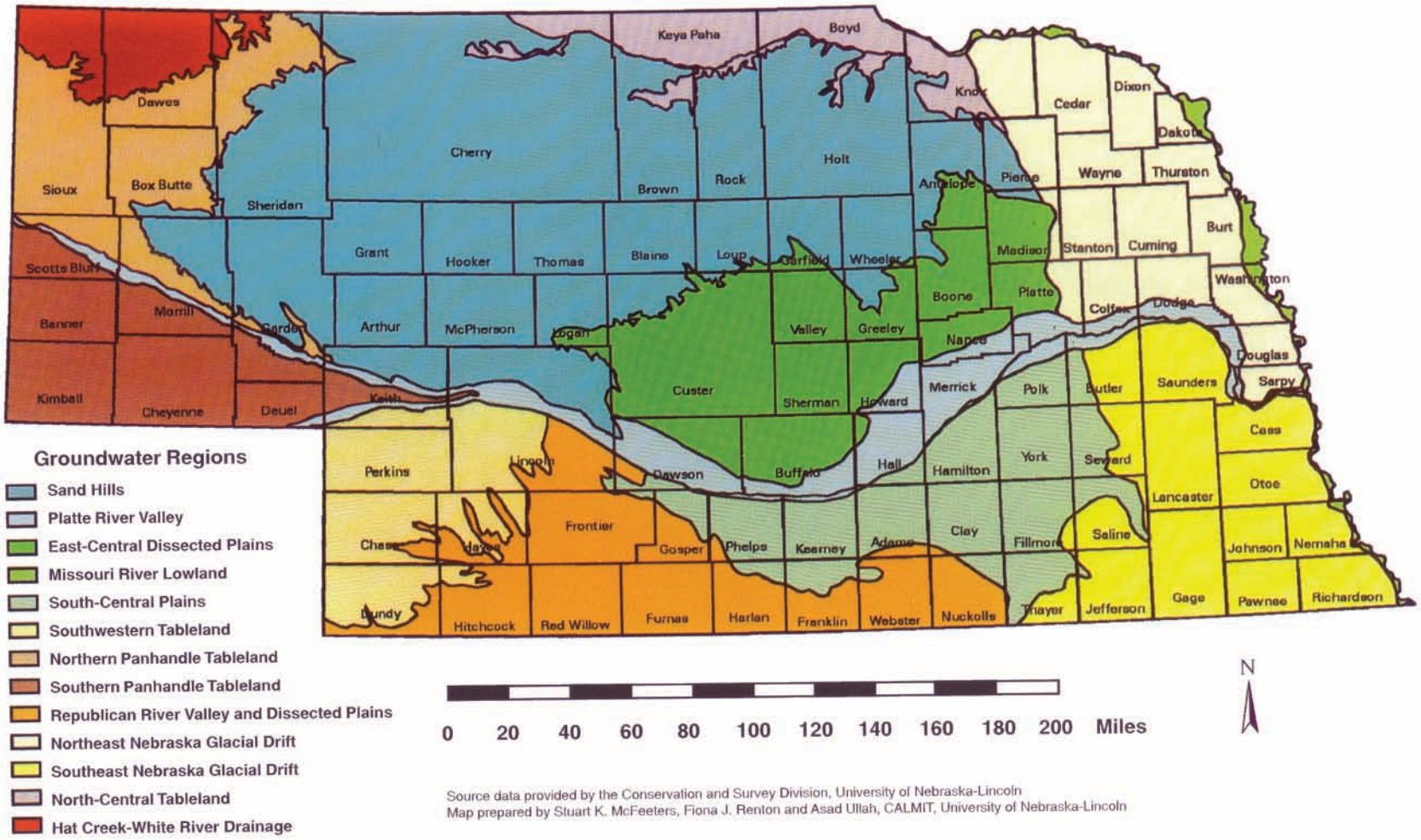
In terms of groundwater and other resources, this evaluation should include (to the extent possible) on-site consultations with appropriate, knowledgeable representatives of the University of Nebraska Conservation and Survey Division, the Natural Resources District in which the site is located, the University's nearest Cooperative Extension Office, the Nebraska Game and Parks Commission, the Nebraska Department of Environmental Quality, the Natural Resources Conservation Service of the U.S. Department of Agriculture, the Geological Survey and the Biological Survey of the U.S. Department of Interior, the local electric power provider, two or more reputable well-drilling contractors familiar with the area, as well as neighboring land and groundwater users.

The last group should be consulted not only in the interest of neighborliness but also to address possible concerns regarding your intentions and their perceived consequences. Aquaculture is not well understood in Nebraska, and such concerns should be candidly and honestly addressed to minimize the possibility of future problems (e.g., complaints or litigation) caused by rumors and misunderstandings. Implementing a "good neighbor policy" right off may also yield valuable insights on otherwise unforeseen local groundwater, electric power outage, well maintenance, local regulatory, property tax, property maintenance, and theft and vandalism problems.

Contact the representative of the Conservation and Survey Division serving the area in which you would like to evaluate a site for aquaculture development for help with the above, particularly in relation to hydrogeological and well-siting questions. Representatives of the Division are based at the University's Regional Research and Extension Centers in or near, Norfolk, North Platte, and Scottsbluff, as well as on the University of Nebraska-Lincoln campus. Conservation and Survey Division or Natural Resources District personnel may be able to help you locate existing wells on (or near) the site, obtain preliminary estimates of pumping depths, and arrange for laboratory analyses of water samples. Ideally, before committing funds to the development of an aquaculture operation, test wells should be installed and run continuously for an extended period to better estimate sustained pumping depth(s).

Figure 10

Nebraska Groundwater Regions



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, Fiona J. Renton and Asad Ullah, CALMIT, University of Nebraska-Lincoln

Major water-table declines in the western half of the state have been exacerbated by the following facts: (1) Normal annual precipitation rates in the west are not sufficient to support the profitable production of many of the crops being raised. (2) To compensate for this, the irrigation wells installed in the irrigable lands of the west, though not so numerous, are typically more heavily used than those in the east. (3) The aquifers in areas of major groundwater depletion are generally quite porous but are highly variable in terms of saturated thickness. The latter in most of these areas is less than 300 feet, though saturated thicknesses of 300 to 500 feet characterize some locales *(Figure 1)*.

A good rule of thumb for aquaculture in the United States is only very large operations can afford to pump water continuously from depths of much greater than 50 feet, regardless of power costs, pumping efficiency, production method(s) or species being cultured. (Some exceptions to this rule will be discussed later in this publication.) In areas of major historical groundwater declines in both the eastern and western halves of Nebraska *(Figure 9)*, the depth to the regional water table *(Figure 2)* is characteristically either more than 50 feet or highly variable. Regardless of the depth to the water table or other factors at any particular site in an area of groundwater decline, no plans to develop an aquaculture operation should be initiated without first consulting the Natural Resources District primarily responsible for the development and enforcement of critical groundwater-use regulations for the area.

Groundwater Regions in Nebraska with Apparent Potential for Aquaculture

Nebraska has been divided by hydrogeologists into 13 groundwater regions *(Figure 10)* each of which is underlain by a series of geological formations comprised of various types of unconsolidated materials (e.g., silts, sands and gravels) and rock. As described in *The Groundwater Atlas of Nebraska* (1998), the age of these layered formations increases with depth, and all but the oldest are largely sedimentary in nature. Each groundwater region is defined primarily on the basis of its hydrogeology and the "principal groundwater reservoir" found under it. In reality, however, each region has numerous aquifers underlying it, of varying sizes and depths, and the "boundaries between regions generally represent zones of gradual change."

Two groundwater regions in Nebraska clearly have potential for large-scale aquaculture development: the Sand Hills and Platte River Valley Regions. The Sand Hills Groundwater Region constitutes most of north-central Nebraska, including all or most of Sheridan, Cherry, Brown, Rock, Holt, Antelope, Garden, Grant, Arthur, Hooker, McPherson, Thomas, Logan, Blaine, Loup, Garfield and Wheeler Counties *(Figure 10)*. Western, southern and eastern boundary areas of the Sand Hills Groundwater Region that may have some potential for aquaculture extend into southern Box Butte County, northern Keith and Lincoln Counties, and Pierce County, respectively. But extensions of the region into Morrill County in the west, and Custer, Valley, Greeley, Boone and Madison Counties in the central and eastern parts of the state appear to have little potential for development *(Figures 3-6)*.

