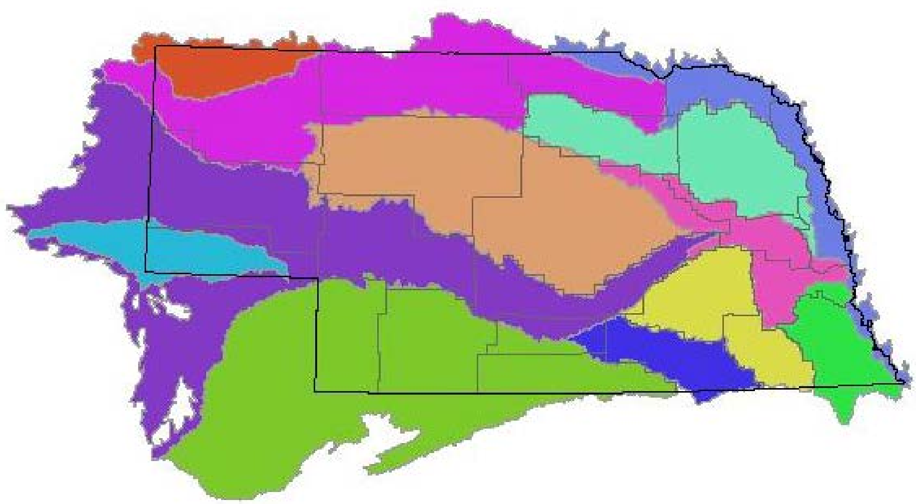
INSIGHT Methods



Nebraska Department of Natural Resources

1.0 Introduction

The Nebraska Department of Natural Resources (Department) has focused significant resources on the development of data and hydrologic tools to support integrated water management planning efforts, both required and voluntary (provided for pursuant to *Neb. Rev. Stat.* § 46-715), as well as to support the proactive annual evaluation that it conducts to evaluate 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 that were utilized by the Department to develop the data and hydrologic analyses that were subsequently used to generate the charts and graphs available on the Department's new INSIGHT website: http://dnr.nebraska.gov/insight/. This document is intended for those users with sufficient background and training in hydrology and water resources management. Appendix A provides a simplified example of the evaluation process and is intended to be suitable for broader audiences.

The INSIGHT website provides various levels of data and information in regard to water quantity within the state. INSIGHT provides basin and subbasin level summaries that include: 1) 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. Additionally, INSIGHT provides access points to the data, hydrologic tools, and models necessary to do the calculations and analyses that are further detailed in this document, as well as in other supporting documentation available on the Department's website.

The first step in the methodology used by the Department to conduct this analysis required a determination of the available hydrologically connected water supplies, i.e., aquifers and streams that are in close connection (Figure 1.1).

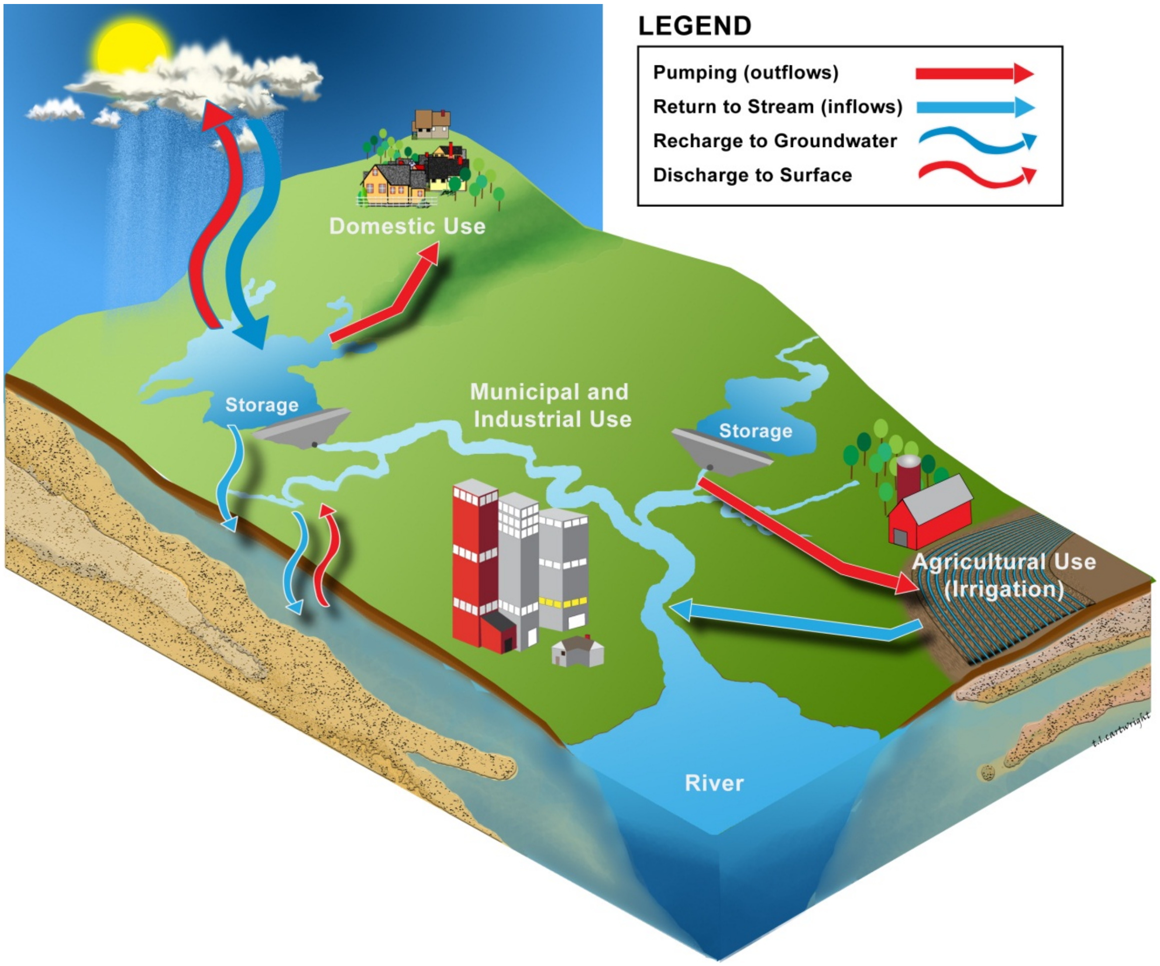


Figure 1.1: Schematic diagram illustrating the interconnected nature of a surface-groundwater system. The methodologies used in this analysis determine the water supplies and uses of these interconnected systems.

