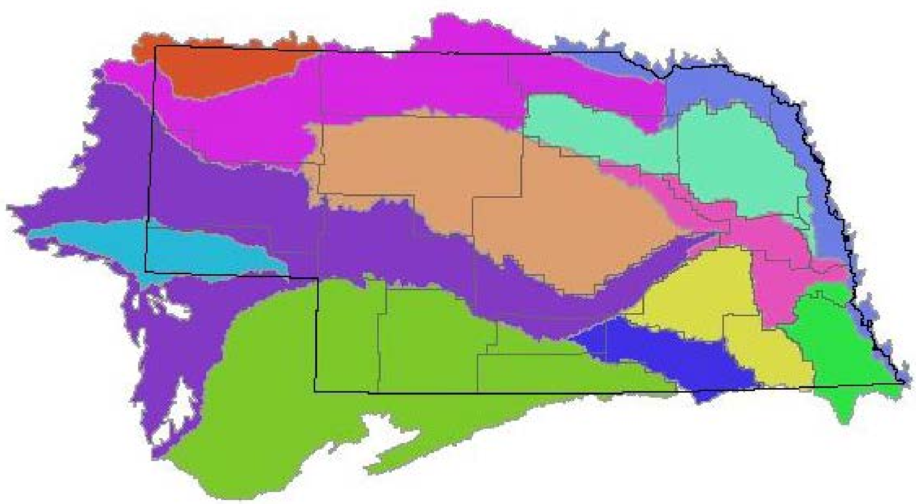
INSIGHT Methods



Nebraska
Department of Natural Resources

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1.0 Introduction

The Nebraska Department of Natural Resources (Department) focuses significant resources on the development of data and hydrologic tools to support required and voluntary integrated water management planning efforts, (provided for pursuant to *Neb. Rev. Stat.* § 46-715), as well as to support the proactive annual evaluation for areas of the state that are not currently fully appropriated (provided for pursuant to *Neb. Rev. Stat*. § 46-713). This document provides a description of the broad-based methodologies utilized by the Department to develop the data and hydrologic analyses for the Department's new website, INSIGHT. The INSIGHT website (http://dnr.nebraska.gov/insight/) displays the charts and data that result from this methodology. This document is intended for those users with sufficient background and training in hydrology and water resources management.

The INSIGHT website provides various levels of data and information in regard to water quantity within the state. Basin and subbasin level summaries that include: 1) the streamflow water supplies available for use, 2) the current amount of demand on these supplies, 3) the long-term demand on these water supplies due to current uses, 4) the projected long-term demand on these water supplies, and 5) the balance between these water supplies and demands are provided in INSIGHT. Additionally, INSIGHT provides access points to the data, hydrologic tools, supporting documentation, and models necessary to perform the calculations and analyses that are further detailed in this document.

The first step in the methodology requires determining the quantity of available hydrologically connected water supplies. Hydrologically connected water supplies are aquifers and streams that are in close connection (figure 1.1).

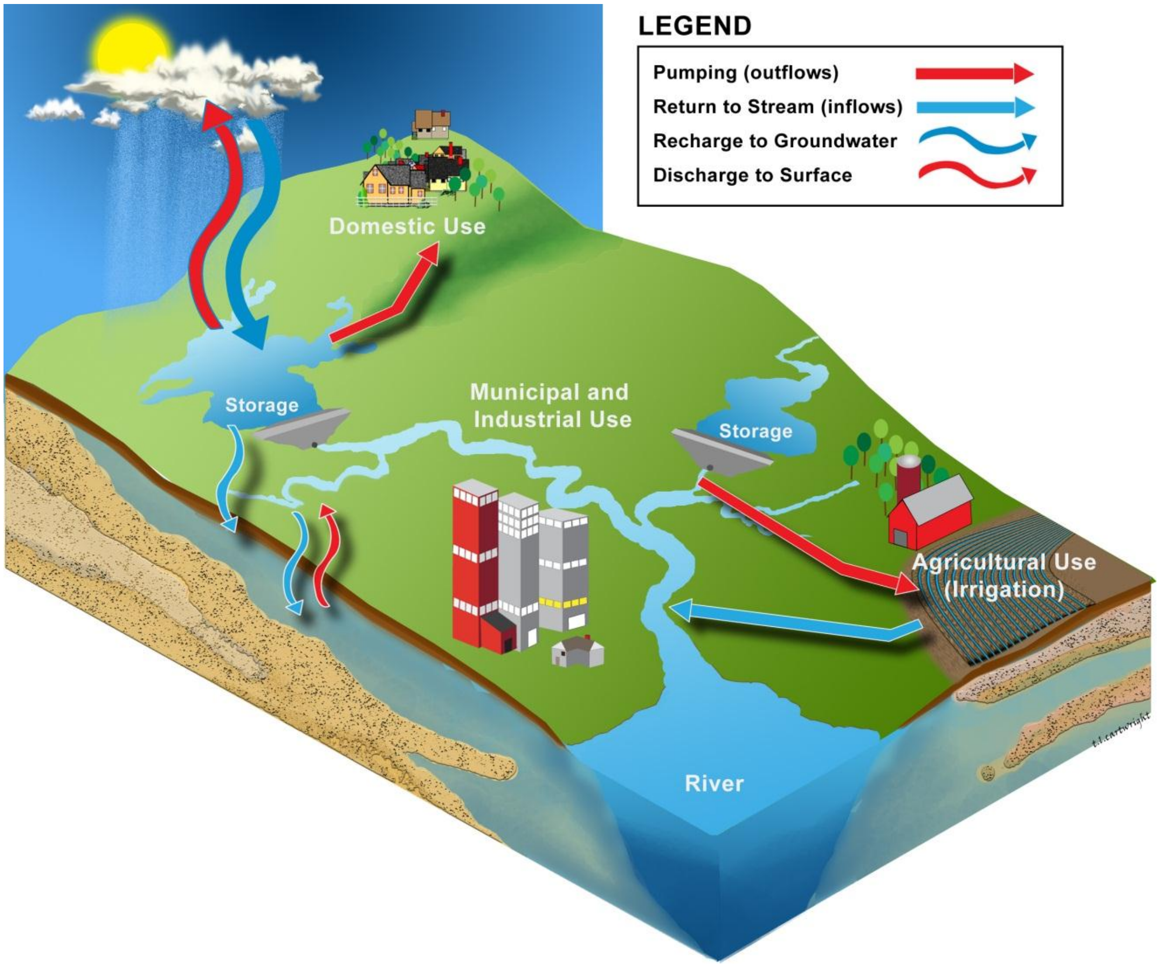

Figure 1.1: Schematic diagram illustrating the interconnected nature of a surface-groundwater system. The methodologies used in these analyses determine the water supplies and uses of these interconnected systems.

The methodology utilized the Basin Water Supply (BWS) concept in conjunction with Total Demand (TD) to determine the balance of water supply and water use[1]. The BWS recreates, at any defined timestep, the amount of streamflow water supply available for use, while the TD, at any defined timestep, recreates the total demand on streamflow water supplies, including those demands that may not always be met. The comparison of these two values is the basis for determining the balance of supplies and uses (figure 1.2). The TD may exceed the BWS in any given year due to removal of storage water from the system (e.g., from

[1] See *Water Matters: Integrated Water Management and the Basin Water Supply* for more information on the basin water supply concept.

reservoirs and aquifers); however, removal of storage water may result in a reduction of streamflow in either the near-term or long-term.

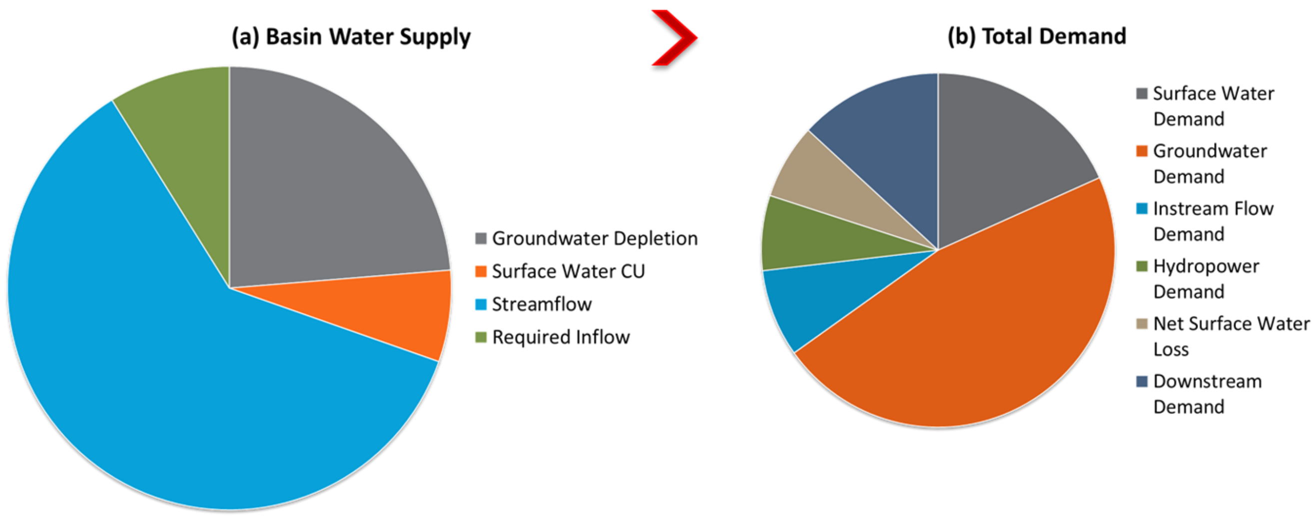

Figure 1.2: One way to visualize the BWS/TD methodology is to use pie charts to demonstrate the relative difference in volume between water supplies and water demands. The BWS is the hydrologically connected water available for use, while the TD is the current utilization of hydrologically connected waters. As long as the BWS pie chart remains larger than the TD pie chart, water supplies are adequate to meet water demands for a given reach and a given span of time.

This document is broken into four sections: 1) calculating BWS; 2) calculating TD; 3) calculating the balance of water supplies and water uses; and 4) examples of the calculations. Neither the details of these methodologies nor the data and tools utilized are meant to be static; the Department will continue to look for ways to improve these methods, improve model performance, and acquire information where data gaps may exist. These analyses provide essential water supply and water demand information as well as information on the potential water opportunities or challenges that lie within a given basin or subbasin.

2.0 Calculating the Basin Water Supply

The BWS represents the total volume of hydrologically connected streamflow originating within a system that is available to meet the TD within a specified timeframe. The BWS, or the volume of water available within a given season or year, varies considerably, mainly due to fluctuations in precipitation. Water from one season or year can only be available for use in subsequent years if a portion of it is captured in either groundwater storage (aquifers) or surface water storage (reservoirs).