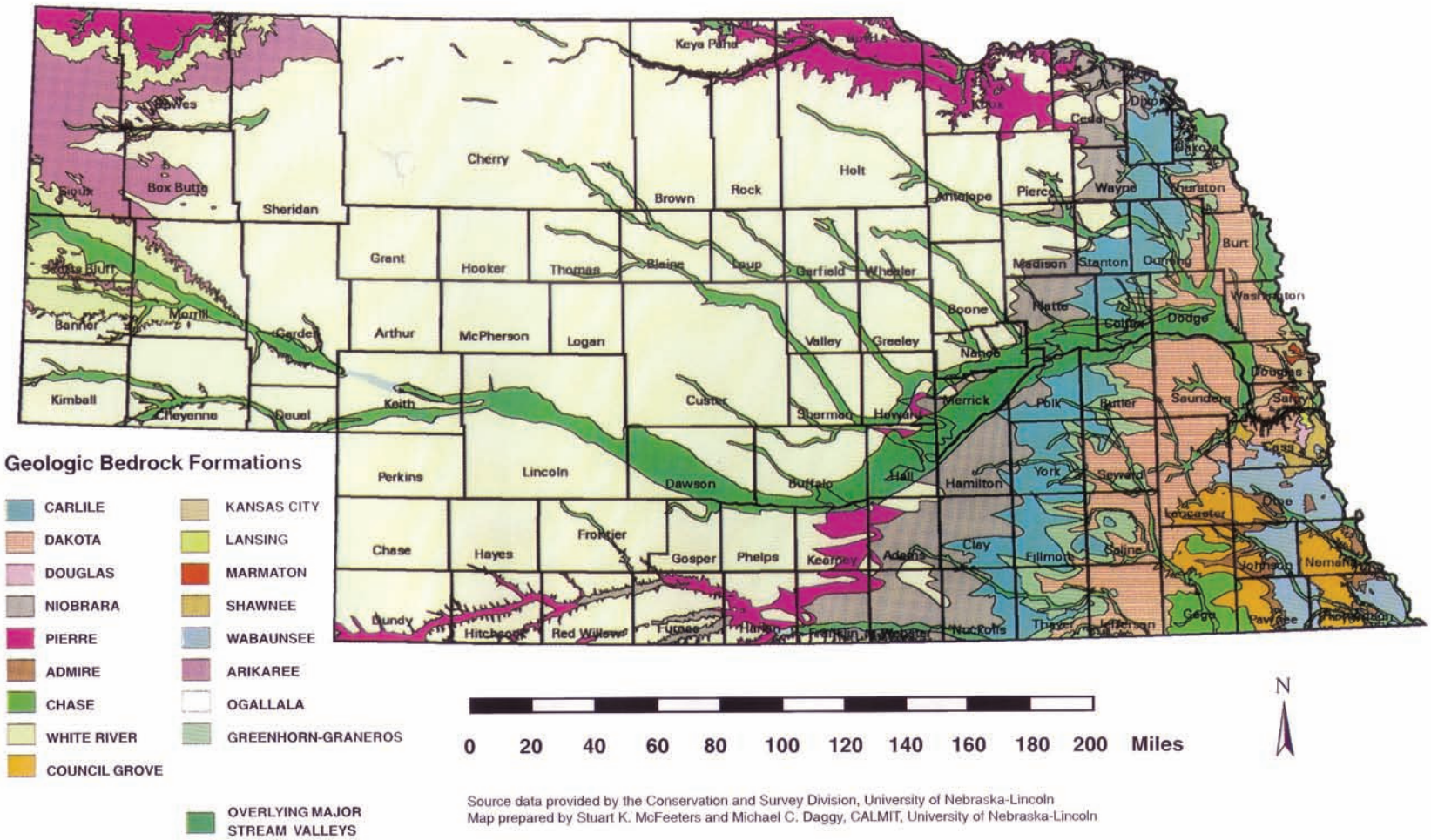
In the Platte River Valley Groundwater Region *(Figure 10)*, the potential for aquaculture development based on hydrogeological considerations appears to be very good to fair in the west, close to the North Platte River in Scotts Bluff, Morrill, Garden and Keith Counties; outstanding to good in several large areas of the Central Platte River Valley, running eastward through Lincoln, Dawson, Phelps, Buffalo, Kearney, Howard, Hall and Merrick Counties; and very good to fair in the east, in certain areas close to the Platte River in Nance, Polk, Platte, Colfax, Butler, Dodge, Saunders, Douglas and Sarpy Counties *(Figures 2-6)*. Based on existing data, the overall potential for aquaculture development in the South Platte River Valley in the west, in Deuel and Keith Counties, appears to be low *(Figures 3-6)*.

Two other groundwater regions in Nebraska may have good potential for aquaculture development in some areas: the Missouri River Lowland Region and the East-Central Dissected Plains Region *(Figure 10)*. The latter region lies between the Sand Hills and Platte River Valley Groundwater Regions in east-central Nebraska, and includes all or most of Custer, Buffalo, Valley, Sherman, Greeley, Howard, Boone, Nance, Madison and Platte Counties. The geology of the East-Central Dissected Plains Region is complex. Like the Sand Hills Groundwater Region, most of the unconsolidated materials comprising the East-Central Dissected Plains Region are underlain by bedrock of the Ogallala Formation *(Figure 11)*, which constitutes the principal groundwater reservoir under nearly all the Sand Hills Region and most of the East-Central Dissected Plains Region *(Figures 1* and *10)*.

With few exceptions, the areas with aquaculture potential in the East-Central Dissected Plains Region are located close to the region's rivers *(Figure 12)*, all of which drain water southeastward from the Sand Hills to the Platte River *(Figures 11,* also *3-6* and *9)*. These areas include stretches along the South Loup River in southern Logan, southwestern Custer and northeastern Buffalo Counties; the Middle Loup River in northeastern Custer, southwestern Valley and central Sherman Counties; the North Loup River in Valley, southwestern Greeley and northern Howard Counties; the confluence of these three rivers in central and southern Howard County; the Cedar River in northeastern Greeley,