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 water available for use (excluding groundwater storage), 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 was 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

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

storage water from the system (e.g., from reservoirs and aquifers); however, removal of storage water may result in a reduction of streamflow in either the near-term or long-term. A simplified example of the overall methodology is provided in the Appendix.

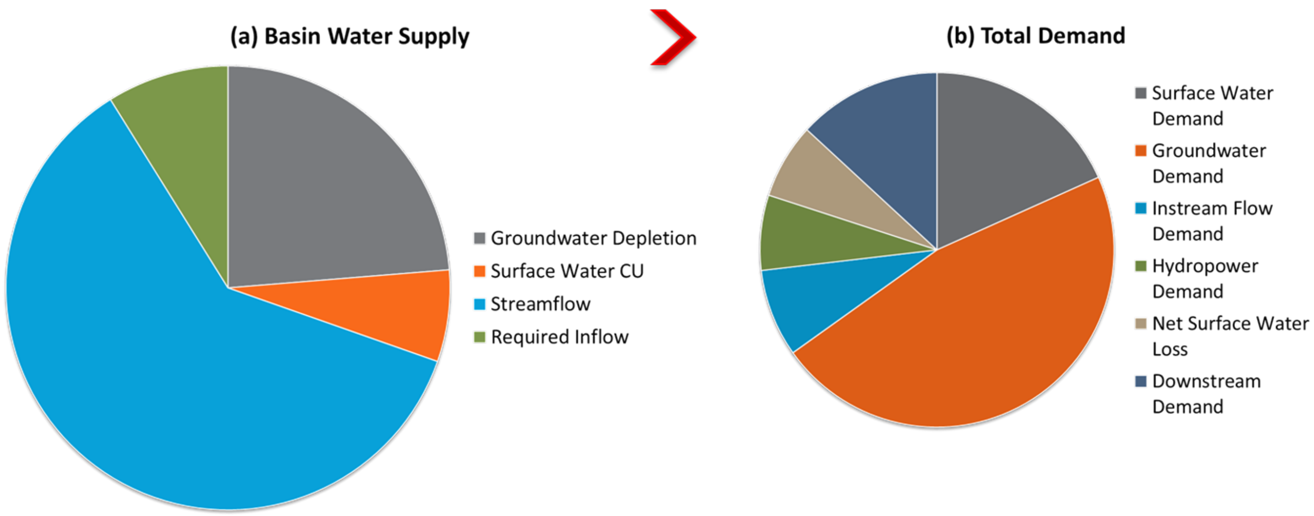


Figure 1.2: One way to visualize the BWS/TD methodology is to use pie charts to demonstrate the relative difference in volume between water supplies and water demands. The BWS is the hydrologically connected water available for use, while the TD is the current utilization of hydrologically connected 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 data 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 Basin Water Supply (BWS) represents the total volume of hydrologically connected streamflow originating within a system that is available for consumption within a given 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 groundwater depletions captures the total amount of hydrologically connected water available for use within a basin or subbasin. 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 was calculated as follows:

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

Each of these components relied upon extensive data collection and/or modeling to define the volume of water in each. 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 were subdivided into two periods within the year: the peak demand season (June, July, and August) and the non-peak demand season (September through May).

2.1 Streamflow

Both the Department and the U.S. Geological Survey (USGS) gage streamflows within the state, so both sources provided 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 gain of the stream reach represents the streamflow. Streamgage data remained unmodified except when high flow events were 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 flow duration curves exhibit the form illustrated in Figure 2.1. Figure 2.1 illustrates that the flows that are exceeded 5% of the time or more (high flows) tend to create a inflection point on the flow duration curve. Thus, for this evaluation the daily streamflow values that had an exceedance probability of 5% or less were set to the value corresponding to the 5% exceedance probability. Figures 2.1 and 2.2 illustrate the resulting streamflow data from applying this cap.

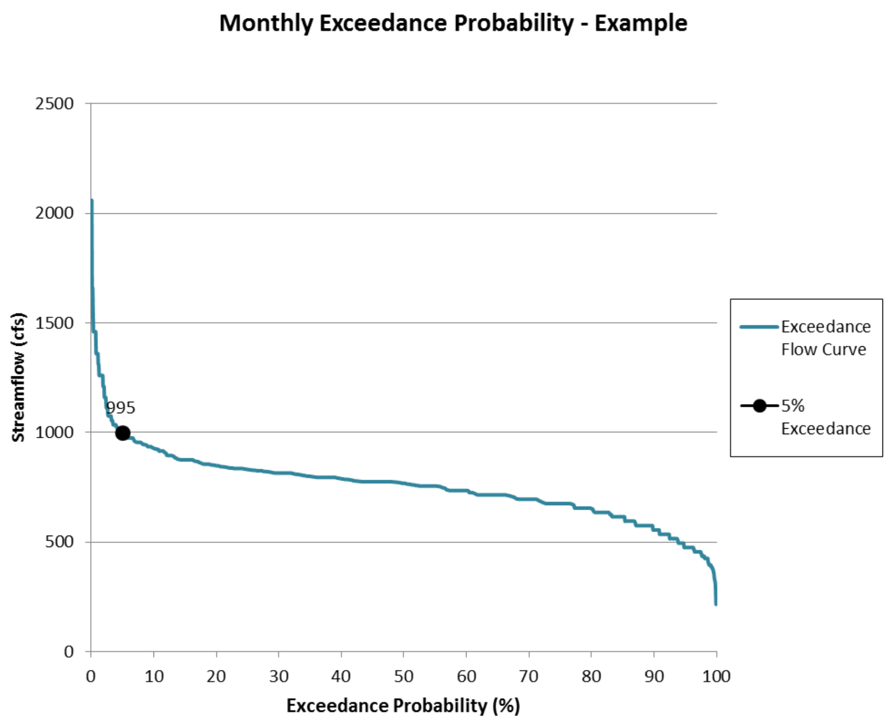


Figure 2.1: Example of a flow duration curve with an inflection point at 5 percent exceedance.

