Fully Appropriated Evaluation Methodology Development

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DATE: April 2013

Executive Summary

As defined in Nebraska Revised Statutes Section 46-713, the procedures for conducting the fully appropriated evaluation must address three key areas:

1) Identify and quantify existing surface and ground water uses
2) Identify and quantify surface water supplies
3) Represent surface/ground water interaction

Through discussions with the Nebraska Department of Natural Resources (DNR), Central Platte Natural Resources District (NRD), and input from Nebraska's water stakeholders, as well as the literature review findings, the following desirable characteristics/components of the fully appropriated evaluation procedures were noted:

1) Reflect long-term variability in water supply (climatic/drought cycles)
2) Reflect year-to-year variability in water supply
3) Reflects seasonal variability in water supply
4) Differentiate between ground and surface water, to the extent possible, in estimating sources and uses
5) Include means to evaluate and quantify conservation measures, as required by statute in the designated overappropriated basins
6) Differentiate between consumptive uses (CU) and non-consumptive uses, including the following sub-categories:
    a. Agricultural
    b. Hydropower
    c. Instream flows
    d. Municipal and Industrial uses
7) Utilize existing datasets/observed data (no explicitly new data collection efforts required)

Based on these statutory requirements and desired characteristics, conceptual refinements to the current methodology for conducting fully appropriated evaluations were developed.

The concepts were tested through application on case studies of the Upper Niobrara River, the central Platte River, and the full Platte River basins. This testing led to further refinements of the concepts, in addition to illustrating their utility. In reviewing the statutory requirements and the desirable characteristics of the methodology, the concepts employed meet this standard. In addition, the proposed methodology provides a direct link between the evaluation process and the integrated management planning process defined by State statute.

Based on application of the concepts to the Niobrara, Lower Platte and Full Platte River case studies described herein, the following recommendations regarding the proposed fully appropriated methodology are made:

Supply

1. Virgin Natural Flow – The use of virgin natural flow to represent water supplies is an appropriate approach for the evaluation. For purposes of this discussion and recommendation, virgin natural flow is defined as estimated supplies undepleted by the activities of man.
2. Statistical Testing – The use of statistical tests, specifically the Kendall Tau and autocorrelation tests, on virgin natural flow estimates are recommended in determining an appropriate period of analysis that represents the cyclical nature of supplies and uses without bias. In the event that every time period evaluated in the Kendall Tau test has a statistically significant trend, the Kendall Tau value can be used to determine the degree of the trend. For values close to 0 (approximately +0.25 to -0.25, for example) the trend may be negligible to the analysis, especially when it is coupled with the autocorrelation test. If a strong enough trend exists (greater than +0.25 or less than -0.25, for example) it is recommended that the statistical analyses be performed on the individual components comprising the virgin natural flow to determine the component(s) causing the trend. The remaining component(s) can then be used to determine the period of analysis in conjunction with the autocorrelation test.
3. Discrete Supply Components – Representation of each discrete component of the computed virgin natural flow provides insight into the relative magnitude of supply components and trends and should be employed. It also provides useful information on the importance of assumptions utilized in building the supply and can serve as a guide on future efforts to refine estimates.
4. Reservoir Storage – For reservoirs with the potential for large carryover storage volumes, supply should incorporate both the total available storage for use as well as change in storage in the analysis.
5. State Line Inflows – For basins with headwaters that originate outside of the State's boundaries, inflows should be estimated using the closest available main stem gage in addition to flows from tributary basins or canals that are not captured by the main stem.

Demand

1. Demand Estimates – Representation of discrete demands, both consumptive and non-consumptive, using the best available information provides a clear picture of water usage, relative magnitude of each demand, and should be employed to the extent possible. The use of 'build' plots that illustrate each component of demand, as well as the cumulative demand, can also be used to consider water use preferences.
2. Consumptive Uses – Primary consumptive uses for consideration in the methodology vary by reach, but include:
    a. Groundwater irrigation consumptive use: Estimates may be made based on well database, irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements.
    b. Surface water irrigation consumptive use: Estimates may be made in a couple of different ways. For those diverters with available historical gaging records, consumptive use may be estimated as a percent of diversions. This approach provides a way to account for water-short years when full irrigation requirements may not be met. Consumptive use estimates may also be made using irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements.
    c. Municipal and Industrial consumptive use: Estimates of consumptive use may be made based on historic groundwater well pumping and wastewater return records. Conversion of total consumptive use to a per capita estimate allows variations in population over time to be represented in the evaluation. Estimates of future usage for municipal and industrial users should be represented in as much as that future usage is accommodated for within their current appropriation.
    d. Reservoir Evaporation: For reservoirs with historic stage data, historic pan evaporation data and reservoir stage/surface area data may be used to estimate evaporation. For the numerous smaller reservoirs throughout the state with permanent pools and no historic data, the Nebraska DNR's dam database may be used to identify locations and estimate pool sizes for estimate evaporative losses.
3. Non-Consumptive Uses – The two primary non-consumptive uses include hydropower and instream flows:
    a. It is recommended that the demand evaluation consider three levels of hydropower demands: 1) no hydropower demand; 2) full hydropower appropriation; and 3) an intermediate demand that may be based on historic hydropower usage, physical capacity of system, adjusted historic flow available at time of granting, etc.
    b. Instream flow demands may be estimated based on the appropriated right, capped to the adjusted historic flow available at the time of granting.
4. Downstream Demands – Evaluation of demands at a particular analysis point on a river or stream should consider downstream demands that are served by flows passing that analysis point. It is recommended that the ratio of virgin natural flows (upstream virgin natural flow to downstream virgin natural flow) be used to allocate these downstream demands to the

upstream reach. This approach provides full consideration of demands, as well as a potential means for discrete evaluation of tributary basins.

5. Precipitation-adjusted crop irrigation requirements – Use of this adjustment for annual crop demands allows variations in the hydrologic cycle to be represented in the evaluation.
6. Use of Groundwater Depletions and Consumptive Use as Demands – Representing groundwater usage using both depletions and consumptive use is a useful approach in determining the impacts of historic usage on current water supplies as well as the future impacts on water supplies based on current water usage in the basin. The use of groundwater depletion demands provides an indication of demands based on current levels of depletions. The use of groundwater consumptive use demands provides an indication of demands based on the full depletive effects of current groundwater development. By comparing the two levels of demands, the relative maturity of groundwater usage in the basin can be assessed and the parameters for management and planning of future uses defined.
7. Canal Losses – While canal losses were not included as a demand represented in the analyses presented in this report, the spatial and temporal discretization used for analyzing water supplies and demands may require that canal losses are represented as demands.

Evaluation

1. Surplus Values – The use of a surplus value (supply less demand) for each time period is recommended as a metric for evaluating appropriated status. Incorporating both supply and demand keeps the data paired and incorporates the flow, demand, and climatic conditions for that time period.
2. Arithmetic Plots – Arithmetic plots of surplus vs. time provide useful information regarding magnitudes of supply, demand, and surplus, as well as potential trends in each term.
3. Frequency Curves – Frequency curves (exceedance curves) are an appropriate and useful tool in assessing surplus probability in annual and seasonal periods over the period of analysis.
4. Three-Step Analysis – The three-step process illustrated in Figure 9.23 for determining a basin's status is an approach that is recommended.
5. Instream Flow Erosion Test – The approach detailed for adjusting historic flow records (prior to granting of instream right) and for adjusting the flow records of the current analysis period is an approach that is recommended and provides a sound basis for evaluating potential erosion of instream flow appropriations.

This Technical Memorandum was created and updated throughout the work effort with the intent of providing a narrative that documents the progression of the methodology development. To that end, this TM is organized sequentially into the following sections that correspond with the project work efforts:

1.0 Background
2.0 Characteristics of Methodology
3.0 Potential Analysis Tools
4.0 Refinements to Criteria
5.0 Approaches Recommended for Development
6.0 Proposed Work Plan for Methodology Development and Testing
7.0 Application to the Upper Reach of the Niobrara River
8.0 Refinements Based on Niobrara River Analysis
9.0 Central Platte River Analysis
10.0 Summary – Central Platte River Analysis
11.0 Full Platte River Analysis
12.0 Final Recommendations

The intent of applying the methodologies to the case study basins was to evaluate the proposed approaches, with a primary focus on methods not results. As such, readily available datasets were used and simplifying assumptions have been made in some cases. Where appropriate, dataset sources have been identified and assumptions noted. Finally, any quantitative descriptions of supplies and demands contained in this document were developed solely for the evaluation of potential methods. It is recognized that the Nebraska Department of Natural Resources, using adopted rules which may or may not include recommendations contained herein, will ultimately conduct the fully appropriated evaluation as dictated by Statute.

1.0 Background

The definition for fully appropriated is derived from Nebraska Revised Statues 46-713:

> *(3) A river basin, subbasin, or reach shall be deemed fully appropriated if the department determines based upon its evaluation conducted pursuant to subsection (1) of this section and information presented at the hearing pursuant to subsection (4) of section 46-714 that then-current uses of hydrologically connected surface water and ground water in the river basin, subbasin, or reach cause or will in the reasonably foreseeable future cause (a) the surface water supply to be insufficient to sustain over the long term the beneficial or useful purposes for which existing natural-flow or storage appropriations were granted and the beneficial or useful purposes for which, at the time of approval, any existing instream appropriation was granted, (b) the streamflow to be insufficient to sustain over the long term the beneficial uses from wells constructed in aquifers dependent on recharge from the river or stream involved, or (c) reduction in the flow of a river or stream sufficient to cause*

noncompliance by Nebraska with an interstate compact or decree, other formal state contract or agreement, or applicable state or federal laws.

Considering this definition of fully appropriated, and the statutory requirements of the DNR's annual evaluation defined in Section 46-713 (1), the procedures must address three key areas:

1) Identify and quantify existing surface and ground water uses
2) Identify and quantify surface water supplies
3) Represent surface/ground water interaction

2.0 Key Characteristics of Methodology

Through discussions with the Nebraska Department of Natural Resources (DNR), Central Platte Natural Resources District (NRD), and input from Nebraska's water stakeholders, as well as the literature review findings[1], the following desirable characteristics/components of any potential refinements to the fully appropriated evaluation procedures were noted:

1) Reflect long-term variability in water supply (climatic/drought cycles)
2) Reflect year-to-year variability in water supply
3) Reflects seasonal variability in water supply
4) Differentiate between ground and surface water, to the extent possible, in estimating sources and uses
5) Include means to evaluate and quantify conservation measures, as required by statute in the designated overappropriated basins
6) Differentiate between consumptive uses (CU) and non-consumptive uses, including the following sub-categories:
    a. Agricultural
    b. Hydropower
    c. Instream flows
    d. Municipal and Industrial uses
7) Utilize existing datasets/observed data (no explicitly new data collection efforts required)

[1] For more information see Literature Review Technical Memorandum, HDR 2011.

3.0 Potential Analysis Tools

Several approaches or tools were identified to address the three key areas of the annual evaluation. These approaches are discussed in the following sections.

3.1 Identify and Quantify Existing Surface and Ground Water Uses

Current Methodology: Uses are not identified. Focus in evaluating Criterion #1 and Criterion #2 is based on net irrigation requirements of corn for the most junior irrigators subject to administration. Non-irrigation rights of junior appropriators are evaluated in Criterion #3; although the 'use' is not explicitly evaluated, rather the ability of the appropriator to meet a defined portion of its full right is evaluated. Ground water use is estimated based on net irrigation requirements and acreage served by each well (assumed 90 acres each). Temporal variation in use is not explicitly considered, but is implicitly represented in the historic gage data. Depletive impacts of ground water use are varied over time based on a well's date of completion.

Net Irrigation Requirement (NIR) – State Wide Mapping: This approach would use the statewide NIR mapping and surface/ground water irrigated acreage databases to quantify surface and ground water agricultural consumptive use. The NIR data is developed based on specific soil types, crop types, and average precipitation depths for specific areas. Cropping pattern databases could also be utilized to estimate NIR of different crop types.

Net Irrigation Requirement – Model: This approach would use a standard methodology or model to determine NIR. The model would use surface/ground water irrigated acreage databases as well as cropping information. The use of a model would allow flexibility to estimate annual variations in NIR due to climatic patterns, land use changes, farming practices, and cropping patterns.

Identify All Uses: This approach would use one of the net irrigation requirement methods above, in conjunction with estimates for non-agricultural uses to estimate all ground water and surface water consumptive uses.

Table 3.1 displays a comparison of certain attributes of the current and potential approaches to the key desirable characteristics.

Table 3.1: Methods to Identify SW/GW Uses

Identify SW/GW Uses	(1) Reflect long-term variability (climatic/drought cycles)	(2) Reflect year to year variability	(3) Reflects seasonal variability in water suppl	(4) Differentiate between SW/GW	(5) Evaluate and quantify conservation measures (for overappropriated areas)	(6) Reflects different uses (CU and Non-CU)	(7) Utilize existing datasets/observed data	Notes
Current Methodology	Yes, but limited. Fixed 20-yr period; relies on administration	No	To some extent (instream flows, 65/85)	Limited - surface water flow only quantified; current GW pumping used for lag test	No	Instream flows only non-CU use addressed	Yes	Historic gage data; all uses assumed reflected in gage data; GW uses discretely reflected in lag test
NIR Consumptive Use - Statewide NIR Map	No - average value with no climatic signal	Yes	Yes - Growing/non-growing at a minimum	Yes	No	No - would identify CU uses only	Yes	Use statewide NIR and SW/GW irrigated acreage datasets to estimate CU. More complex methodology could be employed to reflect climatic signals, conservation practices, etc. Uses existing datasets, but some manipultation required.
NIR Consumptive Use - Model	Yes	Yes	Yes - Growing/non-growing at a minimum	Yes	Yes - primarily tillage practives	No - would identify CU uses only	Yes	Standard practice/technique could be specified. Uses existing datasets, but some manipultation required.
Identify All Uses	Yes	Yes	Yes	Yes	Dependent on NIR methodology	Yes	Yes	Data may be limited in some cases, so assumptions will be required (assumed CU rates/% of use could be applied to non-CU uses). What is use based on - historic supply? Historic CU and Non-CU uses? How to quantify 'beneficial useful purpose' benchmark?

3.2 Identify and Quantify Surface Water Supplies

The following methods for quantification of surface water supplies were identified:

Current Methodology: Total flow values from historic gaging records are used to quantify surface water supplies. A fixed period of the previous 20-years of record is used.

Virgin Natural Flow Hydrograph: Incorporates impacts and operations of existing infrastructure with historic gaging records in order to estimate natural flow. Depending on methods and complexity, components could be discretized to source (runoff, baseflow, etc.).

Virgin Flow Hydrograph (pre-development): For the purposes of this effort, virgin flow patterns refer to pre-development conditions and may incorporate additional components beyond those used to develop a natural flow hydrograph.

Oregon-type Flow Duration Curve (FDC) – Total Flow: Development of a flow duration curve using historic gaging records of total flow. Statistical parameters are used to estimate probability and reliability of water supply.

Flow Duration Curve – Discrete Components: Similar to Oregon-type FDC but estimates of discrete components of total flow (runoff, baseflow, etc.) would be used.

Statistical Evaluation of Precipitation/Runoff: Statistical analysis of historic precipitation and runoff records in order to determine runoff surface water supplies.

Modeling of Surface Water Supplies: Use of model (spreadsheet, STELLA, etc.) to partition historic gaging records into components, reflect operational impacts, and track natural and storage flows.

Table 3.2 displays a comparison of certain attributes of the current and potential approaches to the key desirable characteristics.

Table 3.2: Methods to Identify and Quantify Surface Water Sources

	(1) Reflect long-term variability (climatic/drought cycles)	(2) Reflect year to year variability	(3) Reflects seasonal variability in water supply	(4) Differentiate between SW/GW	(5) Evaluate and quantify conservation measures (for overappropriated areas)	(6) Reflects different uses (CU and Non-CU)	(7) Utilize existing datasets/observed data	Notes
Indentify SW Supplies								
Current Methodology	Yes (20-yr Period)	No	Yes	No - total flow considered	No	NA	Yes	Historic gage data (total flow, no separation of natural and storage flows) and administratvie record used
Virgin Natural Flow Hydrograph	Yes	Yes	Yes	Yes	Yes - depending on complexity of method and representation of watershed runoff	NA	Yes	Would incorporate historic diversions, reservoir operations, reach gains/losses, imported supplies, precip/irrigation runoff, etc.; partitioning of hydrograph
Virgin Flow Hydrograph (pre-development)	Not applicable - Consderation of pre-development or pre-settlement activities irrevalent							Would develop pre-settlement flow hydrographs.
Oregon-type Flow Duration Curve(FDC) - Total Flow	Approach is based and focuses on water to be left in stream and does not consider uses. Not suitable as a stand-alone approach, but could be a tool that can be useful in analyzing historical records							Total flow approach (storage and natural flows); standard approach could be defined to determine historic period of record for analysis
FDC with discrete components	Approach is based and focuses on water to be left in stream, and while it would differentiate sources of supply, does not consider uses.Not a stand-alone approach, but could be a tool that can be useful in analyzing historical records							Would separate baseflow and runoff, potentially allowing evaluation of conservation measures.
Statistical Analysis of Precip/Runoff	Not a stand-alone approach, but a tool that can be useful in analyzing cyclical effects and setting base periods for analysis							Could be used to assess impact of landuse changes
Model of SW supplies - Spreadsheet, STELLA, etc.	Not a stand-alone approach - potential tool for natural flow analysis							Complexity could vary from simple to detailed

3.3 Represent Surface/Ground Water Interaction

The current methodology assumes that depletions from ground water usage are reflected in the historic surface water gaging records. For the 25-year lag test, numerical modeling tools are used when available. Analytic methods, such as the Jenkins method, are employed when numerical models are not available.

Potential refinements to the current methodology could include the use of enhanced analytic or numerical models in order to predict depletive effects of ground water usage for historic and lag test cases. An analysis of baseflow trends could also be employed in estimating depletive impacts of ground water usage on surface water flows.

4.0 Refinements to Criteria

In addition to the three areas of the fully appropriated evaluation, the current evaluation criteria were reviewed. The elements of the existing evaluation criteria below were identified for potential refinement. It is noted that in addition to potential refinements to the current criteria, entirely new evaluation criteria may be considered based on the fully appropriated methodology developed.

65/85 Rule: Update parameters in Water Optimizer (provides economic basis of the 65/85 test) to reflect current production and commodity prices and modify other 65/85 parameters as necessary.

Junior Irrigator Test: Refine to incorporate geographical location within the basin into the junior irrigator test.

Interference for non-CU Uses: Incorporate a numerical standard for acceptable levels of interference. Examples of this concept are illustrated by Oregon's 80% rule and Texas' 75/75 rule.

Period of Record for Analysis: Develop methodology for determining appropriate period of record for conducting the analysis. This could include statistical analysis of flows/precipitation/runoff to include two or more drought cycles to ensure representative period of record is used. Approach may be modified accordingly to account for site specific temporal or spatial variations.

5.0 Approaches Recommended for Development

The following approaches were selected for testing based on their ability to meet many of the desired characteristics.

- Define all surface and ground water uses. Some form of NIR will be used to define agricultural consumptive uses; estimates of consumptive use will be developed for non-agricultural uses.

- Employ a virgin natural flow hydrograph to quantify surface water supplies on both a seasonal and annual basis.
- Utilize the best available tools to represent surface and ground water interaction. Numerical models should be employed where they exist; analytic methods will be used for areas where numerical models do not currently exist until they are available.

The use of the approaches above in the fully appropriated methodology will allow flexibility to readily adapt to new datasets, techniques, and tools as they become available.

6.0 Proposed Work Plan for Methodology Development and Testing

The portion of the Niobrara River basin above Box Butte Reservoir is proposed for use in the methodology development. Following this analysis of methodology development, a test case will be employed on the Central Platte River. This Niobrara River basin is proposed for methodology development based on several factors:

- Datasets are largely compiled and readily available
- Scale of basin, supplies, and uses expedites the methodology development
- Basin supply and uses are relatively straight-forward
- Following initial development, the methodology can be readily applied downstream to include the Box Butte Reservoir in order to further test the methodology as well as add complexity of systems found elsewhere in the state, as necessary.

The proposed work plan for the methodology development included the following tasks.

<u>Task 1 Data Collection</u>

Assemble necessary datasets to estimate uses and surface water supplies for the basin. Anticipated datasets to be compiled include:

- Available flow records from gaging stations
- Precipitation records
- Surface water and ground water irrigated acreage data
- Irrigation well data
- Current and historic land use/cropping data
- Aquifer properties data
- Surface water appropriations
- Historic surface water diversion data
- Other available water use data

<u>Task 2 Estimation of Surface and Ground Water Uses</u>

Agricultural usage will be estimated by using a combination of the Net Irrigation Requirement, irrigated acreage, and cropping pattern datasets. One advantage of the Niobrara River basin is that there is a relatively constant level of use over time. The level of detail used to define agricultural usage will largely be based on the quantity and quality of data available. Estimates of consumptive use for non-agricultural uses will be developed based on available data. Little non-agricultural usage is anticipated for the test basin.

Task 3 Surface and Ground Water Interaction

A numerical model for the test basin does not currently exist. Analytic methods to represent surface/ground water interaction will be investigated. These may include the Jenkins method, or other appropriate analytical techniques. Data from the UNL ground water model of Box Butte County or the current regional ground water model under development will be used to the extent possible.

Task 4 Estimation of Surface Water Supplies

Historic stream gage and diversion records will be used to compute the virgin natural flow hydrograph. Depletions from historic ground water pumping will be estimated and combined with surface water data to estimate virgin natural flows. Annual virgin natural flow values will be partitioned into non-irrigation and irrigation seasons. Precipitation records can be evaluated for a statistical relationship with virgin natural flow. It is anticipated that the annual and seasonal virgin natural flows will be developed for the period of record. These data, in conjunction with the precipitation data, will be evaluated for climatic trends and methods for determining an appropriate period of record. Potential methods or basis for partitioning the historic records include: 1) defining droughts and inclusion of one or more drought cycles; 2) identify breakpoints in trends in the gaging record; or 3) identify consistent periods based on land use or cropping pattern trends. Upon inspection of the virgin natural flow hydrograph, other appropriate methods or basis for partitioning the record may also be considered. The approach will be tested with consideration of application to other basins throughout the state.

Task 5 Criteria

This portion of the Niobrara River is currently designated as fully appropriated. The results of Tasks 2 through 4 will be evaluated independent of the designation in order to investigate appropriate tests and criteria for consideration in evaluating fully appropriated conditions.

Task 6 Finalize Methodology

The findings from the various approaches described in this work plan will be used to develop a methodology for testing on the Central Platte River. It is recognized that the Central Platte test involves a more complex system with storage and substantial non-agricultural uses, requiring expansion of the methodology for more complex systems.

7.0 Application to the Upper Reach of the Niobrara River

This section describes the implementation of the Section 6.0 work plan in evaluating the Niobrara River basin above Box Butte Reservoir. It should be noted that this analysis was conducted using simplifying assumptions and approaches for the purpose of testing methodology concepts. As such, results and quantities referenced in this section are for illustrative purposes only.

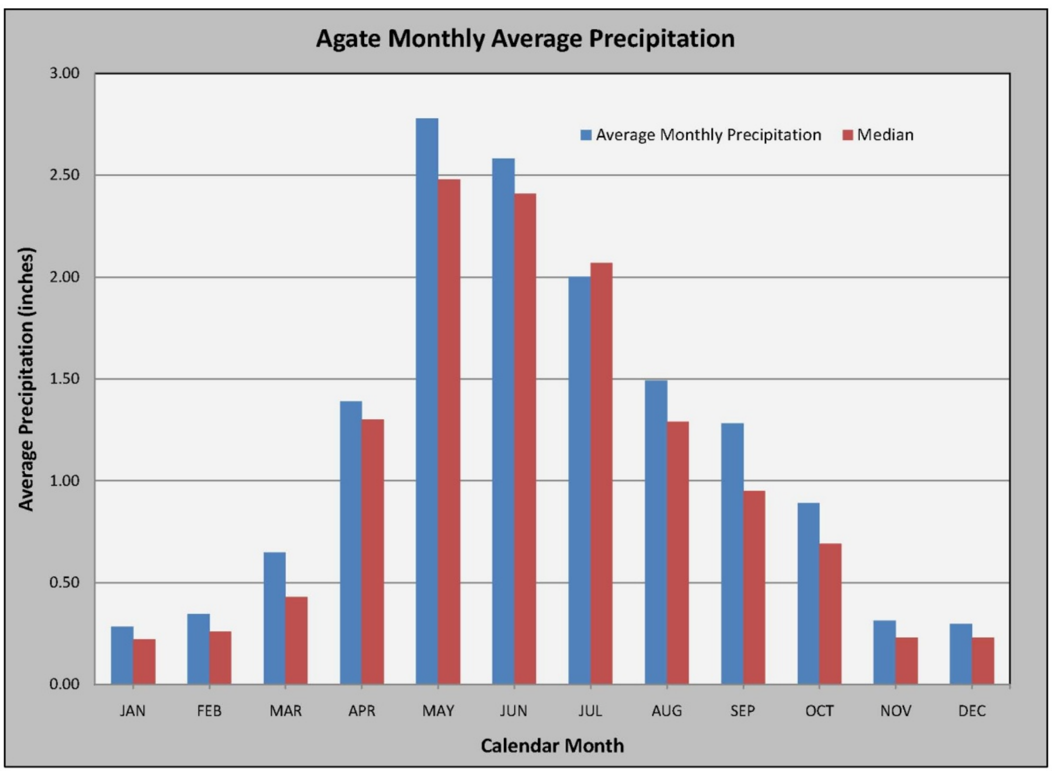
7.1 Data Collection

Data necessary for the evaluation was largely provided by DNR. Specific datasets utilized include:

Gage Records: Flow records were available from three gaging stations on the Niobrara River: 1) State Line gage (1956-2008); 2) Agate gage (1958-1992); and 3) Above Box Butte gage (1956-2007).

Precipitation Records: Monthly precipitation data from the Agate and Hemingford NWS stations and High Plains Climate Center were collected. Due to its proximity, the Agate data was used in this analysis. The irrigation and non-irrigation seasons were determined based on the average precipitation pattern over the period of record, as illustrated in Figure 7.1 and typical irrigation/growing season patterns.

Figure 7.1. Average and Median Precipitation Pattern at Agate Station (1958-2010)

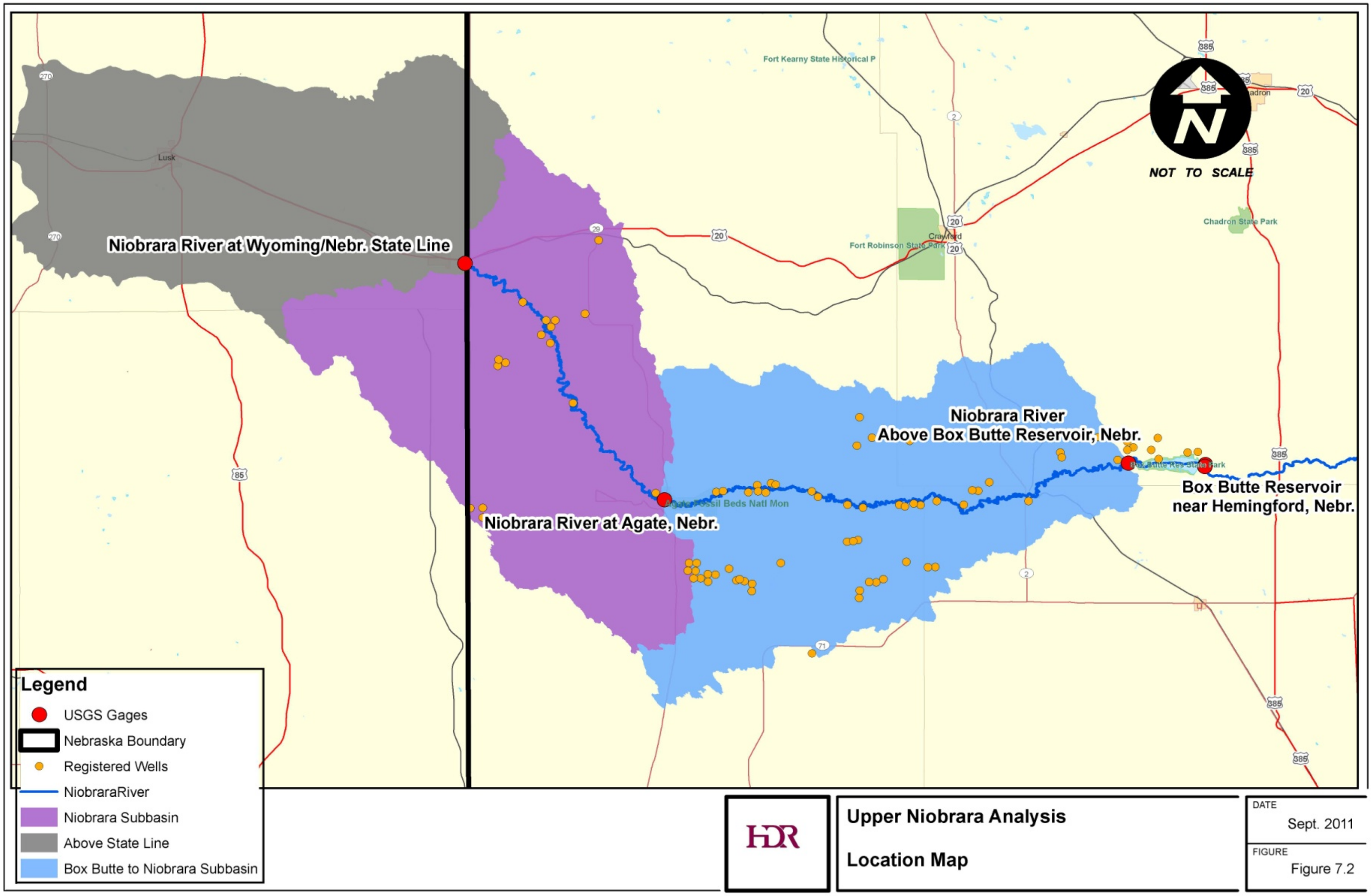


Based on the precipitation pattern and diversion/operation patterns, two seasons were defined. The non-irrigation season was defined as October through April. The irrigation season was defined at May through September.