The summation of streamflow, surface water consumptive use, and streamflow depletions from groundwater pumping (also referred to in this document as groundwater depletions) captures the total amount of hydrologically connected water available for use within a basin or subbasin (figure 2.1). The streamflow water supply that is available is represented by these three components plus "required inflow," i.e., the amount of water that is necessary to flow out of basins or subbasins upstream of a given location. Required inflow does not represent water that is required by law or permit, but rather water that is required under this methodology (see section 2.4 for more details). Thus, the BWS is calculated as follows:

BWS = Streamflow + Surface Water Consumptive Use + Groundwater Depletion + Required Inflow

Determining the volume of water for each of these components relies upon extensive data collection and/or modeling. A small listing of the types of data necessary to calculate the BWS includes time series or areal distributions of the following: stream gages, location of irrigated acres, county crop distributions, aquifer properties, soil types, precipitation, etc. For further temporal refinement of the evaluation, the results are subdivided into two sub-periods within the year: September 1 through May 31 (non-peak season) and June 1 through August 31 (peak season).

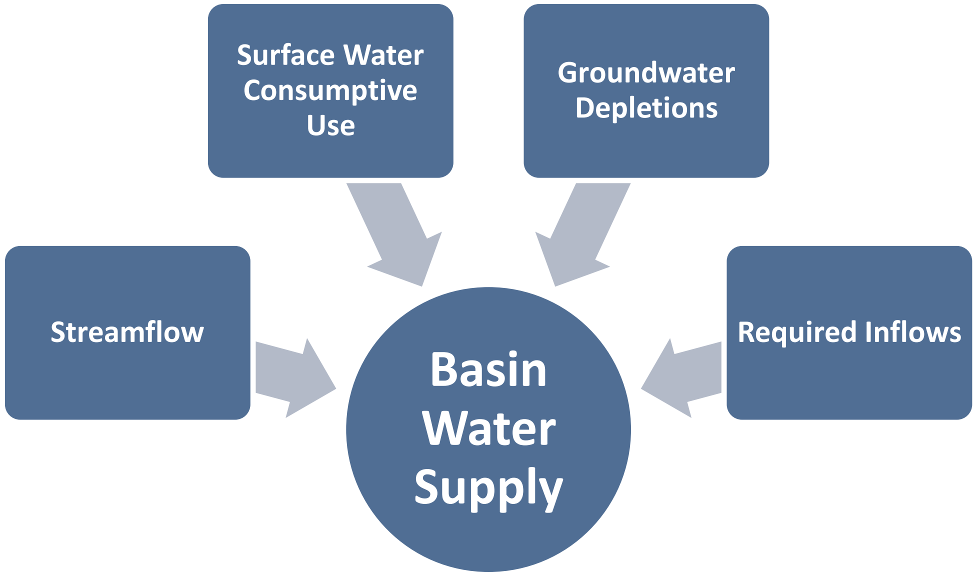

Figure 2.1: Basic components (Streamflow, Surface Water Consumptive Use, Groundwater Depletions, and Required Inflows) necessary to determine the Bain Water Supply. Each component will be detailed further in the document.

2.1 Streamflow

Both the Department and the U.S. Geological Survey (USGS) gage streamflows within the state, requiring utilization of both data sources of streamgage data for the analyses. The streamflow volumes, summed to the appropriate peak, non-peak, or annual seasons, represent the amount of water that originates within that particular subbasin or reach. If an upstream subbasin is present, the streamflow value is represented by the gain of the stream reach within the subbasin by subtracting the upstream gage value from the gage value representing this subbasin[2]. Nine subbasins had upstream subbasins and required use of reach gain calculations instead of directly using streamgage values (table 1). Streamgage data is unmodified except when high flow events are present in the record. Often, extreme flow events produce water that cannot be utilized or stored in either reservoirs or aquifer systems. Analyzing exceedance probabilities, which are based on flow probabilities, is a common method of determining the frequency of these types of events. Flow duration curves illustrate the probability of occurrence for each flow level. Many of the reach-gain flow duration

[2] This reach-gain method can produce negative values (reach losses) that may propagate through the methodology; however, these occurrences are rare and have largely negligible effects. Further consideration of these effects will be addressed in future revisions.

curves exhibit the form illustrated in figure 2.1. Figure 2.1 illustrates an inflection point where high flow volumes are exceeded with low frequency. The inflection point tends to occur around five percent exceedance probability. Thus, for this evaluation, the daily streamflow or reach-gain values with an exceedance probability of five percent or less were set to the value corresponding to the five percent exceedance probability. Figures 2.2 and 2.3 illustrate the analyses and resulting streamflow data from applying this cap.

Table 1: For each subbasin, the exceedance probability of its flow duration curve was evaluated based on either streamflow or reach-gain values.

Streamflow	Reach-gain
Bazile Creek	Niobrara River Box Butte to Gordon
Niobrara River Above Box Butte	Niobrara River Gordon to Sparks
Elkhorn River Above Norfolk	Niobrara River Sparks to Spencer
Big Blue River	Niobrara River Spencer to Verdel
Little Blue River	Elkhorn River Norfolk to Waterloo
North Loup River	Middle Loup River
South Loup River	Lower Loup River
	Lower Platte River Above North Bend
	Lower Platte River N. Bend to Louisville

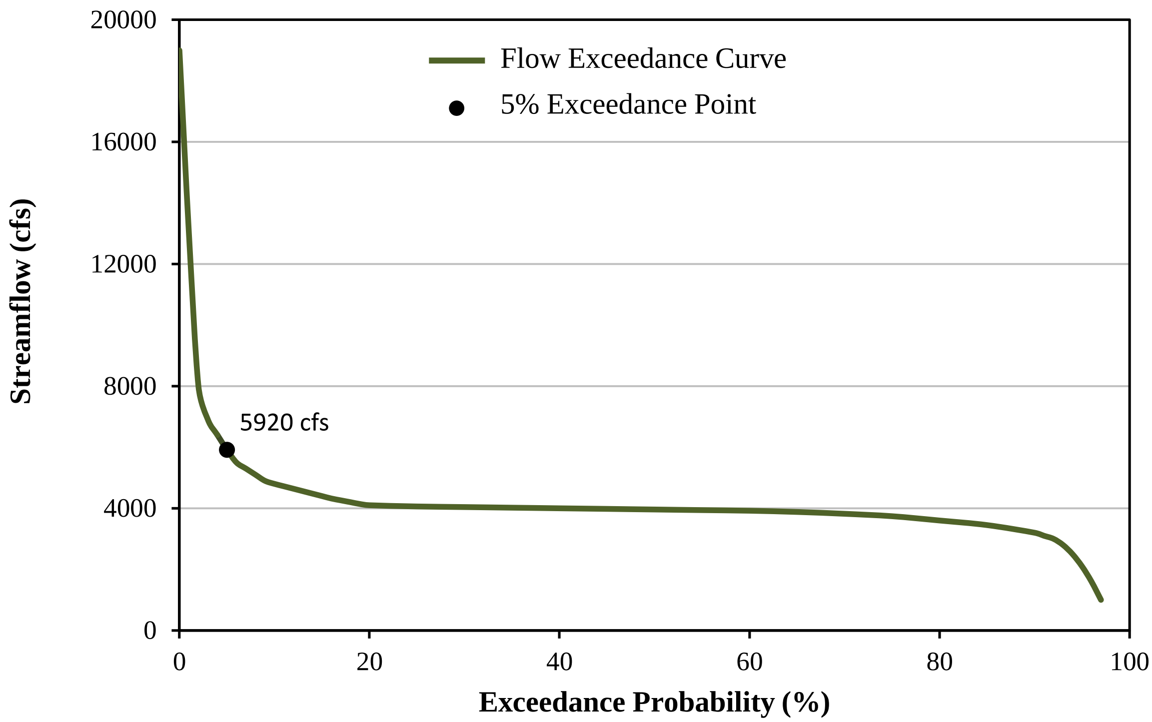

Figure 2.2: Example of a flow duration curve with an inflection point at five percent exceedance.

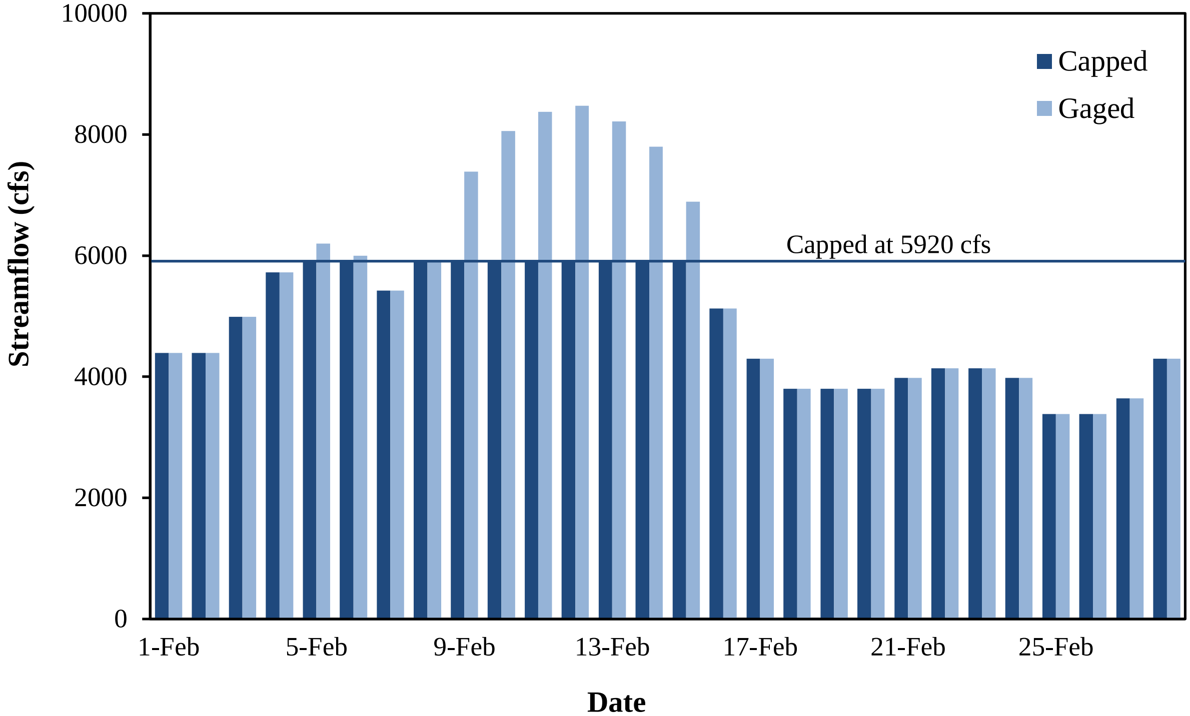

Figure 2.3: Example of using an exceedance probability plot for capping streamflows at five percent exceedance flow probability.