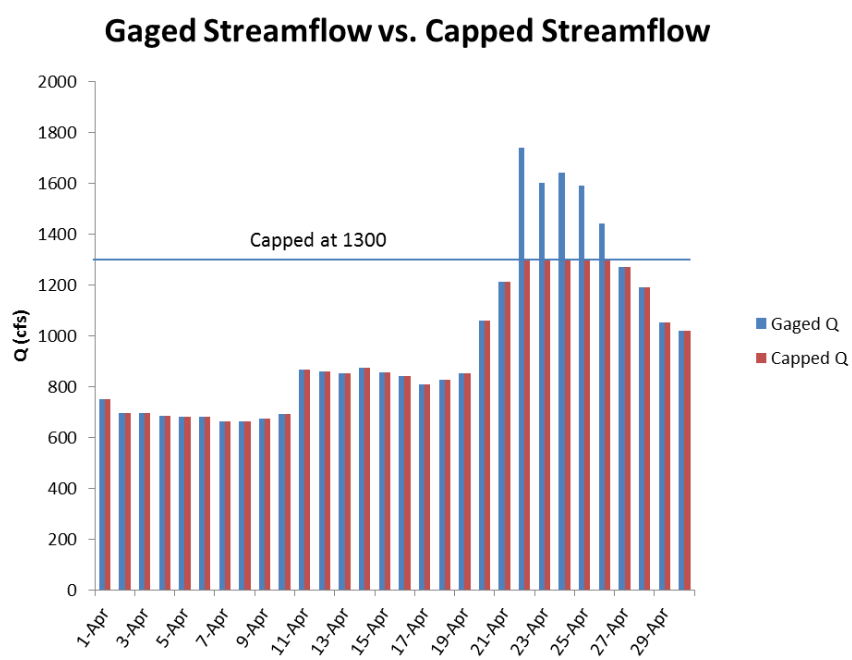


Figure 2.2: Example of an exceedance probability plot and the result from capping streamflows at 5 percent exceedance flow probability.

2.2 Surface Water Consumptive Use

Surface Water Consumptive Use (SWCU) has been separated into four main use categories for purposes of this evaluation: irrigation, municipal, industrial, and evaporation from large water bodies. For the currently evaluated areas, however, there were no municipal[2] or industrial water uses that rely on direct surface water sources; therefore, irrigation and evaporation were the only surface water uses evaluated.

Some of the irrigation uses had data regarding the amount of water diverted on a daily, monthly, or seasonal basis, while other uses had very limited or no time series data. The following sections describe the methods required to calculate consumptive use for the irrigation components. The methods were dependent upon what information is available for each point where water is diverted. There were four equation types used for calculating SWCU.

Recognizing that not all water that is diverted for use is actually consumed, the Department only considered in these analyses the consumptive portion of the water diverted from surface water sources. 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 that are 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).

$$SWCU = SWCUI + SWCUE$$

SWCUI = surface water consumptive use for irrigation

SWCUE = surface water consumptive use for evaporation

[2] Omaha and Lincoln both hold induced recharge permits; however for this evaluation the uses for Omaha and Lincoln were represented in the category of groundwater depletion and groundwater demands.

2.2.1 Surface Water Irrigation

The SWCUI calculations were data dependent, meaning that the equations necessary to calculate the SWCUI depended upon the detail of the data and information available. SWCUI calculations may include information regarding diversions, diversions/returns, diversions/deliveries, diversions/deliveries/returns, or no available data. For example, diversions by irrigation districts are generally measured and recorded by the Department daily, while the information available from many small surface water pumpers is the permitted amount associated with that point of diversion[3].

SWCUI calculations relied upon several main datasets: the Department's point of diversion records, land-cover, gaged diversion and return flow data, crop irrigation requirements, etc. Surface water irrigators fall into two general categories: small diverters and irrigation districts. The amount of data available for each category differed substantially, which required the methods to determine SWCUI to differ depending on data availability. SWCUI calculations fell under four general categories:

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

Type 2) Irrigation: Canal Diversion Records, Field Delivery Records

Type 3) Irrigation: Canal Diversion Records

Type 4) Irrigation: No Diversion Records– data on appropriated 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

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

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 calculations:

The basic equation to calculate SWCUI for Type 1:

SWCUI = Net Diversion – Total Loss

Net Diversion = Diversion – Direct Return

Total Loss = Canal Loss + Field Loss

Canal Loss = Net Diversion – Field Deliveries

Field Loss = Field Deliveries * Field Loss Factor (assumed to be 70%)

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 allowed for the following calculations:

The basic equation to calculate SWCUI for Type 2:

SWCUI = Diversion – Total Loss

Total Loss = Canal Loss + Field Loss

Canal Loss = Diversion – Field Deliveries

Field Loss = Field Deliveries * Field Loss Factor (assumed to be 70%)

2.2.1.3 Type 3: Canals and Small Pumpers with Diversion Data

The Type 3 SWCUI category represented points of diversion where the water diverted from the stream was measured by a gage, but other factors (e.g., direct returns and field deliveries) were not measured. Unless other data were available (e.g., a study or model had been developed and the data were readily available), it was assumed that 65 percent

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[4] Thirty-five percent was utilized based on evaluation of available information for canals that collected such data as well as previous studies.

of the diversion was consumed and 35 percent of the diversion recharged the groundwater system or directly returned.