Surface Water Irrigation Data: Available historic diversion as well as acreage data for surface water diversions was collected. Data included 10 diversion locations above Agate, 16 diversion locations below Agate, and the Mirage Flats diversion data below Box Butte reservoir. The majority of datasets was not continuous and contained significant data gaps. An effort was made to synthesize missing records based on a normalized average diversion (AF diversion/acre) developed from existing records. The normalized diversions were largely random, with considerable variability from canal to canal within a given year and no correlation to spatial or temporal signals. For the final analysis, diversion data as reported was used and missing records were treated as zero diversions.

Groundwater Irrigation Data: Groundwater irrigation data was provided by DNR from registered well data and certified irrigated acreage data from the Upper Niobrara White Natural Resources District (UNWNRD). Figure 7.2 illustrates the location of the registered irrigation wells in the basin. Approximately 23% of the groundwater irrigated acreage lies below the Stateline gage and above the Agate gage location.

Figure 7.2. Registered Well Locations



7.2 Historic Surface Water Uses

Historic surface water consumptive use was estimated as 50% of historic surface water diversions. This estimate is consistent with values observed at other canals in Nebraska with similar operations[2]. No other surface water consumptive uses were represented in the analysis.

7.3 Historic Groundwater Uses

Historic groundwater consumptive use was estimated based on irrigated acreage data and the average corn NIR of 14” for the analysis area.[3] Only irrigation wells were included in the groundwater consumptive use estimates.

7.4 Surface and Groundwater Interaction

Surface and groundwater interaction was estimated using analytic methods. The estimates of surface water depletions due to groundwater pumping were made using the Jenkins[4] method. The Hunt[5] method (which accounts for lower streambed conductance) was also used to as a comparison to the Jenkins method results. Both methods produced similar results. The Jenkins method results were used in this analysis. The computed annual depletions were assumed to be evenly distributed throughout the year.

7.5 Development of Virgin Natural Flow Hydrographs

The virgin natural flow hydrograph was developed at the Agate and Above Box Butte gage locations.

Above Box Butte: For the gage location above Box Butte, the non-irrigation season virgin natural flow was computed by adding 7/12 (October through April) of the annual groundwater depletion to the observed historic flow during the non-irrigation season. The irrigation season virgin natural flow was computed by adding 5/12 (May through September) of the annual groundwater depletion, the consumptive use of surface water irrigated acres between Box Butte and the State Line gage (estimated at 50% of historic diversion), and the observed historic flow during the irrigation season at the Above Box Butte gage station.

Agate: For the gage location at Agate, the non-irrigation season virgin natural flow was computed by adding 23% (based on 23% of GW acreage above Agate) of 7/12 of the annual groundwater depletion to the observed historic flow at Agate during the non-irrigation season. The irrigation season virgin natural flow was computed by adding 23% of 5/12 of the annual groundwater depletion, the consumptive use of surface water irrigated acres between Agate and the State Line gage (estimated at 50% of historic diversion), and the observed historic flow during the irrigation season at the Agate gage station.

The computed virgin natural flows for the Agate and Above Box Butte locations are illustrated in Figures 7.3 and 7.4. A 5-year moving average line was included to smooth annual spikes in the data.

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[2] Estimate derived from several ongoing efforts including synoptic studies of NPPD Platte River canals and COHYST study efforts

[3] From county-wide average NIR mapping developed by Dr. Darryl Martin, UNL, 2006

[4] Jenkins, C.T. Techniques for Computing Rate and Volume of Stream Depletion by Wells, USGS. 1967

[5] Hunt, B. Unsteady Stream Depletion from Groundwater Pumping, Ground water 37, No. 1:98-102, 1999

Figure 7.3. Non-Irrigation Season Virgin Flow Estimates

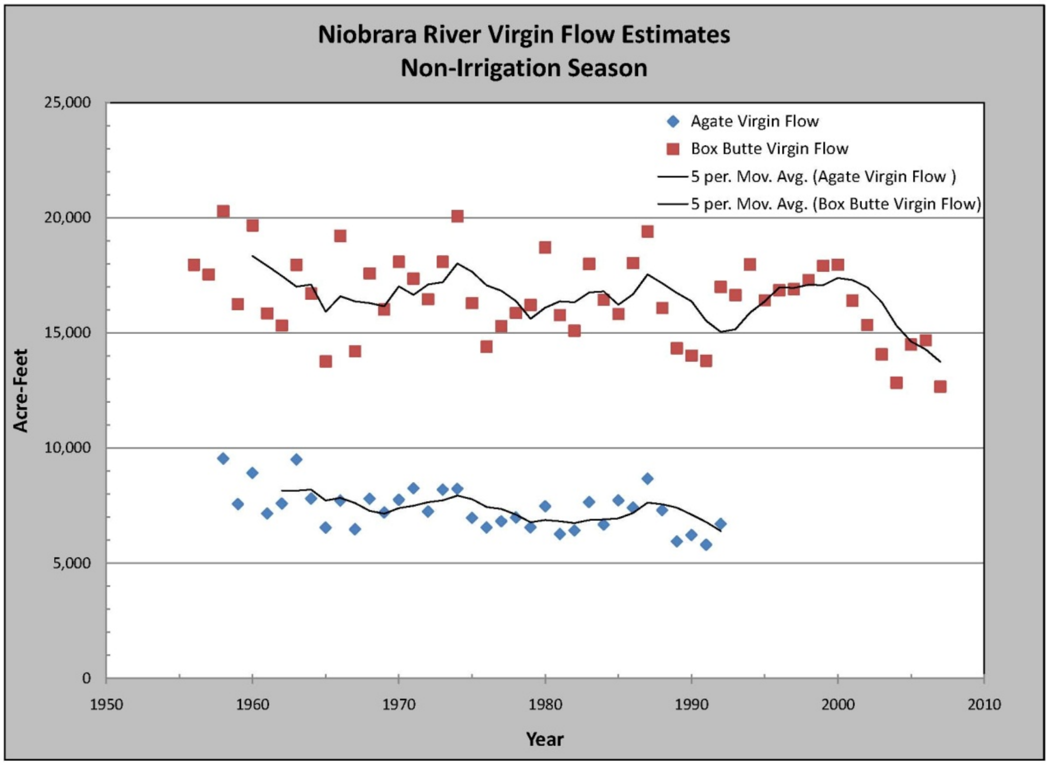
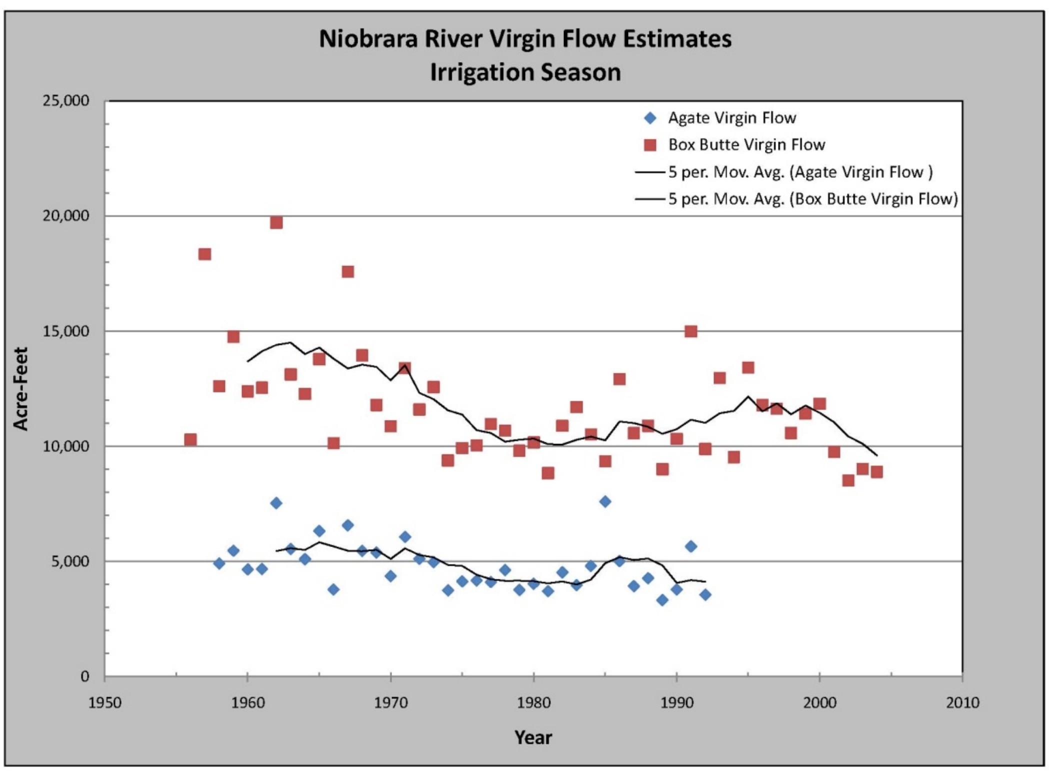


Figure 7.4. Irrigation Season Virgin Flow Estimates



7.6 Statistical Analysis

Two types of statistical analyses were performed to determine an appropriate, unbiased period of record for the evaluation.

Kendall Tau

Kendall's tau statistic can be used to test for the presence of trends. The trend to be tested is defined as a monotonic change over time occurring as either an abrupt or gradual change in the ordinal data. Because the test is nonparametric, the test variables need not be normally distributed, and outliers or missing values present no computational or theoretical problem in application of the test. The Kendall tau statistic can range from -1 to 1. If all values increase with time, the tau coefficient would equal 1, and if all values decrease with time, the tau coefficient would equal -1. If the number of increasing and decreasing data pairs is equal, the tau coefficient will equal 0. By this definition, the Kendall tau is a measure of the correlation between the direction of change in the virgin natural flow values and time, while the sign of tau indicates whether the virgin natural flow values increasing or decreasing with time.

In this application, the test was applied to determine if there is a statistically significant long-term trend in the virgin natural flow data. A Kendall Tau test was performed on the following data sets:

- Agate virgin natural flow for the non-irrigation season
- Agate virgin natural flow for the irrigation season
- Agate virgin natural flow for the entire water year
- Above Box Butte virgin natural flow for the non-irrigation season
- Above Box Butte virgin natural flow for the irrigation season
- Above Box Butte virgin natural flow for the entire water year.

If the Kendall Tau test showed a statistically significant trend, either positive or negative, the data set was reduced by the five earliest years. Truncation of the earlier years was employed to maintain the most recent period of the flow records, where greater certainty in the observed flow data, land use, and cropping patterns exists. This process was repeated until a data set was found to have no statistically significant trend.

Autocorrelation

Autocorrelation describes a degree of similarity between a time series data set and a lagged version of itself. It can be used as a tool for detecting prevalent patterns in datasets, for example wet and dry cycles in flow records. Once the data is lagged, the correlation test is similar to calculating correlation between any two time series data sets. The correlation coefficient can range from -1 to 1. If the data is perfectly negatively or positively correlated with the lagged version of itself, the coefficient will be -1 or 1, respectively. If the coefficient is zero, it is not correlated with the lagged version of itself at all. For this analysis, the virgin natural flow data was lagged by one through 16 years to determine is a cyclical pattern emerged, specifically a sinusoidal pattern of dry hydrologic cycles and wet hydrologic cycles.

There was no statistically significant autocorrelation at Agate for up to 16 lags. At Above Box Butte there was no statistically significant autocorrelation for up to 16 lags, but both the irrigation season and the whole year datasets showed a statistically significant autocorrelation with a one year lag. A first difference was applied to the Above Box Butte irrigation season and the whole year datasets, a typical adjustment to account for autocorrelation if regression of the data is ever required. There was no statistically significant autocorrelation in these new datasets. Table 7.1 summarizes the results of the statistical analyses. Based on the statistical analyses and availability of historic flow records at both the Agate and Above Box Butte gage locations, the 1973-1993 period of record was used in this analysis.

Table 7.1: Results of Statistical Analysis

Analysis	Agate			Above Box Butte		
	Non-Irrigation Season	Irrigation Season	Total	Non-Irrigation Season	Irrigation Season	Total
Dates for no trend (Kendall Tau)	1973-1993	1973-1993	1973-1993	1971-2004	1971-2004	1971-2004
Autocorrelation	No	No	No	No	1-year lag	1-year lag

7.7 Consumptive Use Demand Estimates

In order to facilitate a comparison of water supply (represented by the virgin natural flow) to water use (represented by crop consumptive use), estimates of groundwater and surface water consumptive use demands were made.

The NIR of 14" for this area was used as a baseline for crop consumptive use. This value was then adjusted to account for the variability in precipitation through the analysis period. The adjustment was based on a ratio of the irrigation season average precipitation to the irrigation season precipitation for each year. In this way, crop consumptive use of irrigation water is increased during dry years and decreased during wet years. For example, the average annual precipitation (1958 to 2007) during the irrigation season is 10.1 inches. In 1973, the irrigation season precipitation was 11.5 inches. The resulting adjusted NIR is then (10.1/11.5)*14 inches = 12.2 inches. In this way, the required NIR for wet years is appropriately decreased to reflect a decrease in required irrigation.

7.7.1 Surface Water Consumptive Use Estimate

Consumptive use demand for surface water irrigated acres was developed based on the adjusted NIR requirement and the acres served by the canals.

Above Box Butte: The total surface water irrigated acreage between Box Butte and the State Line gage of 5,841 acres was used to estimate annual surface water irrigation consumptive use.

Agate: The total surface water irrigated acreage between Agate and the State Line gage of 2,204 acres was used to estimate annual surface water irrigation consumptive use.

7.7.2 Groundwater Consumptive Use Estimate

Consumptive use demand for groundwater irrigated acres was developed based on the adjusted NIR requirement and the certified acreage data provided by UNWNRD.

Above Box Butte: The total groundwater irrigated acreage between Box Butte and the State Line gage of 10,360 acres was used to estimate annual groundwater irrigation consumptive use.

Agate: The total groundwater irrigated acreage between Agate and the State Line gage, estimated as 23% of the total or 2,380 acres, was used to estimate annual groundwater irrigation consumptive use.

7.7.3 Surface Water Irrigation Consumptive Use Demand of Mirage Flats

The consumptive use demands of surface water uses downstream of Box Butte reservoir were also considered. For the purposes of this analysis, to test the methodology, only the largest irrigation district of the downstream surface water users, Mirage Flats, was included.

The total acreage served by Mirage Flats is 11,670 acres. The following describes the representation of the Mirage Flats consumptive use.

1. The annual surface water irrigation consumptive use for lands served by Mirage Flats was determined based on the adjusted NIR value and total acres.
2. Irrigation and non-irrigation season evapotranspiration (ET) values were determined for Box Butte Reservoir.
3. The non-irrigation season demand for Box Butte Reservoir applied at the upstream gages is the lesser of three quantities:
    a. Available storage as of Oct. 1 each year in Box Butte Reservoir
    b. Historic non-irrigation season gage flows at Above Box Butte gage
    c. Irrigation season CU for Mirage Flats + non-irrigation season Box Butte ET
4. The irrigation season demand is then equal to: [Mirage Flats CU computed in (1)] – [Non-irrigation season demand computed in (3)] + [Irrigation season Box Butte Reservoir ET computed in (2)].
5. The full irrigation and non-irrigation season demands for Mirage Flats were applied at the Above Box Butte location. Based on the ratio of average virgin flows at Above Box Butte and Agate, 39% of the Mirage Flats irrigation and non-irrigation demands were applied at the Agate location.

7.8 Supply and Use Comparison

To facilitate the comparison of supply and use of Niobrara River flows at the Agate gage, Figures 7.5 and 7.6 were generated. Another way to represent this information is through a flow duration curve (FDC).

Flow Duration Curves (FDC) compare flow quantities and percent of time that discharge is equaled or exceeded in a stream or river. A FDC is a useful tool in assessing water supply/demand. Figures 7.7 and 7.8 are flow duration curves for the same set of data illustrated in Figures 7.5 and 7.6. See Section 8.0 for more detail on how a FDC is constructed and how to read them.

Figure 7.5. Non-Irrigation Season Supply and Use at Agate

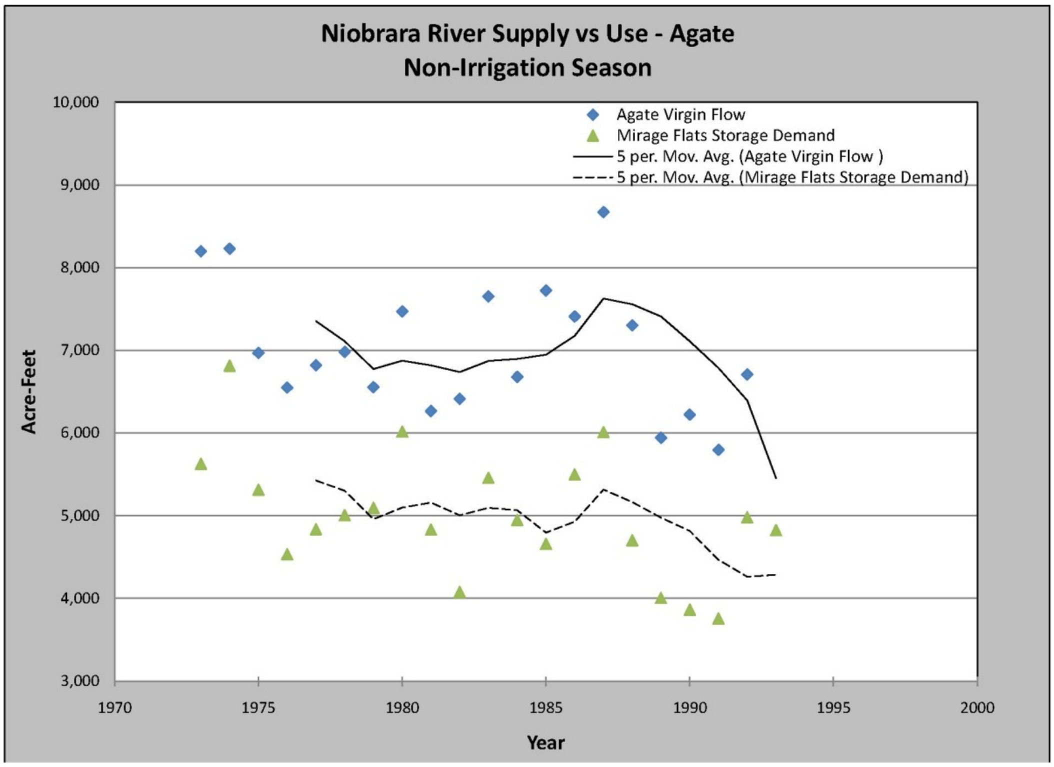


Figure 7.6. Irrigation Season Supply and Use at Agate

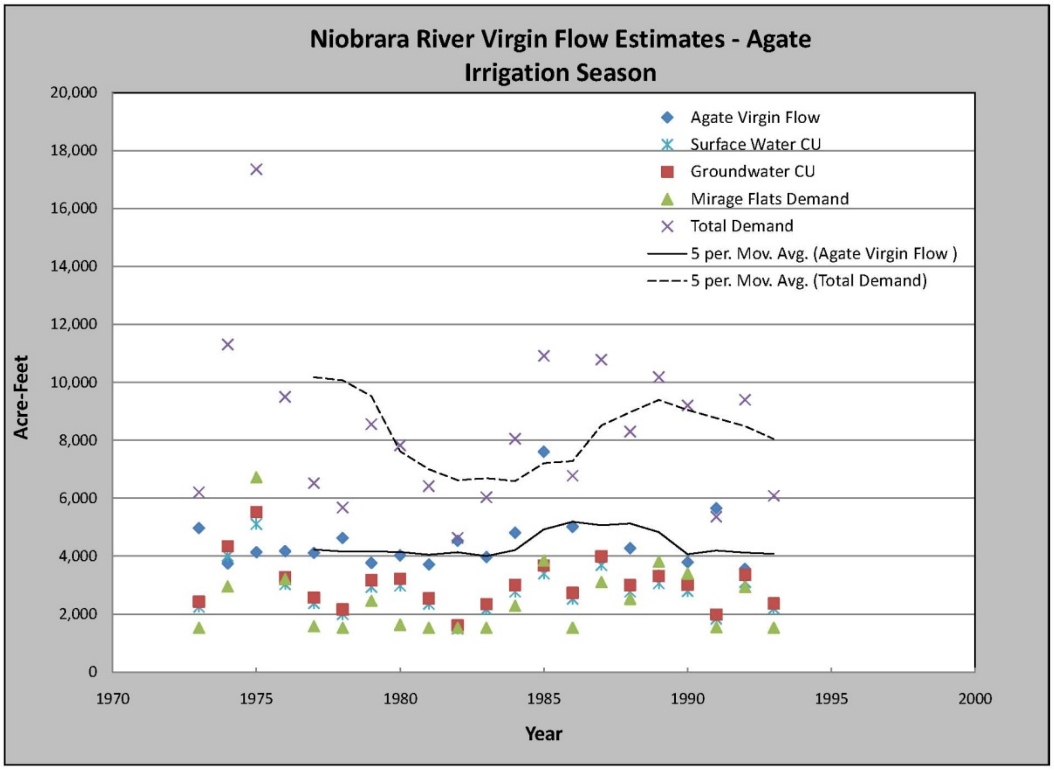


Figure 7.7. Non - Irrigation Season Flow Duration Curve at Agate

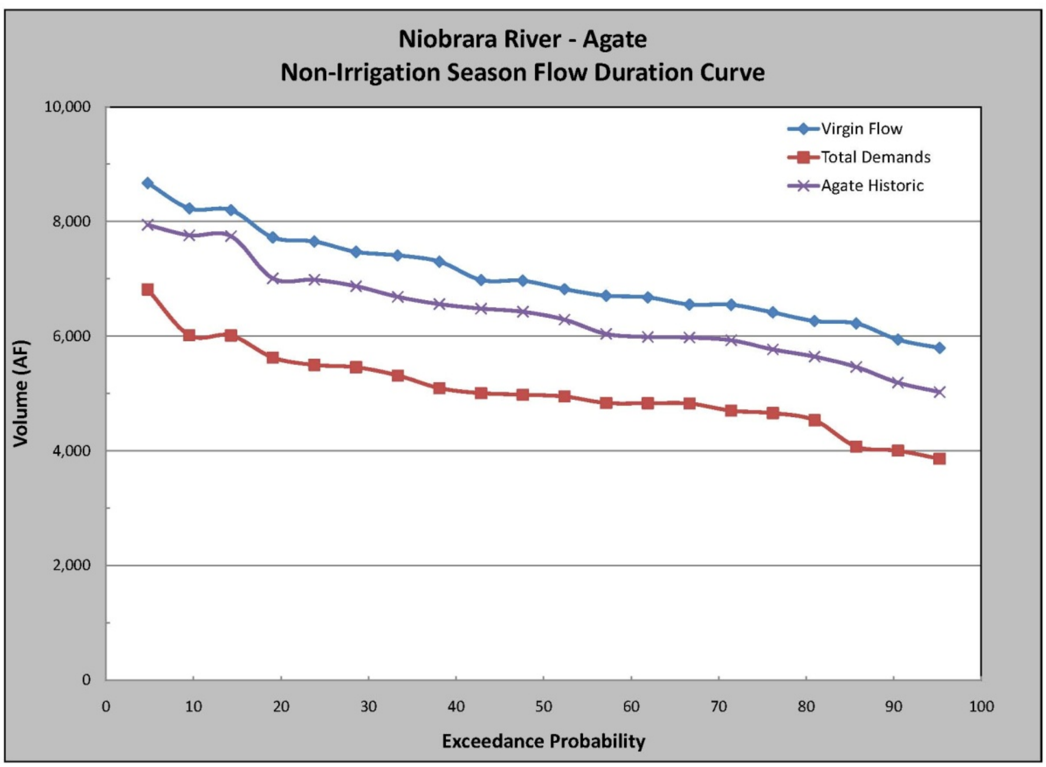
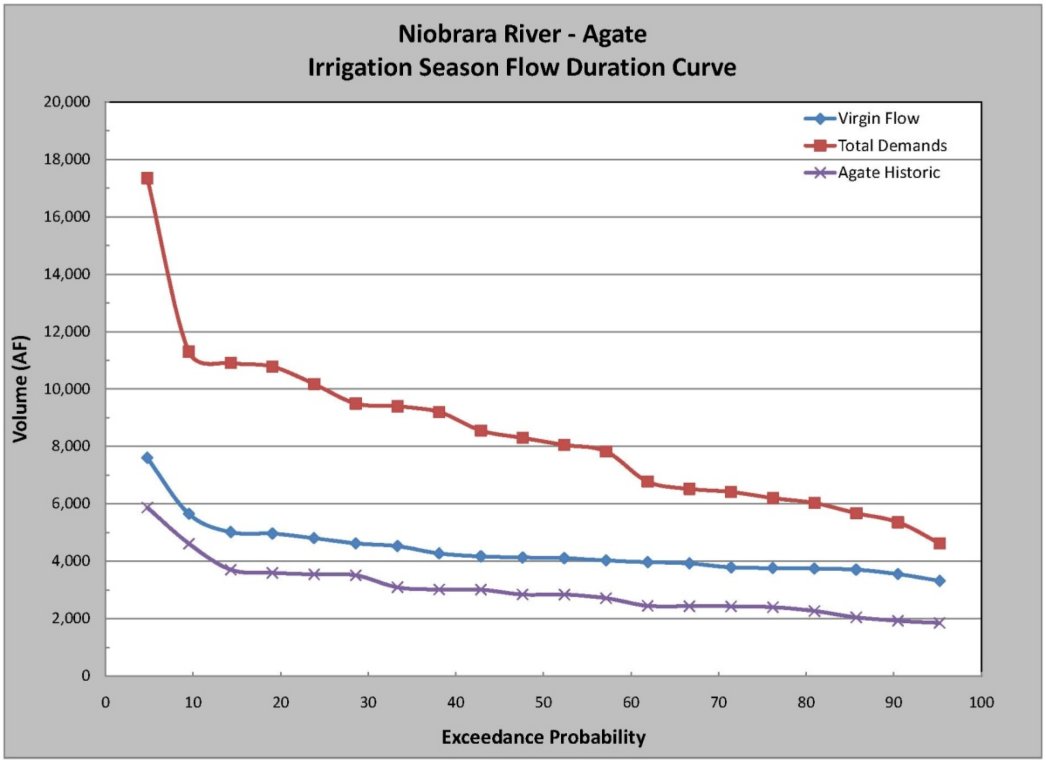


Figure 7.8. Irrigation Season Flow Duration Curve at Agate



7.9 Potential Tests

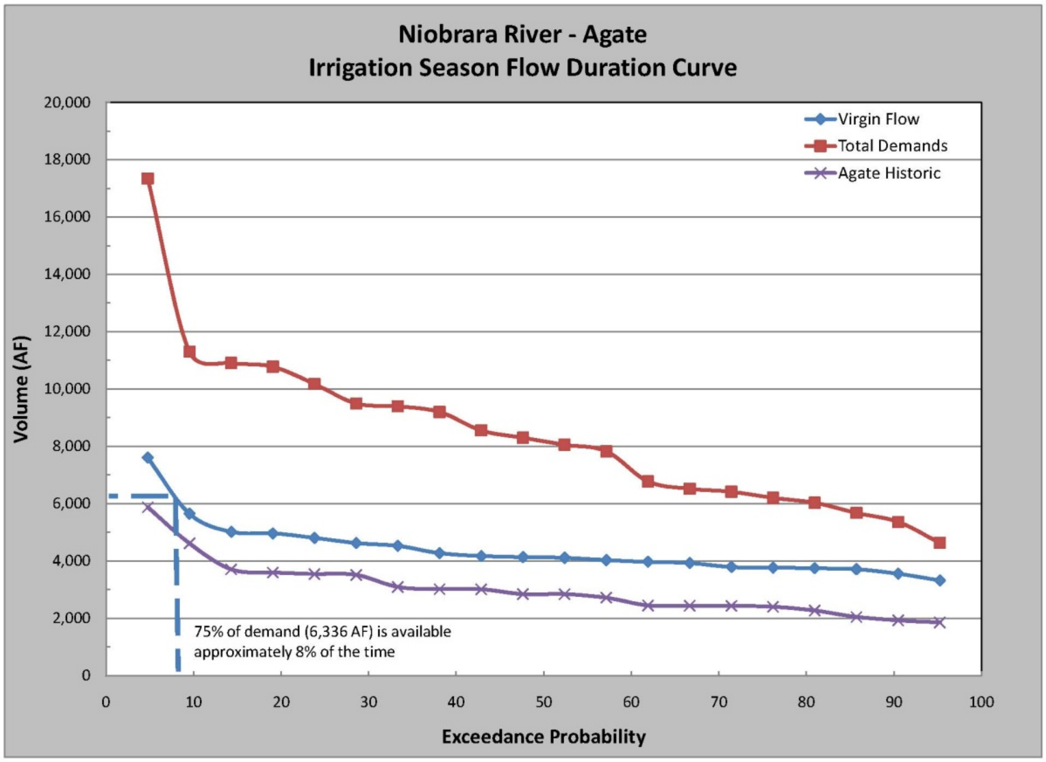
It is recommended that the fully appropriated test include a comparison of the relative certainty of an available supply to meet a percentage of usage. While the mechanics, specific criteria, and computational techniques were often basin or state specific, this approach was commonly found in the literature review of current practices used in water administration and compact accounting throughout the western United States. This type of approach is similar to the 65/85 rule currently employed; however the current 65/85 rule does not include the analysis of total water supplies and uses. Instead, the current 65/85 rule relies only on historic gaged surface flows that are compared to a single representative use.

