Lower Platte South Natural Resources District Water Balance Study

April 24, 2012

Prepared for:

The Lower Platte South Natural Resources District

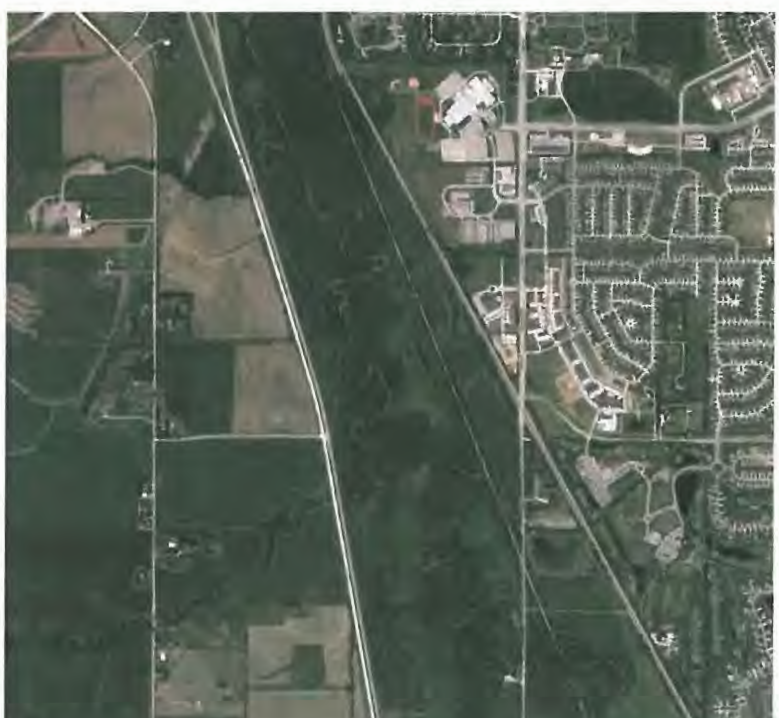
Prepared by:

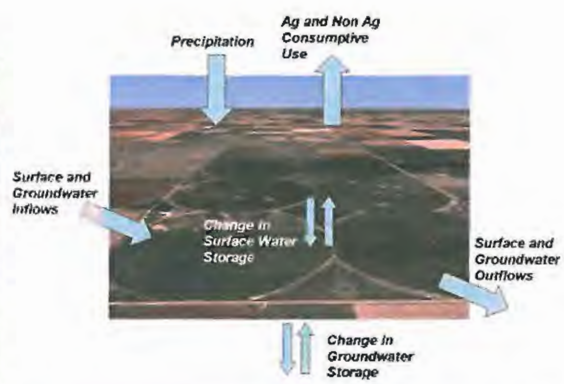
Brown and Caldwell

Brown AND Caldwell

in association with

H_2Options Engineering, LLC





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Prepared for

The Lower Platte South Natural Resources District

Lincoln, Nebraska

April 24, 2012

Brown AND Caldwell

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List of Abbreviations

AF	Acre-feet
CALMIT	Center for Advanced Land Management Information Technologies
CREMAP	Complementary-Relationship-Based Evapotranspiration Mapping
CSD	Conservation and Survey Division
EPA	Environmental Protection Agency
IMP	Integrated Management Plan
KAF	Thousands of acre-feet
LPSNRD	Lower Platte South Natural Resources District
NDNR	Nebraska Department of Natural Resources
NGPC	Nebraska Game and Parks Commission
NRD	Natural Resource District
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

Executive Summary

Introduction

The Lower Platte South Natural Resources District (LPSNRD) has begun a process to develop a voluntary Integrated Management Plan (IMP) for surface and groundwater uses and supplies. The study described in this report was conducted on behalf of the LPSNRD, and the primary purpose of the study was to develop data and information to help the LPSNRD inventory and understand the full spectrum of water supplies and water uses within their district boundaries. It is anticipated that this information will provide a tool to help the LPSNRD develop their IMP and to formulate strategies to meet long term water management goals.

Water balances are useful, and often essential, tools for developing and supporting informed water management decisions. Water balances can provide the framework under which water managers make water management decisions, and they can be tools to help managers set and monitor long term water management goals.

Water balances are not untested or unknown management tools. They are commonly developed over small and large land areas and for a wide variety of applications. A document by the U.S. Geological Survey entitled *Water Budgets: Foundations for Effective Water-Resources and Environmental Management* (Healy, et al., 2007) presents several examples of how water balances have been developed and how they have been used. Water balances in Nebraska were quantified and published in three reports in the late 1960s and early 1970s by Ray Bentall and F. Butler Shaffer (June 1966, March 1972, and June 1979). The Bentall and Shafer reports assessed the availability and uses of water in major river basins in Nebraska.

Description of the Study Area

The LPSNRD is located in eastern Nebraska and includes much of Lancaster and Cass Counties and portions of Butler, Otoe, Saunders, and Seward Counties. The study area for this project encompassed the region within the boundary of the LPSNRD.

The lands within the LPSNRD are largely agricultural but include pasture and grasslands and urbanized areas. The total area for the LPSNRD is 1.07 million acres. Current land uses in the LPSNRD consist of dryland crops (48%), pasture and grassland (32%), forested areas (7%), urbanized areas (7%), and open water/wetland areas (3%). Irrigated cropland (3%) is a relatively small proportion of the land use in the LPSNRD.

Five aquifers, or groundwater reservoirs, underlie the LPSNRD. The Dwight-Valparaiso, Crete-Princeton-Adams, and Waverly aquifers provide the majority of groundwater supply for the LPSNRD. Most of the 418 active, registered irrigation wells in the NRD are drilled into these formations. In addition, the Platte River and Missouri River aquifers provide groundwater supplies for irrigation and municipal uses.

Salt Creek drains the western portion of the LPSNRD and the majority of the total land area in the NRD. Several flood control reservoirs were constructed by the U.S. Army Corps of Engineers in the Salt Creek basin in the 1960s, and they provide flood control, recreation, and habitat benefits. Weeping Water Creek discharges into the Missouri River downstream of Union, Nebraska and drains most of the eastern part of the LPSNRD.

The LPSNRD receives approximately 30 inches of precipitation per year on average (based on 1948 through 2010 records). The amount of average annual precipitation increases from west to east across the LPSNRD with 27.5 inches per year of annual precipitation in the western part of the NRD and 33.5 inches per year in the southeastern part. Precipitation is a direct source and by far the most significant water supply to the LPSNRD.

The Water Balance Equation

Data sets for this project were generated to provide input for the water balance equation. The general equation for the water balance is as follows:

Inflow – Outflow = Change in Storage (Eq. ES-1)

For the purposes of this study, the "Inflow" term in Equation ES-1 consisted of direct precipitation falling within the boundaries of NRDs, surface water inflow, subsurface (groundwater) inflow, and imported water. The "Outflow" term included water that leaves the NRD in the form of consumption (evapotranspiration and open water evaporation), surface water outflows (both gaged and ungaged) and subsurface (groundwater) outflow. "Change in Storage" refers to changes in the amount of water held in the groundwater aquifer below the NRD and in surface water reservoirs within the NRD boundary.

With the above definitions, the general equation can be rewritten and rearranged as shown below:

(Precipitation + Surface Water Inflow + Subsurface Inflow + Imported Water) –

(Consumption + Gaged Surface Water Outflow + Minor Tributary Outflow + Subsurface Outflow) –

(Change in Groundwater Storage + Change in Surface Water Storage) = 0 (Eq. ES-2)

Equation ES-2 is useful to assess the potential error in the inputs to the water balance equation. None of the components of the water balance can be measured with perfect accuracy. As a result, there is measurement error associated with all of the water balance components, and the result of Equation ES-2 will not be zero. The degree to which Equation ES-2 varies from zero may give some understanding as to the magnitude of error of components in the equation.

Input Data for the Water Balance

Existing data sets were used to develop the water balances for this project. Brown and Caldwell did not independently generate any input data for this study. Sources of data include the following:

- Precipitation data were obtained from the High Plains Regional Climate Center.
- Consumption data for both irrigated and dryland cropland, pasture, native grasslands, etc. were obtained from the CropSim model.
- Land use mapping for 2005 was obtained from the Center for Advanced Land Management Information Technologies (CALMIT).
- Soils data were obtained from the Natural Resources Conservation Service Soil Data Mart.
- Streamflow data were available from the U.S. Geological Survey (USGS).
- Change in groundwater levels were obtained from the Conservation and Survey Division at University of Nebraska-Lincoln (CSD) and verified with data from the USGS.
- Historical land use and cropping data were obtained from the National Agricultural Statistics Service (NASS).
- Change in surface water storage data were obtained from the U.S. Army Corps of Engineers (USACE).

- Data describing water usage and urbanization in the City of Lincoln were provided by various City of Lincoln governmental departments.
- CREMAP data was provided by Dr. Jozsef Szilagyi at the University of Nebraska.

The availability of historical input data varied among the data sources. For example, precipitation data was available for more than 60 years, 1948 through 2010. Streamflow data from several gages were typically available from the early 1950 through 2010. In general, most of the water balance components had relatively complete data sets for the 1950 to 2010 time period. In addition, 1950 is generally considered to be the approximate time when irrigation well development began.

Process

Precipitation

Precipitation data were developed by combining annual precipitation data sets from several weather stations spanning the breadth and length of the NRD. Areas of coverage for each weather station were based on Theissen polygons developed using GIS. The annual precipitation data for each weather station (in inches) was multiplied by the area of coverage of that station (in acres) within the NRD as determined in GIS.

Surface Water Inflows and Outflows

Surface water flow data were obtained from the USGS for several gaging stations located throughout the NRD. When available, gaging stations located near the NRD boundary were used to represent surface water outflows. Because the LPSNRD boundary closely follows watershed boundaries, no significant surface water inflows occur in the LPSNRD. Flows in the Platte and Missouri Rivers were not considered to be inflows to or outflows from the NRD.

Surface water outflow data for some streams were not available at district boundaries, because no gaging stations exist on those streams. In these cases, stream outflows were estimated based on relationships between drainage area and annual outflow.

Subsurface Inflows and Outflows

Subsurface inflow and outflow data were assumed to be small for the purposes of this study. In addition subsurface inflows and outflows tend to be of similar magnitude and therefore cancel themselves out in the water balance equation. As a result of these factors, these components were assumed to be insignificant for the purposes of this study.

Consumption

Consumption within the LPSNRD was calculated based on current land uses. The consumption estimate represents expected average levels of consumption based on current land uses assuming that long term trends in temperature and precipitation persist into the future.

Two types of data were necessary to estimate volumes of consumption: land use mapping and annual amounts of consumption for various land uses in terms of inches per acre. Land use data from 2005 was obtained from GIS-based mapping developed by CALMIT. Annual rates of water consumption for current land uses in the NRD were estimated using output from the CropSim model. CropSim calculates consumption for several types of crops and vegetation growing on various types of soils. GIS was used to combine mapping of land use, soil types, and weather stations. Output from CropSim was combined with the GIS mapping to estimate consumption in the NRD based on current, specific land uses; soil types; and historical climatic conditions.