The basic equation to calculate SWCUI for Type 3:

$$\text{SWCUI} = \text{Diversion} * (1\text{- }\%\text{Loss})$$

2.2.1.4 Type 4: Direct Diverters/Pumpers with no Diversion Data

The Type 4 SWCUI category represented points of diversion where the water diverted from the stream was not measured directly. These users lacked data on their daily diversions, but the Department does maintain a database that specifies their location and the number of acres that are appropriated for irrigation. To construct the SWCUI time series for small pumpers, a detailed transient land-use dataset was developed. This dataset details the location and number of irrigated acres per year. National Agriculture Statistics Service (NASS) data provided information needed to adjust the total number of irrigated acres per county, per year, based on reported irrigation in a given county. These NASS adjustments were applied to each point of diversion within a given subbasin to allow for the development of the transient acreage dataset. The net irrigation requirement was then used to estimate the amount of water that was applied to the acreage and completely consumed.

The basic equation to calculate SWCUI for Type 4:

SWCUI = Adjusted Acreage * NIR

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

NIR = net irrigation requirement (all acreage was assumed to be corn)

2.2.1.5 Reservoir Evaporation

Large reservoirs (those listed below) had sufficient data to include evaporative losses in the SWCU calculations. These evaporative losses were incorporated into calculated net evaporation values by accessing information on pan evaporation, surface area, and precipitation. For the areas evaluated, these reservoirs included:

- Box Butte Reservoir
- Calamus Reservoir
- Davis Creek Reservoir
- Elwood Reservoir
- Jeffrey Reservoir
- Johnson Lake
- Lake McConaughy
- Lake Maloney
- Merritt Reservoir
- Sutherland Reservoir

SWCUE = [(Pan evaporation * 0.7 * surface area) – (precipitation * surface area)][5]

[5] 0.7 is commonly used by hydrologist as a multiplier against pan evaporation values

2.3 Groundwater Depletion

Groundwater depletions were considered groundwater withdrawals for three general use categories: irrigation, municipal, and industrial. Groundwater depletions to streamflow were modeled values that consider the effects of groundwater-streamflow interactions. Groundwater depletions were used to calculate the BWS and to represent the near-term total demand for groundwater uses (see Section 3: Calculating the Total Demand).

Groundwater models, both numerical (MODFLOW) and analytical, were utilized 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 numerical models that were utilized cover the entire Niobrara River Basin, Loup River Basin, Big Blue River Basin, Little Blue River Basin, and large portions of the Platte River Basin. Analytical models were used where either insufficient data existed to construct a numerical model, or construction of such a model was currently in progress. These areas were limited to lower portions of the Elkhorn River Basin and the Lower Platte River Basin.

The Department included in its analysis wells that pump greater than 50 gallons per minute (gpm). Most domestic and livestock wells are under 50 gpm; therefore, they were generally not included in the analysis. Municipal and industrial uses over 50 gpm were developed using methods described in Flatwater (2013). Exceptions to this were the Lincoln well field and the two Omaha well fields located in the Lower Platte River Basin, for which water use and return data were utilized. The net pumping values[6] for these well fields were directly included due to the fact that the impacts of these well fields on streamflow manifest rapidly.

[6] Net pumping is the pumping value metered at the wellfield minus the amount that is discharged back into the basin. No returns were assumed for the Omaha wellfields and a value of 65% was utilized as the return percentage for the Lincoln wellfield (based on work done for the LPSNRD water balance study).

A depletions analysis was conducted for each subbasin where a numerical model was available[7]. The depletions analysis consisted of a comparison of two model runs: one that represented historical pumping, and one that represented the basin without pumping. The difference between these two model runs indicated the groundwater depletions. The depletions analysis that was conducted for the majority of the Lower Elkhorn River Basin and Lower Platte River Basin using analytical methods is described in HDR (2014)[8]. These depletion values were summed to each season, (peak and non-peak), and incorporated into the BWS.

[7] 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 on the basin water supply concept.

[8] HDR, Inc. 2013. Depletion Estimates for the Lower Platte River Basin, http://dnr.nebraska.gov/iwm/depletion-estimates-for-the-lower-platte-river-basin.

2.4 Required Inflow

Required inflow is the final component of the BWS. Required inflow was included in the basin or subbasin supply to represent the portion of demand within that area that is reliant upon upstream sources for water supply. The calculation for required inflow was determined by summing the proportionate downstream demands (see Section 3: Calculating the Total Demand) that were 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. 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., subbasin) evaluations.

The required inflow for the subbasins of Spencer to Niobrara, Above North Bend, and North Bend to Louisville utilized the upstream hydropower demands to represent required inflow. This was done to include supplies for these areas while recognizing that no additional downstream demands were assigned to upstream subbasins for these reaches (non-consumptive hydropower or instream flow demands exceeded any downstream demands that would be assigned).

2.5 Determining the Representative Period of Record

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

This evaluation utilized both autocovariance and Kendall Tau statistical methods for this process. The autocovariance analysis of the BWS provided a measure of self-similarity of the time-series data that was useful in determining repetitions in data. In other words, it provided 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. This process aided 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 was performed. Once the representative period of record was identified, a Kendall Tau test was 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 did not suggest the presence of an underlying trend, then the evaluation process continued. If the test suggested that a trend was present, then the representative period may be reevaluated.

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. With the representative period selected, the final step was to create a time series of the BWS for the peak and non-peak seasons.