Ultimately the specific criteria related to the acceptable levels of usage and certainties of supply will be determined by Nebraska DNR. To illustrate the utility of the flow duration curves in conducting the evaluation, an example using an approach similar to that used in Texas was applied; where 75% of the demand must be available 75% of the time.

7.9.1 Agate Test Illustration

To determine 75% of the water usage, the total water usage (groundwater CU + surface water CU + Mirage Flats surface water CU) was averaged over the selected analysis period (1973 to 1993). This annual average irrigation season demand is 8,448 acre-feet. Seventy-five percent of this demand is then 6,336 acre-feet. Using the flow duration curve at Agate as illustrated in Figure 7.9 below indicates that 75% of the demand is available 8% of the time.

Figure 7.9. Supply Frequency and 75% demand at Agate



7.9.2 Other Discussion Items

7.9.2.1 Groundwater Irrigation Usage Demand

Groundwater usage demand may be represented as either the full consumptive use or the computed stream depletions due to groundwater pumping. Using the groundwater consumptive use is similar to applying the lag test included in the current methodology and is useful in projecting the full impacts of usage not yet realized in current supply estimates. Using the depletions as the groundwater usage demand illustrates the current impacts of groundwater usage on current supply estimates. The two approaches 'bookend' the groundwater irrigation usage demands.

7.9.2.2 Relationship of Precipitation to Reach Gain/Loss

Reach Gain/Loss (RGL) values were computed for both reaches (Stateline to Agate, and Agate to Above Box Butte). These computed RGL values were compared with observed precipitation data to test whether RGL can be tied to observed precipitation, and therefore be used in estimating supplies. No definitive trends can be discerned between the RGL and precipitation data for this basin.

7.9.2.3 Relationship of Precipitation to Virgin Natural Flow Estimates

Similar to the RGL analysis, observed precipitation was also compared to the computed virgin natural flow values at Agate and Above Box Butte. Again, the goal was to investigate if precipitation could be directly correlated to water supplies. No definitive trends between precipitation and computed virgin natural flows can be discerned at these locations.

8.0 Refinements based on Niobrara River Analysis

In applying the methodology as proposed in section 6.0 to the Niobrara test case, the general approaches to estimating supplies and demands generally appear to be valid. However, some improvements and changes to the methodology were identified and should be included in the Central Platte case study.

NIR: The concept of applying a climatic signal in order to reflect annual variations in demand by using a precipitation-adjusted NIR appears to be valid. However, applying a ratio of average annual precipitation to observed precipitation was found to over-predict demands in certain years. This occurred because the adjusted NIR value became excessive (exceeding the total crop irrigation requirement in some cases) during drought conditions. For the Central Platte case, the precipitation-adjusted NIR will be the difference between the total crop irrigation requirement of a given crop blend and the observed precipitation of any given year. In this way, the demand of a crop will not exceed the total crop irrigation requirement for that crop.

Virgin Natural Flow Hydrograph: The concept of a virgin natural flow hydrograph in order to estimate supply appears to be a valid approach. In the Niobrara test case, individual surface water point diverters were not considered for simplicity. In the Central Platte analysis, the surface water consumptive use will include the appropriated surface acres for point diverters (NIR estimated) and 50% of recorded diversions.

Groundwater CU vs. Groundwater Depletions: Estimating demands by both the groundwater consumptive use as well as the groundwater depletions in order to account for the lag effect is a useful approach. This gives a good picture of what is happening today and what theoretically will happen in the future based on a certain level of development. This method will continue to be applied in the Central Platte case with some changes as described in Section 9.0.

In the Niobrara case, the groundwater consumptive use was estimated based simply on the percentage of wells within each subbasin and the adjusted NIR. For the Central Platte analysis, the hydrologically connected wells within each subbasin will be considered and the consumptive use will be calculated using the new NIR value described earlier in this section.

The groundwater depletions for the Niobrara case were based on 90 acres/well and a constant NIR value. These methods and assumptions will be used for the Central Platte analysis.

Statistical Analysis: The statistical methods applied in the Niobrara test case (Kendall Tau and autocorrelation tests) appear reasonable and valid in determining an appropriate, unbiased period of record for analysis. These methods will be applied in the Central Platte case in determining the period of record for the analysis.

Precipitation vs. RGL: No discernible relationship between precipitation and RGL was found in the Niobrara test case. No further attempt will be made at this time to correlate precipitation and RGL in the Central Platte case.

Downstream Demands: The downstream demand for the Niobrara test case consisted of Box Butte Reservoir ET and Mirage Flats consumptive use only. The Central Platte test case differs in that there are both consumptive and non-consumptive demands, as well as multiple reaches. This requires a more detailed approach to evaluating downstream demands, as discussed in Section 9.

8.1 Flow Duration Curves

The flow duration curve concept as a method of analysis of supply and uses appear to have utility in the ultimate evaluation. Further discussion on flow duration curves, exceedance and non-exceedance plots, and how to utilize them is therefore warranted[6].

A flow duration curve characterizes the ability of the basin to provide flows of various magnitudes/quantities. Information concerning the relative amount of time that flows at a location are likely to equal or exceed a specified value of interest is extremely useful is planning efforts. The shape and slopes of a flow duration curve is particularly significant in evaluating the stream and basin characteristics. Flow duration curves with flat slopes reflect less variability and relatively constant flows/supplies/demands. Steep or broken curves reflect a higher degree of variability.

To create a flow duration curve, values from the dataset are sorted by magnitude and assigned a ranking of 1 to n, where n represents the number of values in the dataset. The probability or relative certainty, p that a value will be equaled or exceeded is equal to the value's rank divided by (n+1). The flow duration curve is then plotted with the values of the dataset on the y-axis and the probability of exceedance on the x-axis. These curves are also sometimes referred to as exceedance plots. Figure 8.1 illustrates a conceptual example of a standard histogram representation of data (a), and the same data represented by a flow duration curve (b).

[6] Portions from *Streamflow Evaluations for Watershed Restoration Planning and Design*, http://water.oregonstate.edu/streamflow/, Oregon State University, 2002-2005.

Figure 8.1. Example Flow Duration Curve[7]

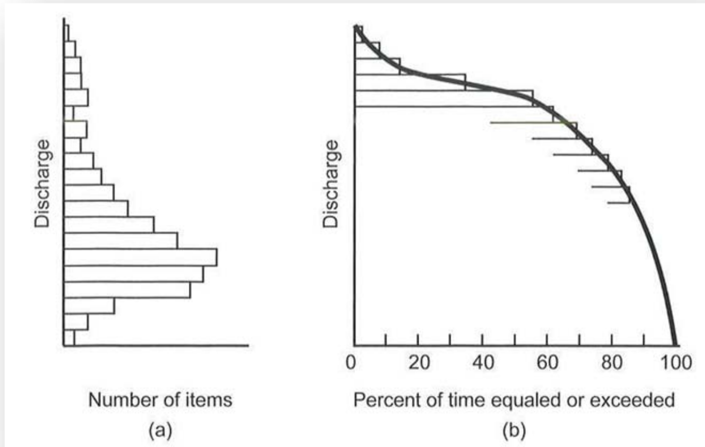
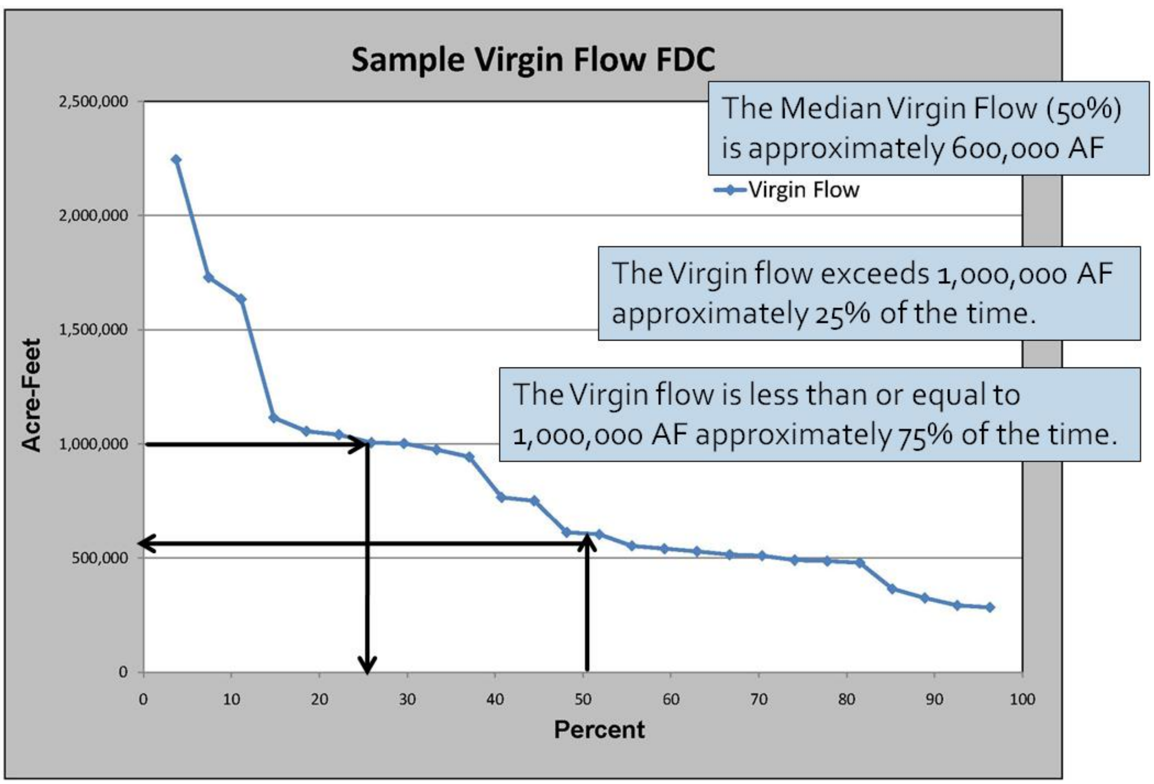


Figure 8.2 illustrates an example of virgin natural flow data in an exceedance plot format, with examples of information that may be interpreted from the exceedance plot.

Figure 8.2. Example Virgin Natural Flow Exceedance Plot



[7] Image from *Hydrology and Hydraulic Systems*, Ram S. Gupta, 2008

The inverse of the x-axis values in the exceedance plot (1-p) can be plotted in a similar way to produce a non-exceedance plot. Figure 8.3 illustrates an annual demand dataset using a standard rectangular plot of annual demand vs. time. Figure 8.4 is the same data represented by a non-exceedance plot with examples of information that may be interpreted from the non- exceedance plot.

Figure 8.3. Example Demand Plot

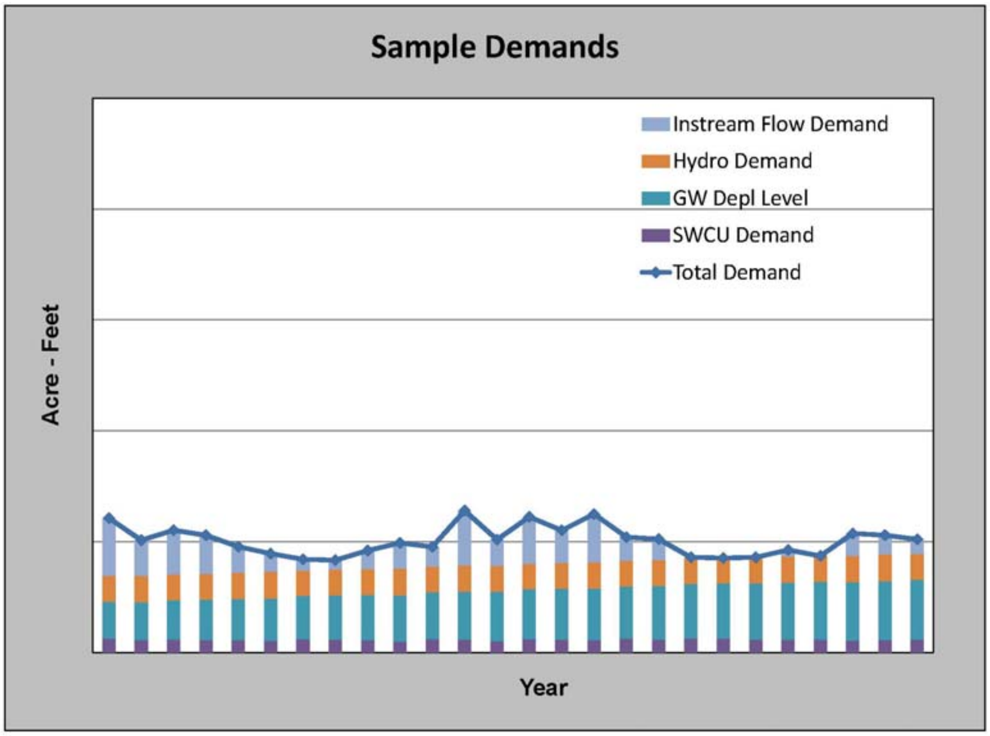
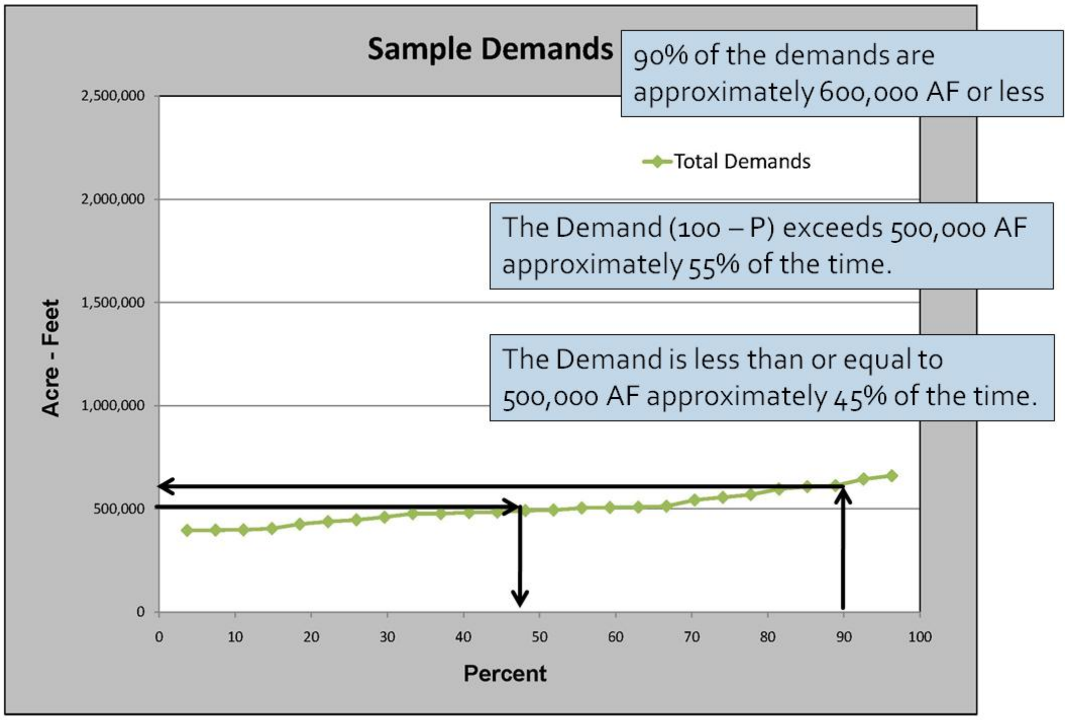
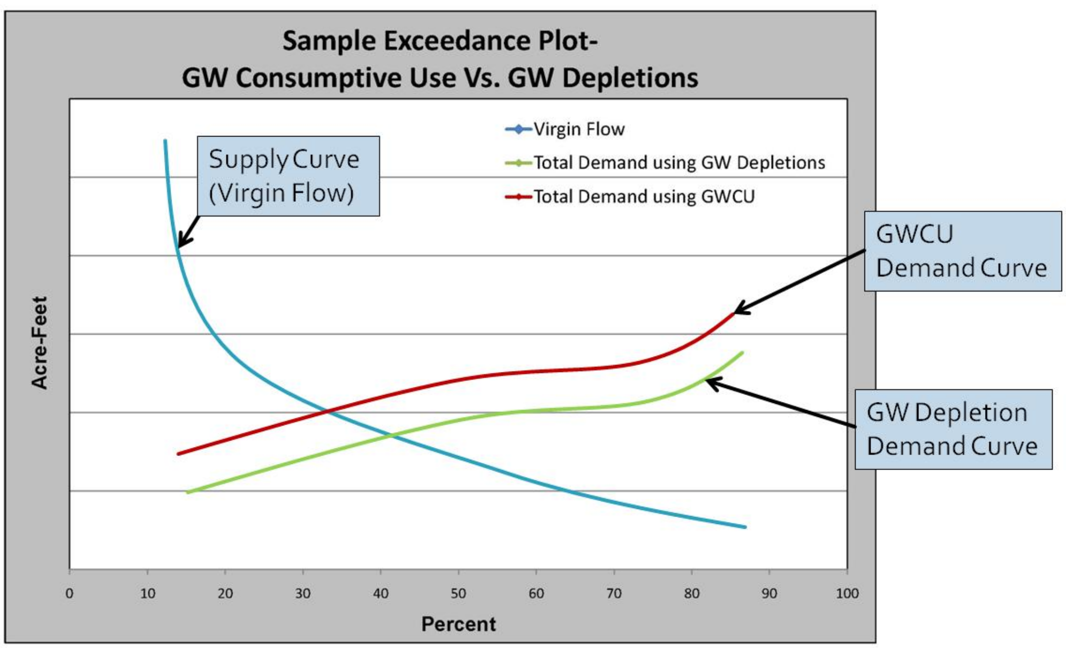


Figure 8.4. Example Demand Non-Exceedance Plot (1-P)



The value of using the exceedance (p) and non-exceedance (1-p) plots in this application lies in the ability to represent the supply and demand characteristics in a single graphic that allows the user to assess the relative probabilities of supply and demand quantitatively. Figure 8.5 is an example of applying these concepts to represent supply and demands.

Figure 8.5. Example Exceedance Plot (Supply) vs. Non-Exceedance Plot (Demands)



Surplus Curves: In using the exceedance vs. non-exceedance plots we discovered a tendency to incorrectly assume the intersection point of the exceedance and non-exceedance curves to hold some intrinsic value, i.e. that a percentage of demands exceeded directly correlated to a percentage of supply available. The direct comparison of the exceedance of the supply versus non-exceedance of the demands, while useful, may be misleading as the two lines do not necessarily correlate. In the generation of the flow duration curves, the data for both the supply and demands are sorted separately which eliminates a direct year-to-year comparison when represented with exceedance and non-exceedance plots.

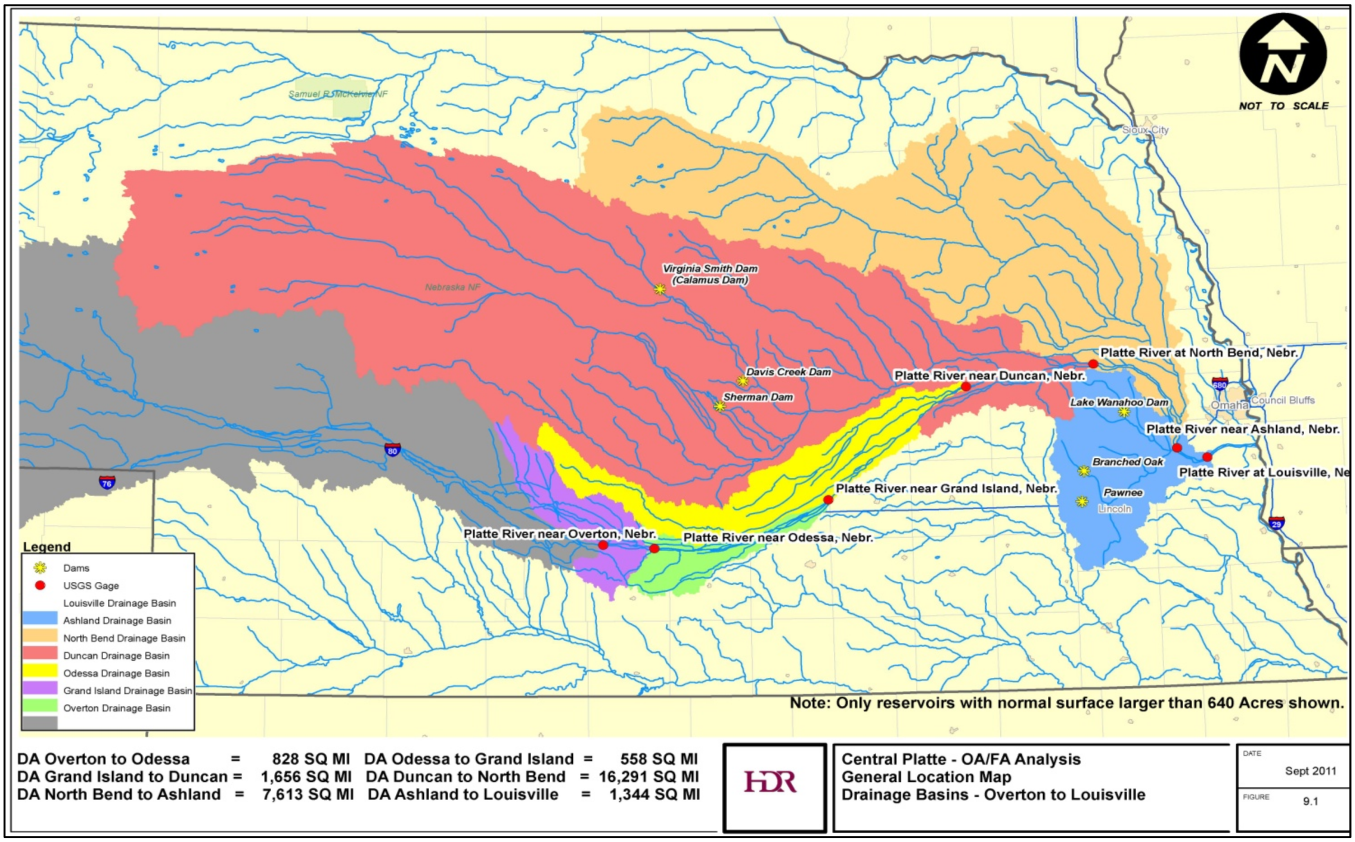
In the Upper Niobrara analysis the years where the greatest supply occurred do not necessarily correlate to the year with the least demand. Further analysis of the raw data reveals that while some high supply years have high demands, other high supply years did not have high demands.

To maintain linkage of supply and demand on an annual or seasonal basis and still capitalize on the informative attributes of the flow duration curve concept, the difference between supply and demand - termed surplus for the purposes of this effort - will also be plotted using the FDC approach. In this way, the direct tie of each year’s supply and demand can be maintained, while still capitalizing on the FDC concept. Surplus plots will be generated in the Central Platte case study.

9.0 Central Platte River Analysis

This section describes the application of the methodology, with the Section 8.0 refinements, in evaluating the Platte River basin from the Overton gage downstream to the Louisville gage. It should be noted that this analysis was conducted using simplifying assumptions and approaches for the purpose of testing methodology concepts. As such, results and quantities referenced in this section are for illustrative purposes only.

Figure 9.1. General Location Map



9.1 Data Collection

Data necessary for the evaluation was largely compiled from existing databases. Specific datasets utilized in this analysis include:

<u>Gage Records</u>: Flow records were available from six gaging stations on the Platte River:

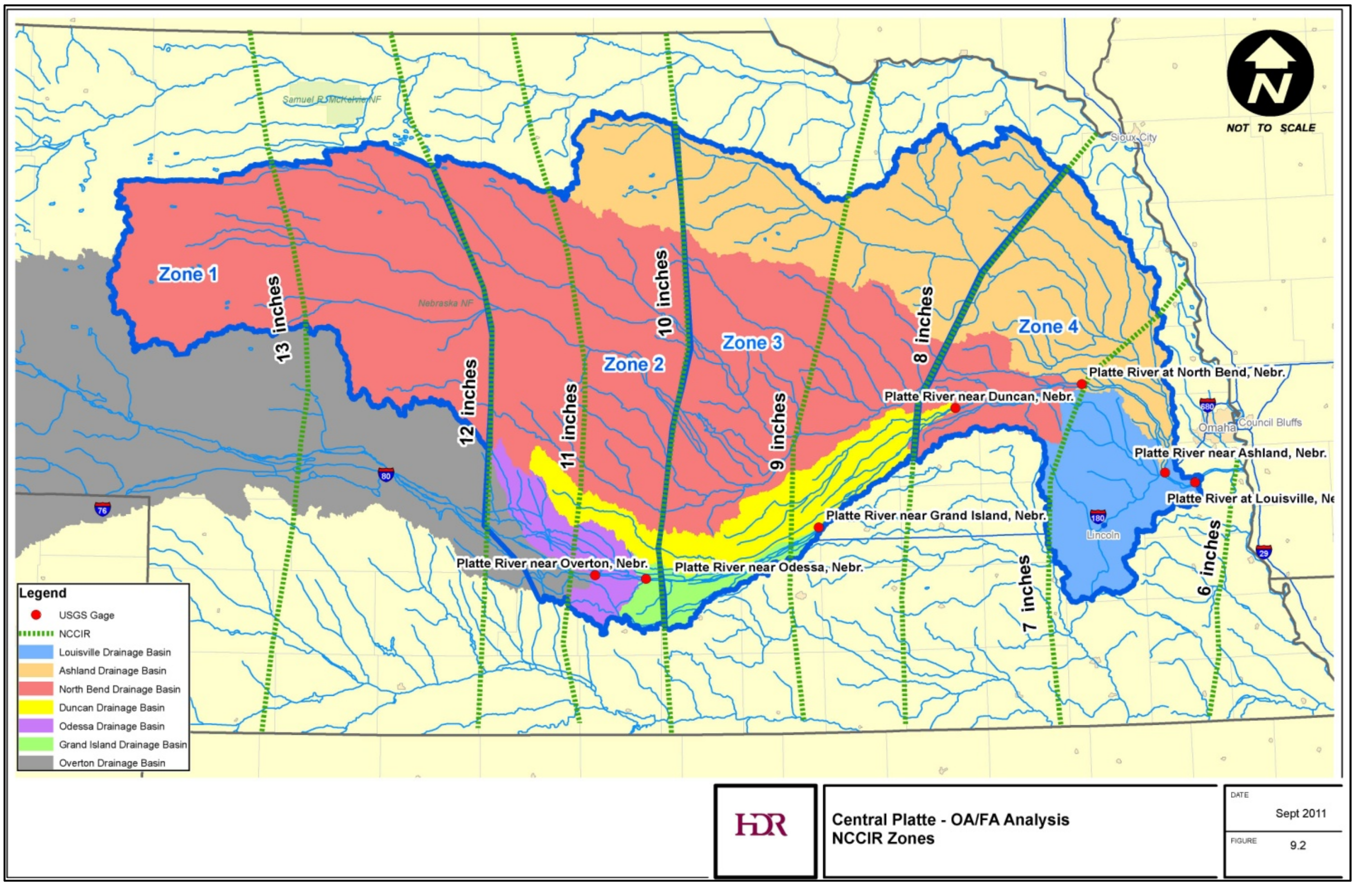
1) Overton gage (1954-2009);
2) Grand Island gage (1954-2009);
3) Duncan Gage (1954-2009);
4) North Bend gage ((1954-2009);
5) Ashland gage (1954-2009; Data Synthesized for Oct 1960 through July 1988); and
6) Louisville gage (1954-2009).