Figure 11

Geologic Bedrock and Overlying Major Stream Valleys of Nebraska*

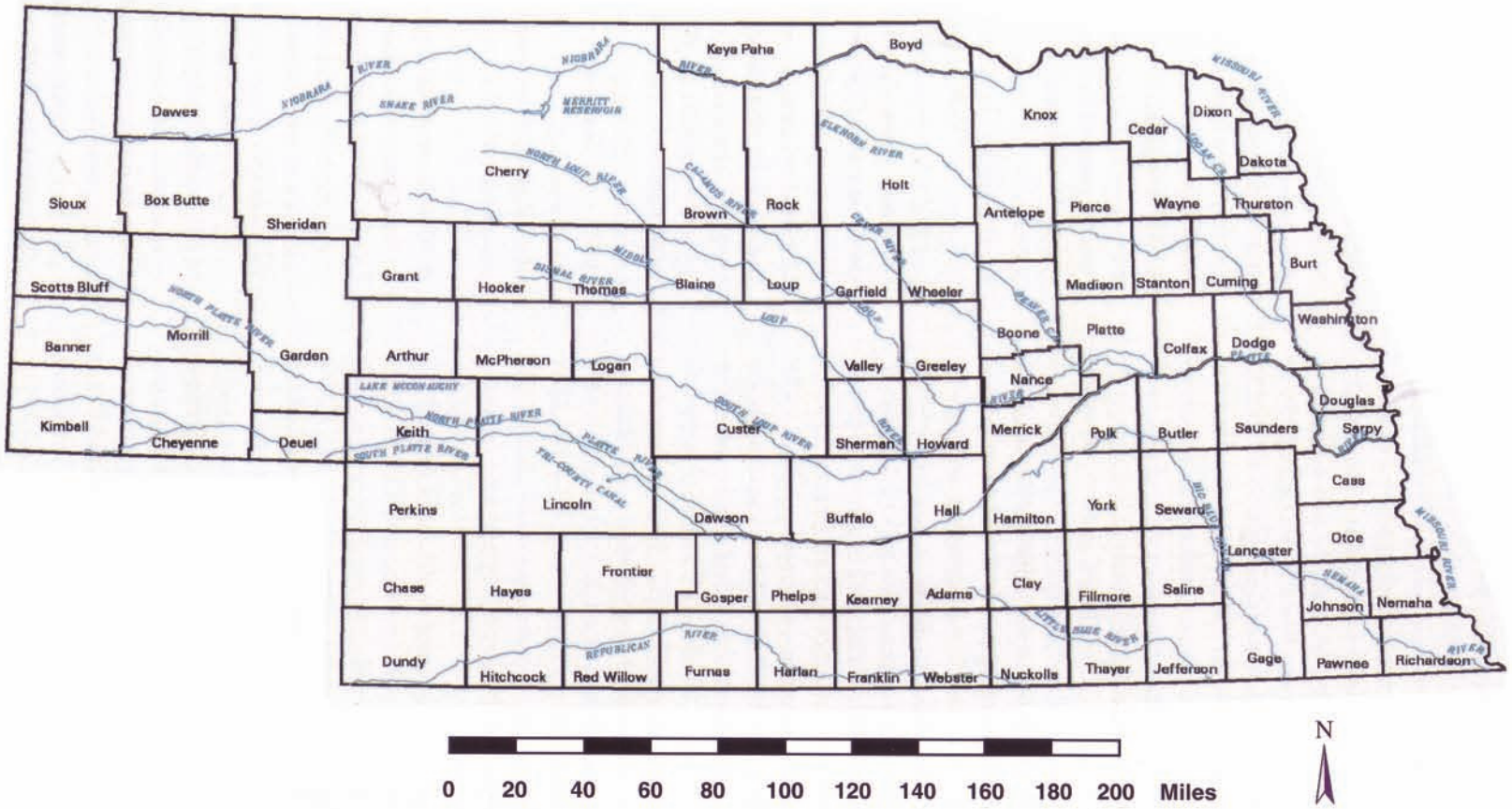


Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters and Michael C. Daggy, CALMIT, University of Nebraska-Lincoln

*The geologic materials comprising the overlying stream valleys consist primarily of unconsolidated aluvial deposits. The names of the streams flowing through these valleys are shown in *Figure 12*.

Figure 12

Major Streams of Nebraska



Source data provided by the Conservation and Survey Division (CSD), University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters, CALMIT, and James W. Weier, CSD, University of Nebraska-Lincoln

southwestern Boone and north-central Nance Counties; the confluence of the Loup and Cedar Rivers in south-central Nance County; (upstream of) the confluence of the Loup and Platte Rivers in Platte County; and the Elkhorn River in southeastern Antelope and northern Madison Counties. The hydrogeology of most of these areas probably limits their potential to intermediate-size or small aquaculture operations.

The Missouri River Lowland Groundwater Region *(Figure 10)* stretches along Nebraska's northeastern and eastern border, close to the Missouri River, from Boyd and Knox Counties in the north to Richardson County in the south. In most areas, this groundwater region is at best only a few miles wide, but the alluvial aquifer underlying it in some locales is close to the surface and capable of supporting wells with pumping capacities sufficient to supply water to small or intermediate-size aquaculture operations. Areas having potential for such development are located in eastern Dakota, Burt and Washington Counties *(Figures 4* and *6)*. Other parts of the region appear to have little potential for aquaculture development. One negative feature of the groundwater in the Missouri River Lowlands is that, depending on location, it is often quite highly mineralized.

The hydrogeology and associated chemistry of water in the aquifers of Nebraska's groundwater regions are complex and often quite variable within each region. For example, most discussions of the Sand Hills Groundwater Region focus primarily on the enormous water-bearing properties of the Ogallala Formation *(Figure 11)*, which is Nebraska's largest principal groundwater reservoir. However, aquifers comprised of highly porous unconsolidated materials of more recent origin overlie the Ogallala Formation in many parts of the Sand Hills. The water in most of these aquifers is probably hydrologically continuous with that in the Ogallala Formation, but some may be separated from the principal groundwater reservoir by layers of impervious materials (e.g., mineralized hardpans, fine silts and clays).

The Ogallala Formation also underlies most of the Platte River Valley Groundwater Region west of central Hall County, and all of the East-Central Dissected Plains Groundwater Region west of western Platte, central Madison, and southeastern Nance and Howard Counties *(Figures 10* and *11)*. However, in the Platte River Valley, many high-capacity wells draw water from saturated alluvial sands and gravels, which depending on location, may or may not be closely connected with the underlying principal groundwater reservoir. Wells in the East-Central Dissected Plains Region draw water primarily from Ogallala Formation deposits, saturated alluvial sands and gravels in existing river valleys, or similar material in buried ancient river valleys. The water from high-capacity wells in the Missouri River Lowland Region comes almost entirely from saturated alluvial deposits of recent geological age.

Overview of Groundwater Quality in Nebraska in Relation to Aquaculture

The chemistry of water drawn from an aquifer can vary considerably, depending on exact location and mineral content of associated geologic materials; well depth, design and maintenance; and depth and rate of sustained pumping. A detailed discussion of the chemistry of well water likely to be suitable for aquaculture in different areas of Nebraska's groundwater regions is beyond the scope of this publication, and given the nature of available data, would probably serve little practical purpose. Some generalizations, however, can be made relevant to aquaculture development in various regions of the state on a broad scale. Collectively, the nature and uncertain relevance of known water-quality data to aquaculture underscore the desirability of testing and evaluating the chemistry of groundwater collected from continually operating wells at or near individual sites being considered for development.

In general, the quality of water from most of the state's aquifers falls within the guidelines considered suitable for freshwater aquaculture. But in reality, the water chemistry requirements of different freshwater species, particularly during their early life-history stages, can vary widely. This fact may be critical to both site and species selection because they are related and should be considered together in planning any aquaculture operation. Based on information derived largely from *The Groundwater Atlas of Nebraska* (1998) and the *Groundwater Quality Atlas of Nebraska* (published by the Conservation and Survey Division in 1978), the following generalizations can be made about the chemistry of the groundwater in Nebraska's four groundwater regions that appear to have significant potential for aquaculture development *(Figure 10)*:

- ***The Sand Hills Region.*** In general, the groundwater underlying this region contains comparatively low concentrations of total dissolved solids (45 to 200 milligrams per liter), though a few central and most regional boundary areas have higher concentrations (201 to 500 milligrams per liter). Total alkalinity and hardness of the region's groundwater range from about 20 to 100 and 6 to 60 milligrams per liter, respectively, which at their lower limits may adversely affect the buffering capacity of water used for aquaculture. In certain areas, concentrations of total dissolved iron, manganese or phosphorus, which by public health standards are considered low, could potentially have adverse effects on some aspects or types of aquaculture. However, based on available information, such effects in most situations are likely to be insignificant or small.

- ***The Platte River Valley Region.*** Shallow wells in this region, especially in the North Platte River and Central Platte River Valleys, can usually provide high volumes of groundwater, but the quality of that water in some areas is a matter of growing concern. The chemistry of the region's groundwater, over time, particularly west of Platte and Polk Counties, has been clearly influenced by both irrigation and fertilizer application practices. High soluble nitrate levels are present in the groundwater at several locales. Concentrations of total dissolved solids in groundwater throughout most of the western two-thirds of the region, west of central Hall County, range from 500 to more than 1,000 milligrams per liter in the near-surface alluvium. Levels of total dissolved solids east of Hall County, in the rest of the region, generally range between 201 and 500 milligrams per liter, though some areas with higher concentrations exist close to the Platte River.

  Total alkalinity and hardness measures of the region's groundwater are variable, ranging from 101 to over 300 and 61 to 360 milligrams per liter, respectively. Total alkalinity throughout most of the region is between 101 and 300 milligrams per liter, which is excellent for most types of freshwater aquaculture. Except for a few areas where total dissolved iron and manganese levels may be higher than desirable, their concentrations both appear to be within acceptable limits (0.0 to 0.3 and 0.0 to 0.05 milligrams per liter, respectively). At present, well over half of the trout and salmon commercially produced in Nebraska are cultured in waters originating from alluvial aquifers in the North Platte River Valley.