2.2 Surface Water Consumptive Use

Surface Water Consumptive Use (SWCU) is separated into four main use categories for the purposes of this evaluation: irrigation, municipal, industrial, and evaporation from large water bodies.

Some irrigation uses have data regarding the amount of water diverted on a daily, monthly, or seasonal basis, while other uses have very limited or no time series data. The following sections describe the methods required to calculate consumptive use for the surface water irrigation components. The methods are dependent upon available information for each water diversion point. Due to these data availability differences there are five equation types for calculating SWCU for irrigation.

There currently are no municipal and industrial water uses that rely on direct surface water sources. However, the cities of Lincoln and Omaha both hold surface water appropriations for induced groundwater recharge to supply water to their municipal well fields, which are included in the surface water consumptive use.

Recognizing that not all water diverted for use is actually consumed, the Department only considers the consumptive portion of the water diverted from surface water sources in these analyses. The total surface water consumptive use for a basin or subbasin, for a given timestep, is the sum of all of the points of diversion located in that basin or subbasin plus evaporation losses from large reservoirs (see section 2.2.1.4 for a listing of the reservoirs evaluated).

$$SWCU = SWCUI + SWCUE + SWCUM$$

SWCUI = surface water consumptive use for irrigation
SWCUE = surface water consumptive use for evaporation
SWCUM = surface water consumptive use for municipal purpose

2.2.1 Surface Water Irrigation

The SWCUI calculations are data dependent, meaning that the equations used to calculate the SWCUI are dictated by the detail of the data and information available for each point of diversion from the stream. The SWCUI calculations may include information regarding diversions; diversions and returns; diversions and deliveries; diversions, delivers, and returns; or permit data. This data comes from several main datasets: the Department's point of diversion records, land-cover, gaged diversions, gaged return flows, crop irrigation requirements, etc. The amount of data available for a point of diversion depends upon the category of surface water irrigation. Surface water irrigators fall into two general groups: small diverters and irrigation districts. Diversions by irrigation districts are generally measured and recorded daily by the Department, while the information available from many small surface water pumpers is only the permitted amount of diversion[3].

[3] Irrigation districts represent the largest portion of surface water consumption for irrigation.

Dependent upon the data available for each point of diversion, SWCUI calculations fall into five general categories:

Type 1) Canal Diversion Records, Direct Return Records, Field Delivery Records

Type 2) Canal Diversion Records, Field Delivery Records

Type 3) Canal Diversion Records, Direct Return Records

Type 4) Canal Diversion Records

Type 5) No Diversion Records – data on permitted acres (mostly small diverters)

2.2.1.1 Type 1: Canal Diversions, Direct Returns & Field Deliveries

Canal surface water consumptive use does not equal the full diverted amount. Several of the large canals have direct returns to the stream that do not count as consumptive use (i.e., water is returned directly to the stream). Most canals, particularly unlined canals, allow water to seep back into the groundwater system. This seepage loss is variable, but is generally assumed to be 35 percent[4], unless other data are available. This category of uses had the most complete amount of information available, including data on canal diversion, direct returns to the stream, and field deliveries.

This information allowed for the following SWCUI Type 1 calculations:

SWCUI = Net Diversion – Total Loss

Net Diversion = Diversion – Direct Return

Total Loss (recharge) = Canal Loss + Field Loss

Canal Loss (recharge) = Net Diversion – Field Deliveries

Canal ET is assumed to be zero or negligible

Field Loss (recharge) = Field Deliveries * (1-ET Factor (assumed to be 65%[5]))

Note: Since canal ET loss is zero, a shortcut approach to determine SWCU is: SWCU=Field Deliveries*ET Loss Factor. The rest of the above calculations provide needed information regarding Net Diversions and recharge. Canal ET will be reassessed as information becomes available.

[4] Thirty-five percent was determined as the remainder of evapotranspiration demands as described below.

[5] Of the water applied, 65% is consumed via evaporation and transpiration by plants (Trenberth et al. 2007. Estimates of the Global Water Budget and Its Annual Cycle Using Observational and Model Data. Journal of Hydrometeorology 8:758-769.). The remaining net diversion (100% - 65% = 35%) is assumed to have recharged to groundwater.

2.2.1.2 Type 2: Canal Diversions and Field Deliveries

This category of uses is similar to Type 1 except that no direct return data is available. With a slight modification, the available information allows for the following SWCUI Type 2 calculations:

SWCUI = Diversion – Total Loss

Total Loss (recharge) = Canal Loss + Field Loss

Canal Loss (recharge) = Diversion – Field Deliveries

Canal ET is assumed to be zero or negligible

Field Loss (recharge) = Field Deliveries * (1-ET Factor (assumed to be 65%[6]))

Note: Since canal ET loss is zero, a shortcut approach to determine SWCU is: SWCU=Field Deliveries*ET Loss Factor. The rest of the above calculations provide needed information regarding recharge. Canal ET will be reassessed as information becomes available.

2.2.1.3 Type 3: Canal Diversions and Direct Returns

This category of uses is similar to Type 1 except that no field delivery data is available. With a slight modification, the available information allows for the following SWCUI Type 3 calculations:

SWCUI = Net Diversion * (1 – Total Loss Factor (assumed to be 35%))

Net Diversion = Diversion – Direct Surface Water Return

Total Loss = Net Diversion * Total Loss Factor (assumed to be 35%)

2.2.1.4 Type 4: Canals and Small Pumpers with Diversion Data

The SWCUI Type 4 category represents points of diversion where water diverted from the stream is measured by a gage, but other factors (e.g., direct returns and field deliveries) are not measured. Unless other data are available (e.g., a study or model had been developed and the data were readily available), it is assumed that 65 percent of the diversion is consumed as evapotranspiration and 35 percent of the diversion is lost as recharge to the groundwater system or directly returned to streamflow (see footnotes 5-6). The basic equation to calculate SWCUI for Type 4 is:

SWCUI = Diversion ∗ (1- Total Loss Factor (assumed to be 35%))

2.2.1.5 Type 5: Direct Diverters/Pumpers with no Diversion Data

The SWCUI Type 5 category represents points of diversion where water diverted from the stream is not measured directly. These users lack daily use data, but the Department does maintain a database that specifies the location and the number of acres appropriated (or permitted) for irrigation. To construct the SWCUI time series for small pumpers, a detailed transient land-use dataset has been developed. This dataset details the location and number of irrigated acres per year. National Agriculture Statistics Service (NASS) data provides information needed to adjust the permitted acreage to the total number of irrigated acres per county, per year, based on reported irrigation in a given county. These NASS adjustments are applied to each point of diversion within a given subbasin to allow for the development of the transient acreage dataset. The net irrigation requirement (NIR)[6] is then used to estimate the amount of water that is applied to the acreage and completely consumed.

During certain portions of the representative period, some surface water users are required to forgo their diversion due to administration for senior water users. This administration can cause those restricted water users to receive less water than their permitted appropriation and therefore reduces the consumption. To account for this, a surface water administration adjustment factor was used.[7] The administration adjustment factor considers the number of days a water user was closed and the likely impact of the lack of that water on a corn crop. The administration adjustment factor reflects the difference in the consumptive use that the restricted water user was able to obtain, versus the consumptive use that they would have obtained with a full water supply. For many surface water users the adjustment factor is simply a value of one, indicating that no adjustment is necessary. The basic equation to calculate SWCUI for Type 5 is:

SWCUI = Adjusted Acreage * NIR * Administrative Adjustments

Adjusted Acreage = appropriated acreage * adjustment factor (based on NASS estimates)

NIR = net irrigation requirement (all acres are assumed to be corn)

[6] Martin, Derrel. 2010. Net Irrigation Requirement, available on the Department's website and through the INSIGHT documentation.

[7] The Flatwater Group, Inc. 2014. Nebraska Surface Water Administration Tool, available on the Department's website and through the INSIGHT documentation.

2.2.2 Reservoir Evaporation

Reservoirs with a capacity greater than 32,000 acre-feet are considered in these analyses. These reservoirs have sufficient data to include evaporative losses in the SWCU calculations. These evaporative losses are incorporated into calculated SWCU by accessing information on pan evaporation, surface area, and precipitation. For the areas evaluated, reservoirs include:

- Box Butte Reservoir
- Calamus Reservoir
- Davis Creek Reservoir
- Merritt Reservoir

The equation for calculating SWCUE is:

SWCUE = [(Pan evaporation * 0.7 * surface area) – (precipitation * surface area)][8]

2.2.3 Surface Water Municipal Use

The Lincoln well field and the two Omaha well fields located in the Lower Platte River Basin hold induced groundwater recharge permits. The net pumping values for these well fields are included as surface water consumptive use due to the fact that the these well fields hold surface water appropriations and their impacts on streamflow manifest rapidly. Net pumping values are calculated from pumping and return data. [9]

2.3 Streamflow Depletions from Groundwater Pumping

Irrigation, municipal, and industrial groundwater withdrawals are the three general use categories considered in the depletion calculations. Streamflow depletions from groundwater pumping in hydrologically connected areas are modeled values that consider the effects of groundwater-streamflow interactions. The depletions are used both to calculate the BWS and to represent the near-term total demand for groundwater uses (see Section 3: Calculating the Total Demand).

[8] The 0.7 is a multiplier to reduce pan evaporation to values more representative of a large water body (Farnsworth et al., 1982. Evaporation Atlas for the Contiguous 48 United States. NOAA Technical Report NWS 33.).

[9] Net pumping is the pumping value metered at the well field minus the amount that is discharged back into the basin. No returns are assumed for the Omaha well fields and a value of 65 percent is utilized as the return percentage for the Lincoln well field (based on work done for the LPSNRD water balance study).

Groundwater models, both numerical (MODFLOW) and analytical, provide estimates of groundwater depletions for the INSIGHT process. Either the numerical models or the analytical models are capable of calculating the impacts of groundwater pumping on streamflows, as these are standard methods for calculating groundwater depletions. The regions covered by numerical models include the Niobrara River Basin, Loup River Basin, Big Blue River Basin, Little Blue River Basin, and large portions of the Elkhorn River Basin and Lower Platte River Basin. Analytical models are used for areas not currently represented by numerical models. These areas are limited to lower portions of the Elkhorn River Basin and the Lower Platte River Basin.

The Department includes wells that pump greater than 50 gallons per minute (gpm) in its analyses. Most domestic and livestock wells are under 50 gpm; therefore, they were generally not included in the analyses. Municipal and industrial groundwater uses over 50 gpm were developed using methods described in Flatwater (2014)[10]. Exceptions to this were the Lincoln well field and the two Omaha well fields located in the Lower Platte River Basin, which are included in the surface water consumptive use as described above.