For this study, most of the CropSim code and input parameters were useable for estimating consumption in the LPSNRD. However, CropSim input parameters describing the growth and water use of pasture and grassland were modified to reflect tall grass prairies that are present in eastern Nebraska.

Change in Groundwater Storage

The CSD publishes change in groundwater level maps for the entire state of Nebraska on an annual basis, tracking groundwater levels from spring to spring (prior to the initiation of pumping). Mapping showing both pre-development to 2010 and 2000 to 2010 changes in groundwater levels were obtained and reviewed. For the purposes of this water balance study, the change in water level from spring 2000 to spring 2010 was used to estimate changes in groundwater storage under current levels of development.

Change in Surface Water Storage

Surface water storage data were obtained from the USACE for ten flood-control reservoirs in the Salt Creek drainage system. The total storage in the ten facilities was summed and used to calculate the annual change in surface storage for the LPSNRD.

Results

Table ES-1 summarizes the water balance components that were quantified using the processes described above.

Table ES-1. Summary of Water Balance Components

Component	Quantity
Land area (million acres)	1.07
Land use percentages	
Dryland crops	48%
Pasture/Grassland	32%
Forested areas	7%
Urbanized lands	7%
Average annual precipitation, 1948-2010 (inches)	30.1
Average annual surface water inflows, (acre-feet)	0
Average annual imported water for City of Lincoln, 1988-2010 (acre-feet)	40,000
Average annual subsurface inflow and outflow, assumed (acre-feet)	Negligible
Average annual surface water outflow, 1980-2010 (acre-feet)	519,000
Average annual consumption (using 1949-2010 climate data) based on 2005 land use (acre-feet)	2,257,000
Percentage of total NRD consumption supplied by rainfall	99.5%
Percentage of total NRD consumption provided by irrigation	0.5%
Percentage of total NRD consumption from pasture/ grassland use	36%
Percentage of total NRD consumption from dryland crops	40%
Decline in groundwater storage (acre-feet)	
Predevelopment to Spring of 2010	30,000
Spring of 2000 to Spring of 2010	44,000
Average annual decline in surface water storage, 1993-2010 (acre-feet)	350

Average Annual Water Balance Based on Current Land Use

Using the input data and analysis process described above and the form of the water balance shown in Equation ES-2, an average annual water balance was developed that reflects current (2005) land uses for the LPSNRD. The water balance based on 2005 land uses was meant to represent the current balance of supplies and demands and could provide insights as to what may be expected if current land uses and climactic trends persist into the future. Table ES-2 shows the components of the average annual water balance based on current land uses.

Table ES-2. Components of the Average Annual Water Balance Based on Current Land Uses

	Amount (KAF)	Period of Assessment
Inflows		
Precipitation	2,729	1980-2010
Surface water inflow	0	
Subsurface inflows	0	
Imported Water	40	1988-2010
Total	**2,769**	
Outflows		
Consumption	2,220	1980-2010 (based on 2005 land use)
Surface water outflow	395	1980-2010
Minor tributary outflow	124	1980-2010
Subsurface outflow		
Total	**2,739**	
Change in Storage		
Groundwater storage	-4	2000-2010
Surface water storage	-1	1993-2010
Total	**-5**	
Remainder	**35**	

Some components of the average annual water balance were assessed over different time periods to better reflect long term supplies and demands under current land uses (see Table ES-2 for the assessment time period used for each component). Most of the water balance components, however, were averaged over the 1980 to 2010 time frame. The precipitation component was assessed over this timeframe, because gaging records suggest that precipitation has increased and the relationship between precipitation and runoff changed in the early 1980s. Surface water outflows appear to have increased since the 1980s, and the average surface water outflow over the 1980 to 2010 time period was included in the water balance. Consumption was estimated using 2005 land uses projected over a long historical record of climatic conditions. Average levels of consumption over the 1980 to 2010 time period were adopted for the average annual water balance. The resulting estimate reflects expected levels of consumption if current land uses and climatic conditions persist into the future, and it incorporates wet, dry, and normal years. The rate of change in groundwater storage can vary depending on changing land use practices. For example, increases in groundwater irrigated land can accelerate consumption of groundwater supplies. A more recent time frame was used to assess changes in groundwater storage. Average annual changes in surface water storage were minimal and reflect a longer time period.

Several observations can be made on the data in Table ES-2:

- The remainder is approximately 35,000 acre-feet per year. While this appears to be a high number, it is relatively small in comparison to total inflows or outflows (1.3%). The relatively low remainder suggests that the water balance is "closing" well and that the water balance components were quantified with an adequate degree of accuracy for the purposes of this report. However, the remainder does indicate that there is measurement or estimation error and uncertainty in the water balance components. Specific, potential sources of error are described in the report.
- Direct precipitation falling within NRD boundaries and consumption (direct evaporation from open water and evapotranspiration from land surfaces) are by far the largest components of the water balance. Precipitation is approximately 99% of the total water supply to the LPSNRD, and consumption is 81% of the total outflow.

Changes in Streamflow

The LPSNRD is interested in how streamflow has been impacted by the growing footprint of urban areas in the NRD and overall changes in land uses. In addition, the NRD would like to understand how potential climate change may impact the water budget. The scope of work for this project included examining the potential impacts of urbanization and climate change.

Brown and Caldwell developed double mass curves that relate cumulative precipitation in the drainage area above a gaging station to the cumulative runoff through the gaging station. The double mass curves will indicate whether a change in the relationship between the two parameters has changed over time. Double mass curves were developed for several streamflow gaging stations in the LPSNRD. The gaging stations that were chosen for the analysis reflect drainage areas that are both impacted and unimpacted by urbanization. The curves show a fairly consistent relationship between cumulative streamflow and cumulative precipitation until the early 1980s. In the early 1980s the double mass curves suggest that the relationship between precipitation and streamflow changed and that more runoff occurred per unit of precipitation after the change than before. Table ES-3 shows the approximate changes in streamflows since the early 1980s.

Table ES-3. Changes in Annual Streamflow Volume since the Early 1980s for Gaged Outflow Locations in the LPSNRD

Gaging Station	Streamflow as a Percentage of Precipitation Prior to Early 1980s	Streamflow as a Percentage of Precipitation After Early 1980s	Approximate Annual Increase in Flow Volume after Early 1980s
Salt Creek at Greenwood	14%	19%	100,000 AF
Weeping Water Creek at Union	14%	20%	30,000 AF

The USGS was contacted regarding the change in the precipitation/streamflow relationship. USGS staff reported that they have observed a change in the precipitation/streamflow relationship in gages across the Midwest. The changes in streamflow have been documented in several references.

Increases in annual precipitation have been observed in eastern Nebraska. Increased precipitation is a major contributor to increases in streamflow. In addition, land and water use changes can impact streamflows. Several sources of data were obtained and assessed to investigate their potential role in changing streamflow trends.

Summary

The components of the water balance were inventoried, and the water balance for the LPSNRD was quantified successfully with a relatively small remainder. The database of information compiled for this study will provide a tool for describing the water supplies and water demands specific to the LPSNRD. The inventory and water balance data and information developed for this project are the primary work products associated with this study. A secondary value that this report provides is information regarding relationships of various water balance components. Understanding these relationships may be beneficial to stakeholders in identifying opportunities for achieving water management goals that will be developed as a part of the IMP.

Data Comparisons and Improvements

Some of the estimates for components of the water balance were compared with estimates that have been conducted using different methods. For example, Dr. Jozsef Szilagyi, Research Hydrologist at the University of Nebraska, has been conducting spatially distributed estimates of consumption in Nebraska using the CREMAP method. Over the period 2000 to 2009, the only overlapping period currently available for comparison, the CREMAP method of estimating consumption produced slightly different but very similar results to the methodologies used in this report. These differences, although relatively small, might be attributable to error in determining specific land uses or changes in vegetative cover and farming practices not captured by the methods used in this study.

The CREMAP method of estimating consumption could potentially be a convenient and efficient way to track up-to-date monthly or annual consumption in the LPSNRD. This information could also be used, in conjunction with land use mapping, to do specific comparisons of consumption from various types of land uses.

Observations on Water Balance Components and Recommendations

Throughout this report, several observations were made regarding trends in water balance components. Many of these observations are summarized below:

- Annual precipitation amounts in the LPSNRD vary and have increased since the 1950s.
- The LPSNRD is consuming about 86% of its precipitation supply leaving about 14% available for groundwater recharge, streamflow out of the NRD, and to support future development needs. Note that imported water from the Platte or Missouri Rivers, to the extent that they could be developed, could provide additional supplies.
- Streamflow out of the LPSNRD has increased over the time period of the study. The relationship between streamflow and precipitation appears to have changed in the early 1980s or late 1970s. Increases in streamflow have been observed in areas of the Midwest by other researchers. Gaged

outflows from the LPSNRD have increased by approximately 130 KAF/yr since the early 1980s. Both increased precipitation and the change in the precipitation/streamflow relationship have contributed to this increase.

- The increase in gaged outflow was assessed on annual time steps. It may be beneficial to research streamflow and precipitation changes on monthly time steps to evaluate whether changes have occurred on a seasonal basis. In addition, it may be useful to evaluate long term changes in the duration and intensity of storms.
- Hydrologic drivers for the change in precipitation and runoff could be investigated to understand (if possible) the potential reliability and permanence of observed increases in precipitation and runoff.
- The IMP stakeholders may choose to consider the 130 KAF/yr of increased streamflow as a "block" of new water that has developed over recent time periods and that could be allocated to offset new water uses, partially mitigate groundwater declines by implementing conjunctive use strategies, etc. Some stakeholders or interested parties, however, may view the increase in streamflow as part of the historical hydrologic record and not a "new" source of supply.
- The IMP stakeholders should consider additional monitoring and data collection programs to better assess streamflow and land use conditions and to track changes over time.

- The specific contributions of urban water use, runoff increases from urbanization, and NRD-wide changes in agricultural land use are potential contributors to increases in streamflow. Further research may be needed to identify the role and extent of these drivers.
- The average annual precipitation amount in the LPSNRD generally equals or exceeds annual crop water requirements and long term, regional groundwater level declines are not as prevalent as in parts of western Nebraska. Withdrawals for municipal and industrial uses can lead to groundwater level declines, especially when return flows or effluent is discharged directly to a stream. Where long term groundwater level declines occur it can be valuable to understand on a finer scale exactly what is happening and determine how the declines may be addressed.
- The LPSNRD is in the eastern part of Nebraska and receives more rainfall supply than most NRDs. As a result, the LPSNRD also has more available streamflow than many NRDs. Conjunctive water management techniques may be a way to use precipitation supplies or excess stream outflows to mitigate shortages or reduce demands for groundwater.
- Understanding the water balance will help the LPSNRD develop management plans to address internal demands (water supply needs within the NRD) and external demands (downstream water needs that depend on outflows from the NRD).