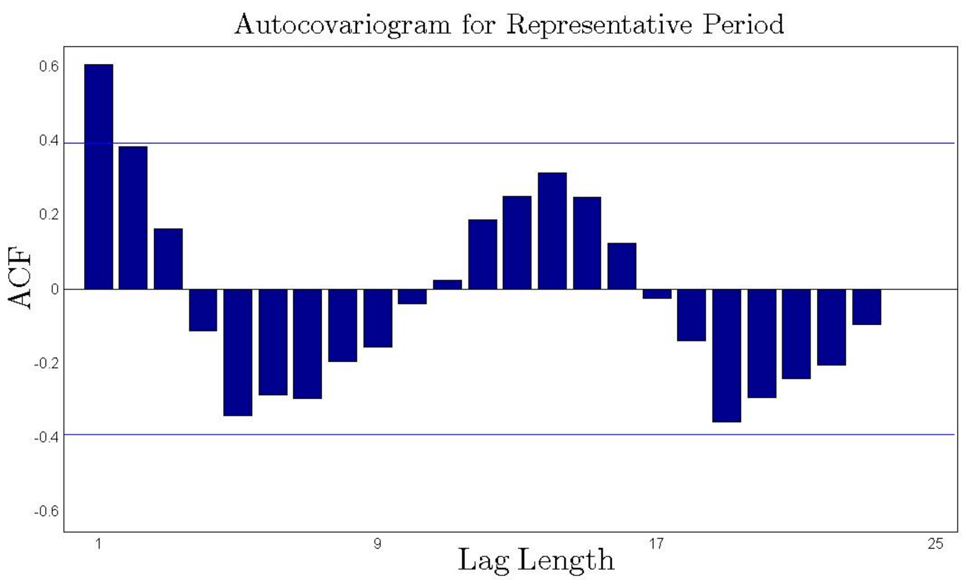


Figure 2.2: Example of an autocovariogram for determining an appropriateperiod of record for use in the evaluation.

3.0 Calculating the Total Demand

The Total Demand (TD) of water within a basin or subbasin was 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.

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

The TD represents the total amount of hydrologically connected water consumed or utilized within a system during a given time frame (i.e., all consumptive and non-consumptive uses). The calculation of TD was completed for near-term demands, long-term demands, and projected long-term demands. The difference between the near-term and long-term demands was that the near-term TD calculation considered the groundwater depletion (current effect of wells on the stream), while the long-term calculation considered the groundwater consumption (full impact of wells on a hydrologically connected stream). The projected long-term demands calculation utilized the same values used to represent the long-term demands, but increased them by 5 percent to provide a sense of the potential for additional long-term water development in a basin[9].

[9] Five percent was utilized for is 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.

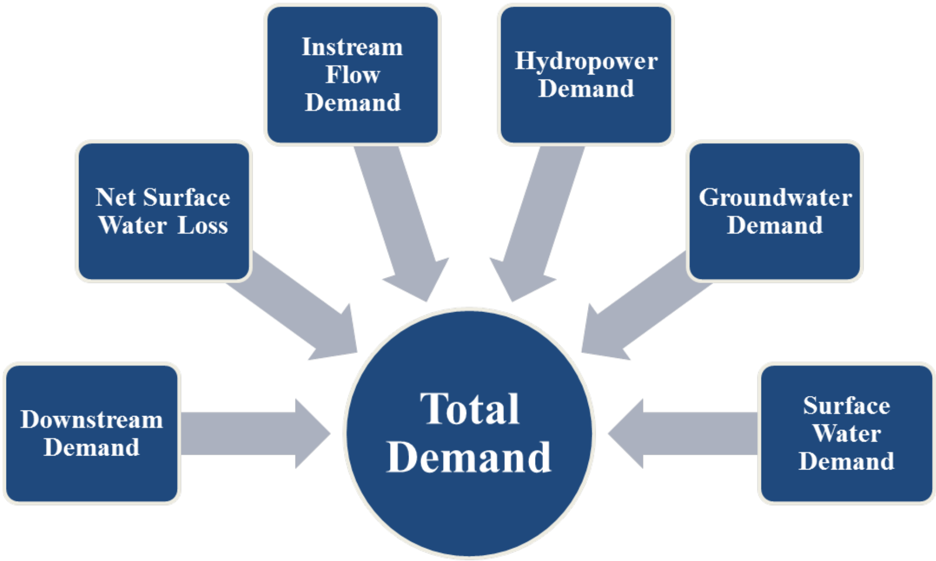


Figure 3.1: Basic components (Downstream Demand, Net Surface Water Loss, Instream Flow Demand, Hydropower Demand, Groundwater Demand, and Surface Water Demand) necessary to determine the Total Use/Demand. Each component will be detailed further in the document.

3.1 Surface Water Demand

The surface water demand was calculated in a similar manner as the surface water consumptive use for the BWS. The only differences were that for the surface water demand calculation, adjustments were made to account for shortages to junior water users caused by administration for senior water users and to redistribute surface water consumptive use from the peak season to the non-peak season, when storage reservoirs provide a portion of a water users water supply.

3.1.1 Surface Water Administration Adjustment Factor

During certain portions of the representative period, some surface water users are required to forgo their diversion due to administration for senior water users. If administration continues for a long enough period, it can cause those restricted water users to receive less water than they have a demand for. To account for this, a surface water administration adjustment factor was used. The administration adjustment factor considered 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[10] reflects the difference in the consumptive use that the restricted water user was able to obtain, versus the consumptive use that they would have been able to obtain with a full water supply. For many surface water users the adjustment factor was simply a value of one, indicating that no adjustment was necessary.

3.1.2 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 was made to those surface water users that utilize large reservoirs for storing water in the non-peak season. The adjustment consisted of calculating the storage change that occurs over the course of the non-peak season (i.e, the storage volume accrued

[10] Flatwater Group, Inc. 2014. Municipal and Industrial Pumping, http://dnr.nebraska.gov/iwm/municipal-and-industrial-pumping; Nebraska Surface Water Administration Tool, http://dnr.nebraska.gov/iwm/nebraska-surface-water-administration-tool; Net Irrigation Requirement, http://dnr.nebraska.gov/iwm/net-irrigation-requirement.

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 was 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 water from wells that pump greater than 50gpm. 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 was the total amount of net water pumped (net irrigation requirement) within that period, irrespective of lag-effects for wells located within the hydrologically connected area. Calculation of long-term groundwater demand relied 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 crop distribution mix for a given area) that was utilized to develop the groundwater pumping datasets utilized in the groundwater models to calculate groundwater depletions. Annual volumes of groundwater consumption were distributed 70 percent to the non-peak season and 30 percent to the peak season. The proportioning between the seasons was intended to match the observed seasonal pattern of groundwater depletions.