Depletions analyses are conducted for each subbasin where a numerical model is available[11]. The depletions analyses consist of a comparison of two model runs: one that represents historical pumping, and another that represents the basin without pumping. The difference between these two model runs indicates the streamflow depletions from groundwater pumping. Refer to HDR (2013)[12] for the details regarding the analytical depletions analyses for portions of the Lower Elkhorn and Lower Platte River Basins. All depletion values are summed to each season (peak and non-peak) for incorporation into the BWS.

[10] The Flatwater Group, Inc. 2012. Municipal and Industrial Pumping, available on the Department's website and through the INSIGHT documentation.
[11] See *Water Matters: Stream Depletion and Groundwater Pumping Part One: The Groundwater Balance (No. 4, June 2010) and Stream Depletion and Groundwater Pumping Part Two: The Timing of Groundwater Depletions (No. 5, July 2010)* for more information.
[12] HDR, Inc. 2013. Depletion Estimates for the Lower Platte River Basin, available on the Department's website and through the INSIGHT documentation.

2.4 Required Inflow

Required inflow is the final component of the BWS. Required inflow represents the portion of demand within a basin or subbasin that is reliant upon upstream sources for a part of the water supply. The calculation for required inflow is conducted by summing the proportionate downstream demands (see Section 3: Calculating the Total Demand) that are assigned to each basin or subbasin located upstream. While the term “required inflow” is used, this does not represent inflows that are required by permit or statute. Water uses within a basin or subbasin are historically developed based upon the typical amount of water available. If there is a basin or subbasin upstream, some uses are developed which count on water flowing into the basin or subbasin and not just the water that originates within the basin or subbasin. Therefore, required inflows must be added to the rest of the basin water supply to completely encompass the available water supply within a basin. The term required inflow is simply a term coined for these methods and it is necessary as a means to provide more spatially refined (i.e., to the subbasin scale) evaluations.

The methodology aims to allow for summations of subbasin level data to the basin level data. This approach works for subcomponents such as depletions or surface water consumptive use; however, there are no basin inflows for the larger basins (with the exception of the Lower Platte) when summing to the basin level. Therefore, required inflows do not exist at the basin level with the exception of the Lower Platte. The required inflows of the Lower Platte consist of proportionate downstream demands applied to the Elkhorn Basin and Upper Platte Basin plus the greater of the inflows from the Loup Basin or the proportionate downstream demands

2.5 Determining the Representative Period of Record

This evaluation utilizes the most recent period of record that represents naturally occurring wet/dry cycles in order to avoid bias between wet and dry periods and accommodate non-stationarity in climate cycles.

Both autocovariance and Kendall Tau statistical methods are used for this process. The autocovariance analysis of the BWS provides a measure of self-similarity of the time-series data that is useful in determining repetitions in data. In other words, it provides a measure of the time periods over which patterns tend to repeat. The resulting autocovariogram plots the coefficients, which range from -1 to 1, that represent the degree of variance between the time-series and a time-shifted version of itself (figure 2.3). This process aides in the identification of a representative period that contains the most recent wet and dry conditions.

In order to ensure that the resulting evaluation is not biased by trends derived from factors beyond the components of the BWS, a trend analysis is performed. Once the representative period of record is identified, a Kendall Tau test is performed on that period of record. The Kendall Tau test, a simple non-parametric test statistic, can be used to identify statistically significant trends within a dataset by measuring concordance. This test statistic ranges from -1 to 1, testing the null hypothesis of zero association. If the Kendall Tau test statistic does not suggest the presence of an underlying trend, then the evaluation process continues. If the test suggests that a trend is present, then the representative period will be reevaluated.

For the current assessment, the autocovariance analysis did not show statistically significant results for any of the accounting points; however, spans of positive and negative correlation did provide insight to identification of the most recent wet and dry periods. Some accounting points provided greater insight into the representative period than others. However, a 25-year period was recurrent among enough accounting points to use 25 years as the period of record for all basins and subbasins. Once the representative period has been selected, the final step is to create a time series of the BWS for the peak and non-peak seasons.

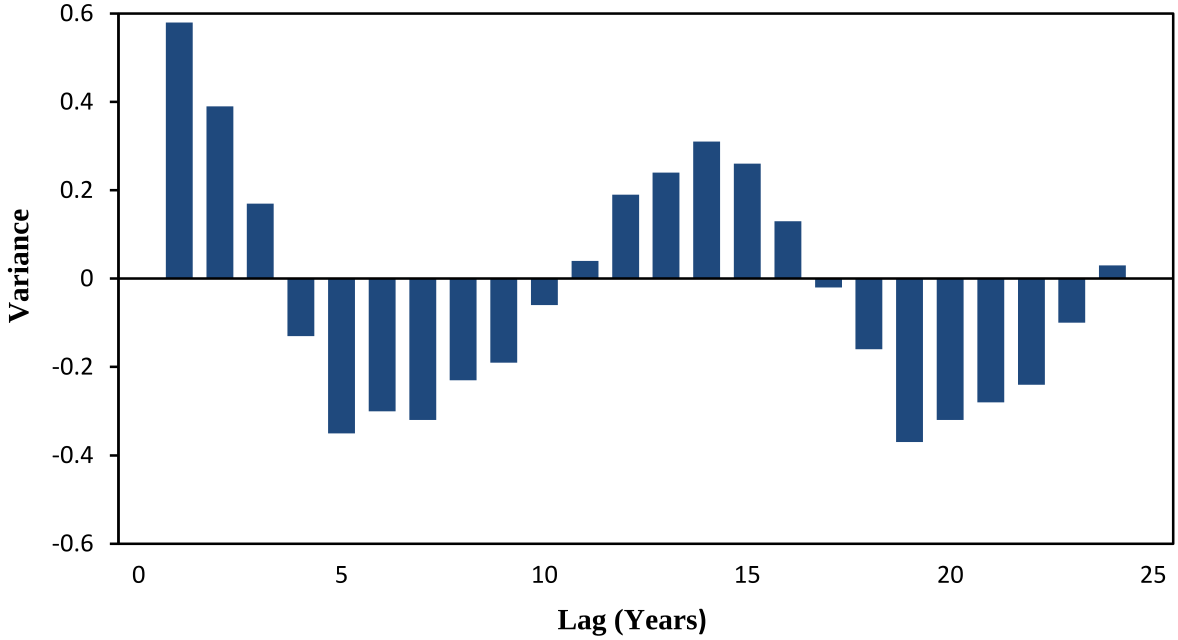

Figure 2.4: Example of an autocovariogram for determining an appropriate period of record for use in the evaluation.

3.0 Calculating the Total Demand

The Total Demand (TD) of water within a basin or subbasin is derived from six main categories of water use: 1) consumptive water demands for surface water uses, 2) consumptive water demands for hydrologically connected high capacity (greater than 50 gpm) groundwater well pumping, 3) streamflow demands for hydropower operations, 4) streamflow demands to meet instream flow demands (accounting for all development in place at the time the appropriation was granted), 5) the net water determined to be necessary to deliver streamflows to meet consumptive demands for surface water irrigation districts (net surface water loss), and 6) the downstream demands (the proportionate amount of BWS necessary to meet demands downstream of a given basin or subbasin). This section provides a further description of these six categories of water demands. The equation for TD is:

Total Demand = Surface Water Demands + Groundwater Demands +
Net Surface Water Loss + Hydropower Demands + Instream Flow Demands +
Downstream Demands

The TD represents the total demand for hydrologically connected water that is consumed or utilized within a system during a given time frame (i.e., all consumptive and non-consumptive uses). Hydropower, instream flow, and downstream demands fall into the category of non-consumptive uses therefore, only the maximum of the three is considered in the final summation of demands. The calculation of TD is completed for near-term demands, long-term demands, and projected long-term demands. The difference between the near-term and long-term demands is that the near-term TD calculation considers the groundwater depletion (current effect of wells on the stream) to be the demand for groundwater, while the long-term calculation considers the groundwater consumption (full impact of wells on a hydrologically connected stream). The projected long-term demands calculation utilizes the same values used to represent the long-term demands, but increases them by five percent to provide a sense of the potential for additional long-term water development in a basin[13].

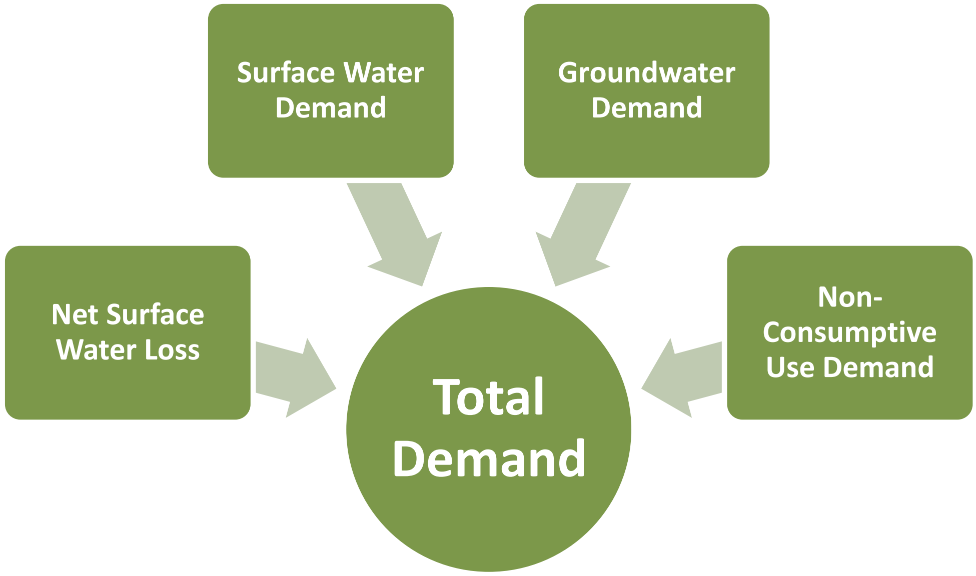

Figure 3.1: Basic components (Net Surface Water Loss, Groundwater Demand, Surface Water Demand, and Non-Consumptive Use Demand) necessary to determine the Total Demand. Each component will be detailed further in the document. Non-consumptive uses include hydropower, instream flow, and induced groundwater recharge demands as well as downstream demands for mainstem surface water consumptive and non-consumptive uses.

3.1 Surface Water Demand

The surface water demand is calculated in a similar manner to the surface water consumptive use for the BWS. The only differences are that for the surface water irrigation demand calculation, no adjustments are made to account for shortages to junior water users caused by administration for senior water users (i.e., demand is equivalent to the full corn irrigation requirement) and surface water consumptive use is redistributed from the peak season to the non-peak season, when storage reservoirs provide a portion of a water users water supply. Any commingled irrigated acres (with access to both surface water and groundwater) were treated as surface water only acres in these analyses so as not to double count any irrigation demands on these acres.