Section 1

Introduction

The Lower Platte South Natural Resources District (LPSNRD) has begun a process to develop a voluntary Integrated Management Plan (IMP) for surface and groundwater uses and supplies. The study described in this report was conducted on behalf of the LPSNRD, and the primary purpose of the study was to develop data and information to help the LPSNRD inventory and understand the full spectrum of water supplies and water uses within their district boundaries. It is anticipated that this information will provide a tool to help the LPSNRD develop their IMP and formulate strategies to meet long term water management goals.

Long term water management goals developed under the IMP will likely address the needs of both internal and external demands. All natural resources districts (NRDs) need to manage resources to meet internal demands (for example, ensuring the sustainability of aquifers within NRD boundaries) while considering the needs of external, downstream demands (for example, in-stream flow requirements). Information describing the uses of water in an NRD and the water leaving an NRD can be very beneficial in developing water management policies to meet internal and external demands. In addition, understanding uses of water may help an NRD evaluate strategies for maximizing the benefit and value of water use within the NRD.

The LPSNRD is fortunate because the voluntary IMP process allows the NRD the opportunity to better understand the potential of its water supply, determine how the NRD will optimize its regulations to better manage water supplies, prevent over use, minimize conflicts, and address water quantity and quality concerns that may be both internal and external to the NRD. The process also provides the opportunity to identify and develop desirable water management strategies without the urgency and constraints associated with IMPs developed after a "Fully Appropriated" designation has been made.

Before the NRD can optimize regulations, it will be important to understand the available water supplies and water demands throughout the NRD. In addition, because future water supplies and demands may be impacted by drivers that are currently either unknown or not well understood (i.e. future climactic conditions, future demands for water from a prospective industry or from market-driven changes in agricultural production, etc.), it is important to understand the physical conditions and economic expectations related to water in order to create an IMP that can adapt to future water management needs.

1.1 Water Balances

A straightforward way to begin developing an understanding of supplies and demands is to develop a water balance. Water balances are useful, and often essential, tools for developing and supporting informed management decisions. Water balances can provide the framework under which water managers make water management decisions, and they can be tools to help managers set and monitor long term water management goals. If created with sufficient detail, water balances are useful in understanding the full spectrum of water supplies and demands and in understanding how changes in management of supplies and land uses can be beneficial in reaching water management goals.

Water balances can be developed on long-term, annual, seasonal, or even monthly timescales depending on the nature of water management issues. Much shorter time steps may even be appropriate for some applications. Shorter time steps may be useful for understanding trends in water balance components, cyclical patterns and durations, observed maximums and minimums, etc. However, when examining the water balance of study areas such as river basins or large geographic regions, monthly or annual time steps are necessary to minimize impacts due to the travel times, lags, and interactions among water balance components.

Water balances are not untested or unknown management tools. They are commonly developed over small and large land areas and for a wide variety of applications. A recent report by the U.S. Geological Survey entitled *Water Budgets: Foundations for Effective Water-Resources and Environmental Management* (Healy, et al., 2007) presents several examples of how water balances have been developed and how they have been used. Several pertinent examples presented in the report are summarized below:

> *Colorado River Basin* – Water balances of various types are used to manage reservoirs, assess the sustainability of aquifers, and to apportion water among Colorado River water claimants.
>
> *High Plains Aquifer* – Water balances have been developed to assess the sustainability of the aquifer in various locations. Water balances can be useful tools for assessing the balance between aquifer withdrawals and recharge.
>
> *San Pedro River Basin* – Changes in the water balance in the San Pedro River basin from 1940 to 2002 were assessed to evaluate the sustainability of supplies to meet both human and environmental needs.

Water balances in Nebraska were quantified and published in three reports in the late 1960s and 1970s by Ray Bentall and F. Butler Shaffer (June 1966, March 1972, and June 1979). The Bentall and Shafer reports assessed the availability and uses of water in major river basins in Nebraska. Components of basin-wide water balances were quantified and included surface water inflows and outflows, precipitation supplies, water consumption, and changes in storage.

Once a water balance is adequately quantified and understood, water managers can focus on how and where water supplies are consumed and managed. Not all consumption is of equal value. Understanding the social and economic value of various types of consumption, along with the degree to which various types of consumption are occurring, will allow water managers and the public to prioritize how supplies should be used. Water that is not consumed either infiltrates into the ground (resulting in aquifer recharge) or runs off the land surface and produces streamflow. Each of these water pathways are beneficial as well and are important considerations for water managers.

1.2 Description of Study Area

The LPSNRD is located in eastern Nebraska and includes much of Lancaster and Cass Counties and portions of Butler, Otoe, Saunders, and Seward Counties (see Figure 1-1). The study area for this project encompassed the region within the boundary of the LPSNRD.

1.2.1 Land Use

The lands within the LPSNRD are largely agricultural but include pasture and grasslands and urbanized areas. The total area for the LPSNRD is 1.07 million acres. Current land uses in the LPSNRD consist of dryland crops (48%), pasture and grassland (32%), forested areas (7%), urbanized areas (7%), and open water/wetland areas (3%). Irrigated cropland (3%) is a relatively small proportion of the land use in the LPSNRD.

1.2.2 Hydrology

Average annual precipitation amounts vary greatly across Nebraska ranging from less than 16 inches per year in western Nebraska to over 34 inches per year in the southeastern part of the state. The LPSNRD receives approximately 30 inches of precipitation per year on average (based on 1948 through 2010 records). The amount of average annual precipitation increases from west to east across the LPSNRD with 27.5 inches per year of annual precipitation in the western part of the NRD and 33.5 inches per year in the southeastern part.

The precipitation that the NRD receives is generally adequate to reliably raise agricultural crops. However, precipitation amounts can vary significantly within the growing season and from year to year. Seasonal dry periods and periodic droughts have led some agricultural producers to install irrigation equipment in areas of the NRD that have adequate groundwater resources.

Precipitation is a direct source and by far the most significant water supply to the LPSNRD, but it is also the original source of supply for other water balance components. For example, a portion of streamflow flowing out of the NRD originated as direct runoff from precipitation events within the NRD. Streamflow occurring as base flow originated from recharge of precipitation or runoff from rainfall events that occurred in the past.

Land uses can impact the rainfall/runoff relationships in drainage areas and have had an impact on the hydrology of the LPSNRD. Historically, conversions of grass prairie to farmland enhanced flood frequency and severity and have also led to excessive erosion in some areas. To help mitigate flooding issues, flood control reservoirs (major reservoirs are described in Section 1.2.3), channel improvements, and levees were constructed in the 1960s. In more recent times, the increasing urban footprint of the City of Lincoln and other urban areas has resulted in higher amounts and rates of stormwater runoff. In response, the City and the LPSNRD have implemented programs and regulations for detaining stormwater runoff and controlling erosion and sediment transport.

1.2.3 Surface Water

Salt Creek drains the western portion of the LPSNRD and the majority of the total land area in the NRD. The creek runs in a northeasterly direction and discharges into the Platte River near Ashland, Nebraska. Major tributaries of Salt Creek include Rock Creek, Oak Creek, Middle Creek, Antelope Creek, and Stevens Creek. Weeping Water Creek discharges into the Missouri River downstream of Union, Nebraska and drains most of the eastern part of the LPSNRD. In addition to these significant waterways, there are a number of smaller creeks and drains that discharge runoff from the LPSNRD into the Platte and Missouri Rivers.

Several flood control reservoirs were constructed by the U.S. Army Corps of Engineers in the Salt Creek basin in the 1960s. These reservoirs include Branched Oak Lake, Pawnee Lake, Twin Lakes, Conestoga Lake, Yankee Hill Lake, Blue Stem Lake, Olive Creek Lake, Stagecoach Lake, Wagon Train Lake, and Holmes Lake. The reservoirs provide flood control, recreation, and habitat benefits. Combined, these reservoirs have maintained an average surface water storage volume of nearly 44,000 acre-feet between 1993 and 2010.

The Platte River forms the eastern part of the northern NRD boundary, and the Missouri River forms the eastern NRD boundary. While these rivers convey large volumes of surface water, their flows are not a significant portion of the water supply to the LPSNRD (with the exception of the City of Lincoln's Ashland wellfield, which is described in Section 3.1.5 of this report). It should be noted, however, that there are some uses of surface water or alluvial groundwater in close connection to the Platte and Missouri Rivers that are certainly important to local water users but that are small in comparison to the magnitude of water balance components. For example, Ashland is supplied by an alluvial wellfield on the Platte River, but the pumping from that wellfield was not quantified for the purposes of this study.

1.2.4 Groundwater

Five aquifers, or groundwater reservoirs, underlie the LPSNRD. The aquifers are described in detail in a 2001 publication prepared by the U.S. Geological Survey (USGS) in cooperation with the LPSNRD (Druliner and Mason, 2001). Figure 1-2 shows the locations of these aquifers. A brief description of each aquifer is provided below:

- The Dwight-Valparaiso aquifer: The Dwight-Valparaiso aquifer is located in the northwestern part of the LPSNRD. It is semiconfined to confined and varies in saturated thickness from about 50 to 275 feet. The depth to water in this aquifer ranges from 10 feet along the southern edge to around 250 feet along the western edge of the aquifer. The sand and gravel deposits of this aquifer are overlain by glacial till and loess deposits. The USGS estimated that the volume of drainable water from this aquifer is approximately 1,340,000 acre-feet assuming a storage coefficient of 0.2. The storage coefficient is typical for unconfined and semiconfined aquifers. The USGS assumed unconfined aquifer conditions when making their assessment of drainable water because of the dynamics of the aquifer system.
- The Crete-Princeton-Adams aquifer: The Crete-Princeton-Adams aquifer lies along the southern border of Lancaster County and in the southern part of the LPSNRD. It is semiconfined to confined and varies in saturated thickness from 50 to 250 feet. The depth to water in this aquifer ranges from 9 feet to around 240 feet. The USGS estimated that the volume of drainable water from this aquifer is approximately 1,540,000 acre-feet assuming a storage coefficient of 0.2.
- The Waverly aquifer: The Waverly aquifer lies along the approximate alignment of Salt Creek and extends from 18 miles northeast of Lincoln to the Platte River. It is semiconfined to confined and has an average saturated thickness of 75 feet. The depth to water in this aquifer ranges from 6 feet to around 40 feet. The USGS estimated that the volume of drainable water from this aquifer is approximately 172,000 acre-feet assuming a storage coefficient of 0.2.
- The Platte River aquifer: The Platte River aquifer runs along the northern boundary of the LPSNRD where the boundary and the Platte River coincide. The aquifer is alluvial and is unconfined. The saturated thickness of the aquifer is relatively uniform and averages 70 feet. Depths to water range from 5 to 10 feet.
- The Missouri River aquifer: Missouri River aquifer runs along the eastern boundary of the LPSNRD. The aquifer is alluvial and is unconfined. The saturated thickness averages 80 feet, and depths to water range from 5 to 10 feet.

The Dwight-Valparaiso, Crete-Princeton-Adams, and Waverly aquifers provide the majority of groundwater supply for the LPSNRD. Most of the 418 active, registered irrigation wells in the NRD are drilled into these formations.

The Platte River and Missouri River aquifers also provide groundwater supplies for irrigation and municipal uses. For example, the City of Lincoln's Ashland wellfield is drilled into and pumps water from the Platte River aquifer. The Town of Plattsmouth uses groundwater wells in the Missouri River aquifer.