- ***The East-Central Dissected Plains Region.*** The chemistry of the groundwater in this region, for the most part, is intermediate between that of the Sand Hills and Platte River Valley Regions. In the identified river valley areas where groundwater is sufficiently abundant and close to the surface to be economically used *(Figures 3-6, 11* and *12)*, the East-Central Dissected Plains Region appears to have some of the best quality groundwater in the state for use in freshwater aquaculture. Measured values for total dissolved solids, total alkalinity, and hardness in most of these areas range from 201 to 500, from 101 to 300, and from 181 to 360 milligrams per liter, respectively. The concentrations of total dissolved iron and manganese in the region generally range from 0.0 to 0.1 and from 0.0 to 0.05 milligrams per liter.

  Notable exceptions to the norm include: (1) The total alkalinity of the groundwater associated with the North Loup River Valley in central Valley, southwestern Greeley and north-central Howard Counties generally exceeds 300 milligrams per liter. (2) The hardness of the groundwater associated with most of the South Loup River and all of the Middle Loup River Valleys in Custer County and extreme west-central Valley County generally ranges between 61 and 180 milligrams per liter. (3) The total dissolved iron content of the groundwater associated with the Elkhorn River Valley in northeastern Madison County generally exceeds 0.3 milligrams per liter. Total alkalinity above 400, hardness below 40 or above 400, or total dissolved iron levels over 0.15 milligrams per liter in water can have adverse effects in aquaculture, depending on a variety of factors.

  Also in the East-Central Dissected Plains Region, the total dissolved manganese concentration in the groundwater to the west of the North Loup River Valley in central and eastern Valley County, and associated with stretches of the Loup and North Loup Rivers in Howard County and the Loup and Cedar Rivers in Nance County, ranges from 0.051 to 0.4 milligrams per liter. Dissolved manganese levels in excess of 0.01 milligrams per liter can potentially have adverse effects on some aspects or types of aquaculture, again depending on a variety of factors – including species, life-history stage, culture system, and chemical interactions in the environment.

  Total dissolved phosphorus levels in the region's groundwater are quite variable, with recorded values ranging from 0.00 to 0.016 milligrams per liter in parts of Valley, Sherman, Greeley and Howard Counties, to measurements over 0.016 milligrams per liter throughout most of the remainder of the region. The latter higher values are similar to those seen in most parts of the Sand Hills Groundwater Region, and can potentially cause problems with excessive algae growth in ponds and other types of aquaculture production systems.

- ***The Missouri River Lowland Region.*** As noted previously, the groundwater resources in certain areas of this region *(Figure 10)* – specifically eastern Dakota, Burt and Washington Counties – appear to have significant potential for aquaculture development, based on water-table depth and aquifer thickness and permeability. But the chemistry of the groundwater in these areas, depending on exact location, may not be well suited for aquaculture. Concentrations of total dissolved solids in the groundwater of most of the areas identified by their hydrogeology as having potential for aquaculture, range between 201 and 500 milligrams per liter, which is within acceptable limits. But measures of total dissolved solids in northeastern Dakota County range from about 500 to over 1,000 milligrams per liter, and in extreme southeastern Washington County exceed 1,000 milligrams per liter.

Following this pattern, other key groundwater chemistry values for the Missouri River Lowland Region tend to be high, and often appear to vary significantly over short distances. Total alkalinity of the groundwater in eastern Dakota County ranges between 101 and 300 milligrams per liter, but in both Burt and Washington Counties generally exceeds 300 milligrams per liter. Total hardness of the groundwater in the eastern parts of all three counties generally ranges between 181 and 360 milligrams per liter, but exceeds 360 milligrams per liter in northeastern Dakota County. Total dissolved iron levels in the groundwater of eastern Burt and Washington Counties range between 0.1 and 0.3 milligrams per liter, but exceed 0.3 milligrams per liter in Dakota County. Sulfate concentrations follow a similar pattern.

Manganese concentrations in the groundwater of eastern Burt and Washington Counties are between 0.051 and 0.4 milligrams per liter. Manganese levels in the groundwater of most parts of Dakota County probably exceed 0.4 milligrams per liter. While not necessarily toxic, these latter values are well beyond the manganese concentrations normally recommended for most types of freshwater finfish aquaculture (i.e., 0.0 to 0.01 milligrams per liter). An important factor complicating the interpretation of information on manganese levels in Nebraska groundwater is the apparent lack of a single unified database that provides measures of this element in well water at close intervals across the state (and particularly in the Missouri River Lowland Region). So, the resolution of verified groundwater manganese-level mappings are "rough."

Another complication is the high probability (though not well documented) that the manganese tolerance limits of different fishes and other aquatic organisms varies significantly with species and life-history stage under different water chemistry conditions. The same is true with other chemical elements and compounds. Such factors underscore the importance of a case-by-case approach to site evaluation for aquaculture development. So, while present indications regarding the groundwater chemistry of Dakota County, as a whole, suggest that it is not a good place to invest in aquaculture, certain sites in the county may be quite suitable for development, depending on goals, species type, production methods and other considerations.

In addition to natural variations in groundwater chemistry, Nebraska, like most states, has areas where groundwater contamination with synthetic chemicals is a problem. The most frequently identified groundwater contaminants in Nebraska are pesticides, especially herbicides, and other agricultural chemicals. A detailed discussion of this topic and its potential ramifications for aquaculture development is beyond the scope of this publication. Fortunately, most truly serious groundwater contamination problems that occur in Nebraska are fairly localized; and so far the more common contaminating agents are not generally present at high enough levels to constitute a deterrent to intensive aquaculture development. To be a problem for aquaculture, most herbicides, such as atrazine, would have to be present at far higher concentrations than are currently being detected in Nebraska's groundwater.

As previously indicated, elevated nitrate levels in groundwater (often associated with fertilizer addition to and leaching from Nebraska croplands) likewise should not constitute a major problem for aquaculture development, even when present at concentrations that pose a potential threat to human health. For more information on groundwater contamination problems in the state, see the University of Nebraska-Lincoln Water Center 1990 publication *Occurrence of Pesticides and Nitrate in Nebraska's Ground Water*, or contact your nearest Cooperative Extension Office for assistance. For specific information on the possibility, nature or degree of groundwater contamination at a site being considered for aquaculture development, contact the Natural Resources District having jurisdiction for the area, or the Nebraska Department of Environmental Quality.

Nebraska Aquaculture Potential by County

Though hydrogeologists have divided Nebraska into 13 groundwater regions, most decisions in the state regarding economic development, water, and natural resources policy are made on the basis of geopolitical boundaries, especially those defining the counties and Natural Resources Districts. To aid in future decision-making with respect to aquaculture development, the information presented graphically by GIS technology in *Figures 3* through *6* was evaluated using an empirical scoring procedure that resulted in assigning each of the state's 93 counties to one of the "aquaculture potential" categories shown in *Table 1*. Initial assignments to the listed categories were based on a county-by-county evaluation and comparison of depths to water tables, and saturated thicknesses and transmissivities of the aquifers underlying each county.

Then, the initial category assignment of each county was examined and, if appropriate, adjusted (downward) based on selected groundwater quality criteria (primarily high total alkalinity and total dissolved iron and manganese measurements) or evidence *(Figure 9)* of major historical declines in groundwater level. The resulting final categorizations outlined in *Table 1* provide a conservative evaluation of the

potential of every Nebraska county for aquaculture development. On balance, the categorization system used emphasizes identifying and separating those counties that definitely have significant potential for aquaculture development from those that have comparatively little. So, for example, the information examined clearly indicates that Holt, Brown and Dawson Counties have extremely good potential for aquaculture development, while Adams, Furnas and Nuckolls Counties do not.

In contrast, fewer definite conclusions can be drawn about the differences between counties listed as having intermediate potential for aquaculture development. For example, Dawes, Frontier and Red Willow Counties clearly have poorer potential for development, based on groundwater availability, than do Gage and Howard Counties *(Figures 3-6)*, which were initially assigned "moderately good" scores in that regard. The latter two counties were categorized in *Table 1* as having "moderately poor" potential because of concerns about groundwater quality (e.g., high total dissolved iron and manganese levels). Similarly, Dodge, Merrick, Morrill and Scotts Bluff Counties were ultimately categorized as having "moderately good to fair," rather than "very good" or "good" potentials for development because of uncertainties regarding groundwater quality.