[13] Five percent was utilized for this evaluation to demonstrate how this process can be used to evaluate future development. Specific values for each subbasin or basin may be calculated and incorporated into future evaluations.

The Lincoln and Omaha municipal well fields in the Lower Platte Basin hold induced groundwater recharge permits (surface water appropriations) that allow for the extraction of streamflow through wells adjacent to the stream. Each of these permits has a total extraction limit associated with it. The surface water demand for these permits was calculated by using the total permitted extraction rates associated with each permit.

3.1.1 Redistributing Surface Water Demands for Reservoirs

Surface water reservoirs are typically designed to capture streamflows during the non-peak season and make those flows available during the peak season. As such, an adjustment is made to those surface water users that utilize large reservoirs for storing water in the non-peak season. The adjustment consists of calculating the storage change that occurs over the course of the non-peak season (i.e., the storage volume accrued between September 1 and May 31) and subtracting this volume from the surface water consumptive use during the peak season for those points of diversion with direct access to that stored water. This amount is assigned to the non-peak season with the remaining portion of surface water consumptive use, beyond that which was met by the stored water, assigned to the peak season.

3.2 Groundwater Demand

The TD calculation evaluated the demand for hydrologically connected[14] water from wells that pump greater than 50 gpm. These wells generally included irrigation wells, municipal wells, and large industrial wells. The method for determining the near-term groundwater demand from these wells utilized the groundwater depletions, which was the same process used to determine depletive effects for the BWS (see Section 2.3).

The long-term groundwater demand considered groundwater consumption, which is the total amount of net water pumped for wells located within the hydrologically connected area within that time period, irrespective of lag-effects. Calculation of long-term groundwater irrigation demand relies upon the same information (i.e., the net irrigation requirement, the land-use datasets that contain the number of acres that are irrigated, and information on the

[14] The Department determined hydrologically connected areas using the 10/50 area as established under Regulation 457 NAC 24.001.02.

crop distribution mix for a given area) that is utilized to develop the groundwater pumping datasets used in the groundwater models to calculate groundwater depletions. Calculation of long-term groundwater demand for municipal and industrial wells pumping more than 50 gallons per minute, besides the Lincoln well field and the two Omaha well fields located in the Lower Platte River Basin, relies on datasets assembled by The Flatwater Group[15]. Note that the Lincoln and Omaha well fields are included in the surface water demands (see above).

Annual volumes of total groundwater consumption are distributed 70 percent to the non-peak season and 30 percent to the peak season. The proportioning between the seasons is intended to match the observed seasonal pattern of groundwater depletions.

Where appropriate (i.e., when overlap occurs between hydrologically connected areas), demands are proportioned between basins or subbasins, as it is not uncommon for pumping from a single well or location to affect stream flow in more than one basin or subbasin. Where a well could impact multiple basins or subbasin, the total pumping impact is proportioned to each basin or subbasin based upon modeled stream depletion factors. For example, if a given location causes a depletion to subbasin A of 20 percent, and a depletion to subbasin B of 30 percent, for a total of 50 percent, then 40 percent (20 percent/50 percent) of the consumption is assigned to subbasin A, and the remaining demand, 60 percent (30 percent/50 percent), is assigned to subbasin B. Once this proportioning is complete, the equation to calculate long-term groundwater irrigation demand within a basin or subbasin is:

[15] The Flatwater Group, Inc. 2014. Municipal and Industrial Pumping, available on the Department's website or through the INSIGHT documentation.

Long-Term Groundwater Demand = Proportioned Groundwater Irrigation Consumptive Use + Proportioned Groundwater Municipal & Industrial Consumptive Use

Where:

Proportioned Groundwater Irrigation Consumption = NIR $*$ Groundwater Irrigated Acres (only within hydrologically connected area) $*$ Proportional Adjustment

Proportioned Groundwater Municipal & Industrial Consumptive Use = Groundwater Municipal & Industrial Consumptive Use (developed using data from Flatwater, only within the hydrologically connected area) $*$ Proportional Adjustment

3.2.1 Determination of the Hydrologically Connected Area and Stream Depletion Factors

The hydrologically connected area is defined as the geographic area within which groundwater is hydrologically connected to surface water. For determining the hydrologically connected areas, the Department relied on the "10/50 area" to define the area hydrologically connected to streams[16]. By definition, a groundwater well constructed in the 10/50 area would deplete river flow by at least 10 percent of the volume of water pumped over a 50-year period. The analyses to determine 10/50 areas is typically not dependent on the quantity of water pumped, but rather on each basin's geologic characteristics (e.g., transmissivity and specific yield of the aquifer) and the distance between each well and the stream. Relying on the 10/50 area as the area that is hydrologically connected to streams does not imply that hydrologic connection does not exist beyond this line, but rather that these impacts manifest on much greater timescales.

The Department utilized both numerical and analytical methods to assess the extent of the hydrologically connected areas. Similar to determination of streamflow depletions from groundwater pumping, numerical models are utilized for all areas with the exception of portions of the Lower Elkhorn River Basin and the Lower Platte River Basin. In those areas

[16] The 10/50 area is established under the current rule (Regulation 457 NAC 24.001.02) for determining hydrologically connected areas.

an analytical approach is utilized. The specific process for performing the modeling using the numerical models is described further in the supporting data sets; however, the general approach utilized is to run the model under a baseline condition (e.g., the last 50 years of the historical simulation) and then complete a new model run for each model cell with a new hypothetical well inserted in that cell. The final step is to then compare the results from the baseline model run and the simulations with the new well that was inserted. Processing is generally as follows:

Step 1: Prepare numerical model files, as needed, so that at least a 50-year time span is simulated.

Step 2: Prepare and execute a 50-year (or more) baseline simulation in which pumping is not increased above the levels defined in the calibrated model version.

Step 3: Prepare and execute a series of 50-year (or more) simulations, in which additional pumping is defined for a single selected cell in the model for the entire simulation period (different cell locations are selected for each run in the series).

Step 4: Calculate the difference in simulated groundwater contributions to surface discharges over 50 years between the baseline (Step 2) and analyses (Step 3) runs as a percentage of the total volume of additional water pumped over that same period.

Step 5: Assign the percentage calculated in Step 4 to the cells in which additional pumping was defined in Step 3.

Step 6: Delineate the 10/50 area for the modeled basin or subbasin.

In areas where an appropriate regional numerical model has not yet been developed, but where appropriate geologic data exist, an analytical methodology is applied. The locations of aquifers in hydrologic connection to perennial streams are determined using the best available science and data on the distribution of groundwater aquifers, perennial streams, and aquifer properties. Once aquifer locations are identified, the availability of additional information has to be evaluated. The following data are necessary for determining the extent of the 10/50 area using analytical approaches: aquifer transmissivity, aquifer specific yield, location of perennial streams, and streambed conductance. The location and extent of perennial streams is determined from the perennial streams GIS coverage available from the USGS National Hydrography Dataset. The following steps were utilized to calculate the extent of the 10/50 area when applying an analytical[17] approach:

Step 1: Identify aquifers in hydrologic connection to perennial streams using the best available science. A point grid was assigned to study aquifers, the point grid was spatially refined to a one-mile square grid so that specific distances from the stream to grid nodes could be identified and stored.

Step 2: Evaluate availability of aquifer and stream data.

Step 3: Perform analyses using the Hunt Method[18] (when streambed conductance data are available) or the Jenkins Method.

Documentation of the models used and results of these analyses are available on the Department's website and through the INSIGHT documentation.

3.3 Net Surface Water Loss

In many situations where surface water is used as a source for irrigation, there is a significant component of the diversion that may be lost in transit to the field (i.e., the water seeps back into the aquifer and returns to the river at a later time). This water is referred to as surface water loss. These situations typically occur in areas where large irrigation districts or canal companies deliver water to multiple patrons. While this water can be beneficial toward recharging the aquifer, it can also represent an additional demand for water. Over time, this aquifer recharge can create "new" water supplies through retiming the water.

In conducting this evaluation, it was also recognized that in certain areas a portion of this surface water loss demand was met by streamflows that were returned to the stream from upstream uses, and these streamflows were not returned to the stream within the same time period (i.e., peak or non-peak) or within the same year. Thus, the Net Surface Water Loss is intended to represent the difference between the water that was recharged and the water

[17] Jenkins, C.T. 1968. Computation of Rate and Volume of Stream Depletion by Wells. In *Techniques of Water Resources Investigations*. U.S. Geological Survey, Book 4, Chapter D1. Washington, D.C.

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

supply increase that it created. For this evaluation it was assumed that the Net Surface Water Loss was the difference of the full diversion and the amount consumed for irrigation.

The subbasins where Net Surface Water Loss is included in the TD are the Middle Loup River, North Loup River, Niobrara River (Box Butte Reservoir to Gordon), and the Niobrara River (Gordon to Sparks).

3.4 Non-Consumptive Use Demands

Hydropower rights, instream flow demands, induced groundwater recharge (non-consumptive portion), and downstream basin or subbasin demands can be grouped into the category of non-consumptive use demands. Non-consumptive use demands represent uses which do not require removing water from the stream. Since the water remains in the stream, the demands are not additive. This means that water supply which meets for example a hydropower demand can also go toward meeting an instream flow demand or a downstream demand. Because of this, the greatest of the non-consumptive demands in a basin or subbasin is considered sufficient to meet all non-consumptive demands within the basin or subbasin. See figure 3.2 for an example of the quantification of the final total non-consumptive use demand within a basin or subbasin.