The Platte River and Missouri aquifers are in close hydraulic connection with surface water flows in the Platte and Missouri Rivers and are recharged from those rivers.

Section 2

Data Inputs and Analysis Process

2.1 Water Balance Equation

Data sets for this study were generated on annual time steps to provide input for the water balance equation. The water balance equation was then applied to the LPSNRD. The general equation for the water balance is as follows:

Inflow – Outflow = Change in Storage (Eq. 1)

This equation can be interpreted as "if there is a difference in the amount of water coming into the system and the water leaving the system, there must be a change in storage within the system."

For the purposes of this study, the "Inflow" term Equation 1 consisted of direct precipitation falling within the boundary of the LPSNRD, surface water inflow, subsurface (groundwater) inflow, and imported water. Precipitation is the primary source of water supply to the LPSNRD. Surface water inflows are waters that flow across the LPSNRD boundary in a surface stream. Because the LPSNRD boundary follows watershed boundaries, surface water inflows are insignificant and were not included in the study. Surface waters originating within the LPSNRD boundary (i.e. streamflow gains, springs, etc.) were not considered an inflow to the LPSNRD. Rather, these waters were considered to be the result of other inflows such as runoff from precipitation. Subsurface inflows are groundwater flows that cross the LPSNRD boundary beneath the ground surface (subsurface inflows were ignored for the purposes of this report as described in Section 2.3.3). Imported water refers to surface water in the Platte River that is pumped for municipal use.

The "Outflow" term included water that leaves the LPSNRD. Water consumed by crops, pasture, native grasses, open water evaporation, etc. exits the LPSNRD through the atmosphere. Surface waters in Salt Creek and other streams that cross the downstream boundary of the LPSNRD are considered to be an outflow. Surface water outflows were segmented into "gaged surface water outflows" and "minor tributary outflows" that are ungaged. Subsurface outflows are groundwater flows that cross the LPSNRD boundary beneath the ground surface (these were ignored for the same reason as subsurface inflows).

It should be noted that Platte River and Missouri River flows were not considered to be surface water inflows or outflows for the following reasons:

- The LPSNRD has no control over the amount of inflow that occurs in these rivers and can only manage water resources within its own boundary to affect outflows.
- Water management activities in other NRDs and in other states impact outflows on these rivers at the LPSNRD boundary. As a result, the water balance did not include inflows and outflows from these two rivers.
- The Platte and Missouri Rivers run along the boundary of the NRD and convey large amounts of water. Inclusion of annual inflows and outflows from these two rivers would unnecessarily skew the data in the water balance of the LPSNRD and would dwarf the magnitude of other components of the water balance.

"Change in Storage" refers to changes in the amount of water held in the groundwater aquifer below the LPSNRD and in surface water reservoirs within the district's boundary. Change in storage related to soil moisture, which may be significant on a seasonal or annual basis, was not quantified for this study because it is small over the long term.

With the above definitions, the general equation (Equation 1) can be rewritten as shown below:

(Precipitation + Surface Water Inflow + Subsurface Inflow + Imported Water) –
(Consumption + Gaged Surface Water Outflow + Minor Tributary Outflow + Subsurface Outflow) =
Change in Groundwater Storage + Change in Surface Water Storage (Eq. 2)

It should be noted that in the above equation, consumption is a lumped term. In reality, consumption takes on many forms – open water evaporation; water use by natural vegetation, dryland crops, irrigated crops, municipalities, livestock; etc. The majority of the water supply in the LPSNRD is consumed by vegetation and by direct evaporation. However, municipal and industrial water use is significant in the LPSNRD and was quantified as described in Section 3.1.5 of this report.

Groundwater pumping for irrigation and municipal uses (with the exception of "Imported Water") is not identified specifically in the above equation. The impacts of groundwater use are reflected in higher amounts of consumption, changes in surface water or subsurface outflow, and changes in the amount of water stored in the soil profile and aquifer. Deep percolation occurring from irrigation generally seeps back into the groundwater aquifer and manifests itself as a change in groundwater storage although significant time lags can occur as this water moves through the vadose zone.

For the purposes of this study, larger reservoirs with measured storage were considered in the "Change in Surface Water Storage" term. Smaller reservoirs and farm ponds also exist throughout the LPSNRD. The evaporative consumption of water at these reservoirs and farm ponds was quantified to the extent that they appear in land use mapping. While the aggregate storage volume of these water bodies is likely significant, it was assumed that there would not be a significant long term average annual change in storage in smaller reservoirs and farm ponds.

The water balance can be rearranged to equal zero. This form of the equation is shown below:

(Precipitation + Surface Water Inflow + Subsurface Inflow + Imported Water) –
(Consumption + Gaged Surface Water Outflow + Minor Tributary Outflow + Subsurface Outflow) –
(Change in Groundwater Storage + Change in Surface Water Storage) = 0 (Eq. 3)

Equation 3 is useful to assess the potential error in the inputs to the water balance equation. For example, if inflow minus outflow minus change in storage does not equal zero, then there must be error in one or all of the water balance components.

It is to be expected that Equation 3 would not equal zero. None of the components of the water balance can be measured with perfect accuracy. Consequently, there is measurement error associated with all of the water balance components, and the result of Equation 3 will not be zero. The degree to which Equation 3 varies from zero may give some understanding as to the magnitude of error of components in the equation.

2.2 Input Data for the Water Balance

Existing data sets were used to develop the water balances for this project. Brown and Caldwell did not independently generate any input data for this study (with the exception of consumptive use data for pasture and grasslands as described in later sections of this report). Sources of data include the Nebraska Department of Natural Resources (NDNR), Center for Advanced Land Management Information Technologies (CALMIT), Conservation and Survey Division at University of Nebraska-Lincoln (CSD), CropSim, U.S. Geological Survey (USGS), High Plains Regional Climate Center, Natural Resource Conservation Service (NRCS), and U.S. Army Corps of Engineers (USACE). The data obtained from these sources were as follows:

- Precipitation data were obtained from the High Plains Regional Climate Center.
- Consumption data for both irrigated and dryland cropland, pasture, native grasslands, etc. were obtained from the CropSim model.
- Land use mapping for 2005 was obtained from CALMIT. This land use map was developed from satellite images.
- Soils data were obtained from NRCS Soil Data Mart.
- Streamflow data were available from the USGS.
- Change in groundwater levels were obtained from CSD and verified with USGS data.
- Change in surface water storage data were obtained from USACE.
- Data describing water usage and urbanization in the City of Lincoln were provided by various City of Lincoln governmental departments.
- CREMAP data was provided by Dr. Jozsef Szilagyi at the University of Nebraska.

Most of the data shown above cover land areas that are both inside and outside of the LPSNRD. For example, change in groundwater level mapping from CSD covers all of Nebraska, not just the lower Platte region. In order to develop data specific to the LPSNRD, GIS was used to combine maps of land use, changes in groundwater levels, etc. with district boundaries. GIS was then used to quantify water balance components according to NRD district boundaries.

The availability of historical input data varied among the data sources. For example, precipitation data was available for more than 60 years, 1948 through 2010. Streamflow data from several gages were typically available from the early 1950 through 2010. In general, most of the water balance components had relatively complete data sets for the 1950 to 2010 time period. In addition, 1950 is generally considered to be the approximate time when irrigation well development began.

2.3 Process

Processes and assumptions for developing input data to the water balance are described in this section. The input data were developed based on the water balance components described in Equation 2 and were quantified based on NRD boundaries.

2.3.1 Precipitation Data

Precipitation data for the LPSNRD was developed by combining annual precipitation data sets from several weather stations located within the boundary of the NRD or in very close proximity to the NRD. Areas of coverage for each weather station were based on Theissen polygons developed using GIS tools. The annual precipitation totals for each weather station (in inches) were multiplied by the area of coverage of the stations (in acres) as determined in GIS. The annual volume of precipitation was summed for each weather station to estimate the total annual volume of precipitation supply to the NRD. Based on the area of the Theissen polygons a weighted average annual precipitation was calculated. Figure 2-1 shows the Theissen polygons associated with the weather stations used in the analysis.

2.3.2 Surface Inflow and Outflow Data

Surface water flow data were obtained from the USGS for several gaging stations located throughout the NRD. When available, gaging stations located near the NRD boundary were used to represent surface water outflows. Because the LPSNRD boundary closely follows watershed boundaries, no significant surface water inflows occur in the LPSNRD. As described in Section 2.1, flows in the Platte and Missouri Rivers were not considered to be inflows to or outflows from the NRD. Several gaging stations in the NRD are not located near an NRD boundary, and they were not useful for representing surface water outflows. A map of gaging stations that were used for the purpose of estimating outflows is included in Figure 2-2.

Surface water outflow data for some streams were not available at district boundaries, because no gaging stations exist on the streams. In these cases, stream outflows were estimated based on relationships between drainage area and annual outflow. Using average annual flow data recorded at various gaging stations throughout the NRD and the drainage area above the gaging stations, a relationship between drainage area and runoff was developed. Next, the drainage areas for all ungaged tributaries in the NRD were determined using hydrologic unit boundary maps available from the NDNR. The total ungaged tributary outflow for the NRD was estimated based on the runoff per unit area relationship and the tributary areas.

2.3.3 Subsurface Inflow and Outflow Data

Subsurface inflow and outflow data were assumed to be small for the purposes of this study. In addition subsurface inflows and outflows tend to be of similar magnitude and therefore cancel themselves out in the water balance equation. As a result of these factors, these components were assumed to be insignificant for the purposes of this study. This approach and these assumptions were verified with LPSNRD staff.

2.3.4 Consumption Data

Consumption within the LPSNRD was calculated based on current land uses. This scenario represents expected average levels of consumption based on current land uses assuming that long term trends in temperature and precipitation persist into the future.

Two types of data were necessary to estimate volumes of consumption: land use mapping and annual amounts of consumption for various land uses in terms of inches per acre. Land use data from 2005 was obtained from GIS-based mapping developed by CALMIT. The mapping was developed using multi-date satellite imagery and has a 28.5 meter resolution. Land use was categorized into 25 different classes reflecting a variety of irrigated and dryland crops, grasslands, urban areas, open water, etc. The classification of various land uses was estimated by CALMIT to be approximately 81% accurate. The 2005 CALMIT land use mapping covers the entire state of Nebraska and was assumed to represent current land use conditions. GIS was used to extract land use data for areas within the LPSNRD boundary.

Annual rates of water consumption for various land uses were estimated using the CropSim model. CropSim calculates consumption for various types of crops and vegetation growing on various types of soils. It has been applied in many areas of Nebraska for various hydrologic modeling studies. For this study, most of the CropSim code and input parameters were useable for estimating consumption in the LPSNRD. However, based on discussions with Dr. Derrel Martin (University of Nebraska professor and creator of CropSim) input parameters describing the growth and water use of pasture and grassland were modified to reflect tall grass prairies that are present in eastern Nebraska.