The coincident period of record 1954-2009 for the six gages was used in the development of the virgin natural flow hydrographs at each gage location. Statistical analyses, further described in Section 9.6, were used to determine the appropriate period of record to use in the analysis.

Precipitation Records:

Monthly precipitation data from the Mullen, Broken Bow, Ericson, Schuyler, Grand Island, Lincoln, Holdrege, Norfolk, and Canaday Steam Plant NWS stations and the High Plains Climate Center were collected. Due to the large area of coverage, the study area was divided into 4 zones as shown in Figure 9.2. For those subbasins that span multiple zones, a weighted average was applied. As in the Niobrara analysis, the non-irrigation season was defined as October through April. The irrigation season was defined at May through September.

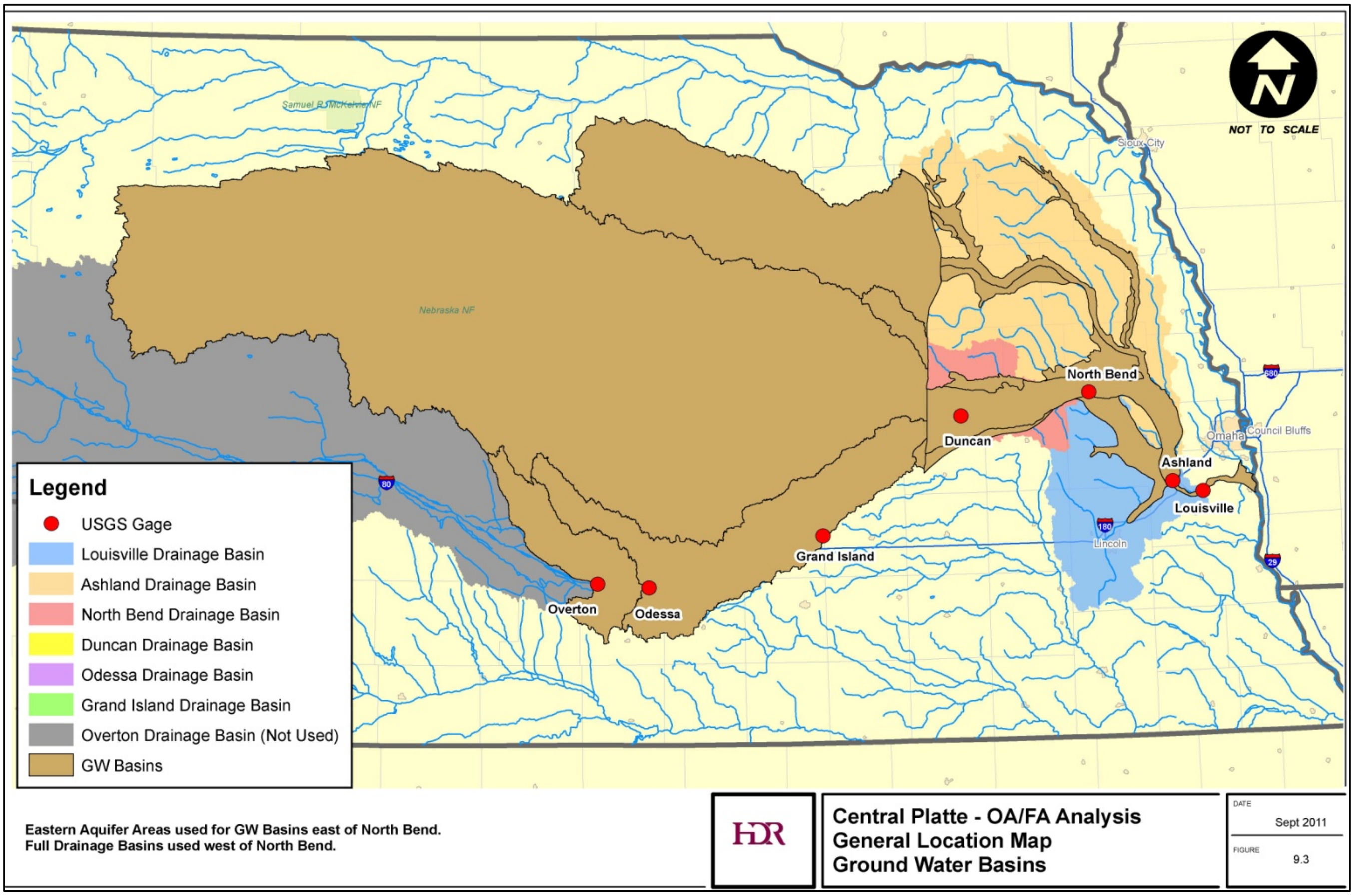
Figure 9.2. NIR/Precipitation Zones



Surface Water Irrigation Data: Available historic diversion as well as acreage data for surface water diversions was collected. Individual surface water appropriator data was collected from the DNR surface water appropriation database. Canal diversion records were gathered for 19 canals in the Loup basin, in addition to diversion records for the Kearney Canal diversion from the Platte River, and the Loup Power Canal diversion from the Loup River. The total of the appropriated acres (canal plus individuals) within each subbasin was used for the purposes of this analysis.

Groundwater Irrigation Data: Groundwater irrigation data for the hydrologically connected area was provided by DNR. Irrigation well locations were derived from the registered well database. Irrigated acreage served by those wells was estimated based on a 90 acres/well approximation. The areas of hydrologic connectivity are shown in Figure 9.3.

Figure 9.3. Hydrologically Connected Groundwater Basins



9.2 Historic Surface Water Uses

Historic surface water consumptive use for irrigation canal diversions was estimated as 50% of historic diversions. This estimate is consistent with values observed at other canals in Nebraska with similar operations[8].

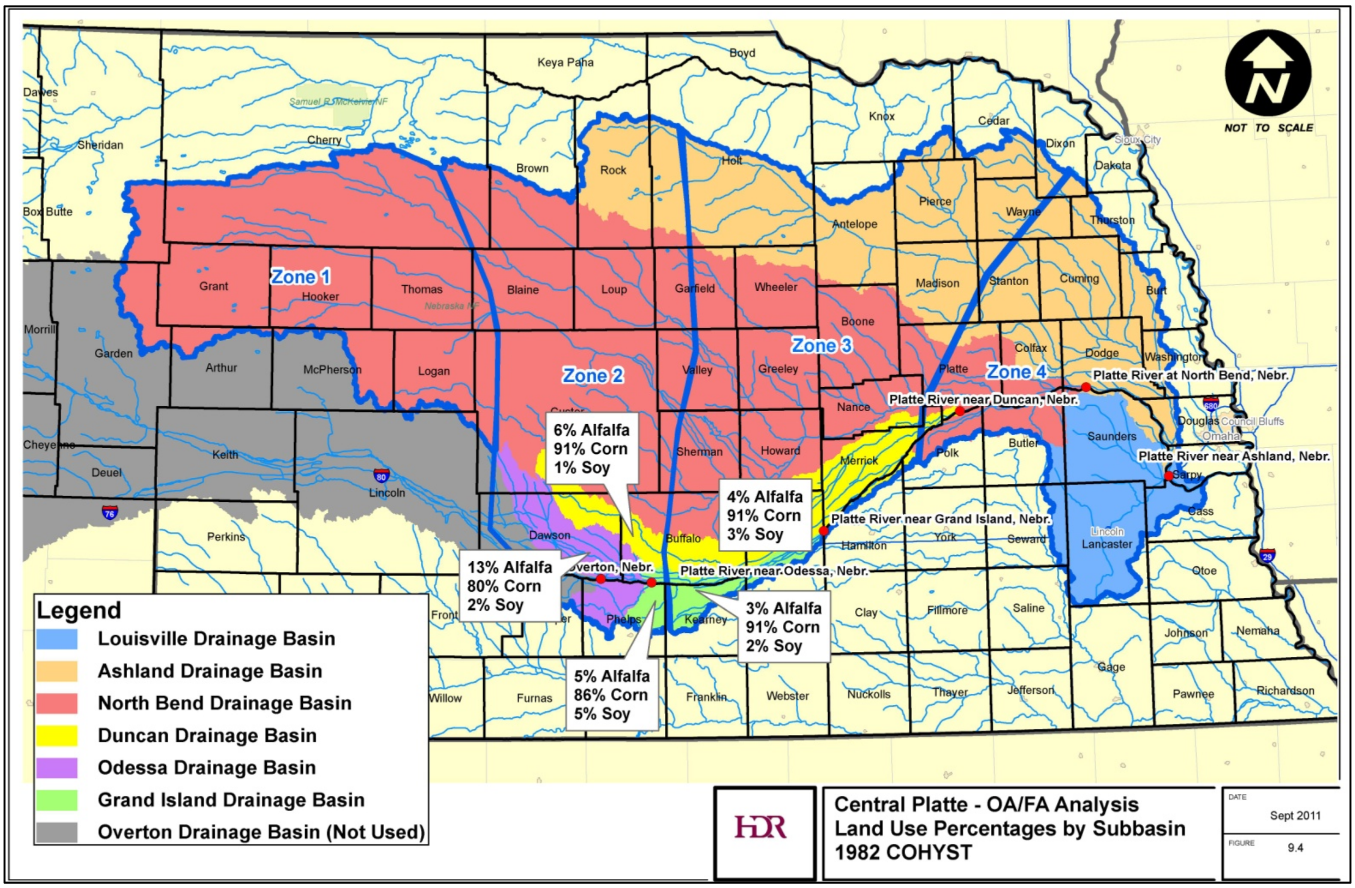
Historic surface water consumptive use for point irrigators (pumps) was estimated using a crop irrigation requirement[9]. The annual irrigation requirement was determined for each of the 4 zones shown previously in Figure 9.2. The annual irrigation value was adjusted to account for the variability in precipitation through the analysis period. The adjustment was based on the observed historic precipitation records. In this way, crop consumptive use of irrigation water is increased during dry years and decreased during wet years. For example, if a crop requirement is 26 inches and the observed

[8] Estimate derived from several ongoing efforts including synoptic studies of NPPD Platte River canals and COHYST study efforts
[9] From county-wide average NIR mapping developed by Dr. Darryl Martin, UNL, 2006

precipitation was 14 inches, then the NIR would be 12 inches. In this way, the required NIR for wet years is appropriately decreased to reflect a decrease in required irrigation. This varies slightly with the method previously used in the Niobrara analysis to prevent the maximum NIR from exceeding the crop irrigation requirement.

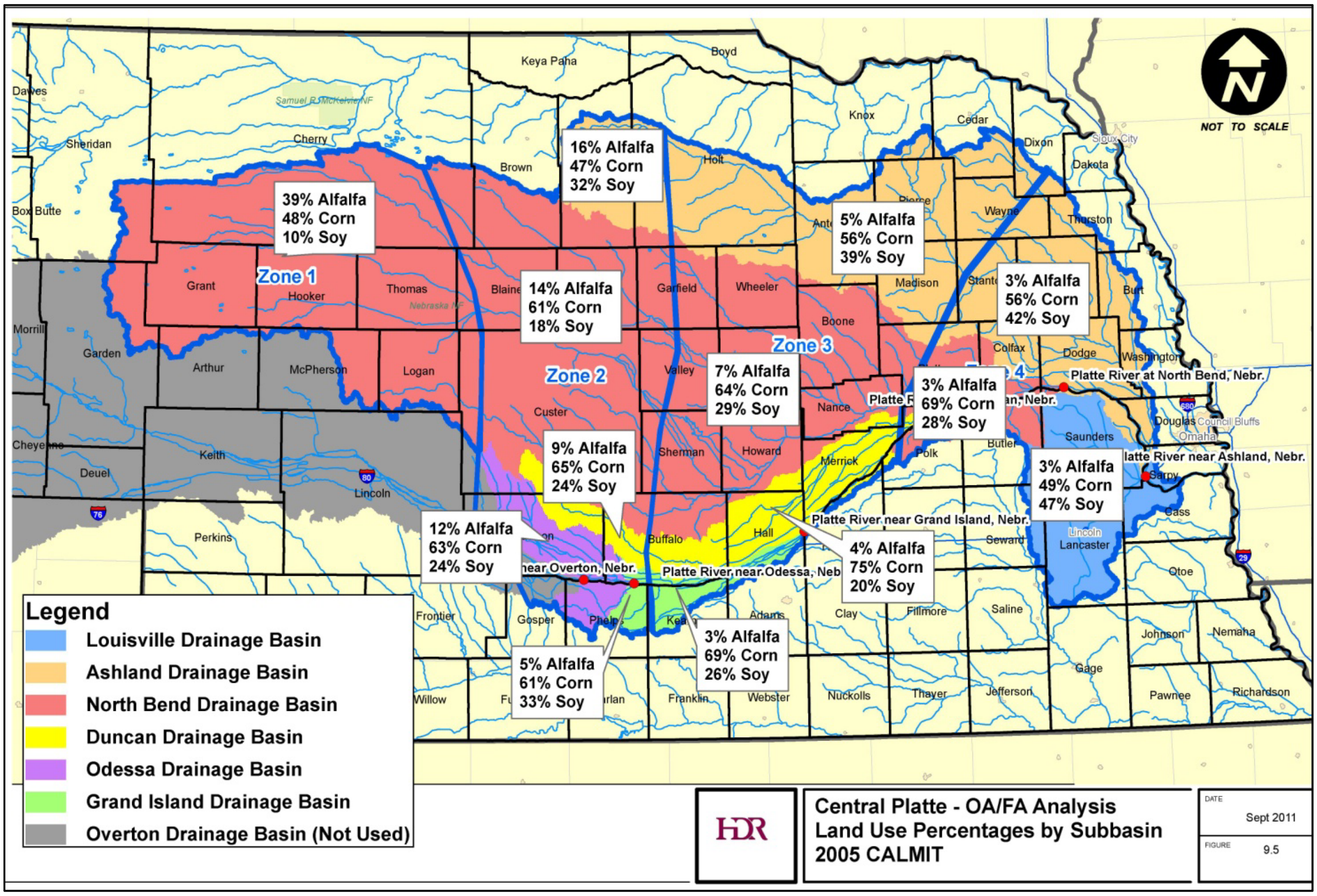
Cropping patterns were determined by comparing the 1982 and 2005 land use data[10] for the Central Platte River subbasins (Figure 9.4) developed for the Platte River Cooperative Hydrology Study (COHYST). No significant change was noted between the two time periods; therefore, the 2005 land use data was used to develop the cropping pattern for this analysis. A weighted NIR was determined based on the reported crop blends for the prevalent crops of corn, soybeans, and alfalfa.

Figure 9.4. 1982 Land Use



10 Data and GIS shapefiles obtained from UNL Center for Advanced Land Management Information Technologies (CALMIT) public domain website: http://calmit.unl.edu/cohyst

Figure 9.5. 2005 Land Use



9.3 Historic Groundwater Uses

Historic groundwater consumptive use was estimated based on irrigated acreage data and the weighted NIR determined for the analysis area. Only irrigation wells were included in the groundwater consumptive use estimates.

9.4 Surface and Groundwater Interaction

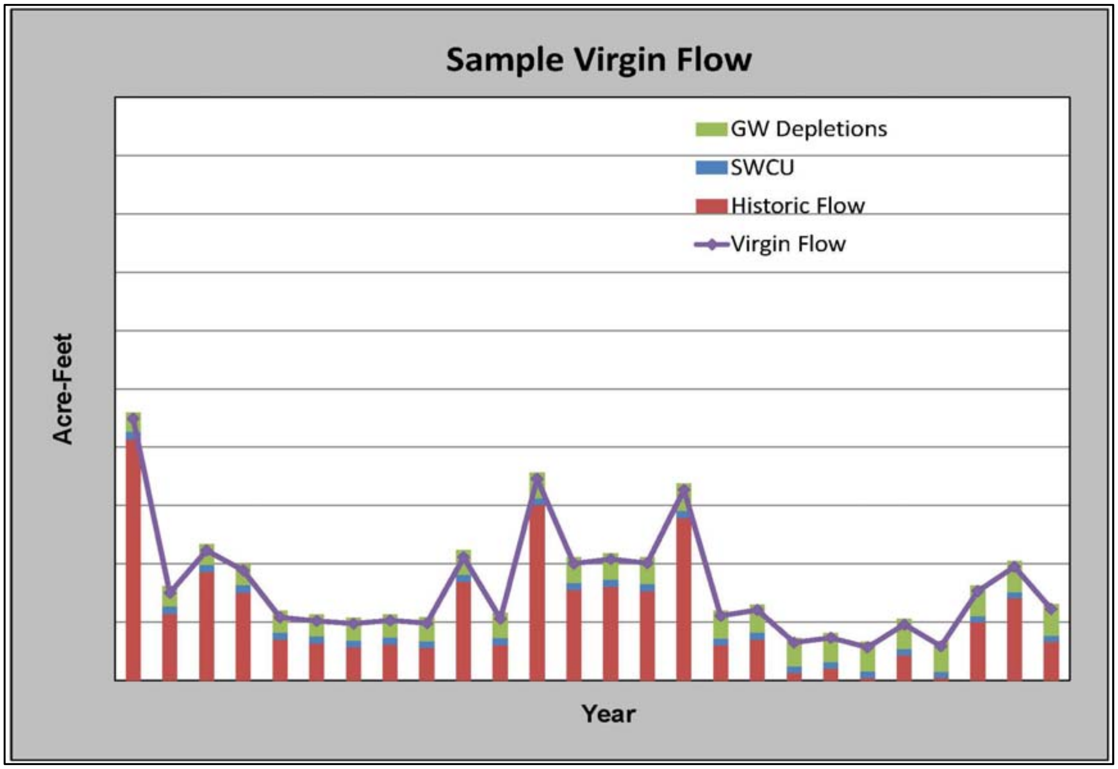
Surface and groundwater interaction was estimated using analytic methods. The estimates of surface water depletions due to groundwater pumping were made using the Jenkins[11] method. The Hunt[12] method (which accounts for lower streambed conductance) was also used to check the Jenkins method results at locations where sufficient data was available, producing similar results. The Jenkins method results were used in this analysis. Annual depletions were assumed to be evenly distributed throughout the year. It is important to note that consumptive use estimates used precipitation-adjusted NIR, however the depletions estimates used in this analysis were based on the NIR without precipitation adjustment for all groundwater irrigated acreage within the study area.

[11] Jenkins, C.T. Techniques for Computing Rate and Volume of Stream Depletion by Wells, USGS. 1967
[12] Hunt, B. Unsteady Stream Depletion from Groundwater Pumping, Ground water 37, No. 1:98-102, 1999

9.5 Development of Virgin Natural Flow Hydrographs

The virgin natural flow hydrograph was developed at six gage locations: Odessa, Grand Island, Duncan, North Bend, Ashland and Louisville. The Overton gage was treated as the upstream limit of the analysis.

Figure 9.6. Sample Virgin Flow Plot



Non-Irrigation Season: For the non-irrigation season virgin natural flow was computed by adding 7/12 (October through April) of the annual groundwater depletion to the observed historic flow during the non-irrigation season.

Irrigation Season: The irrigation season virgin natural flow was computed by adding 5/12 (May through September) of the annual groundwater depletion, the consumptive use of surface water irrigated acres (estimated based on the NIR), and the observed historic flow during the irrigation season.

9.6 Statistical Analysis

Kendall Tau

In this application, the Kendall Tau test was used to determine if there is a statistically significant long-term trend in the virgin natural flow data. A Kendall Tau test was performed on the seasonal virgin natural flow data at each gage location.

If the Kendall Tau test showed a statistically significant trend, either positive or negative, the data set was reduced by the five earliest years. Truncation of the earlier years was employed to maintain the most recent period of the flow records, where greater certainty in the observed flow data, land use, and cropping patterns exists. This process was repeated until a data set was found to have no statistically significant trend. Table 9.1 illustrates the results of the Kendall Tau analysis.

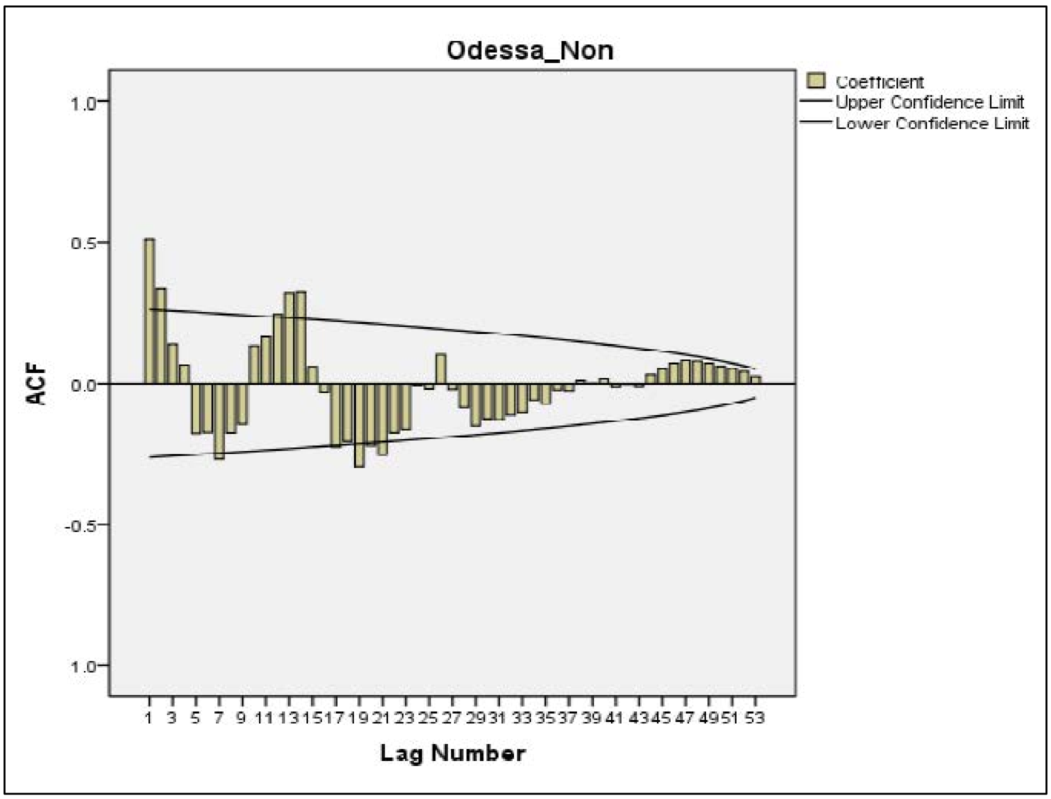
Table 9.1: Results of Kendall Tau Analysis

Statistical Trend Test													
		Non-Irrigation Season						Irrigation Season					
Begin Year	End Year	Odessa	Grand Island	Duncan	North Bend	Ashland	Louisville	Odessa	Grand Island	Duncan	North Bend	Ashland	Louisville
1955	2009	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES
1960	2009	NO	NO	NO	YES	YES	YES	NO	NO	YES	YES	YES	YES
1965	2009	NO	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	YES
1970	2009	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES
1975	2009	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES
1980	2009	YES	YES	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO
1984	2009	YES	YES	YES	YES	NO	NO	YES	YES	NO	NO	NO	NO
1985	2009	YES	YES	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO
1990	2009	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1995	2009	YES	YES	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO
1996	2009	YES	YES	YES	NO	NO	NO	YES	NO	NO	NO	NO	NO
2000	2009	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO

Autocorrelation

A sinusoidal pattern of dry hydrologic cycles and wet hydrologic cycles emerged at several of the gaging stations. Figure 9.7 illustrates the typical sinusoidal pattern computed for the Odessa gage location. To provide an unbiased representation of climatic variations in water supply, care must be taken in selection of the period of analysis to best represent full cycles of the wet/dry cycle variability. For example, inclusion of two dry periods and one wet period would tend to under predict supplies. Ultimately, an analysis period of 1984 through 2009 was selected as an appropriate period for this analysis.

Figure 9.7. Sample Autocorrelation Plot



9.7 Demands

In order to facilitate a comparison of water supply (represented by the virgin natural flow) to water use, estimates of groundwater and surface water consumptive use and non-consumptive use demands were made. The NIR previously discussed in section 9.2 was used as a baseline for crop consumptive use.

9.7.1 Surface Water Consumptive Use Estimate

Consumptive use demand for surface water irrigated acres was developed based on the adjusted NIR requirement and the acres served by the irrigation canals and the individual surface water appropriators' permitted right. A summary of surface water irrigated acres is as follows:

- 7,460 cumulative acres above Odessa
- 13,150 cumulative acres above Grand Island
- 16,000 cumulative acres above Duncan
- 242,100 cumulative acres above North Bend
- 282,570 cumulative acres above Ashland
- 300,450 cumulative acres above Louisville

9.7.2 Groundwater Consumptive Use Estimate

Groundwater usage may be represented by the estimated consumptive use of groundwater irrigated acres or the computed depletions from wells serving those acres. Using the groundwater consumptive use is similar to applying the lag test included in the current methodology and is useful in projecting the full impacts of usage not yet realized in current supply estimates. Using the depletions as the groundwater usage demand illustrates the current impacts of groundwater usage on current supply estimates. The Platte River case study includes both representations of groundwater demands. The two approaches bookend the groundwater irrigation usage demands.

Consumptive Use

Consumptive use demand for groundwater irrigated acres was developed based on the adjusted NIR requirement and the acreage data provided by DNR within the hydrologically connected areas (Figure 9.3). A summary of ground water irrigated acres within the hydrologically connected area is as follows:

- 221,130 cumulative acres above Odessa
- 405,900 cumulative acres above Grand Island
- 1,251,270 cumulative acres above Duncan
- 2,380,590 cumulative acres above North Bend
- 3,032,280 cumulative acres above Ashland
- 3,093,120 cumulative acres above Louisville

Depletions

Groundwater depletions were estimated based on 90 acres per well and the NIR (with spatial variation) for those wells within the hydrologically connected areas (Figure 9.3) – consistent with the depletion data used in generating the virgin natural flow estimates. The depletion estimates were developed and provided by the DNR.

9.7.3 Upstream Demands

Consumptive and non-consumptive demands for reaches upstream of the gage locations were estimated.

1) Consumptive Use Demands - Groundwater and surface water irrigation requirements computed based on precipitation-adjusted NIR values computed using procedures discussed previously.