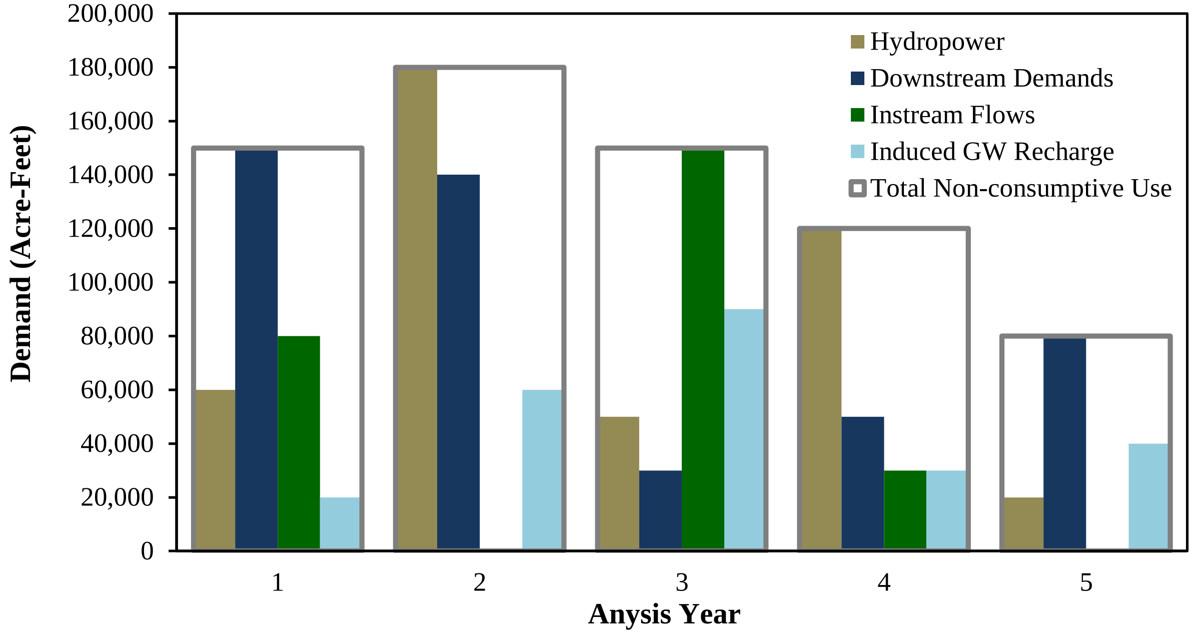

Figure 3.2: An example bar chart comparing each non-consumptive use (hydropower, downstream demands, instream flows, and induced groundwater recharge) to the total non-consumptive use included in the TD calculation. Since water that goes to meet one non-consumptive demand is available to meet other non-consumptive demands within the basin or subbasin, the maximum of the four categories of non-consumptive use is considered sufficient to meet all of the non-consumptive demands.

3.4.1 Hydropower Demand

Hydropower demands exist within the Niobrara River Basin and Loup River Basin. At the basin level, hydropower demands are evaluated by comparing the daily streamflow through the hydropower plant to the permitted hydropower appropriation. If streamflow is greater than or equal to the hydropower appropriation, the demand is considered to be the amount of the appropriation, as that is the maximum amount of water permitted for that use. If streamflow is less than the appropriation, then streamflow depletions from groundwater pumping will also be considered in order to determine if undepleted streamflow would be sufficient to meet the appropriation. The depletions are added to the daily streamflow and this is again compared to the hydropower appropriation. If the undepleted streamflow is greater than or equal to the hydropower appropriation, the demand is considered to be the amount of the appropriation. In the case that the undepleted streamflow available is not adequate to meet the appropriation, the demand for the basin is equal to streamflow and depletions as demand cannot exceed supply. Figure 3.3 illustrates the process used to determine daily hydropower demands for each basin. These daily demands are summarized for each representative period to determine the total hydropower demand for a basin. An example of this process is provided below:

Step 1: Streamflow = 1,800

i. Groundwater depletion = 200

ii. Adjusted streamflow = 1,800 + 200 = 2,000

Step 2: Daily demand (i.e., capacity) for hydropower = 1,900

i. Final hydropower demand on that day = 1,900

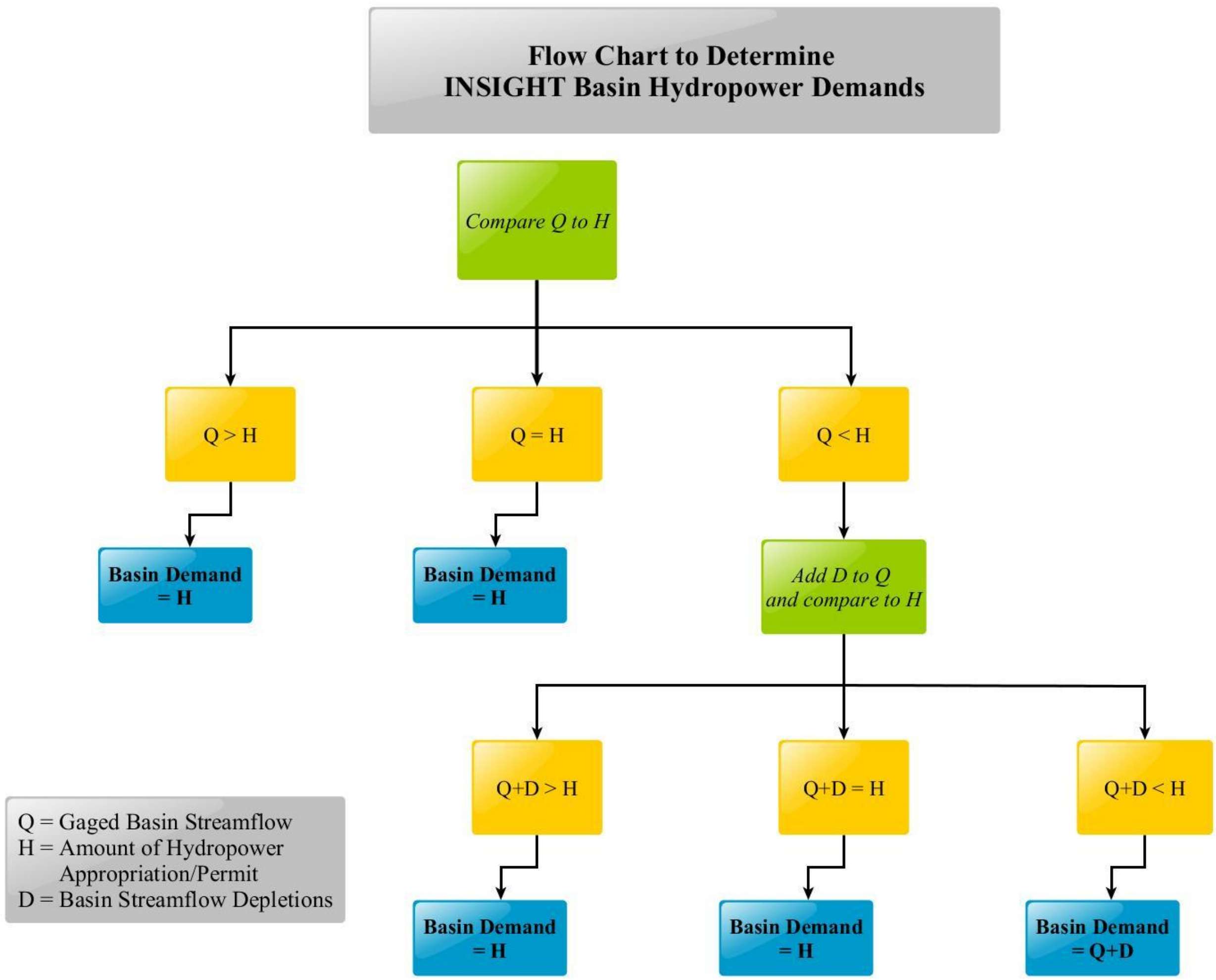

Figure 3.3: Flow chart diagramming the process for determining basin hydropower demands.

3.4.2 Instream Flow Demands

Instream flows were incorporated into the analyses for those areas where these surface water appropriations were currently in place, in a manner that took into account the level of development (both surface water and groundwater) that was in place at the time an appropriation was granted (see *Neb. Rev. Stat*.§ 46-713 (3) of the Ground Water Management and Protection Act). Like hydropower uses, instream flows represent a non-consumptive category of water demand.

Instream flow demands were represented through a three-step process. The first step consisted of adding the total groundwater depletions to the daily streamflow values at the point of the appropriation for the representative period and comparing this value to the daily appropriated right. The second step consisted of converting those daily values to peak and non-peak season volumes and proportioning those volumes to each basin or subbasin. The third step was to subtract the consumption associated with levels of groundwater development in place at the time of the appropriation (i.e., 1993 in the case of the Lower Platte appropriations) from the volumes created in step two (ensuring that all values less than zero were set to zero) to achieve the final instream flow demands. An example of this process is provided below:

Step 1: Calculate undepleted streamflow

i. Groundwater depletion = 200

ii. Adjust streamflow by adding groundwater depletion

Adjusted streamflow = 1,800 + 200 = 2,000

iii. Compare to instream flow permit and utilize minimum of the two (demand cannot exceed permitted amount)

Permit = 2,100, therefore:

Daily instream flow demand = 2,000

Step 2: Make assignments to the basins and subbasins

i. Sum daily values to peak and non-peak season volumes

Peak season = 2,000 * 92 days = 184,000 (do the same for the non-peak season values)

ii. Proportion to the basins and subbasins based on their contribution to the total BWS at the point of appropriation:

Total BWS = 1,000,000

Upper Platte BWS contribution = 200,000, 20%

Loup BWS contribution = 400,000, 40%

Elkhorn BWS contribution = 250,000, 25%

Lower Platte BWS contribution = 150,000, 15%

iii. Assign instream flow demand to each basin based on BWS contributions:

Total Instream Flow Demand = 184,000

Upper Platte assignment= 184,000 * 0.2 = 36,800

Loup assignment = 184,000 * 0.4 = 73,600

Elkhorn assignment = 184,000 * 0.25 = 46,000

Lower Platte assignment = 184,000 * 0.15 = 27,600

Step 3: Reduce assignment by consumptive demands in place at the time of appropriation

i. Determine consumptive demands within each basin

Upper Platte consumptive demands = 50,000

Loup consumptive demands = 60,000

Elkhorn consumptive demands = 40,000

Lower Platte consumptive demands = 10,000

ii. Subtract consumptive demands from each basin’s assignment to determine final instream flow demands assigned to the basins:

Upper Platte final assignment= 36,800 – 50,000 = -13,200 = 0

Loup final assignment = 73,600 – 60,000 = 13,600

Elkhorn final assignment = 46,000 – 40,000 = 6,000

Lower Platte final assignment = 27,600 – 10,000 = 17,600

3.4.3 Downstream Demand

The final component of TD is what is referred to as Downstream Demand. As downstream basins and subbasins have historically relied on a certain portion of water supply being available from upstream sources, it is important to consider this demand in the evaluation. Historically, all downstream portions of streams in the analyses received some percentage of inflow from each tributary. This is the supply on which existing uses were established. Incorporating the interconnected nature of the tributaries, where each subbasin contributes a certain percentage to the total basin flow, allows for finer spatial resolution of the evaluation (i.e., subbasin level analyses). Only surface water consumptive demands, net surface water loss, and non-consumptive demands (hydropower, instream flow, and induced groundwater recharge) are considered when calculating downstream demands. Groundwater demands are not included. Since water that goes toward meeting one non-consumptive demand can also meet other non-consumptive demands, only the maximum non-consumptive demand from downstream basins or subbasins is considered. While this demand is non-consumptive within the upstream basin, the water may be used for consumptive purposes once it passes into the downstream basin.

Several steps were necessary to determine the contributing proportion of each subbasin:

- **Step 1:** Calculate the BWS at the furthest downstream accounting point in a basin (total BWS).
- **Step 2:** Calculate the intrinsic BWS[19] at each subbasin confluence upstream.
- **Step 3:** Calculate the percent contribution for each subbasin relative to the total BWS for the basin. This represents its proportion.