Seasonal amounts and patterns of water use for pasture and grasslands are reflected in "crop coefficients". CropSim uses crop coefficients that have been derived for a variety of crops and other vegetation to convert consumption estimates for a "reference crop" to consumption estimates for specific crops and vegetation. Information describing crop coefficients for tall grass prairie were obtained from research conducted at the Konza Prairie in northeastern Kansas (Hutchinson, et al., 2001; Hutchinson, et al., 2008). The research included a profile of how crop coefficients for tall grass prairie at the site changed throughout the growing seasons during the period of research. The crop coefficients and seasonal change patterns were input into the CropSim model along with parameters that signal when seasonal changes occur (i.e. growing degree days).

Soil mapping was obtained and was combined with mapping of 2005 land use, weather stations, and the NRD boundary in GIS. Each of these mapping coverages were intersected in GIS, which resulted in a mapping coverage that included polygons with attributes describing specific soil types, land uses, and coverage of weather stations. For each of these polygons, annual consumption estimates could be obtained based on the soil type, land use, and weather station used by CropSim. The extraction of CropSim output for each individual polygon was conducted using database queries. Annual consumption volumes based on 2005 land uses were estimated by multiplying annual consumption amounts for various soil types, land uses, and weather stations (in terms of inches per acre) by the land area of polygons with corresponding land use, soil type, and weather station attributes. The annual consumption volumes calculated for each polygon were summed to obtain annual consumption volumes on an NRD basis. The consumption amounts calculated using this process represent consumption relative to 2005 land uses projected across historical climatic records.

2.3.5 Change in Groundwater Storage Data

The CSD publishes change in groundwater level maps for the entire state of Nebraska on an annual basis, tracking groundwater levels from spring to spring (prior to the initiation of pumping). Mapping showing both pre-development to 2010 and 2000 to 2010 changes in groundwater levels were obtained and reviewed. The pre-development to 2010 mapping showed less change in aquifer levels than the 2000 to 2010 mapping.

For the purposes of this water balance study, the change in water level from spring 2000 to spring 2010 was used to estimate changes in groundwater storage under current levels of development. The CSD also provided aquifer specific yield data for the region surrounding the LPSNRD in the form of GIS data. Using GIS, the mapping of change in groundwater levels was combined with the mapping of specific yield, and the resulting polygon file was used to determine change in aquifer storage from 2000 to 2010. Because the CSD groundwater level data represent changes over only a 10-year period, Brown and Caldwell also reviewed available groundwater level data from the USGS Field Water-Level Measurement database to verify the trends indicated by the CSD data.

2.3.6 Change in Surface Water Storage Data

Surface water storage data were obtained from the USACE. The USACE operates ten flood control reservoirs in the Salt Creek drainage system. Storage levels in these facilities fluctuate based on hydrologic conditions and are also controlled on a seasonal basis to enhance aquatic habitat. In general, the facilities are maintained at a prescribed pool elevation that is required for flood control operations.

The USACE provided average annual storage data, compiled from daily storage records, for the ten Salt Creek reservoirs from 1993 to 2010. The total storage in the ten facilities was summed and used to calculate the annual change in surface storage for the LPSNRD.

There are other small water bodies (i.e. farm or stock ponds) within the NRD, but storage in these water bodies is not measured or reported. It was assumed for the purposes of this study that the aggregate amount of water stored in small farm ponds does not change significantly from year to year, and as a result, the annual change in storage from these ponds would be negligible relative to the quantities of water in other components of the water balance.

Section 3

Results

3.1 Components of the Water Balance

The components of the water balance were quantified using the methods and assumptions described in Section 2. The results of these quantifications are described below.

3.1.1 Study Area and Land Use

The LPSNRD land use data described in this section is based on the 2005 land use mapping developed by CALMIT and is assumed to be representative of current conditions.

The LPSNRD covers 1,068,440 acres and consists primarily of dryland agriculture (48%) and pasture/grassland (32%). Other significant land uses include forested areas (7%), urbanized lands (7%), and irrigated cropland (3%). Remaining land uses are farmsteads, wetlands, and open water areas. A map of land use in the LPSNRD is shown in Figure 3-1, and the distribution of land uses is shown in the chart in Figure 3-2.

The distribution of dryland and irrigated crops are shown in Figure 3-3. The most prominent dryland crops are soybeans (24% of the land area in the LPSNRD) and corn (22% of the land area in the LPSNRD). Corn and soybeans are the primary irrigated crops, but they make up a relatively minor part of the overall land use in the LPSNRD (less than 3% according to 2005 CALMIT land use mapping).

3.1.2 Precipitation

Precipitation data were included with the University of Nebraska via CropSim input data files, but the data originated with the High Plains Regional Climate Center. Data included daily precipitation amounts at various weather stations within and surrounding the LPSNRD, as well as coordinates showing the location of each weather station.

Average annual precipitation supplied to the LPSNRD for the time period 1948 through 2010 was 30.1 inches. Although some of the weather stations used for LPSNRD precipitation data are located outside of the district boundaries, their area of coverage (based on the delineation of Theissen polygons) extends into the LPSNRD. Table 3-1 shows the average annual precipitation for stations included in the LPSNRD water balance. The average annual precipitation for the LPSNRD represents the weighted average based on area of coverage for each station. Figure 2-1 shows the area of coverage for each weather station used to estimate precipitation volumes for the LPSNRD.

Table 3-1. Average Annual Precipitation for Weather Stations in and near the LPSNRD

Weather station	Average annual precipitation 1948 - 2010 (inches)
Ashland	29.9
Crete	30.1
David City	29.4
Lincoln Airport	27.8
Nebraska City	33.5
Seward	27.5
Syracuse	31.2
Wahoo	32.1
Weeping Water	32.8

3.1.3 Surface Water Inflows

The LPSNRD boundaries correspond closely to the western and southern boundary of the Salt Creek watershed and the southern boundary of the Weeping Water Creek watershed. As a result, there are no significant surface water inflows entering the LPSNRD from the west and from the south. The Platte River forms part of the northern boundary of the NRD, and the Missouri River forms the eastern boundary. As described previously, surface water inflows and outflows from the Platte and Missouri Rivers were not included in the water balance because they are at the boundary of the LPSNRD and the flows in these rivers are not a significant source of supply for the NRD (with the exception of City of Lincoln water supplies as described below). As a result of the above considerations, surface water inflows were assumed to be insignificant for the purposes of the water balance.

3.1.4 Subsurface Inflows

Because of the nature and location of groundwater aquifers in the LPSNRD, there is little opportunity for significant groundwater flow across the NRD boundaries. The exceptions to this may be in the Platte and Missouri River alluvial aquifers. The groundwater flow in these aquifers is likely dependent on the level of river flow (which is outside the control of the NRD) and is likely to be in some form of long term equilibrium. For these reasons, boundary groundwater inflows and outflows are likely to be very small relative to other water balance components and are very likely to cancel each other out within the water balance. They are assumed to be negligible for the purpose of this report.

3.1.5 Imported Water to the City of Lincoln

The City of Lincoln receives the majority of their municipal water supply from a wellfield along the Platte River near Ashland at a location along the boundary of the LPSNRD. The wellfield withdraws groundwater from the Platte River alluvial aquifer, and the aquifer (in this location) is dependent on Platte River flows to recharge the groundwater withdrawn by the wellfield. The Platte River flows that recharge the alluvial aquifer near the wellfield originate in the drainage area upstream of the LPSNRD. As a result, the water that is pumped from the wellfield to the City of Lincoln was considered to be "imported" water into the LPSNRD.

Alluvial wellfield pumping data were obtained from staff at the Lincoln Water System. The data included monthly wellfield pumpage records and other data for September 1987 through August 2011. Figure 3-4 shows annual pumpage amounts for the years with complete sets of monthly data (1988 through 2010). The amounts of pumping averaged approximately 40,000 AF/year. During the drought of the early 2000s, pumping amounts increased to approximately 45,000 AF/year. In 1993, wellfield pumping was at its lowest during the time period shown at approximately 32,000 AF. The low pumping amount corresponds to high amounts of rainfall. The precipitation recorded at the Lincoln airport in 1993 was the highest annual total for the 1988 to 2010 time period.

3.1.6 Consumption

Consumption data for the LPSNRD was generated using the procedures described in Section 2.3.4. Table 3-2 shows estimates of average annual consumption based on 2005 land use practices. The average annual consumption amounts shown in Table 3-2 were averaged over 1949 to 2010. Table 3-2 shows that pasture/grassland land uses consume the highest volume of water district-wide (36.4% of the total). Dryland corn and dryland soybeans account for 19.6% and 18.3%, respectively, of the total LPSNRD consumption budget. Other dryland and irrigated crops consume smaller proportions of the overall consumption in the LPSNRD. Figure 3-5 presents a graphical depiction of the data shown in Table 3-2 and sorts the land uses from highest to lowest in terms of total average annual consumption based on 2005 land uses.

Table 3-2. Average Annual Consumption (1949 - 2010) Based on 2005 Land Uses in the LPSNRD

CALMIT Land Use Category	2005 CALMIT Land Use (acres)	Average Annual Consumption (inches)	Net Irrigation Requirement (inches)	Net Irrigation Requirement (acre-feet)	Consumption Volume (acre-feet)	Percent of Total
Barren	4,787	29.8			11,900	0.5%
Dryland Alfalfa	16,139	28.6			38,500	1.7%
Dryland Corn	233,039	22.8			443,000	19.6%
Dryland Small Grains	7,097	22.3			13,200	0.6%
Dryland Sorghum	2,660	22.2			4,900	0.2%
Dryland Soybeans	257,258	19.3			413,400	18.3%
Dryland Sunflower	47	20.0			100	0.0%
Irrigated Alfalfa	1,284	36.1	8.7	900	3,900	0.2%
Irrigated Corn	11,700	24.8	4.7	4,600	24,200	1.1%
Irrigated Small Grains	45	24.7	4.6	0	100	0.0%
Irrigated Sorghum (Milo, Sudan)	175	25.0	4.5	100	400	0.0%
Irrigated Soybeans	15,167	22.2	4.3	5,400	28,000	1.2%
Irrigated Sunflower	0	18.8	5.6	0	0	0.0%
Open Water	8,562	41.5			29,600	1.3%
Other Agricultural Land	31	21.4			100	0.0%
Pasture/Grassland	345,300	28.5			820,700	36.4%
Riparian Forest and Woodlands	79,273	39.8			262,900	11.6%
Roads	1,993	21.5			3,600	0.2%
Summer Fallow	163	12.9			200	0.0%
Urban Land	77,705	21.4			138,500	6.1%
Wetlands	5,303	45.1			19,900	0.9%
Total	**1,067,728**			**11,000**	**2,257,100**	

The following are notes further describing the data in Table 3-2 above:

- The total acreage of irrigated crops in Table 3-2 is 28,371 acres. The LPSNRD recently completed a process to certify irrigated acreage in the NRD. The total irrigated acreage identified during the certification process was 22,195.8 acres. It is possible that the cause of this discrepancy is inaccuracies inherent in the process used by CALMIT to determine irrigated and dryland cropping.
- The total acreage in the table is slightly less (712 acres) from the total LPSNRD acreage described in Section 3.1.1. The inconsistency resulted from small differences in GIS mapping coverages for land use and soil types. The small inconsistency does not impact the consumption estimates shown in Table 3-2.
- Urban water consumption in Table 3-2 reflects consumption from outdoor vegetation and urban landscapes and not consumption of water for indoor uses.