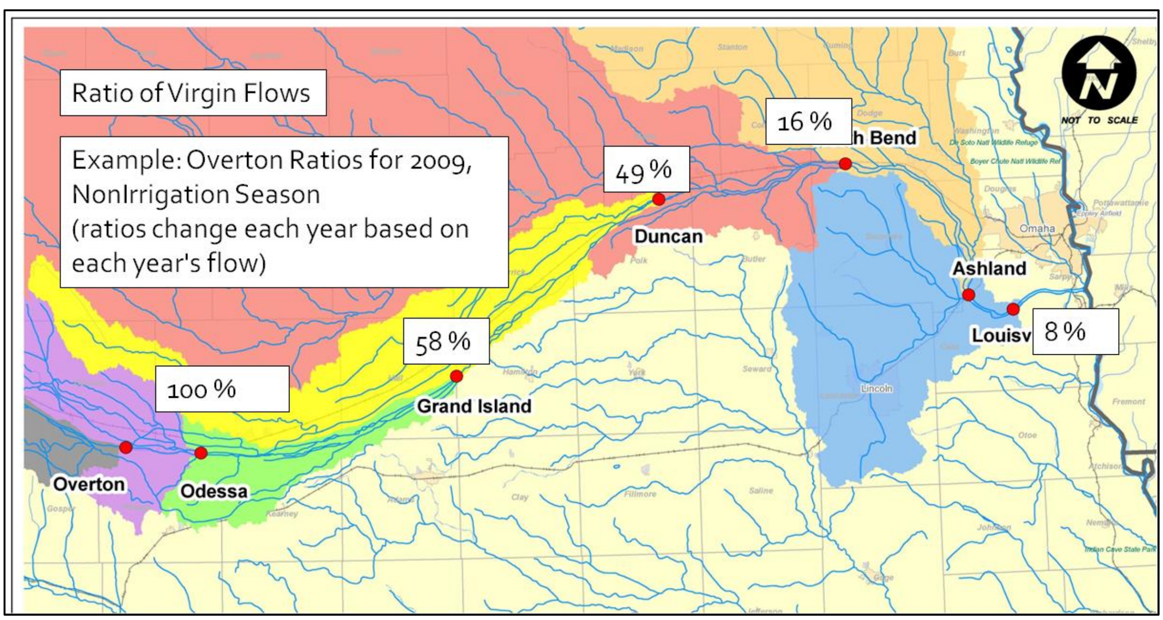
2) Non-consumptive demands – Instream flow appropriations at the gage location (capped to historic observed flow volumes prior to instream flow application - ’54-’89 period for this analysis of Central Platte River based on using 1989 as time of granting the appropriation for this analysis) as well as appropriated hydropower uses upstream, are computed by season.

9.7.4 Downstream Demands

A portion of downstream demands are met by flows passing through upstream reaches. To recognize and account for this in the evaluation, that portion of flow at each gage required to meet downstream demands is estimated and applied at the upstream gage. To facilitate the allocation of downstream demands, main stem appropriations are determined by reach and season. Non-consumptive and consumptive uses are considered separately, as non-consumptive uses are available to meet downstream demands.

1) Non-Consumptive use demands - Downstream non-consumptive use demands are computed as the ratio of virgin flows at the current gage to each downstream gage. This calculation is necessary to determine what percentage of flow the basin has historically contributed to subsequent downstream subbasins. Reach gains and losses are not explicitly accounted for in the calculations, but are reflected in the ratio of virgin flows at the gages. Figure 9.8 shows an example of this process. In this example, the Overton-to-Odessa subbasin contributes 100% of the flow to Odessa, but only 58% of the flow to Grand Island. The process is repeated at all downstream gage locations.

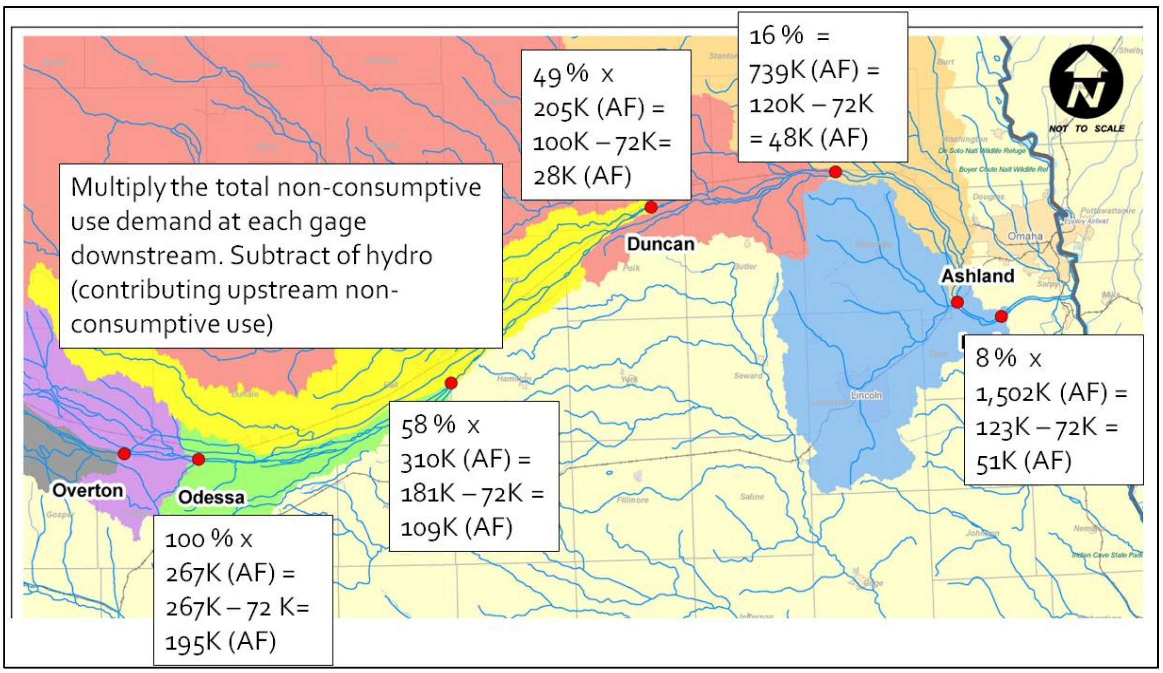
Figure 9.8. Example Ratio of Virgin Natural Flow Ratios for Downstream Gages



These percentages are then multiplied by each non-consumptive use demand at each downstream. The non-consumptive use demand represents the amount of flow that downstream subbasins could reasonably expect to receive based on the upstream basin's historic contribution. Therefore, the upstream basin is only assigned its percentage of the downstream non-consumptive use demand and no more.

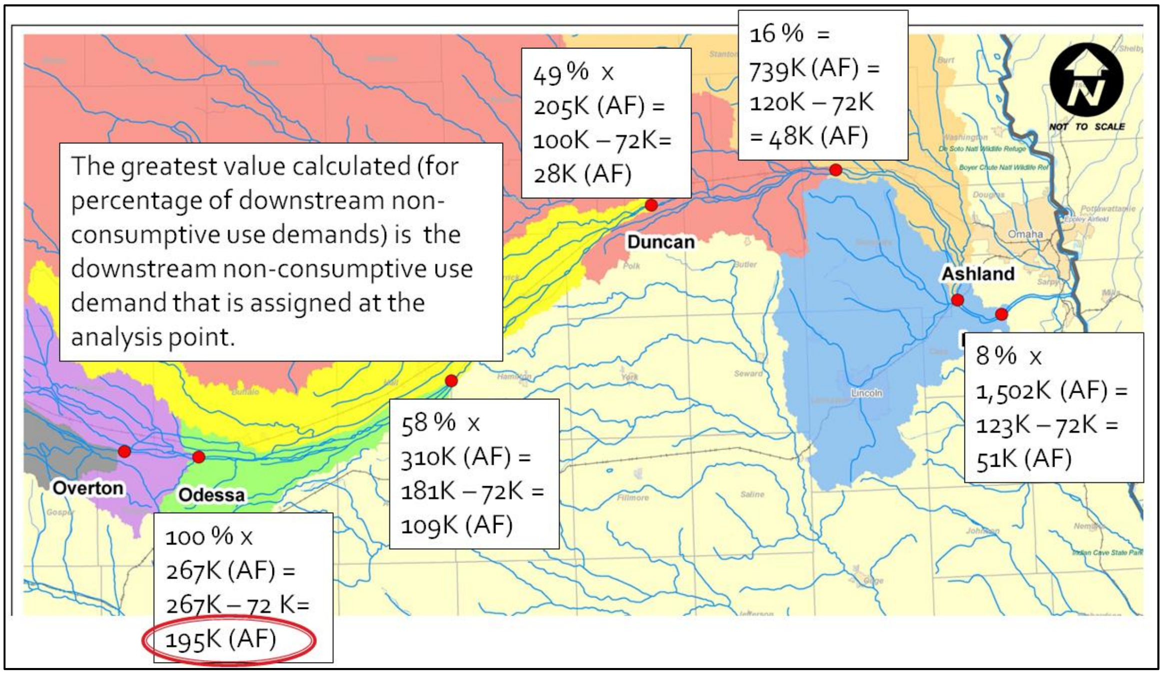
Next, the computed quantity is reduced by any non-consumptive uses already represented in the demands within the basin upstream of the gage, as those flows will be available to meet downstream demands. Figure 9.9 illustrates this process. In this illustration, the Kearney hydropower demand (72,000 AF) represents the non-consumptive use demand within the upstream basin. The instream flow demand varies by gage location and represents the non-consumptive use in each downstream reach. The non-consumptive use demands of the downstream reaches are reduced by the 72,000 AF non-consumptive use demand already reflected in the upstream basin total demand, but still available to meet downstream demands.

Figure 9.9. Example Computation of Downstream Demands – Non –CU (Step 1)



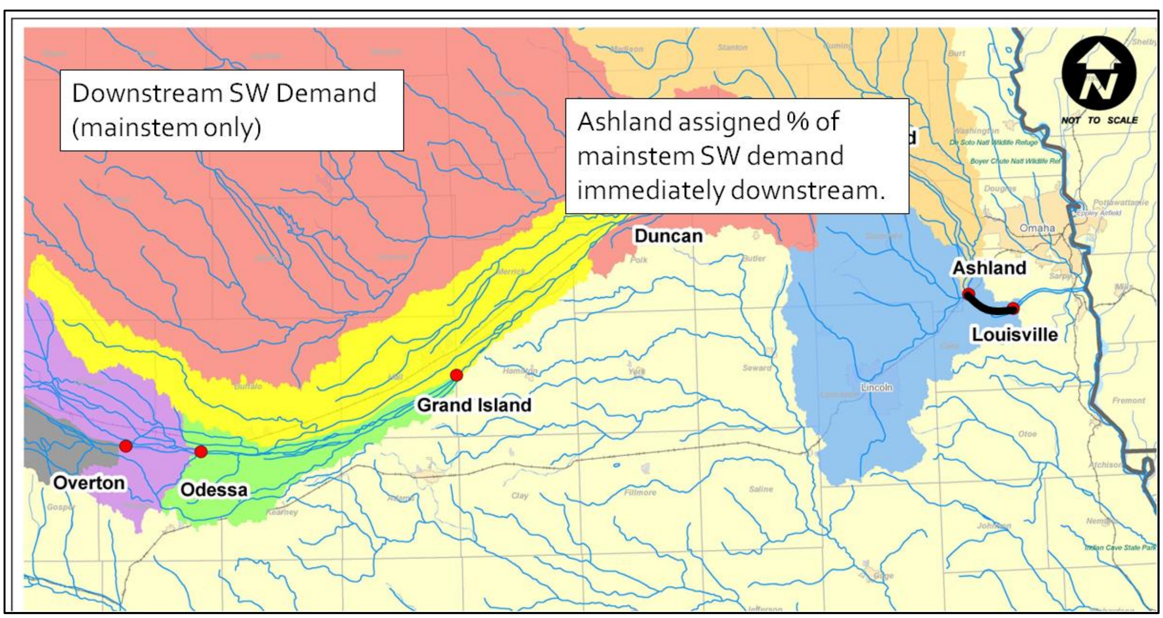
As shown in Figure 9.10, the greatest computed value (including that at the analysis point itself) will be applied at the analysis point as the non-consumptive use demand -in this case, the 195k AF at the Odessa analysis point.

Figure 9.10. Example Computation of Downstream Demands – Non-CU (Step 2)



2) Consumptive Use Demands – Downstream consumptive use demands are computed as the ratio of virgin flows at current gage to immediate downstream gage (similar to the process of non-consumptive use shown above). In Figure 9.11, the Ashland analysis point is assigned a percentage of main stem surface water demands immediately downstream (Ashland-to-Louisville); represented by the ratio of virgin flow at the Ashland and Louisville gages.

Figure 9.11. Example Computation of Downstream Demands – CU (Step 1)



The percentage is then multiplied by the main stem surface water demand Ashland-to-Louisville (Figure 9.12).

Figure 9.12. Example Computation of Downstream Demands – CU (Step 2)

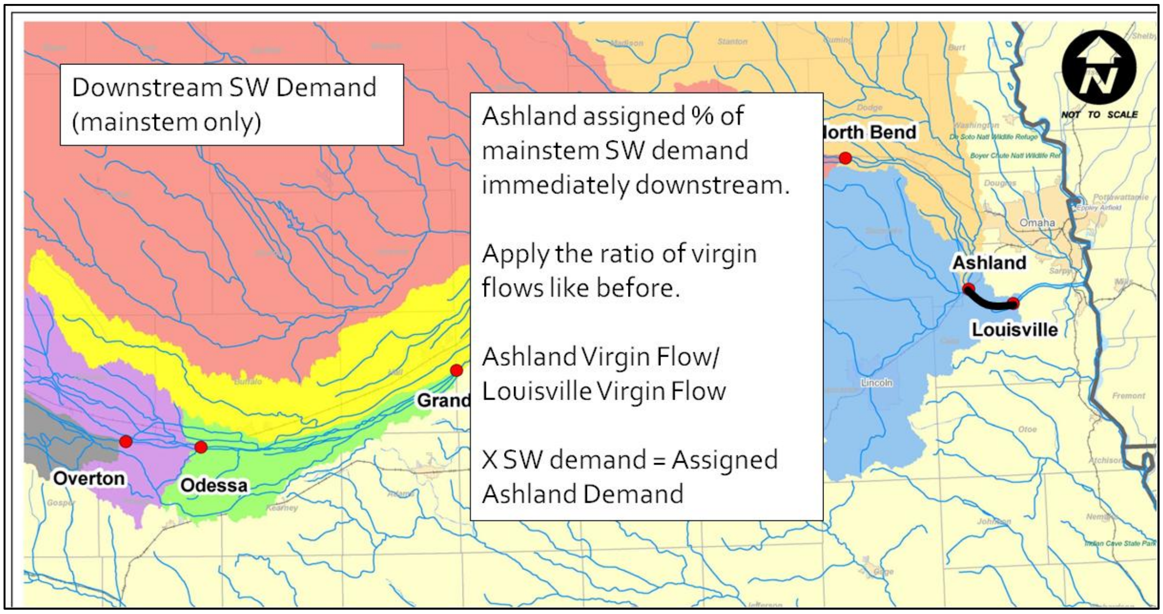
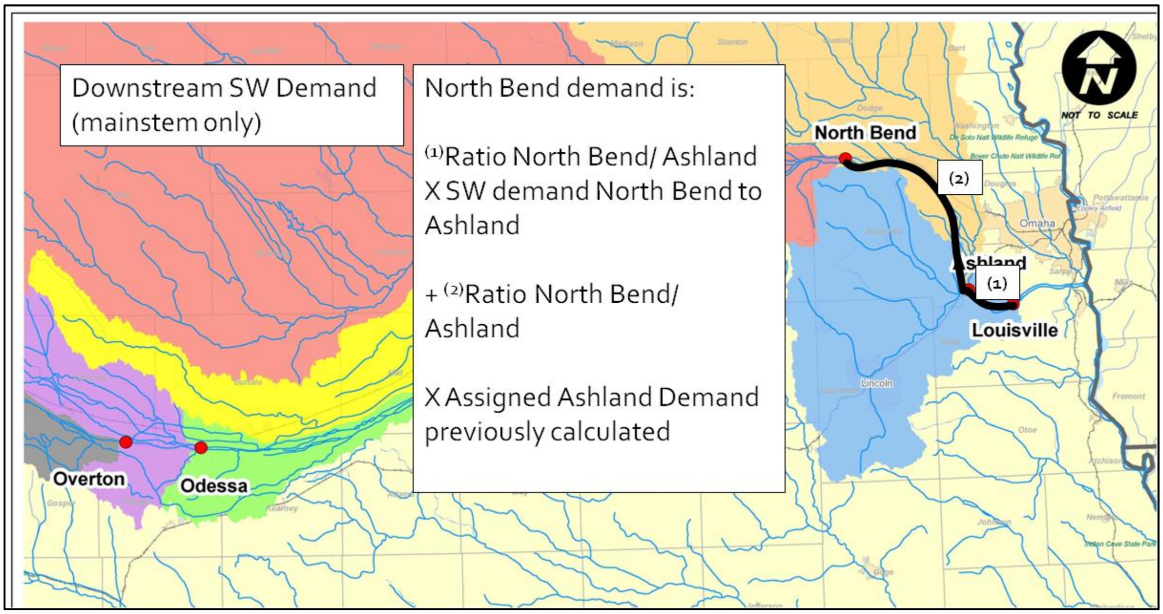


Figure 9.13 illustrates an example calculation for the downstream surface water demands to be applied at North Bend. North Bend is assigned a percentage of the surface water demands from the North Bend-to-Ashland reach. North Bend is also assigned a percentage of the downstream surface water demands for the Ashland-to-Louisville reach.

Figure 9.13. Example Computation of Downstream Demands – CU (Step 3)



When calculating the downstream non-consumptive use demand, the purpose is to ensure adequate water is passed to meet instream flow demands (or other non-consumptive use demands (e.g., hydropower)) downstream. It is important to note that this amount is not cumulative. If the upstream basin provides its portion to meet the largest downstream non-consumptive use demand, sufficient flow would be provided to meet all of the downstream non-consumptive use demands. Again, downstream reach gains and losses are not explicitly calculated but are reflected in the ratios used to determine the percentage of water the basin could reasonably expect to contribute to meet downstream demands.

In contrast to downstream non-consumptive use demand, the calculation of downstream consumptive use demand is cumulative. The upstream basin is assigned a portion of the downstream surface water demands on the main stem channel. The upstream basin would not be assigned the entire downstream surface water demand. Rather, the upstream basin is only assigned the percentage of downstream surface water demands equivalent to the percentage of water the basin could reasonably expect to contribute to each subsequent basin.

9.7.5 Total Demand

Total demand at each location is computed using both estimates for groundwater depletions and the full groundwater consumptive use.

1) Total Demand Based on Full Groundwater CU:

Total demand = (Upstream Consumptive Use Demands) + (Upstream Non-consumptive Use Demands) + (Downstream Main Stem Surface Water Consumptive Use Demands) + (Downstream Non-Consumptive Use Demands)

For simplicity in this test application, storage, reservoir evaporation, and municipal and industrial (M&I) uses were not considered. All of these uses would be included in the usage demands for a fully appropriated evaluation.

As referenced in Section 9.7.4, the availability of upstream non-consumptive uses to meet downstream non-consumptive uses must be accounted in the estimation of demands. In the Central Platte River test case, the Kearney Canal hydropower right is met by diversions from the main stem of the Platte River and the Loup Canal hydropower right is met by diversions from the Loup River. The typical diversion season for Kearney Canal is April-October, with a non-consumptive use demand of 400 cfs during the non-irrigation season (only 3 of the seven months). Non-consumptive use demand for the Kearney Canal is (400 cfs – irrigation consumptive use) during the irrigation season. The computed non-consumptive use demand is placed at the Odessa, Grand Island, and Duncan gage locations.

The Loup Canal non-consumptive use demand is 3,500 cfs throughout the non-irrigation season and (3,500 cfs – irrigation consumptive use) during the irrigation season. The sum of Kearney and Loup Canal non-consumptive demands are placed at North Bend, Ashland, and Louisville. If the Kearney and Loup hydropower non-consumptive use demand meets or exceeds the instream flow demand, the final term in the equation above is 0.

2) Based on Groundwater Depletions:

Total demand = (Upstream Surface water Consumptive Use) + (Upstream Non-consumptive Use Demands) + (Upstream Groundwater Depletions in 2009) + (Downstream Demands) + (Instream Flow – Hydropower, 0)

The use of 2009 depletions in the demand computation above accounts for the current level of depletions on surface flows.

9.8 Supply and Demand Comparison

As discussed, supply, demand, and surplus frequency plots were used in the Central Platte River test case. A scatter plot of the supply, demands, and surplus (equal to supply less demands) versus time was included to illustrate how supply, demands, and surplus vary on an annual basis for the analysis period (1984-2009). In addition, a percent exceedance of the surplus plot was created. In this way, the reader can easily see the percentage of time supplies have exceeded demands and vice-versa. Because of the importance of available supplies during the peak irrigation season months of July and August, the analysis was conducted on the non-irrigation season (October – April), irrigation season (May – September), and the July-August period. The Duncan gage analysis is illustrated in the following figures.