This proportion was then applied to the mainstem surface water demands, net surface water loss, instream flow, and induced recharge demands in subbasins located downstream to determine the amount of water each subbasin would provide as required inflow to subbasins located downstream. The mainstem demands consist only of those surface water demands

[19] The intrinsic BWS is the BWS less required inflow. The calculation of intrinsic BWS for a subbasin is streamflow (streamflow gain) + surface water consumptive use + groundwater depletions.

that water could flow by gravity to meet (i.e., demands located on tributaries downstream of a subbasin are not included). The following provides a simple example:

> A basin consists of four smaller tributary subbasins that all contribute different flows to the larger basin (figure 3.4). The average annual BWS volume of each subbasin is:
>
> > BWS subbasin A = 50
> > BWS subbasin B = 300
> > BWS subbasin C = 100
> > BWS subbasin D = 550
> > Total BWS = 50 + 300 + 100 + 550 = 1000
>
> then:
>
> > Contribution of subbasin A = 50/1000 = 5%
> > Contribution of subbasin B = 300/1000 = 30%
> > Contribution of subbasin C = 100/1000 = 10%
> > Contribution of subbasin D = 550/1000 = 55%
>
> If the total surface water demand for the downstream subbasin (subbasin D) is 500, then the following assignments would be made to each upstream subbasin as downstream demands.
>
> > Subbasin A Downstream Demand = 500 * .05 = 25
> > Subbasin B Downstream Demand = 500 * 0.3 = 150
> > Subbasin C Downstream Demand = 500 * 0.1 = 50
>
> The sum of these three downstream demands (i.e., 225) would then be represented as required inflow to subbasin D.

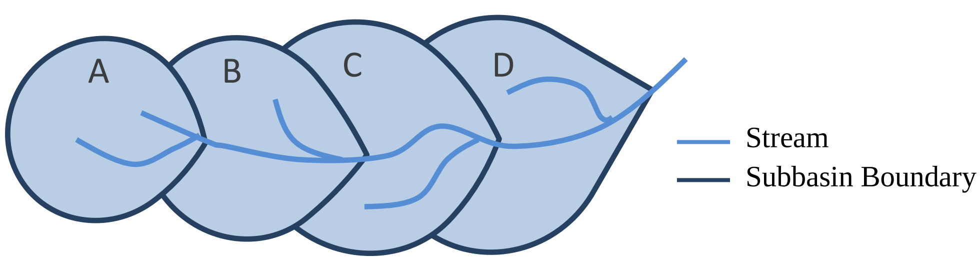

Figure 3.4: Schematic for the subbasins used in calculating downstream demand and required inflows in the above example.

The Niobrara River Basin, Loup River Basin, Elkhorn River Basin, and Lower Platte River Basin are the only basins in this evaluation where downstream demands were assigned. All other basins did not have downstream demands assigned as outflow from those basins as those outflows do not support water uses in Nebraska.

A more detailed approach is utilized to distribute the hydropower demand as downstream demands on upstream subbasins. If the basin streamflow is equal to the hydropower appropriation, then the actual streamflow or stream reach-gain for each subbasin is assigned as the hydropower demand for each basin. If the basin streamflow is greater than the hydropower appropriation, then the streamflow for each subbasin is reduced by the ratio of the hydropower appropriation over the basin streamflow and that value is assigned as the hydropower demand for each subbasin.

If the basin streamflow is less than the hydropower appropriation, the subbasin hydropower demand will be calculated in two parts, a streamflow portion and a depletions portion. First the actual streamflow or stream reach-gain for each subbasin is assigned as the streamflow portion of the hydropower demand for each subbasin. Then the basin depletions are added to the basin streamflow to determine the undepleted streamflow and this is compared to the hydropower appropriation. If the undepleted basin streamflow is greater than the hydropower appropriation, then the depletion portion of the hydropower demand assigned for each subbasin is the subbasin depletions reduced by the ratio of the hydropower appropriation minus the basin streamflow over the basin depletions. If the basin streamflow plus the basin depletions is equal to or less than the hydropower appropriation, then the depletions portion of the hydropower demand for each subbasin is equal to the actual depletion for each subbasin. The total subbasin hydropower demand is the streamflow portion plus the depletions portion.

The process for determining basin hydropower demands and subbasin downstream demands for hydropower demands is outlined in the flow chart below (figure 3.5).

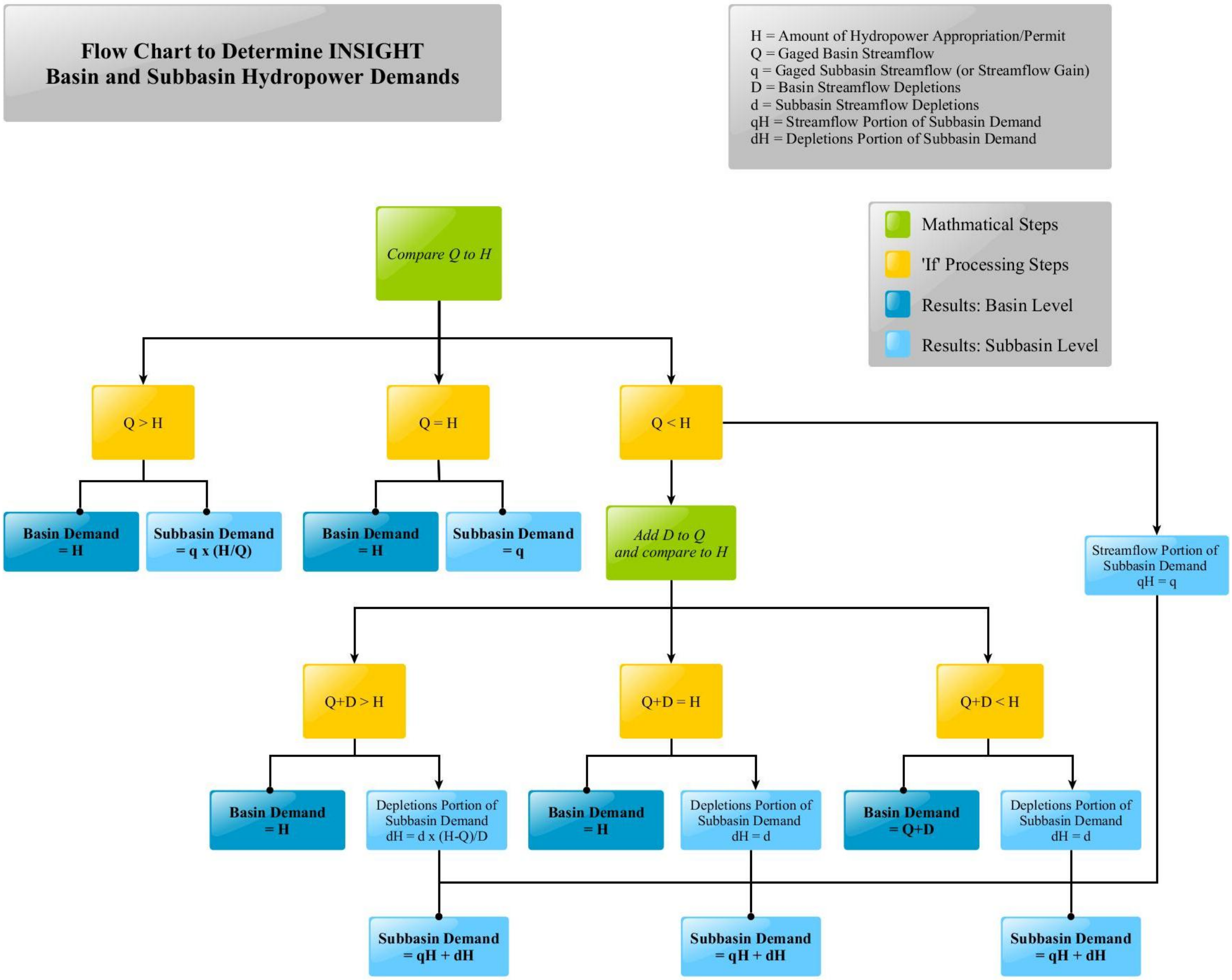

Figure 3.5: A flow chart diagraming the process for determining basin hydropower demands and the subsequent subbasin downstream demands for hydropower demands.

The final downstream demands are calculated by combining the downstream demands calculated for mainstem surface water demands, net surface water loss, instream flow, and induced recharge demands with downstream demands for hydropower. In combining these demands care is taken to ensure that the non-consumptive demand are not duplicated in a manner that would overestimate the total non-consumptive downstream demands.

When non-consumptive hydropower demands exist within a basin, such as the Niobrara River Basin or at the confluence of the Loup River Basin and Lower Platte River Basin, the downstream demands for subbasins located downstream of the hydropower operations will be the greater of the streamflow that exits the subbasin or the downstream demands calculated by summing the mainstem surface water demands, net surface water loss, instream flow, and induced recharge demands. This is done to ensure that all streamflows exiting an upstream subbasin through those hydropower operations are applied toward downstream demands before any additional assignment of downstream demands is made to the upstream subbasin.

4.0 Calculating the Balance of Water Supplies and Water Uses

Once the BWS and the TD are determined, the comparison of the two components can be completed (figure 4.1). To recognize the impact that timing had on the ability of a water supply to meet a beneficial water use, the comparison is done for two time periods in a given year: September 1 through May 31 (non-peak season), and June 1 through August 31 (peak season). Additionally, comparisons are done to evaluate the near-term balance, long-term balance, and projected long-term balance. The projected long-term demands simply built on the long-term demands by adding an additional five percent demand. This projected demand was utilized to provide a sense of the potential for additional water development in a basin.