3.1.6.1 Rainfed and Irrigated Consumption

The consumption component of the water balance can be further broken down into the amount of rainfed consumption by dryland and irrigated crops and native vegetation and by consumption of supplemental irrigation. The net irrigation requirement was considered to be the amount of water consumed by irrigated crops that is in addition to the precipitation supply that is consumed. For example, a field of irrigated corn will consume a certain amount of the precipitation provided to it. While the precipitation supply in the LPSNRD is generally adequate to reliably produce agricultural crops, there are times within growing seasons or during longer term drought when the precipitation supply is not adequate to meet the full water requirements of the crop. The amount of additional water that is needed to meet the full consumptive needs of the crop is the net irrigation requirement, which is also referred to in this report as "consumption provided by supplemental irrigation." Table 3-3 summarizes the total rainfed consumption for cropland, grassland, and native vegetation (consumers of precipitation) and also for supplemental irrigation.

The data shown in Table 3-3 are relatively consistent with findings from other studies (Bentall and Shaffer, 1979; Shaffer, 1972).

Table 3-3. Components of Average Annual Consumption (1949 to 2010) based on 2005 Land Use in the LPSNRD

	Amount (KAF)	Percent of Total Consumption
Rainfed Consumption by Crops and Native Vegetation	2,246	99.5%
Consumption Produced by Supplemental Irrigation	11	0.5%
Total	2,257	100.0%

3.1.7 Surface Water Outflows

Surface water flow data were obtained from USGS streamflow gages. Surface water outflows were considered to be flows exiting the LPSNRD boundary. In many cases, flow data in minor creeks and streams were not available at the district boundaries along the Platte and Missouri Rivers. Stream outflows in these areas were estimated based on the procedures described in Section 2.3.2.

Streams and gages used in estimating surface water outflow for the LPSNRD are shown in Figure 2-2. Average annual outflows for streams in the LPSNRD are shown in Table 3-4.

Table 3-4. Average Annual Surface Water Outflows for the LPSNRD (1980 – 2010)

Gage Name	Average Annual Flow (acre-feet)
Salt Creek at Greenwood, Nebraska	306,000
Weeping Water Creek near Union, Nebraska	89,000
Ungaged surface water outflows	124,000
Total	519,000

Table 3-4 shows stream outflows averaged over a shorter time period than averages calculated for other water balance components. Review of streamflow data in the LPSNRD showed that a change occurred in the relationship between precipitation and streamflow in the early 1980s (see further description in Section 3.3). The time period over which streamflow data was averaged in Table 3-4 reflects the current regime of precipitation and streamflow.

3.1.8 Subsurface Outflows

The same assumptions regarding subsurface inflows described in Section 3.1.4 was used for subsurface outflows. The discussion in Section 3.1.4 is repeated below.

Because of the nature and location of groundwater aquifers in the LPSNRD, there is little opportunity for significant groundwater flow across the NRD boundaries. The exceptions to this may be in the Platte and Missouri River alluvial aquifers. The groundwater flow in these aquifers is likely dependent on the level of river flow (which is outside the control of the NRD) and is likely to be in some form of long term equilibrium. For these reasons, boundary groundwater inflows and outflows are likely to be very small relative to other water balance components and are very likely to cancel each other out within the water balance. They are assumed to be negligible for the purpose of this report.

3.1.9 Change in Groundwater Storage

As described in Section 2.3.5 two sets of mapping were evaluated to assess changes in groundwater storage in the LPSNRD. Long term changes in groundwater storage were quantified using mapped changes in groundwater levels over the predevelopment to spring of 2010 time frame. More recent changes in groundwater storage were assessed using mapped groundwater level changes over the spring of 2000 to spring of 2010. Results of these assessments are shown in Table 3-5. The mapped groundwater level changes are shown in Figure 3-6.

Table 3-5. Change in Stored Groundwater Volume over Various Time Periods

Time Period	Change in Groundwater Storage (acre-feet)
Predevelopment to spring of 2010	-30,000
Spring of 2000 to spring of 2010	-44,000

The data in Table 3-5 suggest that a greater loss of stored groundwater occurred during recent time periods as compared with the longer time period of predevelopment to 2010. While this seems illogical, it is possible that the spring 2000 groundwater levels were generally higher than groundwater levels in the 1950s (the time period that is generally accepted to be representative of predevelopment conditions).

For the purposes of the water balance, long term losses and trends in groundwater storage losses were assessed. In a long term water balance, persistent losses in groundwater storage would be significant. However, short term losses followed by short term recoveries of stored groundwater would tend to be offsetting in the context of a long term water balance. While the data in Table 3-5 suggest that stored groundwater in the LPSNRD is generally decreasing, additional research was conducted to evaluate whether the decrease was due to observed conditions over the specific time frame of measurement or if the decrease is persistent.

Several monitoring well records obtained from the USGS were reviewed to assess whether groundwater levels are trending downward in certain parts of the LPSNRD. The well records indicate that groundwater levels have been persistently declining in the northwest and southwest portions of the LPSNRD in the parts of the Dwight-Valparaiso and the Crete-Princeton-Adams groundwater reservoirs. In addition, the observed decrease over the 2000 to 2010 timeframe appeared to be representative of the general trend in groundwater storage decreases. For the purpose of the water balance, a rate of groundwater storage decline corresponding to the spring of 2000 to spring of 2010 rate was adopted. The average rate of groundwater storage decline over this timeframe was 4,400 AF/year.

3.1.10 Change in Surface Water Storage

Surface water storage data for the flood control reservoirs within the LPSNRD were obtained from the USACE as described in Section 2.3.6. The total annual amount of water stored in the reservoirs between 1993 and 2010 is shown in Figure 3-7. Branched Oak Lake and Pawnee Lake are the largest storage facilities, and show prominently on the figure. Storage amounts for the remaining lakes are less, and lines depicting their annual storage amounts are clustered at the bottom of the figure.

Figure 3-7 shows that total storage amounts generally declined over the 1993 to 2010 timeframe. The average annual decline in water stored in the flood control reservoirs is approximately 350 AF. For the purposes of the water balance, a storage decline of 1 KAF/year was adopted. The amount of annual decline in surface water storage adopted for the water balance is very conservative based on the data provided by the USACE, but it is insignificant relative to the magnitude of other water balance components.

According to the U.S. Corps of Engineers, water level management structures installed by the Nebraska Game and Parks Commission (NGPC) have impacted the amount of storage in the flood control reservoirs. The NGPC uses the water level management structures to periodically decrease water levels in the reservoirs to encourage growth of aquatic vegetation and to enhance overall aquatic habitat.

There are other small water bodies (i.e. farm ponds) within the URNRD, however storage in these water bodies is not measured or reported. It was assumed for the purpose of this study that the change in the amount of water stored in small farm ponds is insignificant on an annual or average annual basis.

3.2 Average Annual Water Balance Based on Current Land Use

Using the input data and analysis process described above and the form of the water balance shown in Equation 3, an average annual water balance was developed that reflects current (2005) land uses in the LPSNRD. The water balance based on 2005 land uses was meant to represent the current balance of supplies and demands and could provide insights as to what may be expected if current land uses and climactic trends persist into the future. Table 3-6 shows the components of the average annual water balance based on current land uses.

Table 3-6. Components of the Average Annual Water Balance Based on Current Land Uses in the LPSNRD

	Amount (KAF)	Period of Assessment
Inflows		
Precipitation	2,729	1980-2010
Surface water inflow	0	
Subsurface inflows	0	
Imported Water	40	1988-2010
Total	**2,769**	
Outflows		
Consumption	2,220	1980-2010 (based on 2005 land use)
Surface water outflow	395	1980-2010
Minor tributary outflow	124	1980-2010
Subsurface outflow		
Total	**2,739**	
Change in Storage		
Groundwater storage	-4	2000-2010
Surface water storage	-1	1993-2010
Total	**-5**	
Remainder	**35**	

Some components of the average annual water balance were assessed over different time periods to better reflect long term supplies and demands under current land uses (see Table 3-6 for the assessment time period used for each component). Most of the water balance components, however, were averaged over the 1980 to 2010 time frame. The precipitation component was assessed over this timeframe, because gaging records suggest that precipitation has increased and the relationship between precipitation and runoff changed in the early 1980s (see Section 3.3 for more details). Surface water outflows appear to have increased since the 1980s (see Section 3.3 for more details), and the average surface water outflow over the 1980 to 2010 time period was included in the water balance. Consumption was estimated using 2005 land uses projected over a long historical record of climatic conditions. Average levels of consumption over the 1980 to 2010 time period were adopted for the average annual water balance. The resulting estimate reflects expected levels of consumption if current land uses and climatic conditions persist into the future, and it incorporates wet, dry, and normal years. The rate of change in groundwater storage can vary depending on changing land use practices. For example, increases in groundwater irrigated land can accelerate consumption of groundwater supplies. A more recent time frame was used to assess changes in groundwater storage. Average annual changes in surface water storage were minimal and reflect a longer time period.

3.2.1 Observations on the Average Annual Water Balance

Several observations can be made on the data in Table 3-6:

- The remainder is approximately 35,000 acre-feet per year. While this appears to be a high number, it is relatively small in comparison to total inflows or outflows (1.3%). The relatively low remainder suggests that the water balance is "closing" well and that the water balance components were quantified with an adequate degree of accuracy for the purposes of this report. However, the remainder does indicate that there is measurement or estimation error and uncertainty in the water balance components. The positive remainder suggests that the inflow estimate was too high, the outflow estimate was too low, or that the change in storage was overestimated. It is likely that a combination of all three of these factors has occurred. Potential sources of error include:
    - Consumption values may not fully reflect evaporative losses from smaller scale soil and water conservation measures such as terraces, filter strips, or the degree of no-till or minimum till implementation. In addition, consumption on irrigated lands was estimated based on the full irrigation demand of crops. The impacts of potential errors in consumption estimates from conservation measures and less than full irrigation may offset each other to some degree.
    - The eastern part of Nebraska receives more precipitation than western parts of the state. As a result, runoff occurs more frequently and in greater annual amounts than in the western Nebraska. Runoff from precipitation accumulates in roadside ditches, in farm ponds, and in wetlands. Evaporation of ponded runoff was quantified through this study to the extent that CALMIT land use data included wetlands and bodies of open water in ponds and reservoirs. However, it is possible that small bodies of water (such as roadside ditches) with higher annual rates of consumption associated with evaporation were not fully captured in the processes used for this study.
    - Processes used by CALMIT to identify different land uses in 2005 were reported to be approximately 81% accurate. Misidentification of land uses could lead to inaccurate estimates of consumption on some fields. Comparisons of CALMIT land use data were made with land use data from other sources. These comparisons are described below:
        - The total acreage of irrigated crops in Table 3-2 is 28,371 acres, which is based on CALMIT land use data. The LPSNRD recently completed a process to certify irrigated acreage in the NRD. The total irrigated acreage identified during the certification process was 22,195.9 acres. The possible cause of this discrepancy is inaccuracies inherent in the process used by CALMIT to determine irrigated and dryland cropping.
        - 2005 land use data for Lancaster County obtained from the National Agricultural Statistics Service (NASS) was compared with 2005 CALMIT land use data in Lancaster County. The table below shows differences in land use categorizations between these two data sources.