Figure 9.14. Duncan Non-Irrigation Season – Supply, Demand, and Surplus

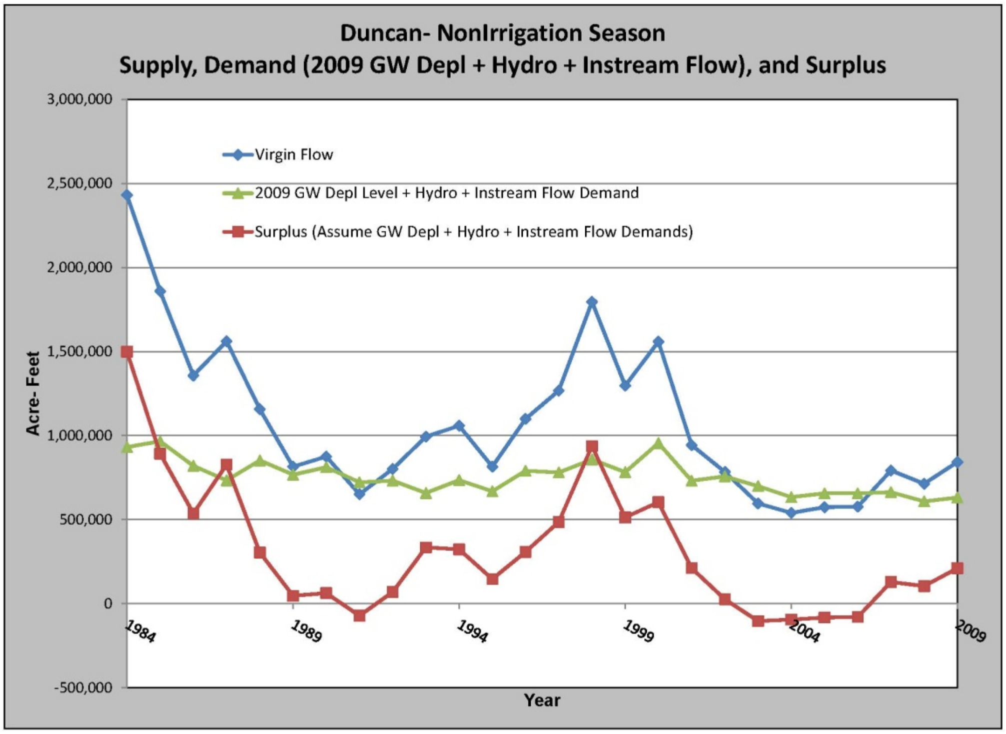


Figure 9.15. Duncan Non-Irrigation Season - Supply and Demand Exceedance Plot

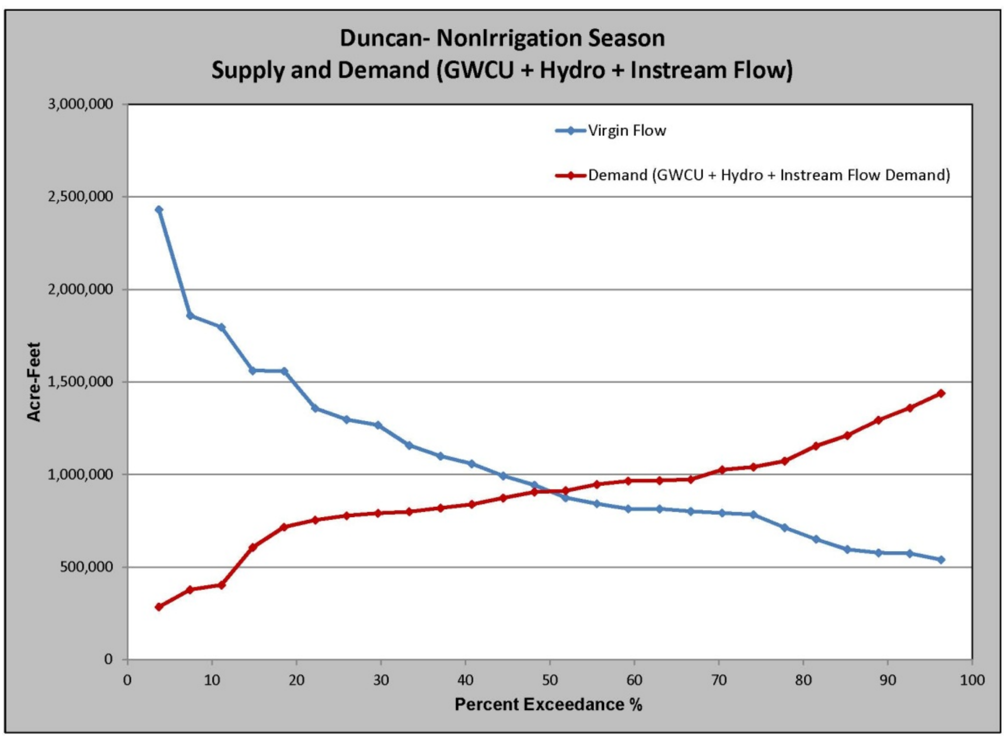


Figure 9.16. Duncan Non-Irrigation Season - Surplus Exceedance Plot

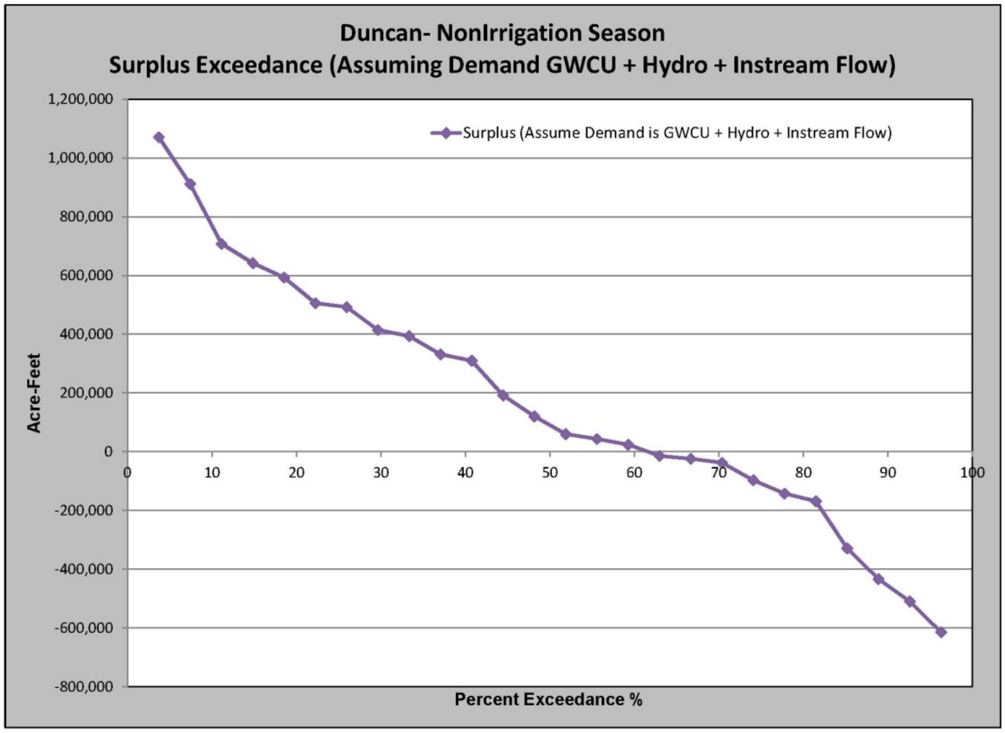


Figure 9.17. Duncan Irrigation Season – Supply, Demand, and Surplus

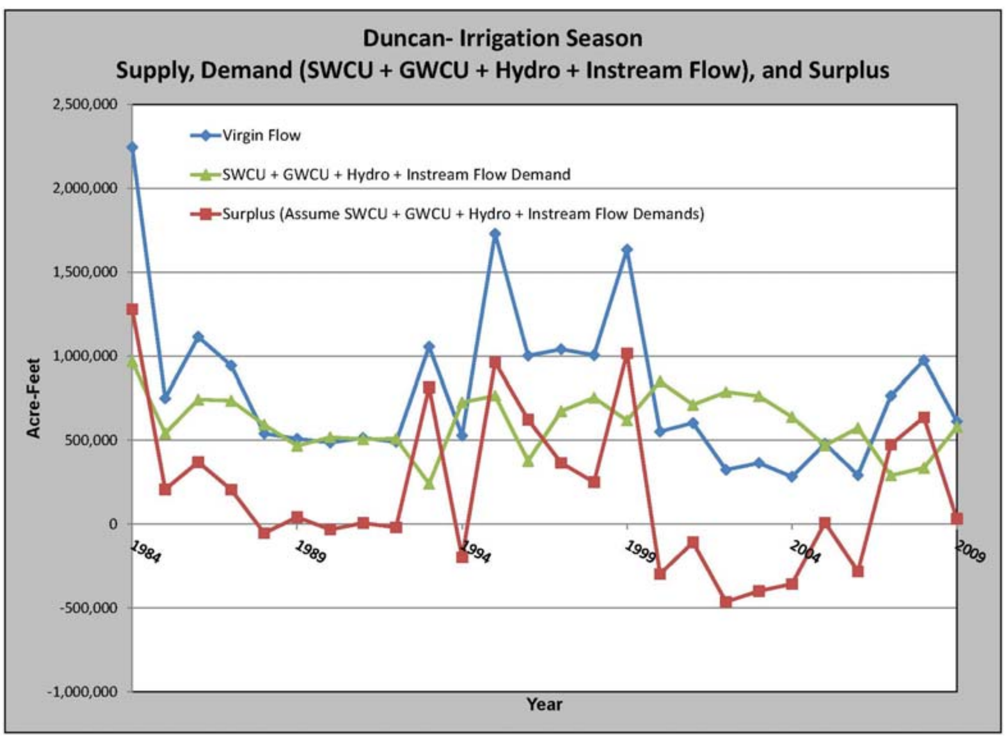


Figure 9.18. Duncan Irrigation Season - Supply and Demand Exceedance Plot

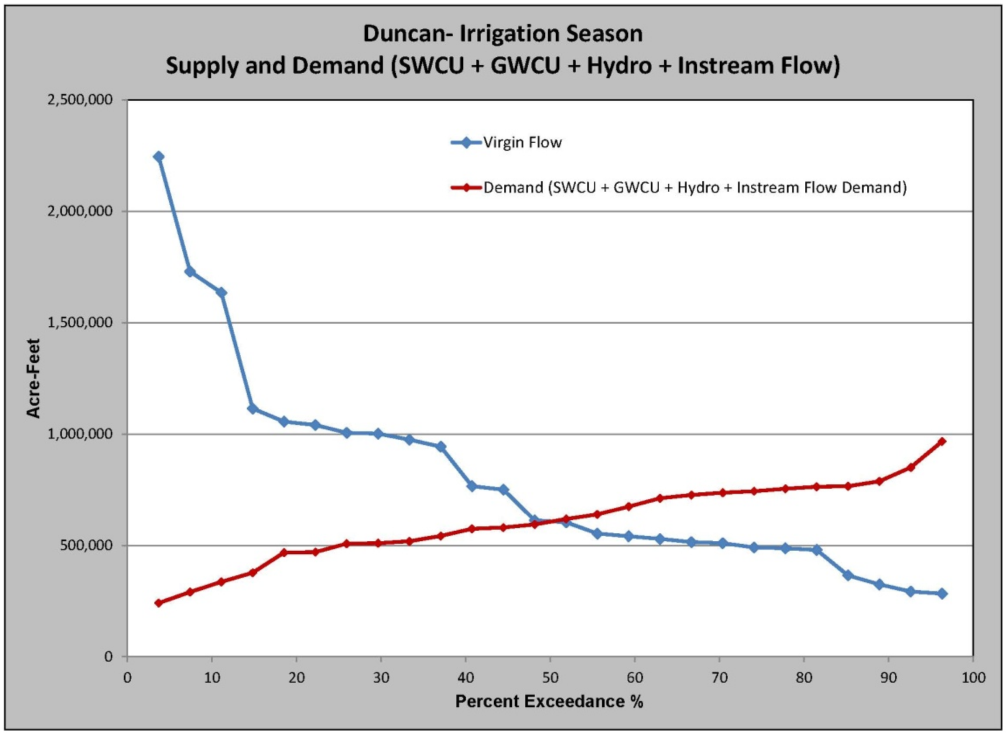


Figure 9.19. Duncan Irrigation Season - Surplus Exceedance Plot

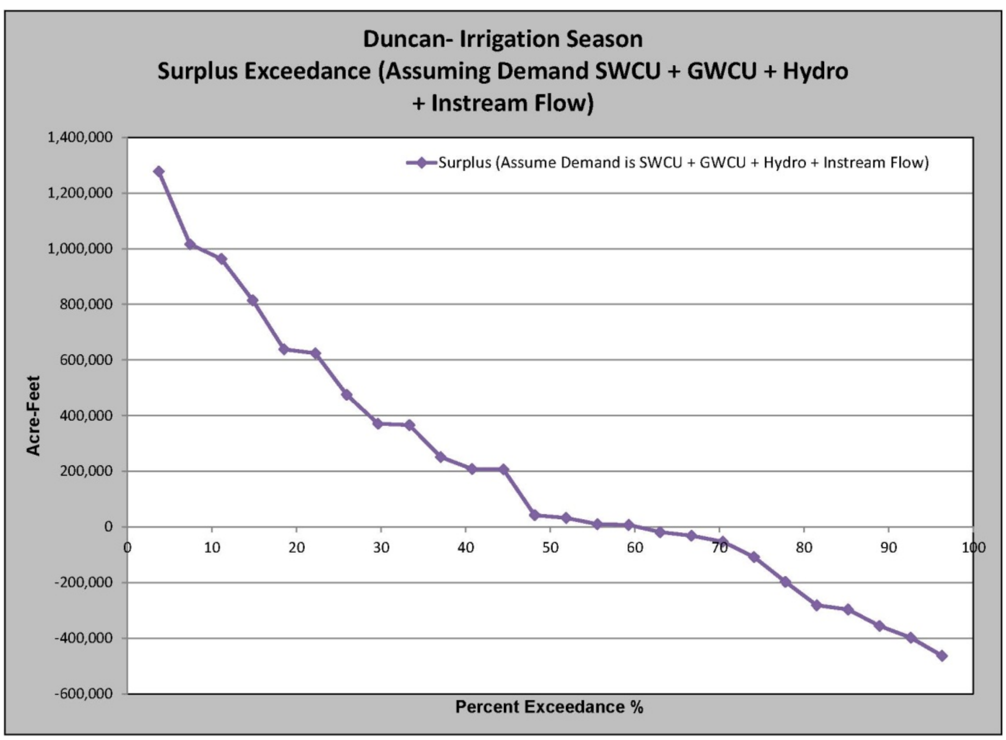


Figure 9.20. Duncan Jul/Aug, - Supply, Demand, and Surplus

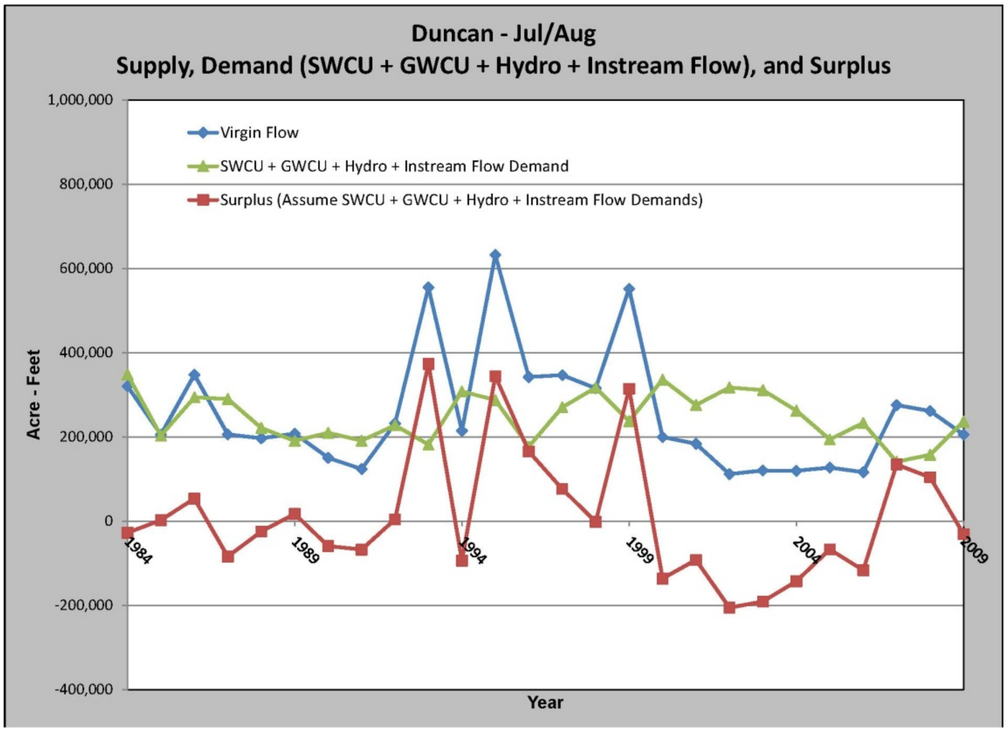


Figure 9.21. Duncan Jul/Aug - Supply and Demand Exceedance Plot

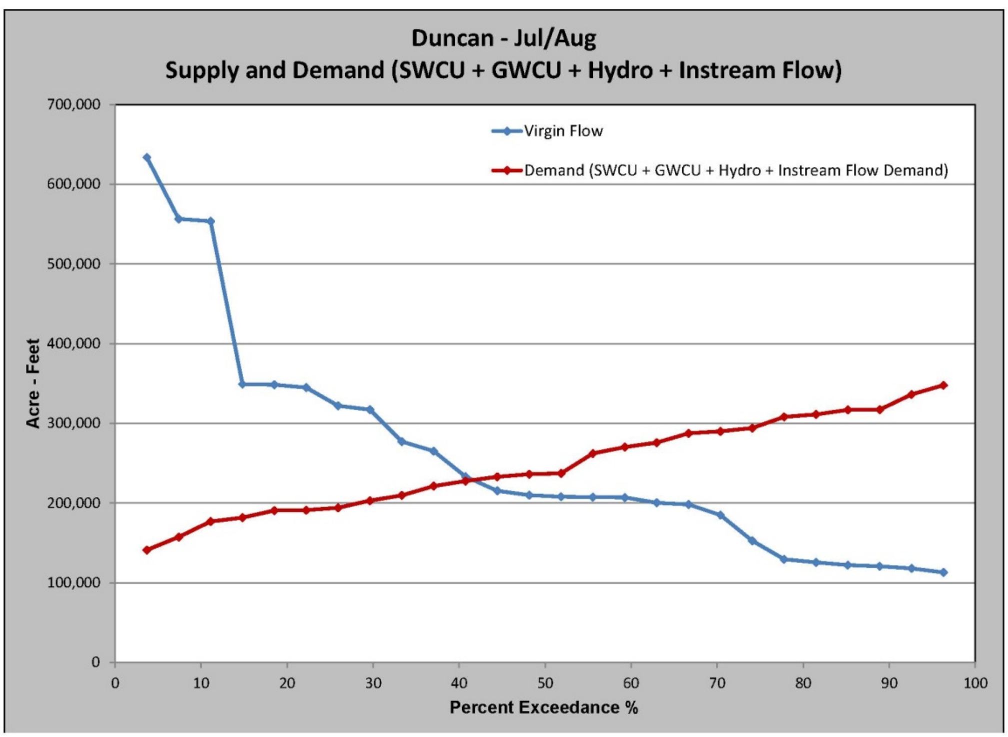
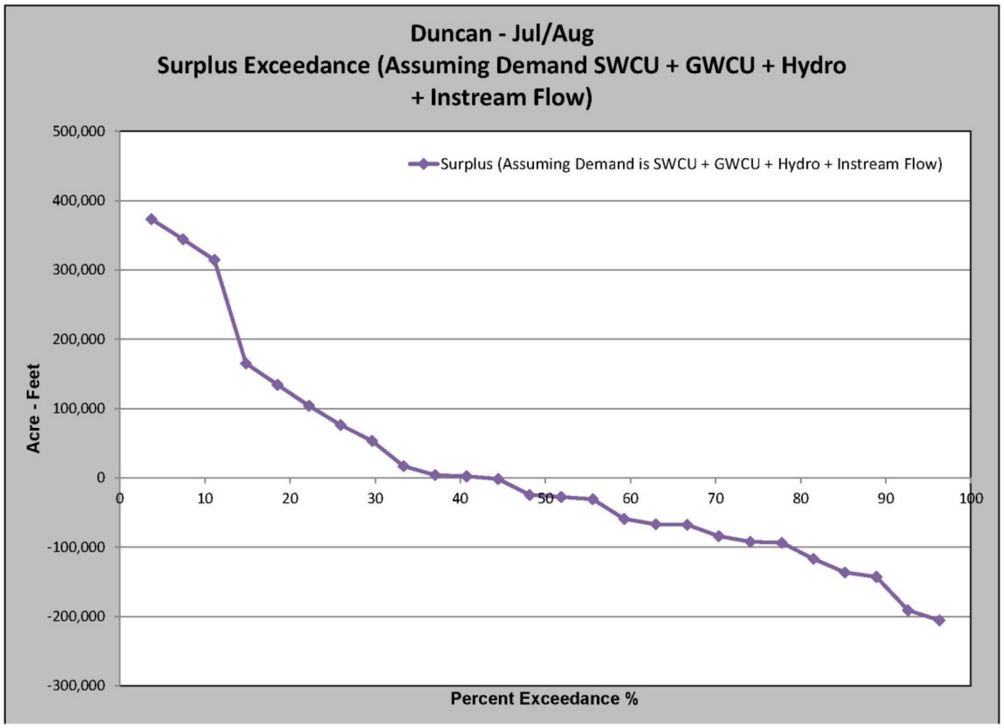


Figure 9.22. Duncan Jul/Aug - Surplus Exceedance Plot

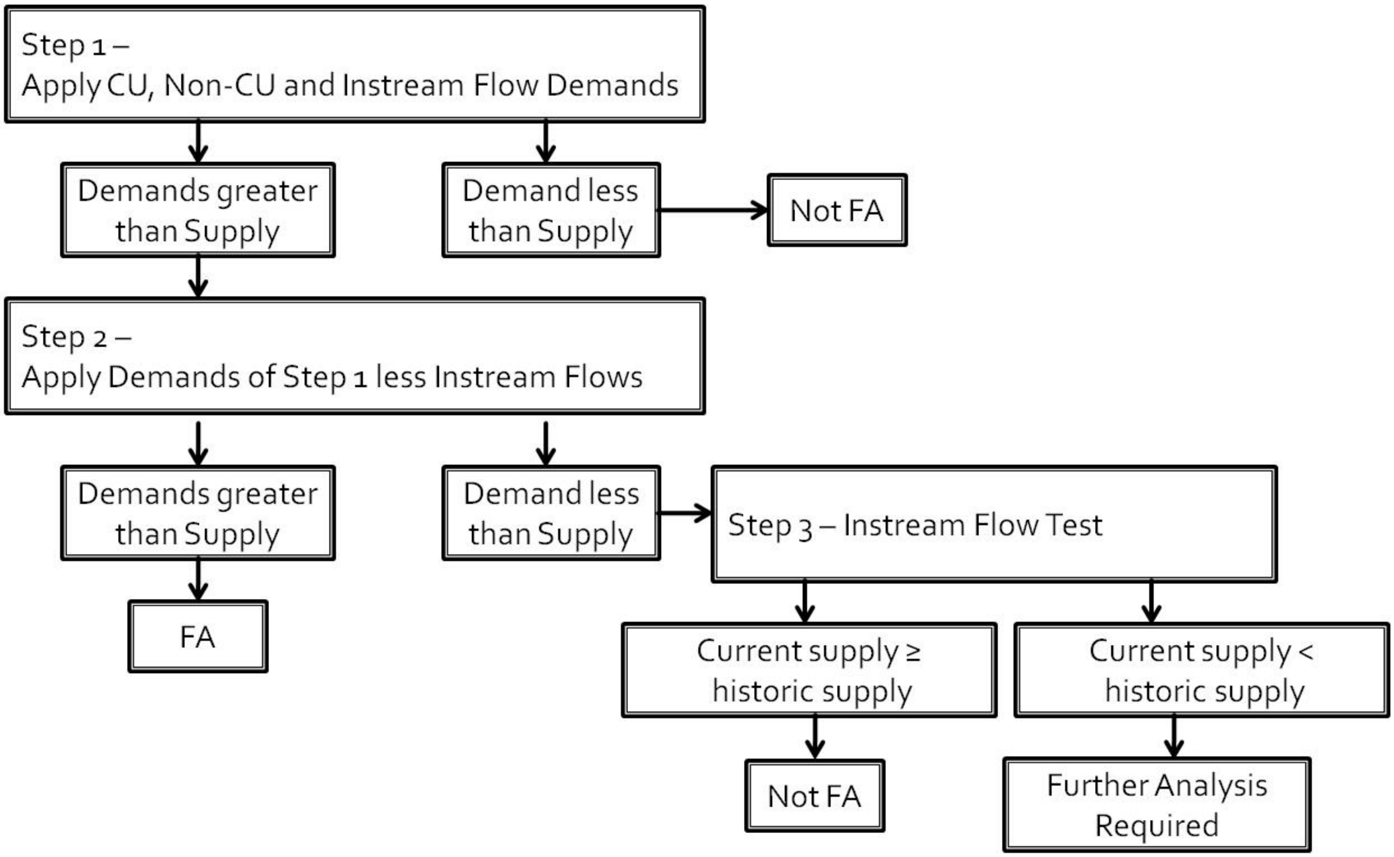


9.9 Proposed Methodology for Comparing Supplies and Demands

A proposed methodology for comparing supplies and demands was developed based on state statute and tested in the Central Platte River analysis. The methodology involves three steps, as illustrated in Figure 9.23.

Generic terms of “supply” and “demand” have been used in Figure 9.23 to represent the virgin natural flow and the consumptive and non-consumptive uses that have been discussed in detail in this technical memorandum. Similarly, generic symbols of “<” and “>” have been used in Figure 9.23 to represent the relative comparison of supplies and demands. Ultimately the specific quantitative criteria related to the acceptable levels of usage and certainties of supply will be determined by Nebraska DNR and applied at those evaluation points depicted by the generic symbols.

Figure 9.23. Methodology Flow Chart



9.9.1 Step 1 – Supplies and Total Demands

The first test compares computed virgin natural flows with total demands. Should the demands be less than supplies, the reach is determined to be not fully appropriated. If total demands are more than virgin natural flows, the analysis is continued to Step 2.

9.9.2 Step 2 – Supplies and Demands – Less Instream Flows

The second test is conducted to determine if the instream flow demand is the cause of demands exceeding supplies in Step 1. If the demands (less instream flow demands) still exceed supplies, the reach is determined to be fully appropriated. If the demands (less instream flow demands) are less than supply, the analysis must proceed to Step 3 where the Instream Flow Test is applied.

9.9.3 Step 3 - Instream Flow Test

An instream flow test (or 'erosion test') is performed to determine if flows to satisfy the right have been eroded over time. The test is performed by comparing expected flows at the time the instream flow appropriations were granted to the computed supplies for the period of analysis. The use of expected flows is consistent with State Statutes[13], which states that subbasins shall be deemed fully appropriated

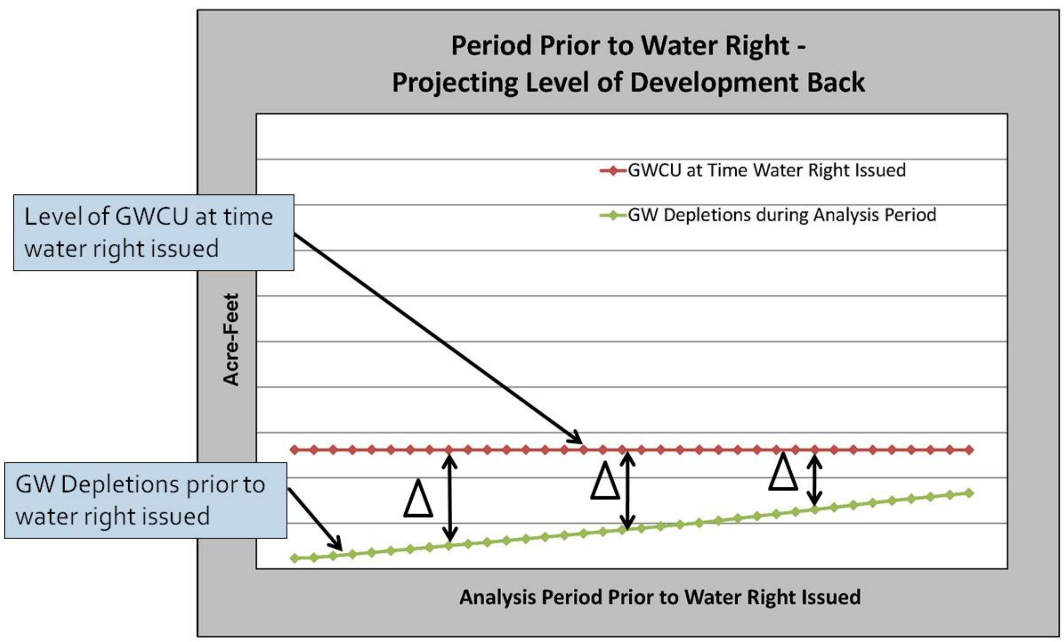
[13] Nebraska Revised Statues, Section 46-713

when "……….***then-current*** *uses of hydrologically connected surface water and ground water in the river basin, subbasin, or reach cause or will in the reasonably foreseeable future cause (a) the surface water supply to be insufficient to sustain over the long term the beneficial or useful purposes for which existing natural-flow or storage appropriations were granted and the beneficial or useful purposes for which,* ***at the time of approval****, any existing instream appropriation was granted…….".*

To determine the expected flows available to the instream flow appropriation, the supplies prior to the granting of the appropriation must be adjusted to account for the level of development present at the time of the granting. This adjustment accounts for the lag effect of uses that have yet to be realized as depletions to the stream.

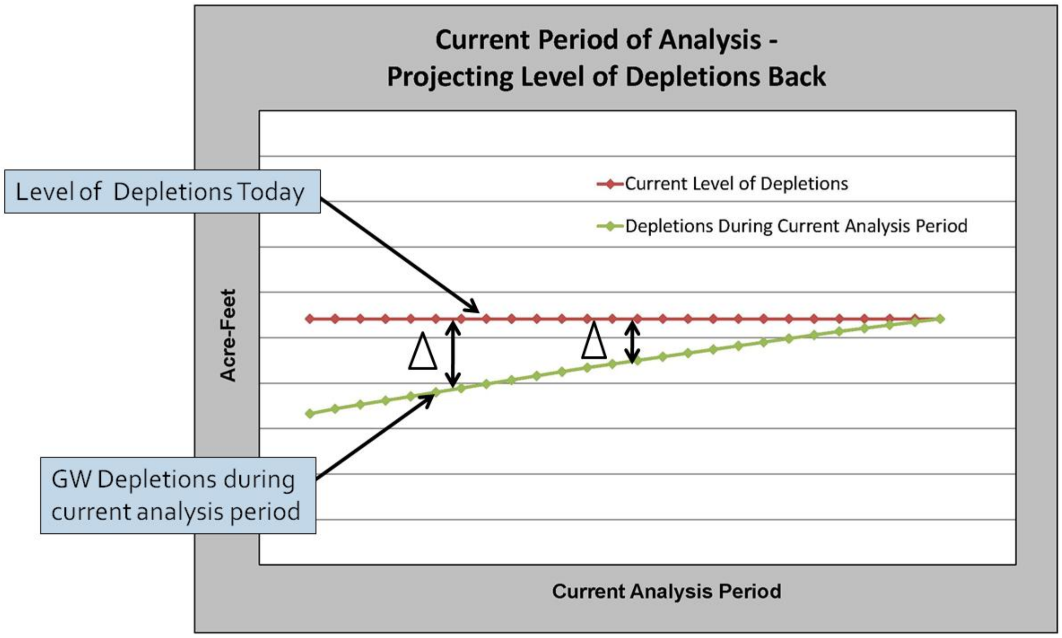
For the Central Platte River analysis, the adjustment to the 1954-1989 historic flows consists of reducing the observed historic flows by the consumptive use of those acres irrigated by groundwater in 1989 (i.e. 1989 level of development). Conceptually, this adjustment (delta, Δ) incorporates the lag effect of groundwater irrigation in the 1954-1989 period that had not yet resulted in depletions to the stream in 1989. This adjustment then yields the amount of water the appropriator could reasonably expect to have at the time the right was issued. This adjustment is conceptually illustrated in Figure 9.24.

Figure 9.24. Supply Adjustment for Period Prior to Water Right Granting



The supplies for the current period of analysis must also be adjusted to account for current level of development. For the Central Platte River analysis, the current analysis period (1984-2009) flows are reduced by projecting the current (2009) level of depletions back to 1984 and subtracting the difference (delta, Δ) of each year's depletion level from supplies. This accounts for current levels of development.

Figure 9.25. Supply Adjustment for Current Period of Analysis



The results of these adjustments on the supply and demand curves are illustrated in Figures 9.26 through 9.29.