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

Long-Term Groundwater Demand = Net Irrigation Requirement ∗ Groundwater Irrigated Acres (for only those acres contained within the hydrologically connected area) ∗ Proportional Adjustment (to account for overlap areas)

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" as the area that is hydrologically connected to streams[11]. 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 analysis 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. Numerical models were utilized for all areas with the exception of portions of the Lower Elkhorn River Basin and the Lower Platte River Basin. In those areas an analytical approach was 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 was 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 was to then compare the results from the baseline model run and the simulations with the new well that was inserted. The output was generally processed as follows:

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

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 analysis (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 may be applied. The following steps were utilized to calculate the extent of the 10/50 area when applying an analytical[12] approach:

Step 1: Identification of Aquifers that are in Hydrologic Connection to Perennial Streams

The locations of aquifers in hydrologic connection to perennial streams were determined using the best available science. The types of information used in this assessment included the distribution of groundwater aquifers, perennial streams, and aquifer properties.

[12] 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.

Step 2: Data Preparation

Once aquifer locations were identified, the availability of additional information had 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,
- Locations of perennial streams,
- Point grid of distances to streams,
- Streambed conductance (to apply the Hunt Method[13]).

Data on aquifer properties (e.g., transmissivity and specific yield) were identified using the best available science. The location and extent of perennial streams were identified from the perennial streams GIS coverage available from the USGS National Hydrography Dataset. The point grid was spatially refined to a one-mile grid so that specific distances from the stream to grid nodes could be identified and stored.

Step 3: Analysis

The analysis of locations for determining whether a hydrologic connection (10 percent depletion in 50 years) exists was performed following the calculation procedures established through the Hunt Method (when streambed conductance data are available) or the Jenkins Method.

Documentation of the models used and results of these analyses are available at:
http://dnr.nebraska.gov/iwm/technical-reports

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

3.3 Hydropower Demand

Demands on water supplies to support hydropower water uses were represented in the analysis as “non-consumptive” uses, meaning that water supplies that are available to meet hydropower needs may also be used to meet other non-consumptive demands such as instream flow or induced recharge or downstream demands for consumptive uses. Hydropower demands exist within the Niobrara River Basin, Platte River Basin, and Loup River Basin. Hydropower demands were represented by evaluating the water supplies that were diverted on a daily basis through the representative period and the groundwater depletions to those daily values when the diversion was operational and the full capacity of the diversion was not realized. An example of this process is provided below:

Step 1: Streamflow = 1,800 cubic feet per second (cfs)

i. Groundwater depletion = 200 cfs
ii. Adjusted streamflow = 1,800 + 200 = 2,000 cfs

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

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

If the rate of diversion for hydropower on a particular day were equal to zero, then that day’s demand would have been set equal to zero. Additionally, if the appropriated rate of diversion for hydropower had been greater than the adjusted streamflow then the final hydropower demand on that day would have been set to the adjusted streamflow value.

3.4 Instream Flow Demands

Instream flows were incorporated into the analysis 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 46-713 (3) of the Ground Water Management and Protection Act). Like hydropower uses, instream flows represent a non-consumptive category of water demand. Water supplies available to meet hydropower demands (described above) can also be used to meet instream flow demands and other downstream demands; therefore, where those instances occur (e.g., the Loup River Basin), careful consideration was given to ensure that these non-consumptive uses were not counted twice. To avoid such duplication, only the "additional" volume of instream flow demand was represented. This does not imply that demands for instream flow do not exist in those areas, but rather that hydropower demands are equivalent or in excess of those demands.

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

Step 2: Make assignments to the basins and subbasins

i. Sum daily values to peak and non-peak season volumes = 2,000 * 92 days for peak season = 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 contribution = 150,000, 15%

Instream Flow Demand Assigned to each basin
Total Instream Flow Demand = 184,000
Upper Platte assignment= 184,000 * 0.2 = 36,800
Loup BWS assignment = 184,000 * 0.4 = 73,600
Elkhorn BWS 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. Upper Platte consumptive demands = 50,000
Loup BWS consumptive demands = 60,000
Elkhorn BWS assignment = 40,000
Lower Platte assignment = 10,000

ii. Final instream flow demands assigned to the basins:

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

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

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

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

3.5 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 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 (stateline to above Box Butte Reservoir), Niobrara River (Box Butte Reservoir to Gordon), and the Niobrara River (Gordon to Sparks).

3.6 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 analysis 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 analysis). 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 BWS at each subbasin confluence upstream.

Step 3: Subtract upstream BWS to get water supply intrinsic to that subbasin.

Step 4: 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 total demand downstream to determine the amount of water each subbasin would provide as required inflow to subbasins located downstream[14]. The total demand downstream of a basin only consisted of those surface water and groundwater demands 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:

[14] When calculating the total demand downstream in areas where hydropower demands exists, groundwater depletions were utilized for proportioning the hydropower demand. This was done to be consistent with the methods utilized for calculating the hydropower demands.

A basin consists of four smaller tributary subbasins that all contribute different flows to the larger basin, each with an average annual flow volume:

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 TD 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.

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.

4.0 Calculating the Balance of Water Supplies and Water Uses

Once the BWS and the TD were determined, the comparison of the two components could be completed. To recognize the impact that timing had on the ability of a water supply to meet a beneficial water use, the comparison was 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 were 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 5 percent demand. This additional projected demand was utilized to provide a sense of the potential for additional long-term water development in a basin.