The hydrogeology and groundwater chemistry of Nebraska are complex and tend to be variable, both between and within counties. The only place in the state where this rule *may* not apply is in certain areas of the Sand Hills Groundwater Region *(Figure 10)*—for example, in Arthur, Grant and western McPherson Counties *(Figures 1-6)*. In contrast, in the eastern third of the state, groundwater chemistry exhibits increasing complexity and variability the further east one goes, due to the greater variability in mineral content of the geologic bedrock *(Figure 11)* and more recent geologic materials. Because of this, any attempt to categorize the chemistry of groundwater in the state's eastern counties, relative to aquaculture development, is inherently more difficult than doing so for most of the western counties.

In developing *Table 1*, the category assignments of many eastern counties, and several western counties (i.e., Dawson, Deuel, Hall, Howard, Kearney, Keith, Morrill and Scotts Bluff Counties), were adjusted downward because of concerns about groundwater chemistry. These concerns, depending on the county and individual circumstances, may or may not be real in terms of their actual importance to aquaculture development. This uncertainty needs to be kept in mind when making decisions about promoting aquaculture development, as well as siting operations; and again underscores the importance of evaluating individual sites on their own merits.

Table 1. Estimated Potential of Nebraska Counties for Aquaculture Development Based on Depth to Water Table, Aquifer Thickness and Transmissivity, and Groundwater Chemistry

Outstanding	Excellent	Very Good
Holt	Brown	Dawson
Rock	Cherry	Loup
Wheeler	Garfield	McPherson
	Lincoln	Sheridan
Good		
Arthur	Custer	Hall
Blaine	Garden	Kearney
Colfax	Grant	Keith
Moderately Good to Fair		
Antelope	Logan	Phelps
Buffalo	Madison	Platte
Butler	Merrick	Polk
Dodge	Morrill	Saunders
Dundy	Nance	Scotts Bluff
		Sherman
Moderately Poor		
Boone	Franklin	Pierce
Box Butte	Frontier	Red Willow
Burt	Gage	Saline
Chase	Greeley	Sarpy
Dakota	Hitchcock	Thomas
Dawes	Hooker	Valley
Douglas	Howard	Webster
	Kimball	York
Very Poor		
Adams	Furnas	Nuckolls
Banner	Gosper	Otoe
Boyd	Hamilton	Pawnee
Cass	Harlan	Perkins
Cedar	Hayes	Richardson
Cheyenne	Jefferson	Seward
Clay	Johnson	Sioux
Cuming	Keya Paha	Stanton
Deuel	Knox	Thayer
Dixon	Lancaster	Thurston
Fillmore	Nemaha	Wayne
		Washington

Geographic Areas with Aquaculture Potential

The information presented in *Figures 1* through *9* and *Table 1* suggests that there are five geographic areas in Nebraska that have significant potential for aquaculture development based on their groundwater resources (see *Figure 13).* The counties comprising these areas, a brief description of them, and their probable (or possible) strengths and drawbacks with respect to aquaculture development are as follows:

- ***Northeast-Central Area of the Sand Hills Region.*** This area includes almost all of the southwestern half of Holt County west of the Elkhorn River, most of the southern two-thirds of Brown and Rock Counties, the southeastern corner of Cherry County, and large parts of the northern thirds of Blaine, Loup, Garfield and Wheeler Counties. The area comprises about half of the headwaters regions of both the Elkhorn River and the Loup River system *(Figures 11* and *12).* The area's main attributes are its high groundwater quality and volume, typically shallow groundwater depths, high aquifer transmissivities, and relatively low land and electric power costs. These assets combined suggest that this area has the potential for developing a major aquaculture industry, once the appropriate species and production technologies are identified.

  Potential drawbacks of the area are its relative remoteness, limited transportation infrastructure, an uncertain relationship between the availability of three-phase electric power and the groundwater resources needed for aquaculture, high-permeability soils that limit commercial-scale production largely to the use of intensive culture technologies, and the risk of groundwater contamination because of this soil permeability. Also, because of the high water tables, wetlands are common to the area. Depending on how various wetland regulations are interpreted and enforced, wetlands can either be an asset or constraint to aquaculture development. Regardless, wetlands regulations must be considered when evaluating a site for aquaculture, as they will almost certainly affect both construction and water-use practices.

- ***West-Central Area of the Sand Hills Region.*** This area includes the southwest corner of Cherry County, the southeastern half of Sheridan County, a narrow extension across southern Box Butte County, parts of northern and eastern Garden County, most of Grant and Arthur Counties, parts of north-central Keith County, the western margin of Hooker County, and the west-central third of McPherson County. This area is comprised largely of both low and high relief sand dunes that have been stabilized by grassland vegetation. The principal groundwater reservoir underlying the area is thick, particularly under Grant, Hooker, Arthur and McPherson Counties (where in some spots the saturated thickness exceeds 1,000 feet), but in most locales has little or no unconsolidated coarse fraction (i.e., gravels).

  Interspersed among the dunes of this area are numerous meadows, where the water table is often quite close to the surface. Numerous ponds and small lakes, the surfaces of which are essentially continuous with the surrounding water table, are present in certain meadowlands and valleys. The area's main attributes and drawbacks are similar to those of the Northeast-Central Area of the Sand Hills Region, though some distinct differences exist (primarily in degree): The West-Central Area of the Sand Hills Region is one of the most sparsely populated rural areas in the central United States. Access by road to many potentially excellent sites for aquaculture development, particularly in the winter, may be even more limited than in the Northeast-Central Area of the Sand Hills Region. The same may be said with respect to the availability of three-phase electric power.

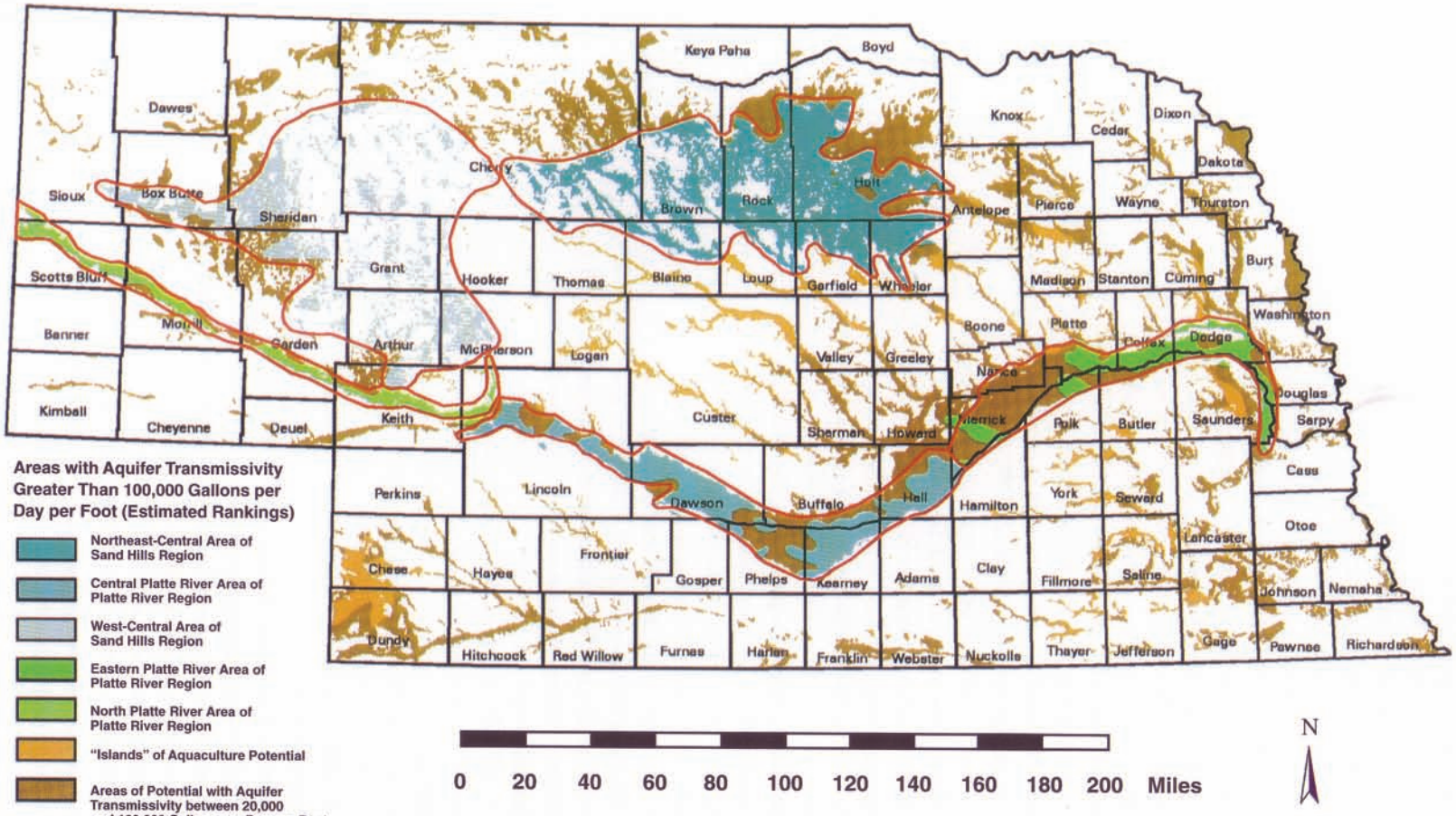
- ***North Platte River Area of the Platte River Region.*** This area is defined primarily by the alluvial aquifer underlying the North Platte River Valley in Scotts Bluff, Morrill, Garden and Keith Counties and western Lincoln County *(Figures 11* and *12).* The area's principal attributes are a good transportation infrastructure, ready access to low-cost three-phase electric power, and a near-surface aquifer with abundant, generally good-quality groundwater that is hydrologically connected to the North Platte River. Though the area's soils are typically highly permeable, some locales appear to have soils with sufficient clay or mineral content to allow for the construction of conventional aquaculture production ponds that can be drained.