Figure 9.26. Sample Instream Flow Analysis - Period Prior to Water Right Granting

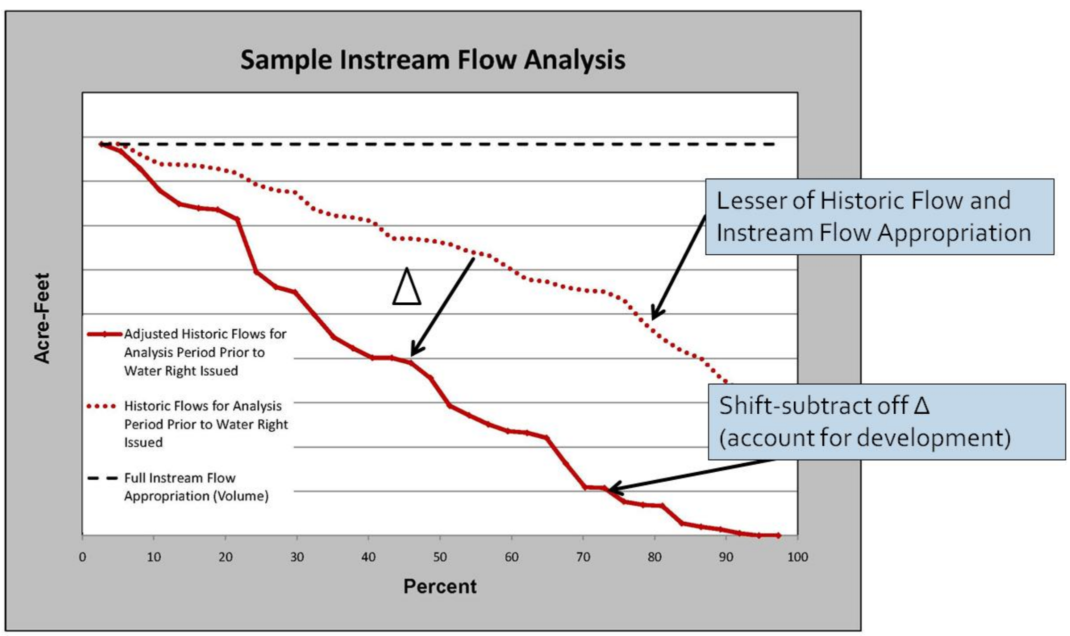


Figure 9.27. Sample Instream Flow Analysis - Current Analysis Period

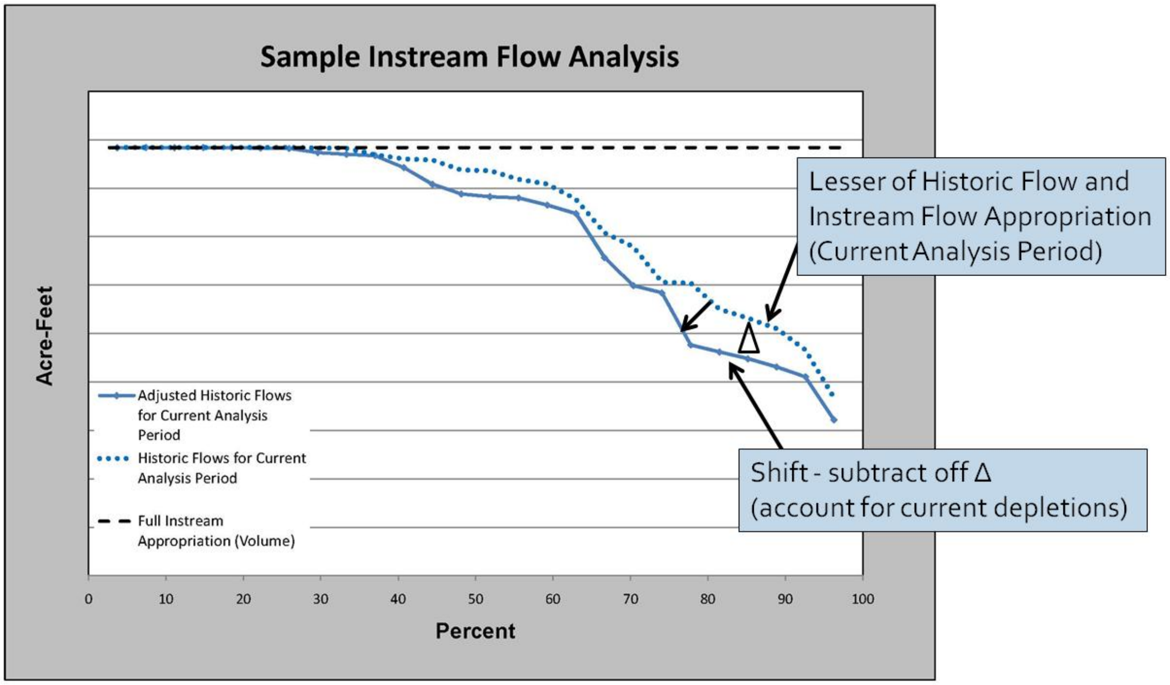


Figure 9.28. Sample Instream Flow Analysis - Comparison of Both Analysis Periods

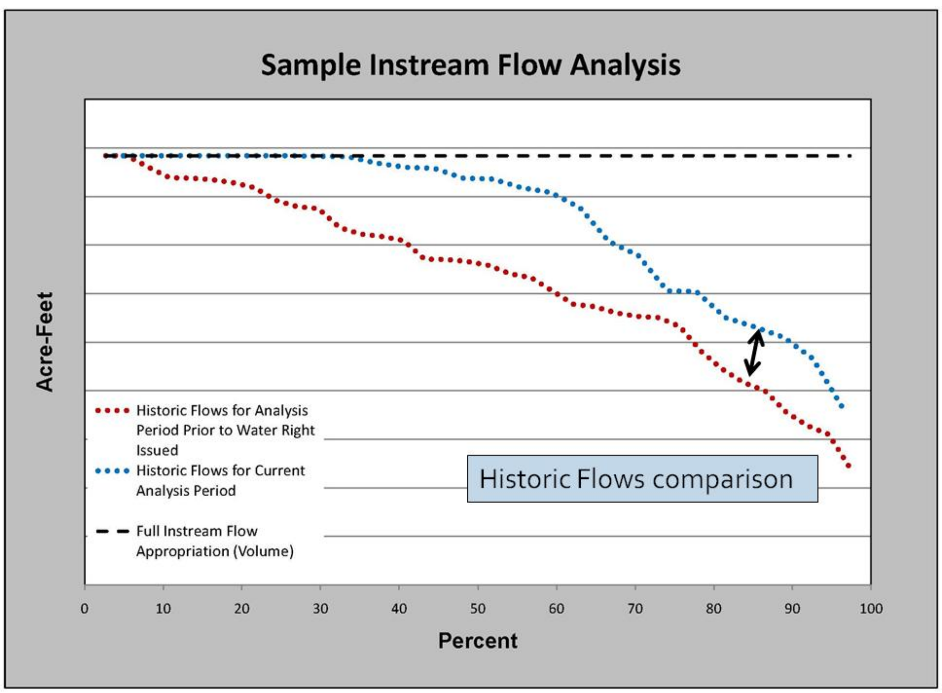
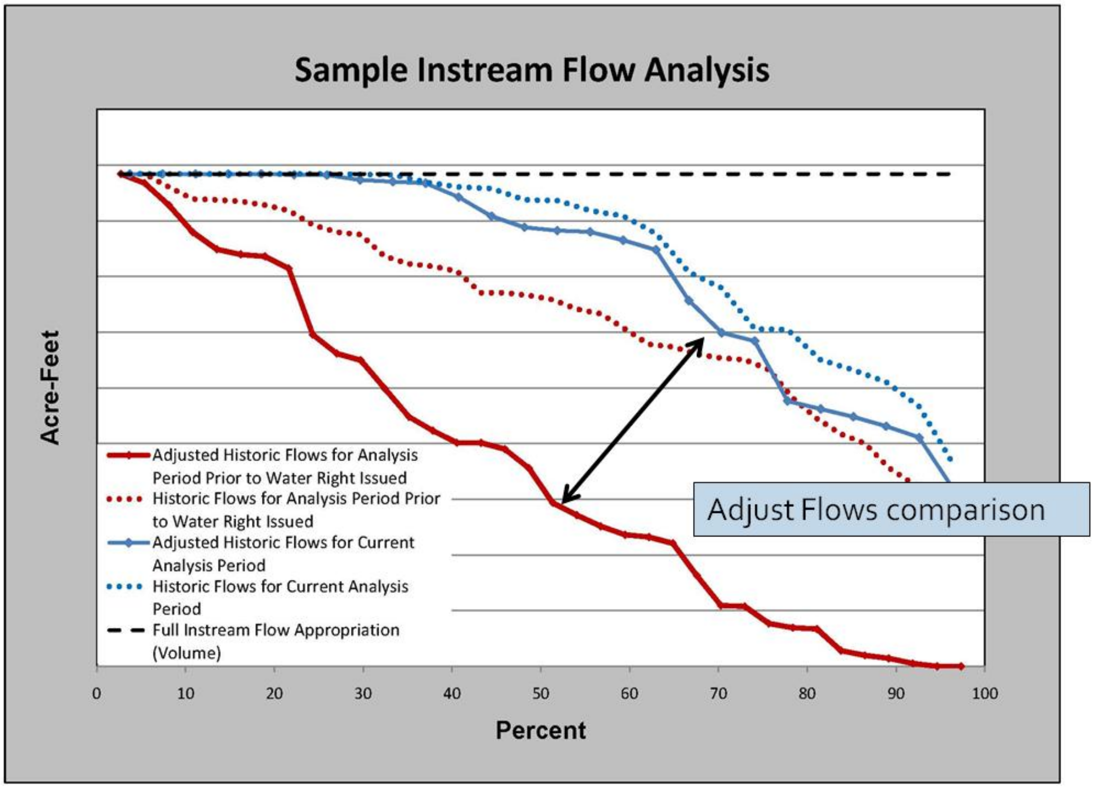


Figure 9.29. Sample Instream Flow Analysis, Comparison of Analysis Periods with Adjustments



In the event that the exceedance curve of the adjusted historic flows for the current analysis period exceeds the exceedance curve of the adjusted historic flows for the period prior to the water right issuance (i.e. current analysis period flow exceeds flows prior to water right issuance at each exceedance percentage), the reach can be determined to be not fully appropriated.

Should the exceedance curve of the adjusted historic flows for the period prior to the water right issuance exceed part or all of the exceedance curve for the adjusted historic flows for the current analysis period, further analysis must be conducted. The additional analysis would include inspecting the daily historic gage record to determine time(s) of shortage to instream flows and the relative significance of those shortages. Factors impacting the significance of the shortage could include duration, quantity, timing, and location.

10.0 Summary – Central Platte River Analysis

As defined in Nebraska Revised Statutes Section 46-713, the procedures for conducting the fully appropriated evaluation must address three key areas:

1) Identify and quantify existing surface and ground water uses
2) Identify and quantify surface water supplies
3) Represent surface/ground water interaction

Through discussions with the Nebraska Department of Natural Resources (DNR), Central Platte Natural Resources District (NRD), and input from Nebraska's water stakeholders, as well as the literature review findings, the following desirable characteristics/components of the fully appropriated evaluation procedures were noted:

1) Reflect long-term variability in water supply (climatic/drought cycles)
2) Reflect year-to-year variability in water supply
3) Reflects seasonal variability in water supply
4) Differentiate between ground and surface water, to the extent possible, in estimating sources and uses
5) Include means to evaluate and quantify conservation measures, as required by statute in the designated overappropriated basins
6) Differentiate between consumptive uses (CU) and non-consumptive uses, including the following sub-categories:
    a. Agricultural
    b. Hydropower
    c. Instream flows
    d. Municipal and Industrial uses
7) Utilize existing datasets/observed data (no explicitly new data collection efforts required)

Based on these statutory requirements and desired characteristics, conceptual refinements to the current methodology for conducting fully appropriated evaluations were developed.

The concepts were tested through application on case studies of the Niobrara River and Central Platte River. This testing led to further refinements of the concepts, in addition to illustrating their utility. In reviewing the statutory requirements and the desirable characteristics of the methodology, the concepts employed meet this standard. In addition, the proposed methodology provides a direct link between the evaluation process and the integrated management planning process defined by State statute.

10.1 Recommendations

Based on application of the concepts to the Upper Niobrara and central Platte River case studies, the following recommendations regarding the proposed fully appropriated methodology are made:

1. <u>Virgin Natural Flow</u> – The use of virgin natural flow to represent water supplies is an appropriate approach for the evaluation. For purposes of this discussion and recommendation, virgin natural flow is defined as estimated supplies undepleted by the activities of man.
2. <u>Demand Estimates</u> – Representation of discrete demands, both consumptive and non-consumptive, using the best available information provides a clear picture of water usage and should be employed to the extent possible.

3. Consumptive Uses – Primary consumptive uses for consideration in the methodology vary by reach, but include:
    a. Groundwater irrigation consumptive use: Estimates may be made based on well database, irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements. Use of precipitation-adjusted crop irrigation requirements allows variation in the hydrologic cycle to be represented in the evaluation.
    b. Surface water irrigation consumptive use: Estimates may be made in a couple of different ways. For those diverters with available historical gaging records, consumptive use may be estimated as a percent of diversions. This approach provides a way to account for water-short years when full irrigation requirements may not be met. Consumptive use estimates may also be made similar using irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements.
    c. Municipal and Industrial consumptive use: Estimates of consumptive use may be made based on historic groundwater well pumping and wastewater return records. Conversion of total consumptive use to a per capita estimate allows variations in population over time to be represented in the evaluation.
    d. Reservoir Evaporation: For reservoirs with historic stage data, historic pan evaporation data and reservoir stage/surface area data may be used to estimate evaporation. For the numerous smaller reservoirs throughout the state with permanent pools and no historic data, the Nebraska DNR's dam database may be used to identify locations and estimate pool sizes for estimate evaporative losses.
4. Non-Consumptive Uses – The two primary non-consumptive uses include hydropower and instream flows. Hydropower demand may be estimated based on appropriation, historic records, and physical capacity of system. Instream flow demands may be estimated based on the appropriated right, capped to the adjusted historic flow available at the time of granting.
5. Use of Groundwater Depletions and Consumptive Use as Demands – Representing groundwater usage using both depletions and consumptive use is a useful approach in determining the impacts of historic usage on current water supplies as well as the future impacts on water supplies based on current usage.
6. Statistical Testing – The use of statistical tests like the Kendall Tau and autocorrelation tests on virgin natural flow estimates are recommended in determining an appropriate period of analysis that represents the cyclical nature of supplies and uses without bias. In the event that every time period evaluated in the Kendall Tau test has a statistically significant trend, the Kendall Tau value can be used to determine the degree of the trend. For values close to 0 (approximately +0.25 to -0.25, for example) the trend may be negligible to the analysis, especially when it is coupled with the autocorrelation test. If a strong enough trend exists (greater than +0.25 or less than -0.25, for example) it is recommended that the statistical analyses be performed on the individual components comprising the virgin natural flow to determine the component(s) causing the trend. The remaining component(s) can then be used to determine the period of analysis in conjunction with the autocorrelation test.

7. Frequency Curves – Frequency curves (supply exceedance, demand non-exceedance, and surplus probability) are an appropriate and valuable tool in assessing supplies and demands relative to each other that can be evaluated over seasonal, annual, and period of analysis time periods.
8. Three-Step Analysis – The three-step process illustrated in Figure 9.23 for determining a basin's status is a logical progression that adheres to State statutes.
9. Instream Flow Erosion Test – The approach detailed for adjusting historic flow records (prior to granting of instream right) and for adjusting the flow records of the current analysis period are consistent with State statutes and should be employed in the evaluation.

10.2 Areas of Additional Refinement

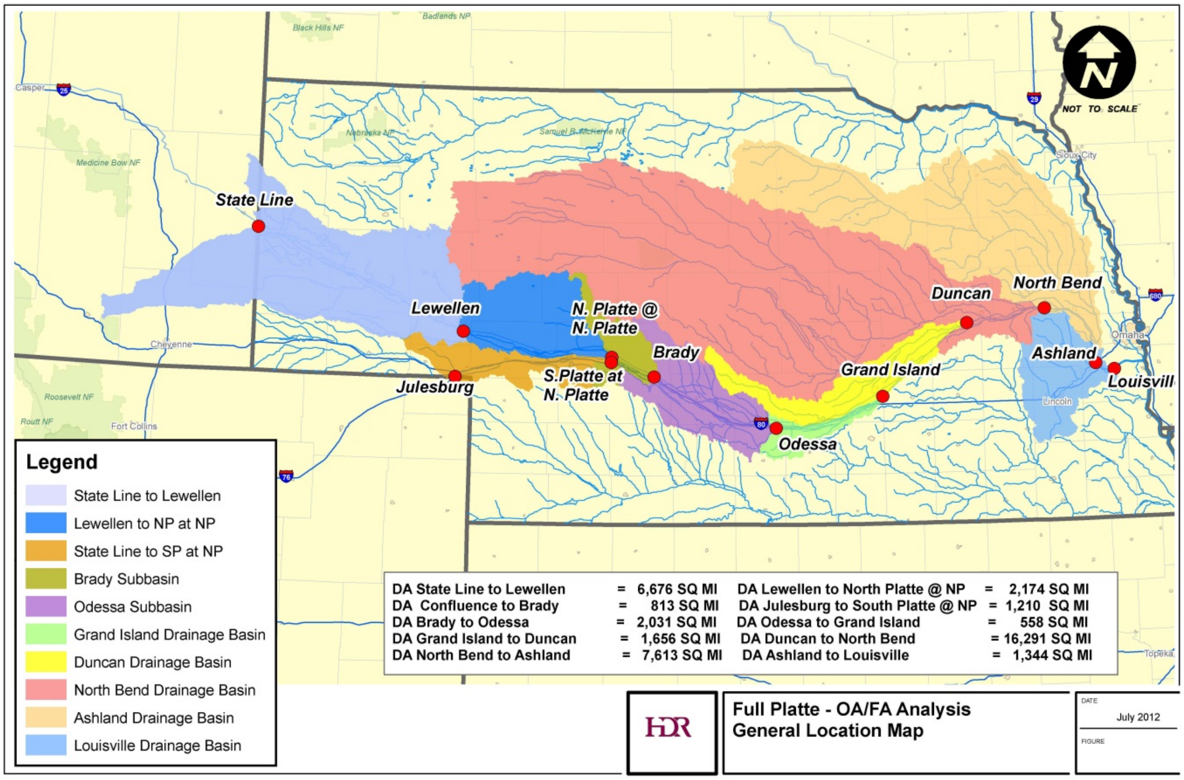
Through the test applications of the Upper Niobrara and Central Platte Rivers, the complexity of the fully appropriated evaluation process was clearly illustrated. Based on these tests, additional areas of further investigation were noted, as described below:

- Reservoir Operations: Further work is necessary on defining the approach to represent large reservoirs with multiple operation scenarios, multiple use and storage appropriations, and multi-year storage accounts.
- Estimates of Virgin Natural Flow at Upstream Reach Extent: A key simplifying assumption was made in each of the case studies – the historic gage flow at the upstream end of the reach represented the virgin natural flow. The upstream reach extent must be defined for the analysis reach to represent virgin natural flows entering an analysis reach.
- Conservation Measures: State statute requires that the impacts of conservation measures on stream flows be determined in areas designated as over-appropriated. Portions of the recommended approach will provide data that may be useful in this assessment; however a detailed approach to quantifying the impacts of conservation measures needs to be developed.

11.0 Full Platte River Analysis

This section describes the application of the methodology, with the Section 9.0 and 10.0 refinements, in evaluating the Platte River basin from the state line gages at Wyoming and Colorado downstream to the Louisville gage. As with the previous tests of the methodology, it should be noted that these analyses were conducted using simplifying assumptions and approaches for the purpose of testing methodology concepts. As such, results and quantities referenced in this section are for illustrative purposes only. The gages used to define the reaches for the analysis are illustrated in Figure 11.1.

Figure 11.1. General Location Map



Of particular interest in the full Platte River analysis, was testing approaches to address the following concepts:

- Estimating virgin natural flow at State Line
- Representation of Lake McConaughy and carryover storage
- Representation of hydropower demands
- Additional irrigation canals
- Partitioning of supplies and demands to North and South Platte rivers
- Representation of municipal and industrial demands

11.1 Data Collection

Data necessary for the evaluation was largely compiled from existing databases. Specific datasets utilized in this analysis include:

Gage Records: Flow records were available from seventeen gaging stations on the Platte River system:

1) North Platte River at Wyoming/Nebraska State Line (1988-2009);

2) Horse Creek at Lyman, Nebraska (1988-2009);

3) Fort Laramie Canal from North Platte River (1988-2009);

4) Mitchell Gering Canal from North Platte River (1988-2009);

5) Interstate Canal from North Platte River (1988-2009);

6) South Platte River at Julesburg, Colorado (1988-2009);

7) South Platte River at North Platte gage (1988-2009);

8) North Platte River at North Platte gage (1988-2009);

9) Platte River at Brady gage (1988-2009);

10) Platte River at Cozad gage (1988-2009);

11) Platte River at Overton gage (1988-2009);

12) Platte River at Odessa gage (1988-2009);

13) Platte River at Grand Island gage (1988-2009);

14) Platte River at Duncan Gage (1988-2009);

15) Platte River at North Bend gage (1988-2009);

16) Platte River at Ashland gage (1988-2009);

17) Platte River at Louisville gage (1988-2009).

State Line Gage: The North Platte River at Wyoming/Nebraska State Line gage measures only a portion of the inflows that cross the state line and contribute to the North Platte River in the uppermost basin above Lewellen. Horse Creek, Interstate Canal, Fort Laramie Canal, and Mitchell Gering Canal all bring flows across the state line that can be considered as North Platte River flows. To account for total North Platte basin inflows into Nebraska, the "State Line" gage at Wyoming was synthesized as:

> (North Platte River at Wyoming/Nebraska State Line gage) + (Horse Creek gage) + (83% of the Interstate Canal gage) + (Mitchell Gering Canal gage) + (Fort Laramie Canal gaged flow at State Line) = Total North Platte Basin flows into Nebraska

Interstate canal is gaged only at the point of diversion from the North Platte River and water usage to serve Wyoming lands was estimated at 17%[14].

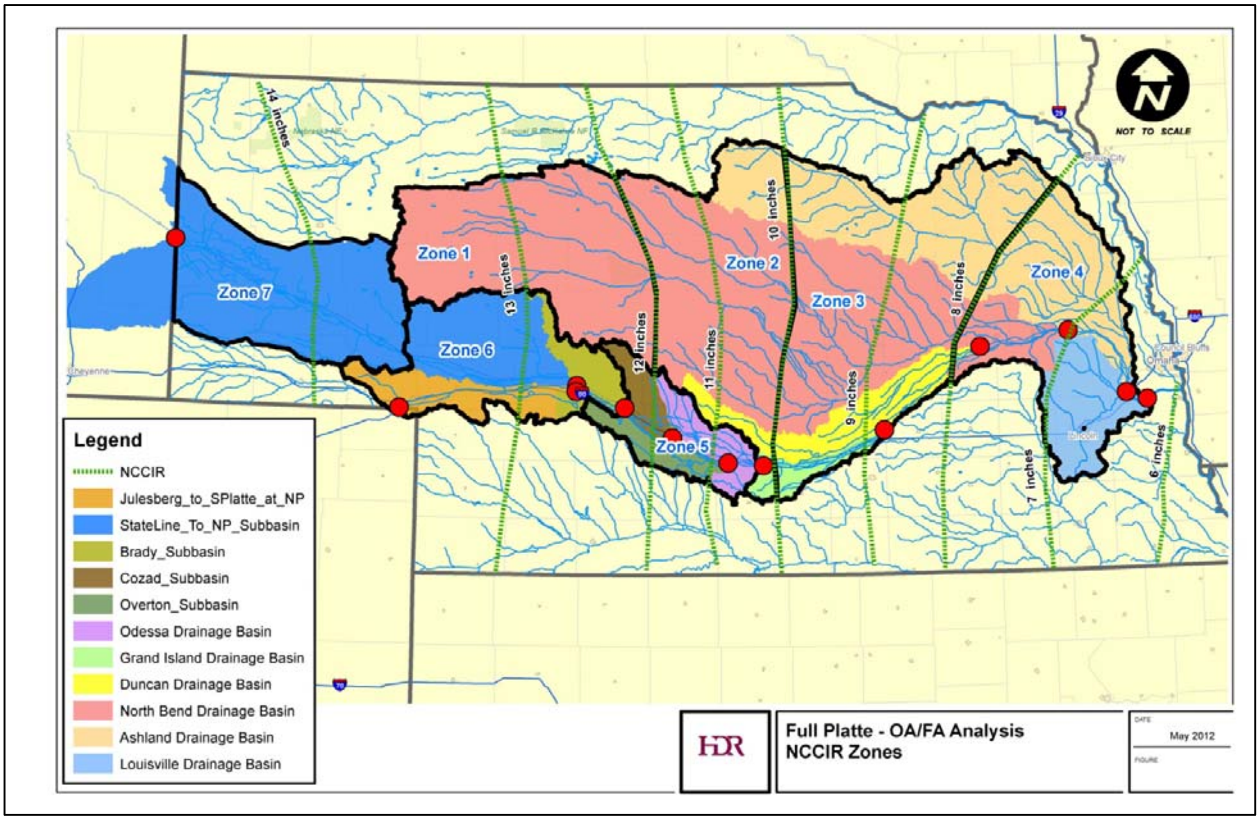
The coincident period of record 1988-2009 for the seventeen gages was used in the development of the virgin natural flow hydrographs at each gage location for this analysis. The 1988-2009 period was determined based on Kendall-Tau and autocorrelation statistical analyses, as described in Section 9.?, of the North Platte River and South Platte River inflows at the State Line to ensure representative a dataset that is without statistically significant bias.

Precipitation Records: In addition to the data collected from the central Platte River test, monthly precipitation data from the Medicine Creek Dam and Kingsley Dam National Weather Service stations via the High Plains Climate Center were compiled. Due to the large area of coverage and climatic variability, the study area was divided into 7 zones as shown in Figure 11.2. Zones 1-4 that were used in the previous analysis were maintained and zones 5-7 were added to represent the additional basins for the full Platte River analysis. It is recognized that a few of these zones overlap (zones 1 and 6; zones 2

[14] Per conversation with T. Hayden, NDNR and D. Strauch, Pathfinder Irrigation District

and 5). For simplicity in this analysis, the original zones for Phase I were retained and zones 5-7 were created separately for the purpose of the full Platte River analysis. For those subbasins that span multiple zones, a weighted average was applied. As in the previous analyses, the non-irrigation season was defined as October through April. The irrigation season was defined at May through September.

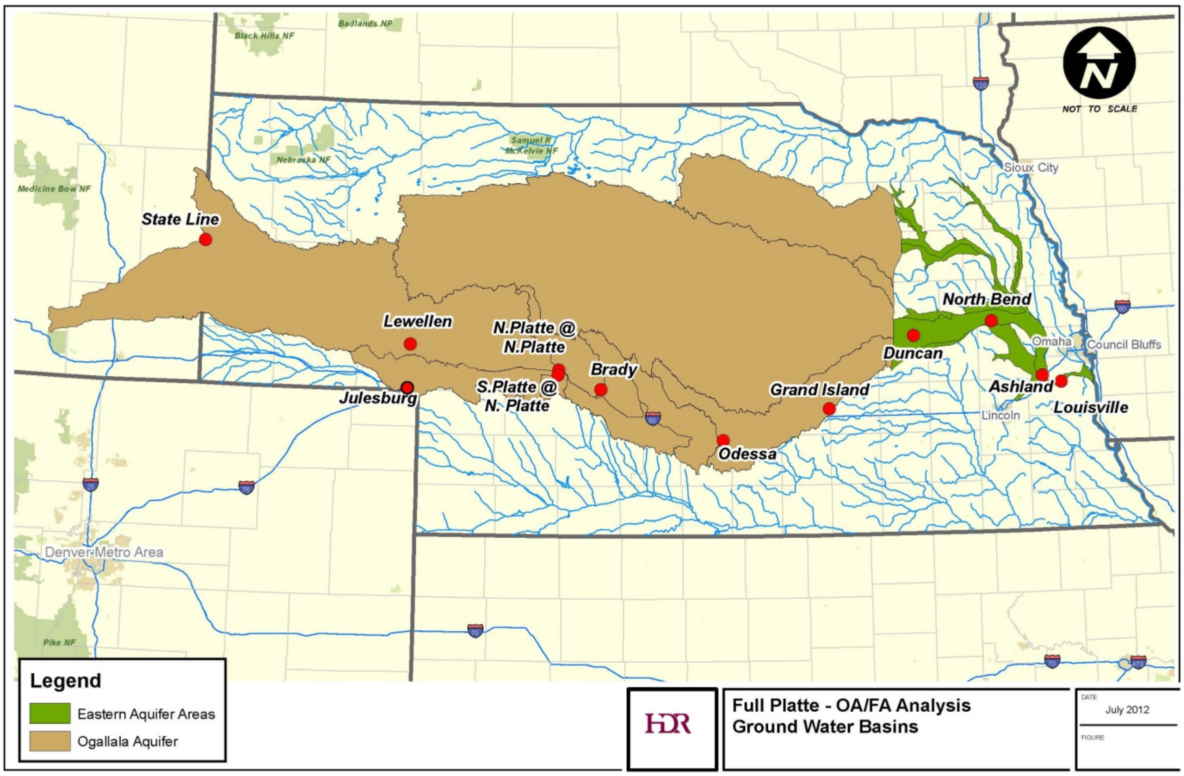
Figure 11.2. NIR/Precipitation Zones



Surface Water Irrigation Data: Available historic diversion as well as acreage data for surface water diversions was collected. Individual surface water appropriator data was collected from the DNR surface water appropriation database. Canal diversion records were gathered for 53 canals on the North Platte River above North Platte, 1 canal on the South Platte River above North Platte, 3 irrigation canals on the Tri-County system located within the Brady basin, 6 irrigation canals and the Kearney Canal diversion from the Platte River in the Odessa basin, 19 canals in the Loup basin, and the Loup Power Canal diversion from the Loup River. For the period of analysis of 1988-2009, the diversion data records for the canal diversions are fairly complete. The total of the appropriated acres (canal plus individual appropriators) within each subbasin was used for the purposes of this analysis.

Groundwater Irrigation Data: Groundwater irrigation data for the hydrologically connected area was estimated using the Jenkins method and processed using Python scripting tools within ArcGIS. The well shapefile from the DNR database was clipped to the study area and hydrologic zones. Raster data for transmissivity, specific yield, and NCCIR for the state of Nebraska (also from by DNR database) was also compiled. The Python script utilizes the Jenkins method to calculate depletion values based on the datasets referenced above and spatial distance from the receiving stream. Depletion values were developed assuming the irrigated acreage served by each well is 90 acres. Figure 11.3 illustrates the areas of hydrologic connectivity[15] used in the analysis. Figure 11.5 illustrates the well locations from the DNR well database.