Table 3-7. Comparison of 2005 CALMIT and 2005 NASS Land Use Data in Lancaster County

Land use category	CALMIT Acreage	NASS Acreage
Total Irrigated Land	14,777	15,200
Corn (irrigated and dryland)	96,506	129,500
Soybeans (irrigated and dryland)	113,581	124,700
Sorghum (irrigated and dryland)	3,174	4,800
Alfalfa (irrigated and dryland)	6,232	36,500
Small Grains (dryand)	7,041	8,400
Total Cropland	226,534	303,900

The data in the table show similar amounts of overall irrigated acreage using the two methods. However, the two methods showed significant discrepancies when comparing different types of cropland. Corn acreage estimated using CALMIT data was approximately 30,000 acres less than the estimate in NASS. Alfalfa estimates were significantly different as well. As stated previously, the CALMIT land use identification process was estimated to be 81% accurate and would account for part of the discrepancy. In addition, NASS data was compiled using survey responses from farmers and statistical methods, and there are estimation errors in the NASS data. It is unknown which data source more accurately reflects actual land uses in Lancaster County. However, the discrepancies in the methods highlight a potential area for additional research.

- It is possible that estimates of consumptive use associated with pasture and grassland are less accurate than with dryland or irrigated crops. Vegetative cover on agricultural fields tends to be relatively uniform, whereas vegetative cover in uncultivated areas may be uneven and populated with different types of vegetation. As a result, there may be more error associated with consumption estimates on uncultivated lands than on crop lands.
  - Tall prairie grass crop coefficients were used to estimate consumption on pasture and grasslands. The crop coefficients were developed on grasslands that were not grazed or hayed. Pasture and grasslands that are grazed or harvested would consume less water than grasslands with taller, unmanaged grasses. Consumption estimates for pasture and grassland may be overstated to some extent in areas where grasses are more intensely managed.
- Inaccuracies associated with statistical relationships used to estimate minor tributary outflows could be contributing to the remainder. However, the amount of minor tributary outflow from these streams is a smaller component of the water budget.

- Direct precipitation falling within NRD boundaries and consumption (direct evaporation from open water and evapotranspiration from land surfaces) are by far the largest components of the water balance. Precipitation is approximately 99% of the total water supply to the LPSNRD, and consumption is 81% of the total outflow.

3.3 Changes in Streamflow

The LPSNRD is interested in how streamflow has been impacted by the growing footprint of urban areas in the NRD and overall changes in land uses. In addition, the NRD would like to understand how potential climate change may impact the water budget. The scope of work for this project included examining the potential impacts of urbanization and climate change.

To begin these evaluations, Brown and Caldwell developed double mass curves that relate cumulative precipitation in the drainage area above a gaging station to the cumulative runoff through the gaging station. The double mass curves will indicate whether a change in the relationship between the two parameters has changed over time. The curves could be a useful tool to identify increases in streamflow that have resulted from larger and larger areas of impervious land associated with the development of urban areas.

A double mass curve was developed for the Salt Creek stream gage at 27th Street in Lincoln (see Figure 3-8). This stream gage is just downstream of the Theresa Street wastewater treatment plant, and much of the urban drainage area in Lincoln lies above this gage. Changes in annual runoff amounts from urbanization and changes in the amount of water used for municipal purposes could potentially be observed in this gaging station. Figure 3-8 shows a fairly consistent relationship between cumulative streamflow and cumulative upstream precipitation until the early 1980s. In the early 1980s the double mass curve suggests that the relationship between precipitation and streamflow changed and that more runoff occurred per unit of precipitation after the change than before.

Double mass curves were developed for several other stream gages to examine whether the change in the precipitation/streamflow relationship occurred throughout the LPSNRD or whether the change was restricted to gages downstream of urban areas. Double mass curves were developed for Salt Creek at Greenwood (downstream of Lincoln, see Figure 3-9), Salt Creek at Roca (upstream of Lincoln and in a rural area, see Figure 3-10), Stevens Creek near Lincoln (east of Lincoln and in a rural area, see Figure 3-11), and Weeping Water Creek at Union (in the eastern part of the LPSNRD and in a rural area, see Figure 3-12). Each of the double mass curves shows a similar change in the early 1980s or late 1970s in the relationship between streamflow and precipitation. Because all of the double mass curves exhibited a change in the precipitation/streamflow relationship and many of these curves were developed for streamflow gages with rural watersheds, changes from rural to urban land uses are not the sole contributor to the change in the precipitation/streamflow relationship.

The USGS was contacted regarding the change in the precipitation/streamflow relationship. In particular, the USGS was asked whether streamflow measurement technology changed in the late 1970s or early 1980s and if this could be the reason that the precipitation/streamflow relationship appeared to change. USGS staff reported that there was not a change in streamflow measurement technology in the early 1980s, but that they have observed a change in the precipitation/streamflow relationship in gages across the Midwest. The changes in streamflow have been documented in several references. Anderson and Norton (2007) examined streamflow records for several gages in the Missouri River basin and found that streamflows had exhibited an increasing trend in the eastern part of the basin from 1957 to 2006. Streamflows decreased in several gages the western and northwestern part of the basin. McCabe and Wolock (2002) examined streamflow data at 400 sites across the conterminous U.S. over the 1941 to 1999 time period and found that a noticeable increase in annual minimum and median daily streamflow occurred in the early 1970s, primarily in eastern U.S. gages. They also examined whether the change occurred gradually or in a stepwise fashion and found that the change occurred as a step change that coincided with increases in precipitation.

Increases in annual precipitation have been observed in eastern Nebraska. The U.S. Environmental Protection Agency (EPA) documented increasing precipitation trends in a paper describing potential impacts of climate change in Nebraska (EPA, 1998). In the paper, the EPA describes observations of average annual precipitation that have shown 5% to 10% increases over the 1900 to 1996 time period in the eastern part of Nebraska. Precipitation observations showed decreasing trends in the western part of the state. Precipitation trends for two of the weather stations used in this study (the Lincoln and Nebraska City stations) were plotted and are shown in Figure 3-13. Over the 1948 to 2010 time period, annual precipitation amounts have shown an increasing trend in those weather stations.

In addition to increased amounts of annual precipitation, land and water use changes can impact streamflows. Several sources of data were obtained and assessed to investigate their potential role in changing streamflow trends.

Regional changes in land use were evaluated using annual data describing agricultural land use for Lancaster County obtained from NASS and annexation data provided by the City of Lincoln. Annexation data was provided as a GIS map showing the areas that have been annexed by Lincoln and the years of annexation. The data are summarized in Figure 3-14. It is unknown whether the annexed areas were developed or undeveloped when they were annexed. As a result, the annexation mapping shown in Figure 3-14 should be interpreted as depicting a general trend in growth of the urban footprint. The general trend in urban land use and annual NASS data showing trends in cropping and agricultural land use for Lancaster County are shown in Figure 3-15. Figure 3-15 shows increasing areas of urban land use and an increasing trend in the acreage of soybeans in Lancaster County starting in the early 1980s.

In the mid 1970s, the total amount of cropland in Lancaster County increased by approximately 15% to 20%. The conversion of grassland or pasture to cropland and the increasing trend in soybean cultivation (which has lower consumptive use and higher runoff and erosion potential) could be an additional driver for increasing trends in streamflow. Note that these trends are reflective of Lancaster County only and not the entire NRD. The investigation of land use changes and their impact on streamflow primarily focused on Lancaster County and the expanding urban footprint of Lincoln.

Changes in urban land use and increased need for municipal water supplies could also positively impact streamflows as more water is discharged through wastewater treatment plants. Data from the Lincoln Water System and the Lincoln Wastewater System were obtained to investigate trends in municipal water use and discharge from wastewater treatment plants. Unfortunately, data were not available prior to the observed change in the precipitation/streamflow relationship, and the impact of municipal water usage could not be evaluated as a driver for the change. Figure 3-4 shows the annual pumpage at Lincoln's Ashland Wellfield from 1988 to 2010. The figure shows a somewhat increasing trend in wellfield pumping that is likely heavily influenced by the drought in the early 2000s and heavier pumping from the wellfield. Discharge from Lincoln's Theresa Street and Northeast wastewater treatment plants for the years 1987 through 2010 are shown in Figure 3-16. The total discharge of the two wastewater treatment plants shows a generally increasing trend. In the late 1980s the total discharge from the wastewater treatment plants was around 26,000 AF/year, and in the late 2000s, the annual discharge amounts had climbed to approximately 30,000 AF/year. Although relatively small, this change has increased the amount of streamflow leaving the NRD over time.

Conversion of agricultural and native landscapes to urban land uses can impact the volume of stormwater runoff that reaches streams. The City of Lincoln and the LPSNRD produced a summary diagram of potential increases in stormwater runoff with urbanization that is available on the City of Lincoln's website (http://lincoln.ne.gov/city/pworks/watrshed/educate/runoff/). The diagram suggests that runoff volumes from natural ground cover may range from 0% to 20% of precipitation with infiltration amounts of 80% to 100%. The diagram also shows approximate percentages of runoff volume increases with increasing intensity of urban development and impervious areas. For example, urban residential areas may have runoff percentages of 40% to 70% of precipitation with infiltration amounts ranging from 30% to 60%. Increasing urbanization and impervious land surface impacts both runoff volumes and peak runoff rates, which increase streamflow and the potential for flooding and erosion problems.

The City of Lincoln and municipalities across the U.S. have analyzed the impacts of urbanization on streamflow and have implemented stormwater management programs to reduce the potential for flooding and erosion potentially caused by urbanization. These programs are focused on implementing best management practices to reduce peak flow rates and also maintaining runoff volumes at pre-development levels. The City of Lincoln requires that peak stormwater runoff rates in newly-developed areas match pre-development peak runoff rates. In addition, the City of Lincoln encourages the use of Low Impact Development techniques to not only reduce peak runoff rates, but to also reduce overall runoff volumes from urbanized areas to levels commensurate with pre-development conditions. In summary, current stormwater management programs and policies are directed at mitigating potential harmful increases in streamflow that result in potential erosion and flooding due to the expanding urban footprint of the City of Lincoln.

3.3.1 Summary of Changes in Streamflows

Figures 3-8 through 3-12 show that the amount of streamflow as a percentage of precipitation has increased through the period of study. The approximate increases in streamflow are shown in Table 3-8 for the gaged stream outflow locations used in this study.