  Potential drawbacks of the area include high groundwater total alkalinity levels in some locales, moderately high (though variable) groundwater iron concentrations in most locales, a moderately high risk of groundwater contamination by insecticides and nematocides used to treat certain crops (e.g., potatoes, sugar beets) produced in the area, and (often perceived) competition for groundwater by irrigators and other users. Given the recharge rate of the area's groundwater and the fact that most forms of intensive aquaculture are in fact low-consumptive users of water, the latter drawback is more of a political and educational problem than a real one.

- ***Central Platte River Area of the Platte River Region.*** This area is defined primarily by the alluvial aquifer underlying the Platte River Valley in Lincoln, Dawson, Phelps,

Figure 13

Geographic Areas in Nebraska with Aquaculture Potential with a Depth to Groundwater from 0 to 50 Feet



Source data provided by the Conservation and Survey Division, University of Nebraska-Lincoln
Map prepared by Stuart K. McFeeters and Michael C. Daggy, CALMIT, University of Nebraska-Lincoln

Buffalo, Kearney, Hall and Adams Counties *(Figures 11-13)*. The area's principal attributes and drawbacks are similar in nature to those of the North Platte River Area of the Platte River Region, with the following exceptions: The groundwater resources of the Central Platte River Area underlie far more acres, generally have a greater saturated thickness, and typically lie at a shallower depth – all factors suggesting that this area has the potential for development of a major aquaculture industry.

Also, the Central Platte River Area has superior transportation assets (i.e., Interstate 80, federal and state highways, county highways and secondary roads, main railroad lines, and regional airports), plus three-phase power that is available almost everywhere. With the possible exception of parts of Dawson, Phelps, Buffalo and Hall Counties, overly high groundwater alkalinity levels do not appear to be a problem; nor are high groundwater iron levels – except possibly in parts of Phelps and Kearney Counties. Because of differences in principal crops produced and especially related types of pesticides applied, the risk of groundwater contamination by insecticides or nematocides appears to be lower in the Central Platte River Area than the North Platte River Area.

- ***Eastern Platte River Valley Area of the Platte River Region.*** This area is defined primarily by the alluvial aquifer underlying the Platte River Valley in nearly all of Merrick County, the southern margin and southeastern corner of Nance County, the southern quarter to one-third of Platte, Colfax and Dodge Counties; the northern margins of Polk and Butler Counties; the extreme northern and eastern margins of Saunders County; and the extreme eastern margins of Douglas and Sarpy Counties *(Figures 11-13)*. The greatest potential for aquaculture development for this area, based on groundwater resources, appears to lie (in order of estimated potential) in Colfax, Merrick, Platte and Dodge Counties. The groundwater chemistry of eastern Nebraska, as previously indicated, is complex and variable in nature, both between and within counties.

In terms of aquifer thickness, transmissivity, and depth to water, the area's groundwater resources resemble those of the North Platte River Area more than any other, while its transportation and electric power assets appear to more closely resemble the Central Platte River Area. One unique feature of the Eastern Platte River Area is that most of it is mantled with soil types having sufficient clay content to construct conventional aquaculture production ponds that are drainable. In large part because of these soils, the risk of groundwater contamination in the Eastern Platte River Area appears to be significantly lower than in the other four geographic areas discussed.

Another notable attribute of the Eastern Platte River Valley Area, particularly for small aquaculture operations, is its close proximity to the state's largest markets.

All five of these geographic areas with significant aquaculture potential have noteworthy advantages and disadvantages. For example, the Northeast-Central Area of the Sand Hills Region clearly appears to have the state's most abundant and readily available supply of groundwater *(Figures 2, 3* and *5)* that seems highly suitable for aquaculture development. Likewise, the West-Central Area of the Sand Hills Region has an enormous volume of groundwater in storage, though on analysis, it does not appear to be quite so uniformly available in terms of depth to water. However, the groundwater in both these areas tends to be soft and relatively low in minerals (though there are some locales where quite the reverse is true).

Water that is *too* soft and devoid of minerals can present problems in some forms of aquaculture, just as water that is too hard and mineral laden can. In overview, presently available information suggests that too soft a water is not such a widespread problem in the Sand Hills that it should adversely affect the overall potential of either of the two Sand Hills areas for aquaculture development. However, due caution in this regard is warranted in evaluating the groundwater chemistry of individual sites, particularly in relation to the water chemistry requirements (or tolerance limits) of the species being considered for culture. Such caution should be used in evaluating any site.

Compared to the Sand Hills areas, the three areas identified as having significant potential for aquaculture development in the Platte River Valley Region appear to have better infrastructure assets to support such development, though the groundwater resources of these three areas are not so prodigious. In practical terms, however, the groundwater resources of these areas, especially the Central Platte River Area, are more than sufficient to support major aquaculture development. Two complicating factors in the Platte River Valley Region are (1) the possibility that in some locales the available groundwater may contain minerals or contaminants that could adversely affect certain types of aquaculture production, and (2) an adversarial political environment between competing users of groundwater.

Assuming overall "good" levels of water quality, one reasonable ranking of the potential for aquaculture development of the five identified areas, taking all known factors into consideration, is as follows *(Figure 13)*:

1. Northeast-Central Area of the Sand Hills Region

2. Central Platte River Area of the Platte River Region

3. **West-Central Area of the Sand Hills Region**

4. **Eastern Platte River Valley of the Platte River Region**

5. **North Platte River Valley of the Platte River Region**

Throughout Nebraska, there are also many small "islands" of potential – e.g., in Logan, Custer, Valley, Boone, Madison and Gage Counties *(Figures 13* and *3-6)*. The validity of this "islands" concept is borne out by the fact that several successful small aquaculture operations are located in counties listed in *Table 1* as having "very poor" potential (e.g., Adams, Red Willow and Wayne Counties). Ironically, there is remarkably little correlation between where aquaculture operations now exist in Nebraska and where hydrogeological factors indicate there is significant potential for development. As previously noted, "well over half of the trout and salmon commercially produced in Nebraska are cultured in waters originating from alluvial aquifers in the North Platte River Valley." Historically, Scotts Bluff County has had the highest number of operational fish farms in the state.

Wetland and Other Considerations

A complication built into most forms of land-based aquaculture (in contrast to aquaculture done in estuaries or marine settings) is that the economic desirability of siting operations in areas having minimum depths to groundwater, to minimize pumping costs, often comes into conflict with regulations designed to protect wetlands. Such conflicts can often be avoided by (1) a thorough understanding of the applicable regulations, and how and why their interpretation by regulators may vary in different regions and areas; and (2) very careful site selection and planning with respect to facility design and operation. Depending on how one approaches the latter, locating an aquaculture operation close to a wetland can be construed as either a positive benefit or a liability.