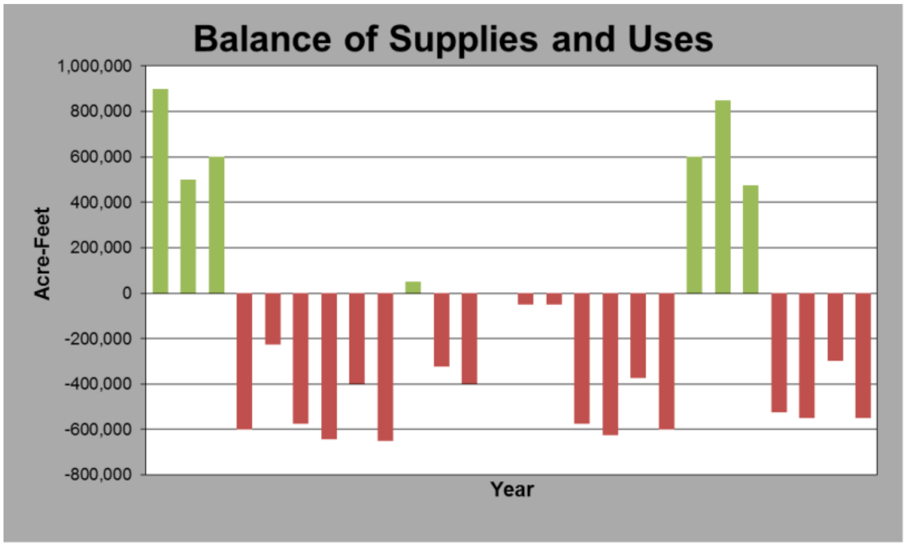


Figure 4.1: A fictional chart illustrating the balance between BWS and TD. The amount and year in which the BWS is greater than TD will be shown in green, while the amount and year in which the BWS is less than TD will be shown in red.

4.1 Near-Term Balance

The determination of the balance between current water supplies and current demands focused on a comparison of near-term BWS and the near-term demands over the representative period. The comparison yielded results that describe the amount, location, and timing of the surplus and deficit in water supply (e.g., positive values indicate water is available beyond the current demand).

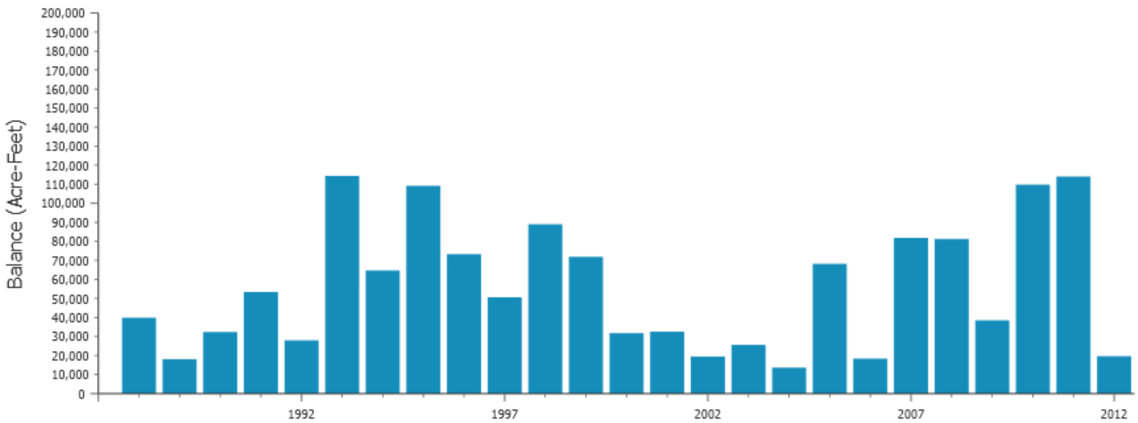


Figure 4.2: Method to display the near-term balance between BWS and TD for a representative basin during peak season (June – August).

4.2 Long-Term Balance

The determination of the balance between current water supplies and uses in the long-term focused on the comparison of surplus and deficits of BWS and long-term TD over the representative period. Long-term TD was distinguished from current demand by the difference between current impacts of well development and the long-term consumption of hydrologically connected wells. Additionally, the required inflows for the near-term B WS were replaced with the downstream demands that were assigned to each basin or subbasin.

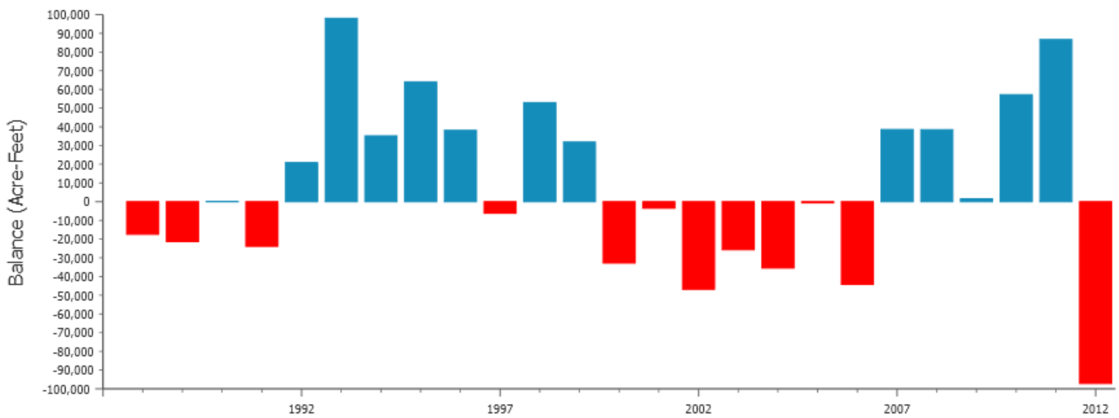


Figure 4.3: Method to display the long-term balance between BWS and TD for a representative basin during peak season (June – August).

4.3 Projected Long-Term Balance (With Future Development)

The determination of the balance between current BWS and projected long-term demand was 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.