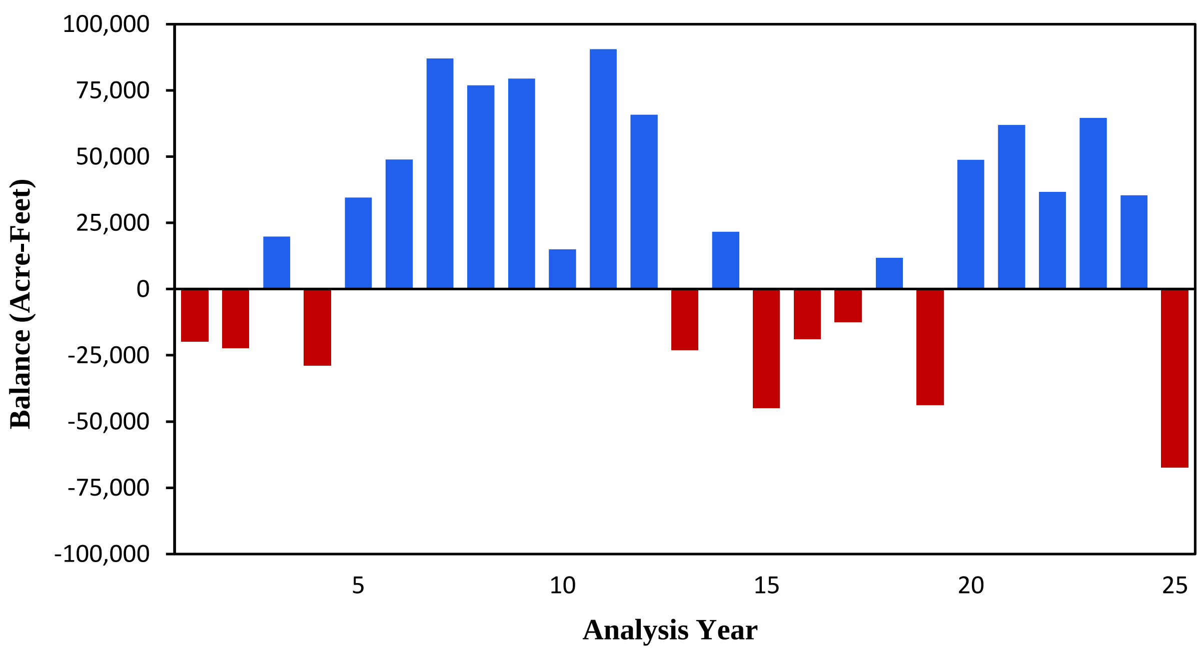

Figure 4.1: Example illustrating the balance between basin water supply (BWS) and total demand (TD) over a representative period. In years in which BWS is greater than TD, the balance amount is shown in blue. In years in which BWS is less than TD, the balance amount is shown in red.

4.1 Near-Term Balance

This determination of the balance between current water supplies and uses focuses on a comparison of BWS and the near-term TD over the representative period. The comparison yields results that describe the amount, location, and timing of surpluses and deficits in water supply (e.g., positive values indicate water is available beyond the current demand).

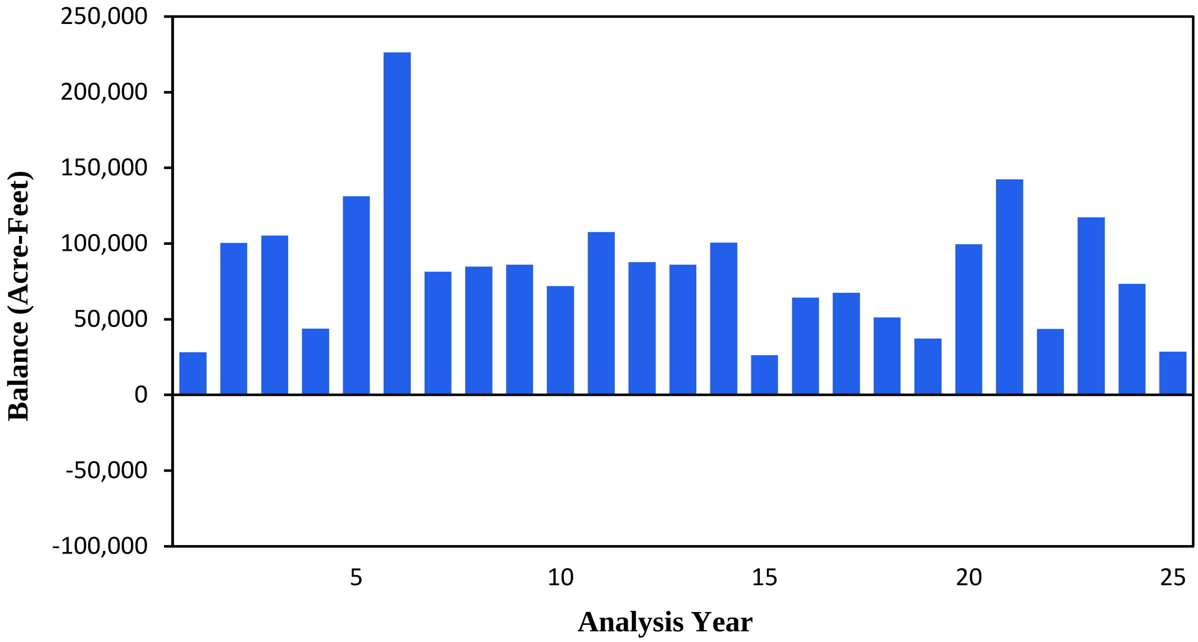

Figure 4.2: Sample results of near-term balance between basin water supply (BWS) and total demand (TD) for a representative basin during peak seasons (June-August). Twenty-five years of analyses are shown using representative weather and water data from 1988-2012.

4.2 Long-Term Balance

This determination of the balance between current water supplies and uses focuses on the comparison of BWS and long-term TD over the representative period. The comparison yields results that describe the amount, location, and timing of surpluses and deficits in water supply (e.g., positive values indicate water is available beyond the demand). Long-term TD is distinguished from near-term TD by the difference between the current impacts of well development (reported as streamflow depletions from groundwater pumping) and the long-term consumption of hydrologically connected wells.

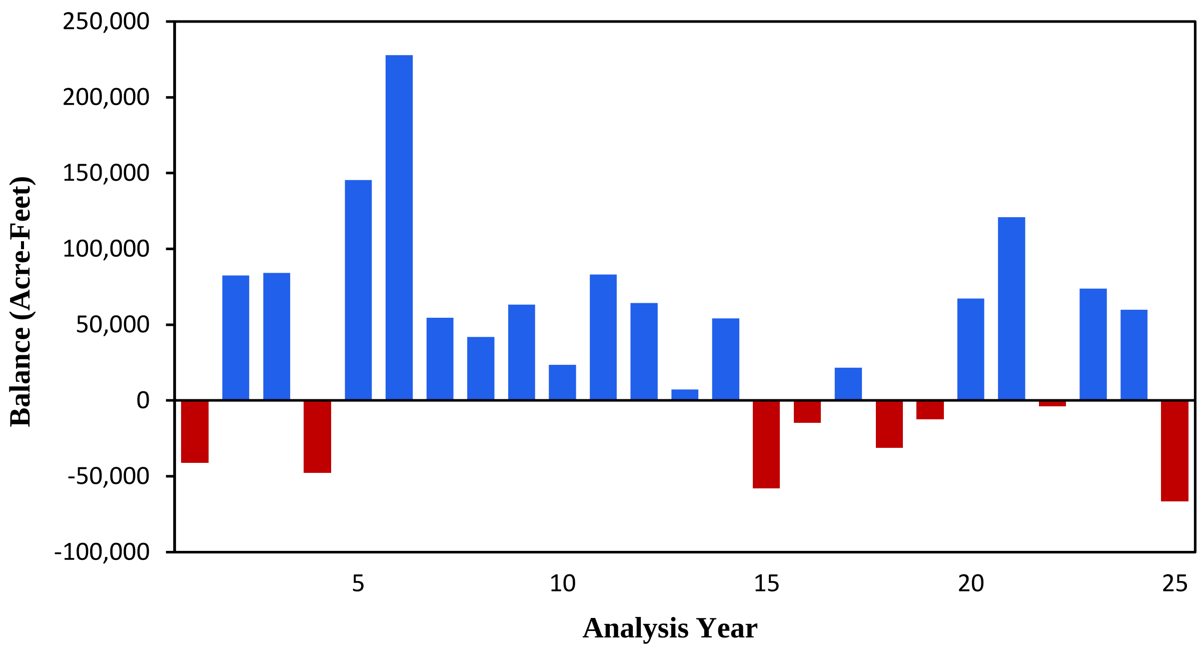

Figure 4.3: Sample results of long-term balance between basin water supply (BWS) and total demand (TD) for a representative basin during peak seasons (June-August). Twenty-five years of analyses are shown using representative weather and water data from 1988-2012.

4.3 Projected Long-Term Balance (With Future Development)

This determination of the balance between BWS and projected long-term TD is not intended to represent actual detailed projections of future development potential, but rather to give a sense of how much potential there may be in a given basin or subbasin for additional development that would not compromise current water users' supplies.

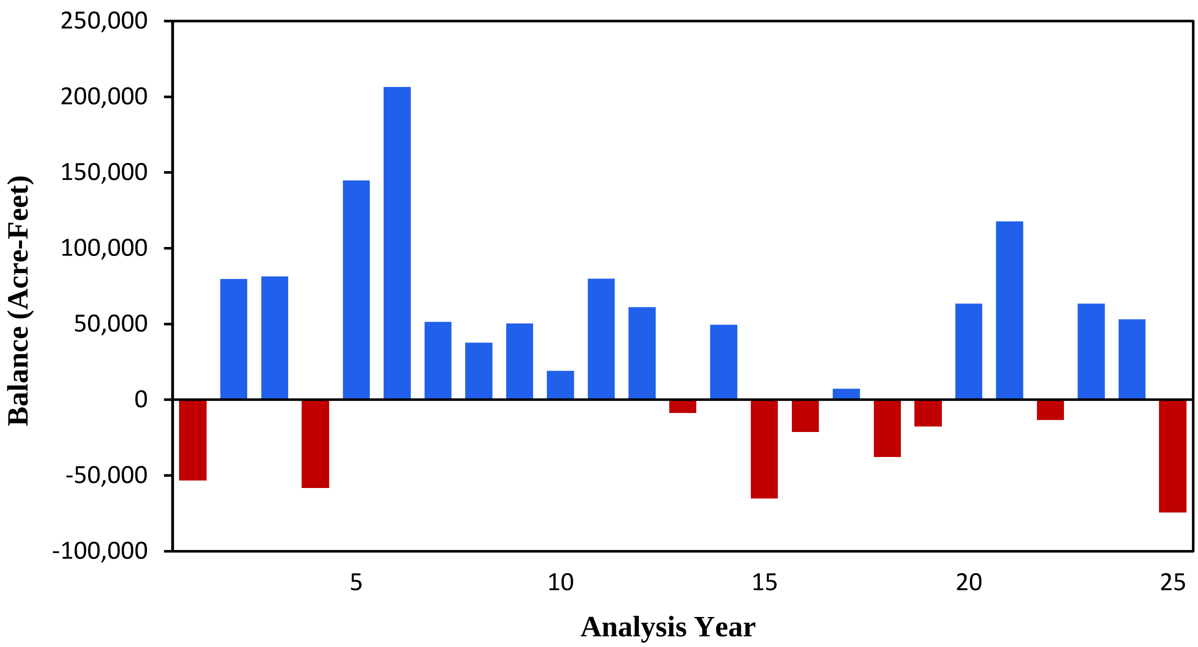

Figure 4.4: Sample results of the projected balance between basin water supply (BWS) and total demand (TD) for a representative basin during peak seasons (June-August). Twenty-five years of analyses are shown using representative weather and water data from 1988-2012.