Wetlands are common to all five areas in Nebraska that have been identified as having significant potential for aquaculture development. The presence of these wetlands should be viewed as a very positive asset to aquaculture development in the state. This is true because wetlands are a major source of groundwater recharge, a fact that should be given careful thought when considering what to do with aquaculture effluents. With appropriate engineering and nutrient management to ensure good water quality, aquaculture effluents could be recharged to regional aquifers by creating wetlands, thereby implementing a cycle of economic benefit and natural resources sustainability.

Wetlands regulations, as they typically apply to aquaculture, are normally overseen by the U.S. Army Corps of Engineers, with input and assistance from other local, state and federal agencies. In Nebraska, these include the Natural Resources Districts, the Nebraska Game and Parks Commission, the Nebraska Departments of Environmental Quality and Water Resources, the Geological Survey and the Fish and Wildlife Service of the U.S. Department of the Interior, and the Natural Resources Conservation Service of the U.S. Department of Agriculture. When considering a site for aquaculture development, the U.S. Army Corps of Engineers, and other appropriate agencies should be consulted before finalizing plans or investing significant financial resources.

Excessive groundwater pumping can have a major effect on wetland water tables. Pumping water continuously from wells produces an area of water-table drawdown (cone of depression), the depth of which is inversely related to the transmissivity of the groundwater reservoir being pumped. Thus, pumping water from an aquifer with a low transmissivity (e.g., 20,000 gallons per day per foot) will produce a wider and deeper cone of depression than pumping from an aquifer with a high transmissivity (e.g., 100,000 gallons per day per foot) *(Figures 3-8)*. This fact needs to be kept in mind when estimating pumping costs, and evaluating the environmental impact of siting an aquaculture operation in or near a wetlands area.

Earlier, a rule of thumb for aquaculture siting in the United States was mentioned: that, "only very large operations can afford to pump water continuously from depths of much greater than 50 feet, regardless of power costs, pumping efficiency, production method(s), or species being cultured." All such rules of thumb should be viewed with caution. But as a starting point, the "50-feet rule" was used as a guide in generating the GIS analyses shown in *Figures 3* through *8*. The operating assumption made in conducting these analyses was that the types of aquaculture production technologies employed to develop a major aquaculture industry in Nebraska would depend on the large-scale sustainable use of groundwater, perhaps integrating aquaculture with irrigated agriculture and environmentally sound groundwater recharge techniques.

A factor complicating this assumption is that over the past 20 years major advances have been made toward developing intensive recirculating aquaculture systems, which ideally would require very little "new" input water to operate. The question of whether or not recirculating systems are now, or will ever prove to be, economically competitive has for years been one of the most controversial issues in aquaculture. Present indications are (at best) that to be competitive such systems must be large, well financed with long-term investment capital, integrated with other economically

productive activities (e.g., ethanol, power or animal feed production), and managed by individuals who are technically very sophisticated. Various technologies that have been (or are still being) developed, resulting from research on recirculating systems, over time, will probably be gradually integrated into mainstream commercial aquaculture.

One myth commonly associated with recirculating aquaculture systems is that they can be operated in areas where little or no water is available. In reality, water is still needed to make up for evaporative loss and to provide some turnover. Moreover, water in abundance is still required to provide for emergency flushing under circumstances when even well designed systems break down. Water availability and pumping costs will inevitably be important considerations, even in the most technically sophisticated recirculating systems. The greatest potential benefit of such systems is that they may provide a means of utilizing water more efficiently. One obvious practical benefit of this would be to be able to economically access groundwater from depths greater than 50 feet. Given this possibility, *Figures 7* and *8* provide GIS analyses of groundwater availability in Nebraska for areas where the depth to water is between 51 and 100 feet.

Lastly, it must be emphasized that the "50-feet rule of thumb" for groundwater pumping does not apply to all forms of aquaculture. In particular, present standard methods of culturing trout or salmon in tanks or raceways require such large volumes of continuously flowing water per pound of fish produced that the cost of pumping groundwater from a depth of more than a few feet, or even at all, is often prohibitive – especially if the fish are being reared for sale in major food markets. In such markets, producers who must pump water from wells have great difficulty competing with commercial trout culture operations that have access to high-volume springs or artesian water sources, and with the global salmon aquaculture industry which takes advantage of tidal flushing through large marine net-pens to provide water exchange.

Accordingly, trout growers who must pump water typically depend on specialty niche markets to achieve profitability. In Nebraska and the Midwest generally, most of the trout raised are sold as fingerlings or juveniles for stocking in private ponds or other waters for recreational purposes, including fee fishing. Some trout producers raise "catchable-size" fish for stocking and run recreational fee fishing operations to achieve or increase profitability. But regardless of the markets served, success in any trout aquaculture enterprise requires a clear understanding that the cost of pumping water from wells increases proportionately with pumping depth, and that pumping water from "too deep" (depending on the specific circumstances) is often cost prohibitive.

Evidence to date suggests that there is little likelihood of land-based salmon aquaculture systems being able to compete successfully with the salmon net-pen industry in major food markets, especially if pumping large volumes of groundwater is required. As with trout, specialty niche markets for salmon fingerlings and juveniles do exist, though they are not so well defined as for trout. One specialty niche market for both fresh food-size trout and salmon are "white-tablecloth" restaurants. In recent years, various new technologies, which involve using pure oxygen and enhanced waste removal methods, have been developed that can reduce the amount of water required to culture trout and salmon. But the cost-effectiveness of such technologies under commercial conditions, in a context of highly competitive national and global food markets, remains questionable. Species selection and production technologies as they apply to Nebraska aquaculture will be reviewed in detail later in the *NEBRASKA AQUACULTURE* series.

Summary and Conclusions

Successfully developing an aquaculture industry or siting an individual aquaculture operation requires careful consideration of a number of critical factors, among the most important of which is an abundance of low-cost, high-quality groundwater. The principal determinates of the availability of such groundwater, when artesian water is not present, are water-table depth, aquifer permeability and saturated thickness, and the availability of low-cost power for groundwater pumping. Nebraska sits astride one of the world's largest geologic groundwater reservoirs, which in turn underlies numerous water-rich aquifers comprised of alluvial or other unconsolidated materials. Because of the abundance of water, the state ranks third in the nation in total annual groundwater usage, primarily for agricultural irrigation. Three-phase electric power is available throughout much of the state at very low cost, compared to the rest of the nation.

Analyses based on a review of hydrogeological and other resources information and the use of Geographic Information Systems (GIS) technology suggest that as many as 36 of Nebraska's 93 counties have significant potential for aquaculture development. This conclusion was based on a combination of quantitative and empirical analyses of published and computer database information on groundwater abundance, availability and chemical content, as well as other factors (e.g., transportation assets, significant historical water-table declines). Of the 36 counties, 11 were rated as having outstanding to very good potential, nine were rated as having good potential, and 16 were rated as having moderately good to fair potential.

Sixteen of the 36 counties rated as having significant potential for aquaculture development are located in the Sand Hills Groundwater Region; 17 are in the Platte River

Groundwater Region; three have significant, available groundwater resources in both the Sand Hills and Platte River Regions; and seven have significant, available groundwater resources associated with other hydrogeological regions of the state. Of the 11 counties rated as having outstanding to very good potential for aquaculture, nine (Brown, Cherry, Garfield, Holt, Loup, McPherson, Rock, Sheridan and Wheeler Counties) are located in the Sand Hills Groundwater Region, and two (Dawson and Lincoln Counties) are in the Platte River Groundwater Region.

The analyses conducted revealed that "islands" of potential exist in some counties rated as having moderately poor to very poor overall potential for aquaculture development. Some established aquaculture operations are located in such islands of potential, but all of these operations are small. Five geographic areas in the state were identified as having significant potential for aquaculture development. Two of these areas are in the Sand Hills Groundwater Region, and three are in the Platte River Valley Groundwater Region. The potential for aquaculture development outside these five areas appears to be limited, though future advances in the engineering of intensive aquaculture production systems may change this perspective.