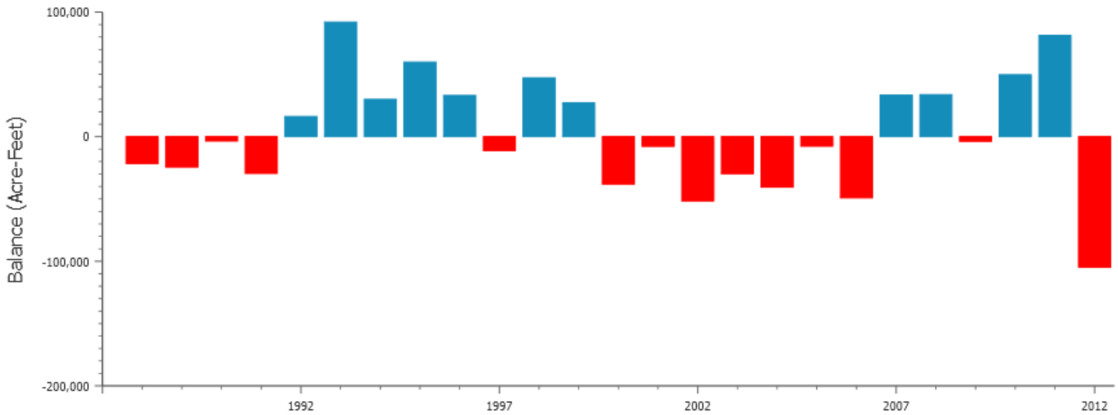
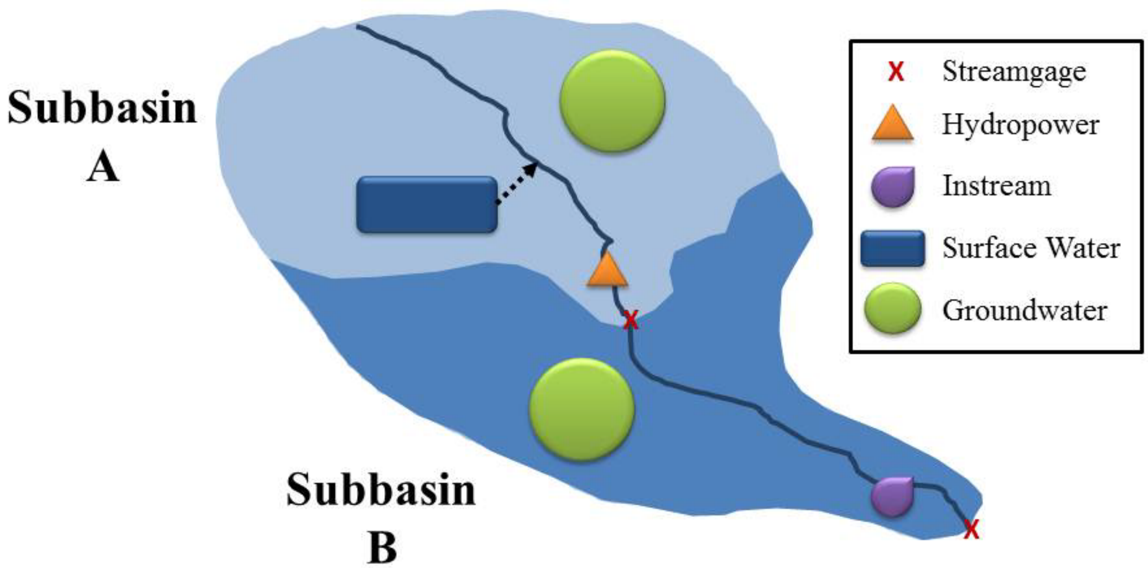


Figure 4.4: Method to display the projected balance between BWS and TD for a representative basin during peak season (June – August).

Appendix: Simplified Example of the Basin Water Supply/Total Demand Concepts

Subbasins A and B will be used in the following example of the basin water supply (BWS) and total demand (TD) concepts. In this example, water from Subbasin A flows downstream to Subbasin B.



In this example, “Hydropower” represents non-consumptive demands for streamflows that are used for hydropower purposes, “Instream” represents non-consumptive demands that remain within the stream channel to provide beneficial use for fish, recreation, and wildlife, “Surface Water” represents consumptive uses that are supplied by surface water, and “Groundwater” represents consumptive uses that are supplied by groundwater.

Calculating BWS: An example of how BWS is calculated for Subbasins A and B.

BWS = Streamflow + Surface Water + Groundwater					
Subbasin A + Subbasin B		***Subbasin A***		***Subbasin B***	
X Streamflow at gage	1200 AF	X Streamflow at gage	400 AF		
Surface Water	100 AF	Surface Water	100 AF	Surface Water	0 AF
Groundwater	700 AF	Groundwater	300 AF	Groundwater	400 AF
Total BWS	**2000 AF**	**Total BWS**	**800 AF**	**Total BWS**	2000 - 800 = **1200 AF**
		Proportion of Total Supply	800/2000 = **40%**	**Proportion of Total Supply**	1200/2000 = **60%**

Calculating TD: A simplified example of how TD is calculated for Subbasins A and B.

TD = Groundwater + Surface Water + Hydropower + Instream + Downstream Demand

Subbasin A		***Subbasin B***	
Groundwater	300 AF	Groundwater	300 AF (mainstem)
			100 (tributary)
Surface Water	100 AF	Surface Water	0 AF
Total Consumptive Demand	300 + 100 = 400 AF	Total Consumptive Demand	300 AF
Hydropower	300 AF	Hydropower	0 AF
Instream	0 AF	Instream	500 AF (mainstem)
Total Non-consumptive Demand	300 AF	Total Non-consumptive Demand (mainstem)	500 AF
Total Demand (in basin)	400 + 300 = 700 AF	Total Demand	300 + 100 + 500 = 900 AF
Downstream Demands (mainstem only) Consumptive Non-consumptive	40% of 300 = 120 AF 40% of 500 = 200 AF 320 AF	Downstream Demands	0 AF
Final Downstream Demand	320 - 300 (in basin non-consumptive) = 20		
Total Demand	700 + 20 = **720 AF**	**Total Demand**	**900 AF** (320 AF of which are downstream demands assigned to Subbasin A)

Calculating balance: A simplified example of how the balance of water supplies and uses is calculated. A negative balance indicates that the demand exceeds the supply, whereas a positive balance indicates that there is sufficient supply available to meet the demand.

Balance = BWS - TD

Subbasin A		***Subbasin B***	
BWS	800 AF	BWS (exclusive to subbasin B)	1,200 AF
		Downstream Demand Assigned to subbasin A (required inflow)	320 AF
TD	720 AF	TD	900 AF
Balance	**+80 AF**	**Balance**	**+ 620 AF**