Table 3-8. Changes in Annual Streamflow Volume since the Early 1980s for Gaged Outflow Locations in the LPSNRD

Gaging Station	Streamflow as a Percentage of Precipitation Prior to Early 1980s	Streamflow as a Percentage of Precipitation After Early 1980s	Approximate Annual Increase in Flow Volume after Early 1980s
Salt Creek at Greenwood	14%	19%	100,000 AF
Weeping Water Creek at Union	14%	20%	30,000 AF

The data in Table 3-8 show that overall gaged stream outflows from the LPSNRD have increased in total volume, but the percentage of streamflow relative to precipitation amounts has increased as well. The increasing trend in annual amounts of precipitation shown in Figure 3-13 and cited in other studies has contributed to increased annual volumes of runoff. In addition, it is possible that increased antecedent moisture in the soil profile from increased rainfall, changes in cropping patterns and impacts of urbanization have all contributed to the increase in percentage of streamflow relative to precipitation amounts. Because these drivers of increased streamflow have occurred simultaneously, it is difficult given the scope of this project to identify the specific impacts of each driver. However, it is likely that increases in precipitation have been the primary driver for increased streamflow.

Section 4

Summary

4.1 Completion of Project Objectives

The components of the water balance were inventoried, and the water balance for the LPSNRD was quantified successfully with a relatively small remainder. The database of information compiled for this study will provide a tool for describing the water supplies and water demands specific to the LPSNRD. The inventory and water balance data and information developed for this project are the primary work products associated with this study. A secondary value that this report provides is information regarding relationships of various water balance components. Understanding these relationships should be beneficial to stakeholders in identifying opportunities for achieving water management goals that will be developed as a part of the IMP.

4.2 Data Comparisons and Improvements

Some of the estimates for components of the water balance were compared with estimates for those components that have been conducted using different methods. For example, Dr. Jozsef Szilagyi, Research Hydrologist at the University of Nebraska, has been conducting spatially distributed estimates of consumption in Nebraska using the Complementary-Relationship-Based Evapotranspiration Mapping (CREMAP) method. CREMAP uses daytime surface temperature (acquired via satellite) and atmospheric data (mean air temperature, humidity, sunshine radiation, etc.) to estimate latent heat flux on a monthly timestep (Szilagyi, et al., 2011). Figure 4-1 shows mapping of average annual consumption (2000 through 2009) for the entire state of Nebraska. Dr. Szilagyi provided CREMAP estimates of consumption for 2000 through 2009 for the LPSNRD. He also provided estimates of precipitation for the same time period. Precipitation data were obtained from the PRISM database and are at a 2.5 minute aerial resolution. Table 4-1 shows a comparison of precipitation and consumption estimates averaged over the 2000 to 2009 time period using both CREMAP and the methods described in this report.

Table 4-1. Comparisons of Consumption and Precipitation Derived by Different Methods

Avg. Annual CREMAP consumption (2000-2009) (KAF)	Avg. Annual Consumption based on methods in this report (2000-2009) (KAF)	Consumption Ratio (CREMAP/this study)	Avg. Annual Precipitation from PRISM database (2000-2009) (KAF)	Avg. Annual Precipitation based on methods in this report (2000-2009) (KAF)	Precipitation Ratio (PRISM/this study)
2,244	2,154	0.97	2,531	2,585	1.02

Table 4-1 shows that estimates of consumption and precipitation were very similar in each method, and estimates using both methods are likely adequate for identifying potential management opportunities and comparing alternatives. The two methods were not analyzed to assess the reason for the differences or to determine which methodology yields more accurate results. It should be noted that the CREMAP method estimated higher average annual amounts of consumption, which tends to agree with the observation described in Section 3.2.1 that consumption may be slightly understated because of unquantified evaporative losses from runoff stored in small impoundments such as roadway ditches and small farm ponds. Another potential reason for differences in the methods is that this study relied on 2005 CALMIT data for land uses and assumes those land uses represent existing conditions. CREMAP results reflect consumption from actual land uses during the 2000 to 2009 time period. Differences between the two methods could occur if land uses during the 2000 to 2009 time period varied from those in 2005 that were used for this study.

Both the method used in this study and the CREMAP method for consumption quantification provide a tool for the LPSNRD to improve its understanding of the hydrology in the NRD. The method used for this study (based on CropSim) provides a tool to quantify consumption specific to various land use types in the area and to devise consumption trade off opportunities among the various land uses. However, because the information used to develop consumption estimates (CALMIT land use, CropSim output, etc.) is not available in "real-time," it is not easy to develop regular, current estimates of consumption in the basin. CREMAP is a tool that could be used for this purpose.

4.3 Summary of Observations on the Water Balance and Recommendations

Throughout this report, several observations were made regarding trends in water balance components. Many of these observations are summarized below.

- Annual precipitation amounts in the LPSNRD vary and have generally increased since the 1950s. Prior to 1980, the annual precipitation amount for the LPSNRD averaged 2,630 KAF/yr (estimated over the 1948 to 1979 timeframe). From 1980 to 2010, annual precipitation amounts averaged 2,729 KAF/yr, which is 99 KAF/year more than the 1948 to 1979 average.
- The data in Table 4-1 shows that the 2000-2009 average annual precipitation was approximately 2,560 KAF while the 2000-2009 average consumption is about 2,200 KAF (considering both the CREMAP method and the methods used for this report). The resulting ratio of consumption to precipitation is 0.86, which suggests that under current land uses the LPSNRD is consuming about 86% of its available supply leaving about 14% available for groundwater recharge, streamflow out of the NRD, and to support future development needs. Note that imported water from the Platte or Missouri Rivers, to the extent that they could be developed, could provide additional supplies.
- Streamflow out of the LPSNRD has increased over the time period of the study. The relationship between streamflow and precipitation appears to have changed in the early 1980s or late 1970s. Increases in streamflow have been observed in areas of the Midwest by other researchers. Gaged outflows from the LPSNRD have increased by approximately 130 KAF/yr since the early 1980s. Both increased precipitation and the change in the precipitation/streamflow relationship have contributed to this increase.
  - Average annual precipitation volumes increased by 99 KAF/yr after the early 1980s, but stream outflows increased by 130 KAF/yr during the same time period. The higher stream outflow compared to precipitation suggests that land use changes and changes in the timing and intensity of rainfall have also contributed to increases in stream outflows.
  - The increase of gaged outflow does not include streamflow increases from ungaged, small tributaries. It is likely that those outflows have increased as well.
  - The increase in gaged outflow was assessed on annual time steps. It may be beneficial to research streamflow and precipitation changes on monthly time steps to evaluate whether changes have occurred on a seasonal basis. In addition, it may be useful to evaluate long term changes in the duration and intensity of storms.

- Hydrologic drivers for the change in precipitation and runoff could be investigated to understand (if possible) the potential reliability and permanence of observed increases in precipitation and runoff.
- The IMP stakeholders may choose to consider the 130 KAF/yr of increased streamflow as a "block" of new water that has developed over recent time periods and that could be allocated to offset new water uses, partially mitigate groundwater declines by implementing conjunctive use strategies, etc. Some stakeholders or interested parties, however, may view the increase in streamflow as part of the historical hydrologic record and not a "new" source of supply.
- The IMP stakeholders should consider additional monitoring and data collection programs to better assess streamflow and land use conditions and to track changes over time. Streamflow and land use changes are important because stream outflows go to satisfying external demands of the LPSNRD, and changes in land use (including implementation of water conservation measures) can impact stream outflows. More comprehensive monitoring of these components will help the LPSNRD better understand relationships between streamflow and land use and will aid in developing strategies for meeting internal and external water demands.

- The specific contributions of urban water use, runoff increases from urbanization, and NRD-wide changes in agricultural land use are potential contributors to increases in streamflow. However, because these impacts have occurred concurrently and with increases in precipitation, it is difficult to identify their specific role in streamflow increases. Further research may be needed to identify the role and extent of these drivers.
- The average annual precipitation amount in the LPSNRD generally equals or exceeds annual crop water requirements and long term, regional groundwater level declines are not as prevalent as in parts of western Nebraska. Irrigation provides supplemental water to meet crop growth and development needs but does not generally increase the average annual groundwater consumption beyond the regional long term recharge potential. In this case, irrigation simply acts as an insurance policy to address climatic variability and not as a source for significant additional consumption on an NRD-wide basis. However, this does not mean that areas of over pumping cannot exist. When crops such as alfalfa or pasture are irrigated and where the crop water requirement significantly exceeds average annual precipitation supplies, declines may still occur. Withdrawals for municipal and industrial uses can also lead to groundwater level declines, especially when return flows or effluent is discharged directly to a stream. Where long term groundwater level declines occur it can be valuable to understand on a finer scale exactly what is happening and determine how the declines may be addressed. In these areas, it may be beneficial to derive smaller scale water balances to improve the understanding of local water supply and management needs.
- The LPSNRD is in the eastern part of Nebraska and receives more rainfall supply than most NRDs. As a result, the LPSNRD also has more available streamflow than many NRDs. Rainfall and associated streamflow is a renewable source of water supply. During wet periods in the hydrologic cycle, the amount of precipitation that the LSPNRD receives is more than what is needed to meet consumption demands and stream outflow volumes are high. Conjunctive water management techniques may be a way to use precipitation supplies or excess stream outflows to mitigate shortages in non-renewable supplies such as stored groundwater. Methods to use excess precipitation supply by increasing infiltration and aquifer recharge could potentially be implemented (to the extent that they are not already implemented) to lessen long term mining of non-renewable groundwater resources. Smaller scale features or practices such as terracing, reduced tillage, constructed wetlands, etc. are potential ways to capture excess runoff and induce recharge. Excess streamflow could be stored in existing or new surface storage facilities or diverted into infiltration basins to recharge the groundwater aquifer (provided that intentional recharge is feasible given the hydrogeologic conditions in the LPSNRD). Surface water stored in reservoirs or in the groundwater aquifer could be released or pumped during

dry times when streamflows are low. With an understanding of water demands and the variability of water supplies, conjunctive water management could potentially be helpful in the development of future water management strategies.

- Understanding the water balance will help the LPSNRD develop management plans to address internal demands (water supply needs within the NRD) and external demands (downstream water needs that depend on outflows from the NRD). For example, it is likely that additional stream outflows described in Section 3.3 have been beneficial to external, downstream demands. Internal demands could be met by implementing conjunctive water management strategies or by developing trading mechanisms or consumption offsets that would maintain the overall consumption "budget" for the NRD while allowing new or different uses of water.

Section 5

Limitations

This document was prepared solely for the Lower Platte South Natural Resources District in accordance with professional standards at the time the services were performed and in accordance with the contract between the Lower Platte South Natural Resources District and Brown and Caldwell dated August 21, 2011. This document is governed by the specific scope of work authorized by the Lower Platte South Natural Resources District; it is not intended to be relied upon by any other party except for regulatory authorities contemplated by the scope of work. We have relied on information or instructions provided by the Lower Platte South Natural Resources District and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

Further, Brown and Caldwell makes no warranties, express or implied, with respect to this document, except for those, if any, contained in the agreement pursuant to which the document was prepared. All data, drawings, documents, or information contained this report have been prepared exclusively for the person or entity to whom it was addressed and may not be relied upon by any other person or entity without the prior written consent of Brown and Caldwell unless otherwise provided by the Agreement pursuant to which these services were provided.

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