In overview, there is remarkably little correlation between where aquaculture operations presently exist in Nebraska and where hydrogeological considerations indicate that there is major potential for aquaculture development. This observation reflects the fact that Nebraska's (small) existing aquaculture industry has evolved largely on a hit-or-miss basis, as has been true in most states of the Midwest. Tremendous amounts of information exist on the groundwater resources of Nebraska, as well as other states. However, little of this information is available in a form that can be readily utilized to make informed decisions about aquaculture development or siting. This publication provides a starting point for making informed decisions about aquaculture development and siting in Nebraska.

Recommendations

The identification of critical resources and potential environmental constraints is essential to the planned development of a sustainable aquaculture industry. Many of the same considerations are important in siting individual aquaculture operations. Action on the following recommendations should help policy makers, economic developers, business leaders, entrepreneurs, and potential aquaculturists make informed decisions about aquaculture development and siting in Nebraska:

1. Determine on a regional and local basis the relationships that exist between the availability of groundwater and three-phase electric power, roads and other transportation assets, the clay content of soils for pond construction, and the presence and nature of legally designated wetland areas – all as they apply to potential aquaculture development. To make this task manageable, make these determinations on a county-by-county basis, starting with those that have been identified in this publication as having outstanding potential for aquaculture development, and working through those 36 counties that have been identified as having significant potential for development.

2. Evaluate the technical and economic feasibility and potential environmental impacts of recharging the groundwater used in aquaculture operations back into the ground via existing wetlands, constructed wetlands, and constructed recharge lagoons. This effort should include systematic test-well monitoring for changes in groundwater chemistry at experimental and proposed sites; a systematic evaluation of different aquaculture feeding practices and methods of managing solid wastes and dissolved nutrients in aquaculture effluent; and an examination of existing laws and regulations, as well as the legal ramifications of all relevant proposed changes in those regulations, that govern groundwater recharge methods.

3. Develop procedures for integrating aquaculture with irrigated agriculture, focusing on the use of aquaculture effluents as applied to different types of conventional and nonconventional irrigation systems. This effort should also include an evaluation of various methods of minimizing, collecting and "de-watering" solid wastes generated by aquaculture operations; the use of such wastes as a fertilizer, both for direct application and retail marketing; and the direct and indirect costs and benefits derived from various approaches to integrating aquaculture with irrigated agriculture.

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Bibliography and Suggested Reading

Aguillar-Manjarrez, J., and L.G. Ross. 1993. Aquaculture development and GIS. Map Aware 7:49-52.

Avault, J.W., Jr. 1996. Fundamentals of aquaculture. AVA Publishing, Baton Rouge, Louisiana. 889pp.

Bankston, J.D., Jr., and F.E. Baker. 1994. Selecting the proper pump. Southern Regional Aquaculture Center Publication Number 372. Louisiana Cooperative Extension Service and Sea Grant Program, Louisiana State University, Baton Rouge, Louisiana. 8pp.

Bankston, J.D., Jr., and F.E. Baker. 1995. Powering aquaculture equipment. Southern Regional Aquaculture Center Publication Number 375. Louisiana Cooperative Extension Service and Sea Grant Program, Louisiana State University, Baton Rouge, Louisiana. 8pp.

Beem, M. 1991. Aquaculture: realities and potential when getting started. Southern Regional Aquaculture Center Publication Number 441. Oklahoma State University, Stillwater, Oklahoma. 8pp.

Bleed, A., and C. Flowerday, editors. 1990. An atlas of the Sand Hills, second edition. Resource Atlas Number 5a. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 265pp.

Boyd, C.B. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama. 482pp.

Chen, A.H., and P.B. Wigley. 1996. Groundwater-level changes in Nebraska, 1994. Water Survey Paper 74 (Map with explanatory text on back). Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 2pp.

Coche, A.G., and T. Laughlin. 1985. Simple methods for aquaculture: soil and freshwater fish culture. FAO Training Series 6. Food and Agriculture Organization of the United Nations, Rome, Italy. 174pp.

Conte, F.S. 1992. Evaluation of a freshwater site for aquaculture potential. Western Regional Aquaculture Center Publication Number 92-101. University of California, Davis, California. 22pp.

Elder, J.A. 1969. Soils of Nebraska. Resource Report Number 2. Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska. 60pp.

Ellis, M.J., and P.B. Wigley. 1987. Groundwater levels in Nebraska. Nebraska Water Survey Paper Number 65. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 70pp.

Engberg, R.A., and R.F. Spalding. 1978. Groundwater quality atlas of Nebraska. Resource Atlas Number 3. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 34pp.

Exner, M.E., and R.F. Spalding. 1976. Groundwater quality of the Central Platte Region, 1974. Resource Atlas Number 2. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 48pp.

Exner, M.E., and R.F. Spalding. 1990. Occurrence of pesticides and nitrate in Nebraska's ground water. Water Center, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 34pp.

Fetter, C.W. 1988. Applied hydrogeology. Macmillan Publishing Company, New York. 592pp.

Flowerday, C.A., editor. 1986. The groundwater atlas of Nebraska. Resource Atlas Number 4. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 32pp.

Flowerday, C.A., editor. 1993. Flat water: a history of Nebraska and its water. Resource Report Number 12. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 292pp.

Flowerday, C.A., R.D. Kuzelka, and D.T. Pederson. 1998. The groundwater atlas of Nebraska, second edition. Resource Atlas Number 4a. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 44pp.

Gosselin, D.C., J. Headrick, X.H. Chen, S. Summerside, R. Tremblay, and K. Bottger. 1996. Domestic well-water quality in rural Nebraska. Data Analysis Report (done in fulfillment of a May 1995 cooperative agreement between the University of Nebraska-Lincoln Conservation and Survey Division and the Nebraska Department of Health). Document on file with, and available from, the Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, and the Nebraska Department of Health, Lincoln, Nebraska. 160pp.

Kapetsky, J.M., J.M. Hill, L.D. Worthy, and D.L. Evans. 1990. Assessing potential for aquaculture development with a geographic information system. Journal of the World Aquaculture Society 21:241-249.

McGuire, V.L., and J.B. Sharpe. 1997. Water-level changes in the High Plains Aquifer – predevelopment to 1995. Water-Resources Investigations Report 97-4081 (Maps with explanatory text). U.S. Geological Survey, Denver, Colorado, 2pp.

Nebraska Natural Resources Commission. 1998. Estimated water use in Nebraska, 1995. Nebraska Natural Resources Commission (in cooperation with the Nebraska District of the U.S. Geological Survey), Lincoln, Nebraska. 64pp.

Nebraska Aquaculture Board. 1994. Nebraska aquaculture report (to the Nebraska Unicameral, Ninety-Third Legislature Second Session). Nebraska Department of Agriculture, Lincoln, Nebraska. 34pp.

Pillay, T.V.R. 1990. Aquaculture principals and practices. Fishing News Books, Blackwell Scientific Publications, Oxford, Great Britain. 575pp.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler, and J.R. Leonard. 1982. Fish hatchery management. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 517pp.

Ross, L.G., E.A. Mendoza, and M.C.M. Beveridge. 1993. The application of Geographic Information Systems to site selection for coastal aquaculture: an example based on salmonid cage culture. Aquaculture 112:165-178.

Soderberg, R.W. 1995. Flowing water fish culture. Lewis Publishers, Boca Raton, Florida. 147pp.

Solley, W.B., R.R. Pierce, and H.A. Perlman. 1998. Estimated use of water in the United States in 1995. U.S. Geological Survey Circular 1200. U.S. Geological Survey, Denver, Colorado. 71pp.

Steele, G.V., and P.B. Wigley. 1994. Groundwater-level changes in Nebraska, 1992. Nebraska Water Survey Paper Number 72. Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, Lincoln, Nebraska. 6pp.

Wang, J.K., editor. 1993. Techniques for modern aquaculture (Proceedings of an aquacultural engineering conference). American Society of Agricultural Engineers, St. Joseph, Michigan. 604pp.

Weeks, J.B., E.D. Gutentag, F.J. Heimes, and R.R. Luckey. 1988. Summary of the High Plains Regional Aquifer-System analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Professional Paper 1400-A. United States Government Printing Office, Washington, D.C. 30pp.

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