Figure 11.3. Hydrologically Connected Groundwater Basins



11.2 Historic Surface Water Uses

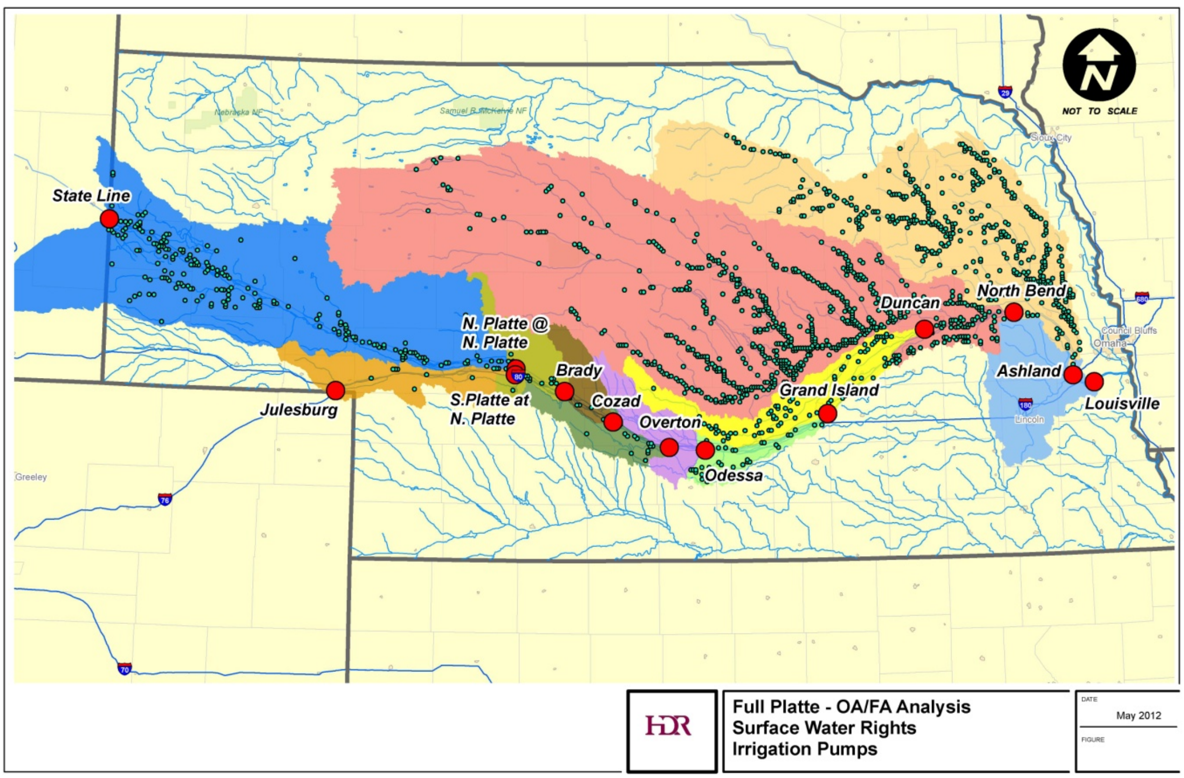
Historic surface water consumptive use for irrigation canal diversions was estimated as 50% of historic diversions. This estimate is consistent with values observed for canals in Nebraska[16]. The CNPPID Tri-County system was treated differently. E65, E67, and Phelps canals were estimated at different average percentages of efficiency based on CNPPID delivery records (approximately 50% for E67 prior to 2003 and 96% thereafter; 42% for E65; and 36% for Phelps).

[15] The limits of hydrologically connected groundwater uses were provided by DNR.

[16] Estimate derived from several ongoing efforts including synoptic studies of NPPD Platte River canals and COHYST study efforts

Historic surface water consumptive use for point irrigators (pumps) was estimated using a crop irrigation requirement [17]. The annual irrigation requirement was determined for each of the 7 zones shown previously in Figure 11.2. The annual irrigation value was adjusted to account for the variability in precipitation through the analysis period. The adjustment was based on the observed historic precipitation records. In this way, crop consumptive use of irrigation water is increased during dry years and decreased during wet years. For example, if a crop requirement is 26 inches and the observed precipitation during the irrigation season was 14 inches, then the NIR would be 12 inches. In this way, the required NIR for wet years is appropriately decreased to reflect a decrease in required irrigation. This prevents the maximum NIR from exceeding the crop irrigation requirement. The location of point diversion appropriators is illustrated in Figure 11.4.

Figure 11.4. Surface Water Rights – Individual Surface Water Appropriators



Cropping patterns were determined by comparing the 1982 and 2005 land use data[18] for the Central Platte River subbasins developed for the Platte River Cooperative Hydrology Study (COHYST). No significant change was noted between the two time periods; therefore, the 2005 land use data was used to develop the cropping pattern for this analysis. A weighted NIR was determined based on the reported crop blends for the prevalent crops of corn, pasture/grass, soybeans, and alfalfa.

[17] From county-wide average NIR mapping developed by Dr. Darryl Martin, UNL, 2006

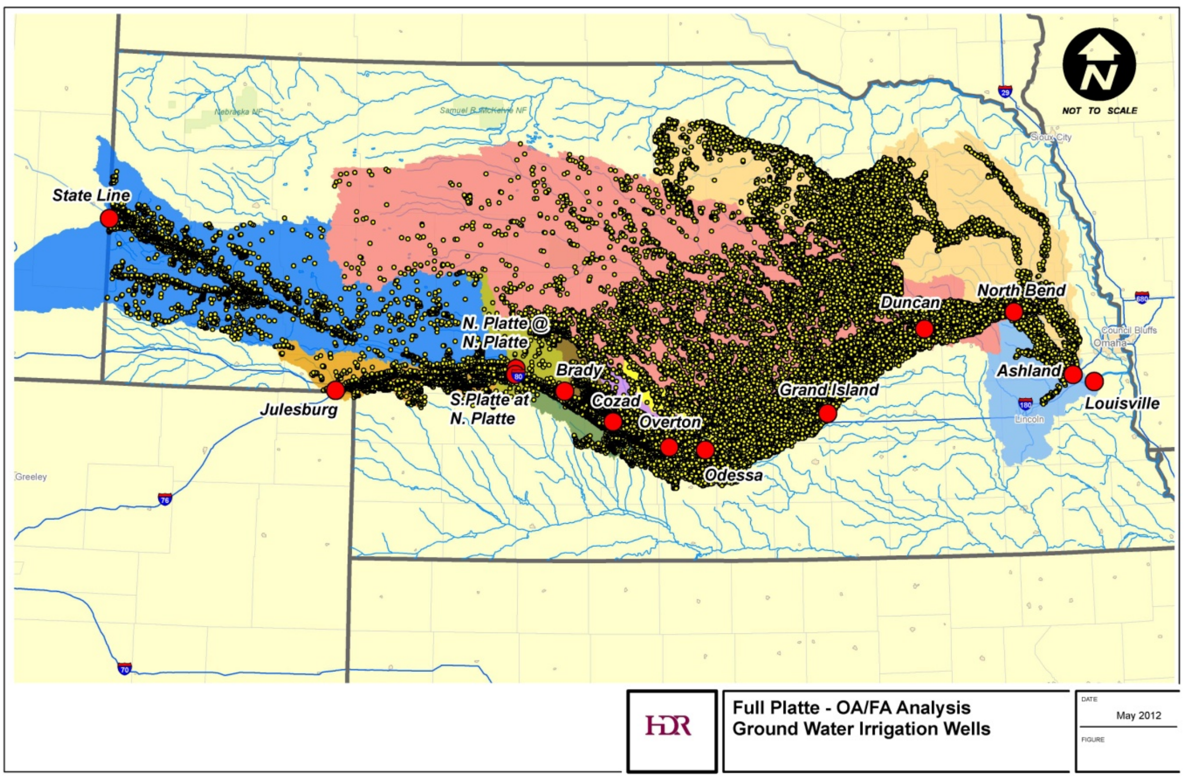
[18] Data and GIS shapefiles obtained from UNL Center for Advanced Land Management Information Technologies (CALMIT) public domain website: http://calmit.unl.edu/cohyst

Comparison of cropping patterns from 1982 and 2005 land use data in the North Platte River basin above North Platte did show a slight shift in cropping patterns away from sugar beets to grass/pastureland. For simplicity in this analysis, a consistent cropping pattern based on 2005 CALMIT data was used.

11.3 Historic Groundwater Consumptive Use

Historic groundwater consumptive use was estimated based on irrigated acreage data and the weighted NIR determined for the analysis area, determined as described in Section 11.2. Only irrigation wells were included in the groundwater consumptive use estimates.

Figure 11.5. Hydrologically Connected Groundwater Wells



11.4 Surface and Groundwater Interaction

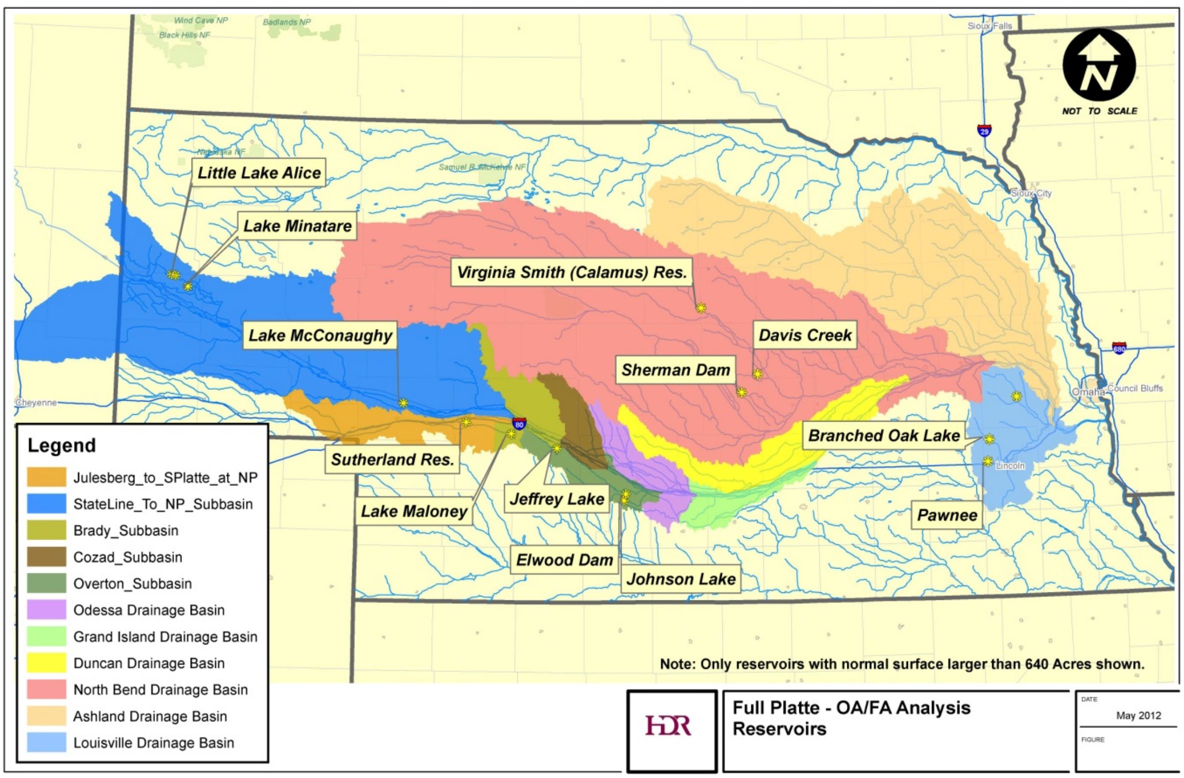
Surface and groundwater interaction was estimated using analytic methods. The estimates of surface water depletions due to groundwater pumping were made using the Jenkins[19] method and the Python script as described in Section 11.1. Annual depletions were assumed to be evenly distributed throughout the year. It is important to note that consumptive groundwater use estimates used precipitation-adjusted NIR, however the simplified depletions estimates used in this analysis were based on the NIR without precipitation adjustment for all groundwater irrigated acreage within the study area.

[19] Jenkins, C.T. Techniques for Computing Rate and Volume of Stream Depletion by Wells, USGS. 1967

11.5 Reservoir Evaporation

Evaporation was considered for reservoirs having a normal surface area greater than 1 square mile. Lake McConaughy, Lake Alice, Little Lake Alice, Minatare, Sutherland, and Maloney reservoirs were applied at the North Platte River at North Platte gage. Elwood, Jeffrey, and Johnson reservoirs were applied at the Brady gage. Davis Creek, Sherman, and Virginia Smith dams were applied at North Bend. Branched Oak and Pawnee lakes were applied at Louisville. Pan evaporation data was not explicitly measured for the period of analysis (1988-2009); therefore, evaporation values were calculated from the Daily Penman equation (reference crop alfalfa) from the Automated Weather Data Network and a constant surface area value for each reservoir used for this analysis. Reservoir evaporation was calculated for the Irrigation and July/August seasons only.

Figure 11.6. Reservoirs within Area of Analysis



11.6 Development of Supply

The virgin natural flow was developed at each of the gage locations on both an annual and seasonal basis. The different components that comprise the basin supply are represented within a build plot. In this way, it is easy to visually analyze the relative magnitude of the components that create the supply as well as any trends that may exist within the datasets. See Figures 11.7 through 11.16 for examples of the supply build plots.

11.6.1 Available Storage in Supply

For the full Platte River basin analysis, consideration must be given to the storage water available in Lake McConaughy. Lake McConaughy differs from other reservoirs (such as Box Butte in the Upper Niobrara test case) in that it typically has a large, multi-year, carryover storage volume. Theoretically, this water was available to downstream users with storage rights to offset downstream demands. This is especially true for those years when more water is stored in McConaughy than was delivered to those downstream users that hold a storage water right.

The Lake McConaughy active storage volume (stored volume less the 80,000 AF deadpool) was included as available in the total supply for those downstream analysis points. This storage volume was corrected by the change of storage within each analysis year (Oct 1 to Oct 1 in the plots below). In this way water released after Oct 1 that was included in the available storage, but subsequently shows up at the downstream gage is not double counted. As can be seen in figures 11.7 to 11.16, the Lake McConaughy storage represents a decreasing percentage of the overall supply as you move downstream. It is recognized that Lake McConaughy storage is only available to serve those demands with storage use appropriations for Lake McConaughy. Differentiating demands with and without storage appropriations was not completed in this analysis and therefore only total supplies and demands are considered. Lake McConaughy storage is also unavailable to meet demands in the Lewellen and South Platte basins.

11.6.2 North Platte River versus South Platte River Contributions

Based on analysis of virgin flow over the analysis period, the South Platte River contributes approximately 23% of the total flow in the Sutherland Canal return while the North Platte River contributes approximately 77%. Therefore, 77% of Sutherland Canal return was applied to the Lewellen to North Platte basin supply while 23% was applied to the Julesburg to South Platte basin supply.

Figure 11.7. Supply, South Platte River at North Platte

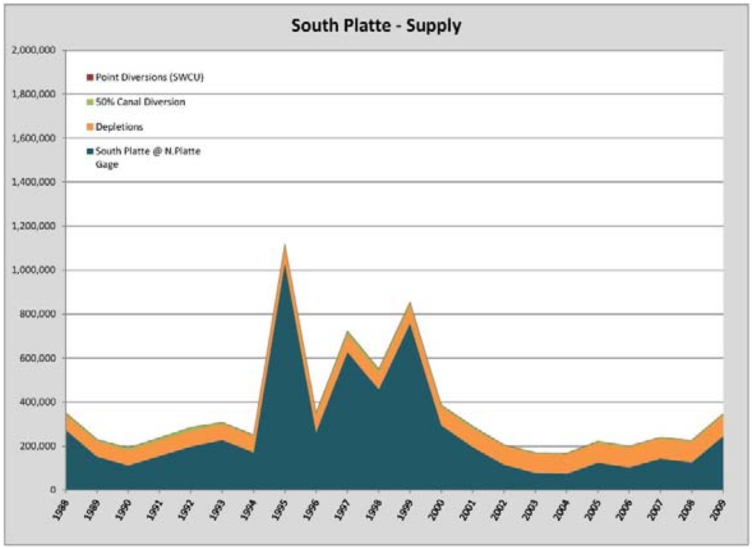


Figure 11.9. Supply, North Platte River at North Platte

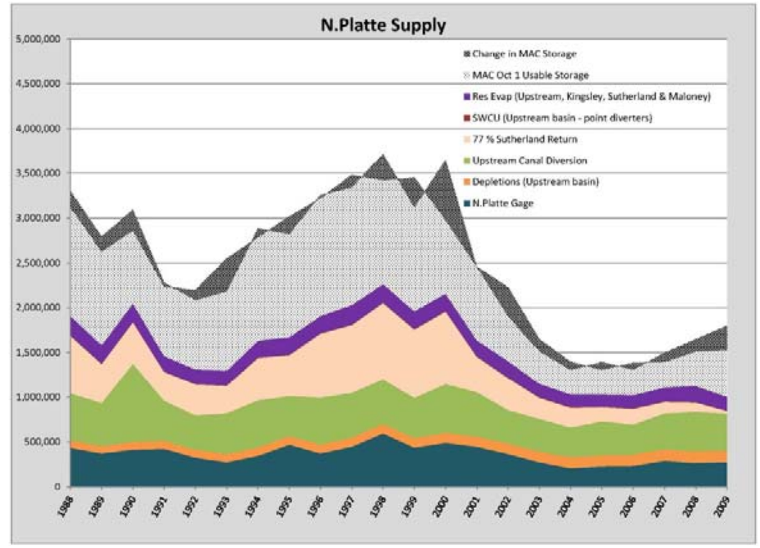


Figure 11.8. Supply, North Platte River at Lewellen

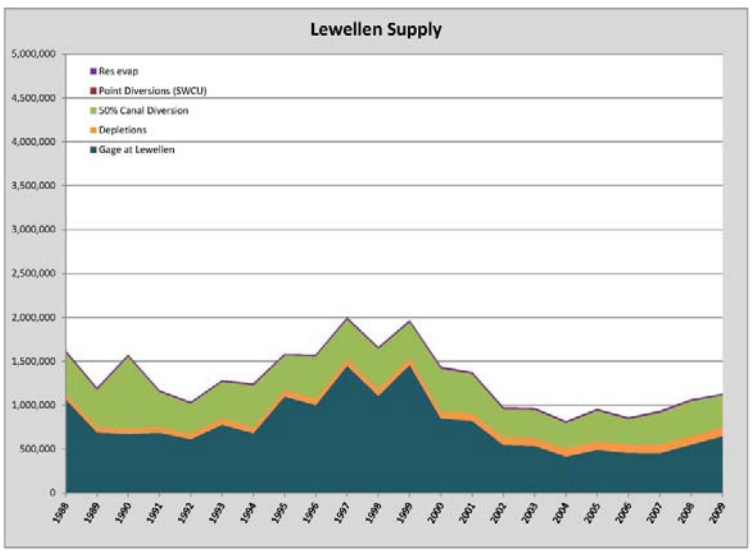


Figure 11.10. Supply, Platte River at Brady

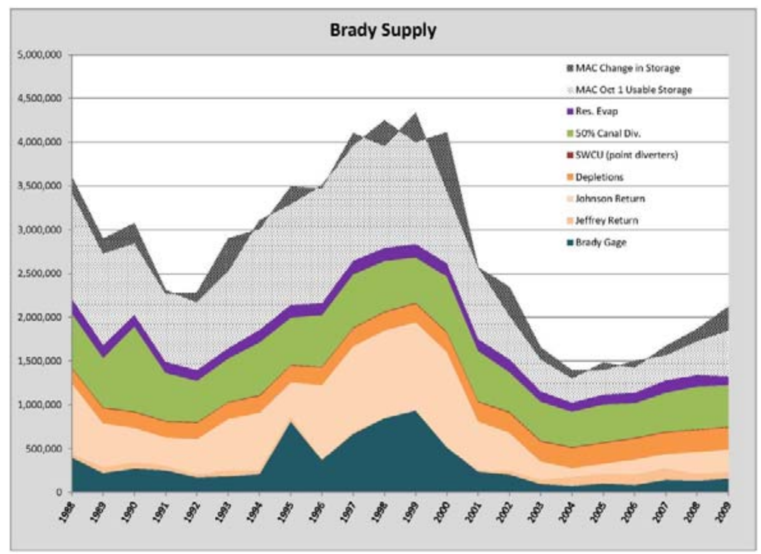


Figure 11.11. Supply, Platte River at Odessa

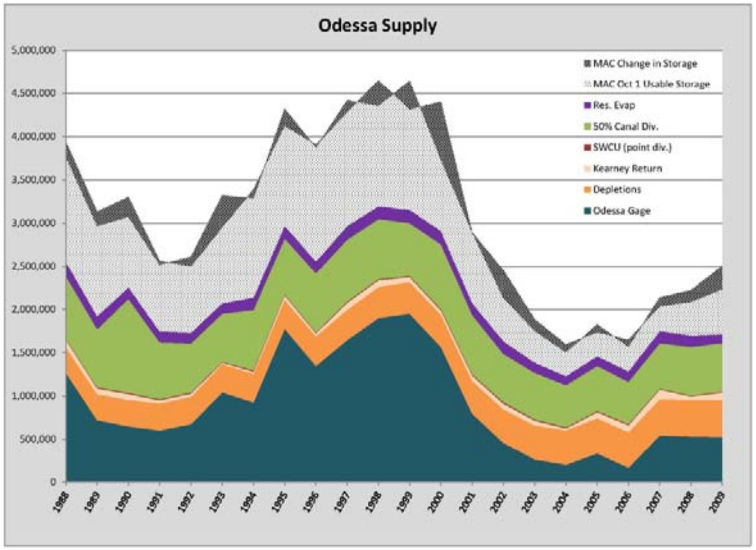


Figure 11.13. Supply, Platte River at Duncan

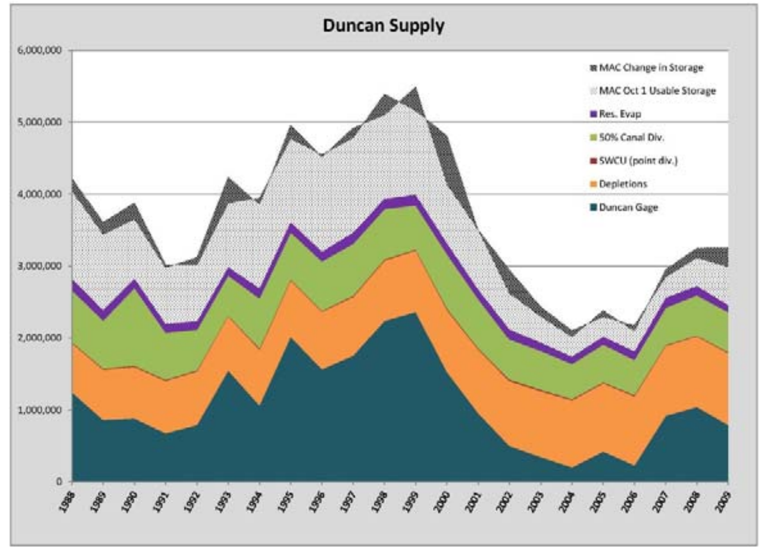


Figure 11.12. Supply, Platte River at Grand Island

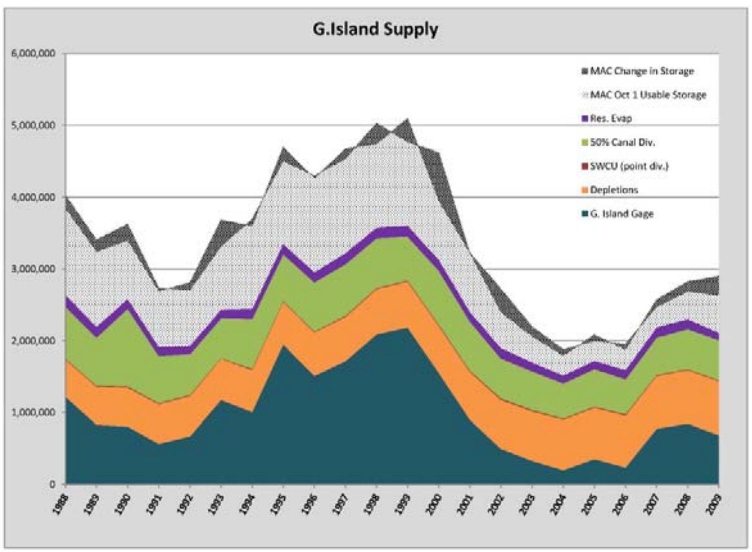


Figure 11.14. Supply, Platte River at North Bend

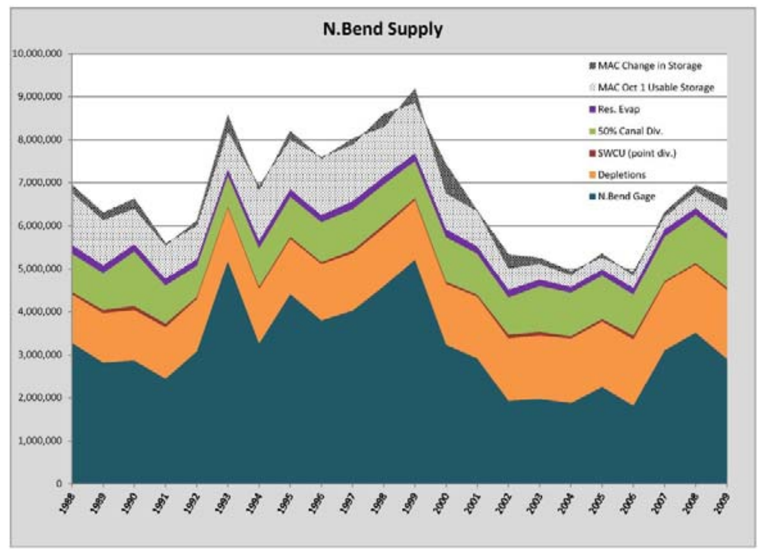


Figure 11.15. Supply, Platte River at Ashland

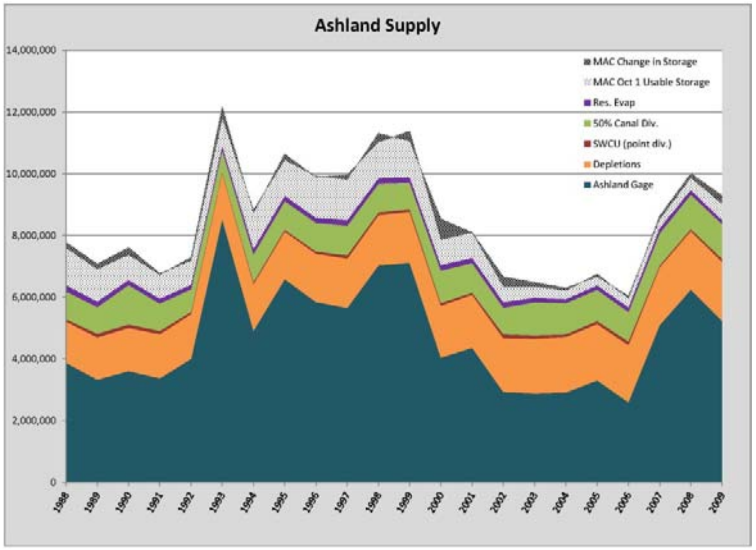
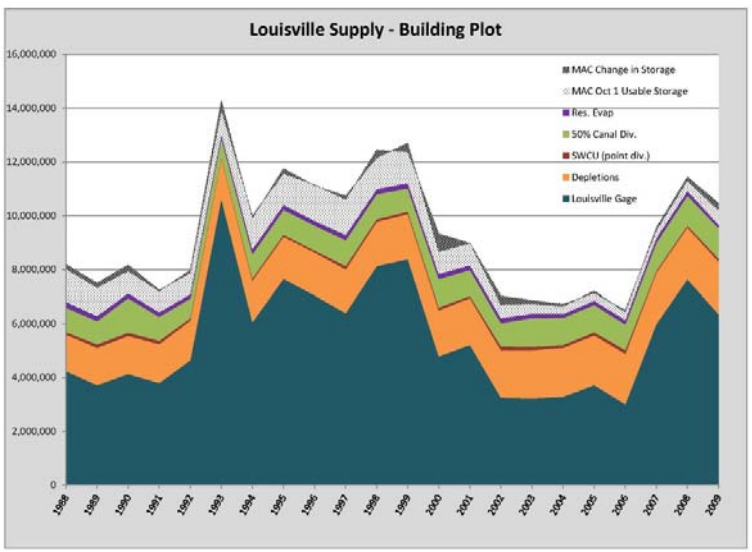


Figure 11.16. Supply, Platte River at Louisville



11.7 Demands

11.7.1 Upstream Demands

Upstream consumptive use demands were calculated according to the methods described in Section 9.7.3. Groundwater and surface water irrigation requirements were computed based on precipitation adjusted NIR values.

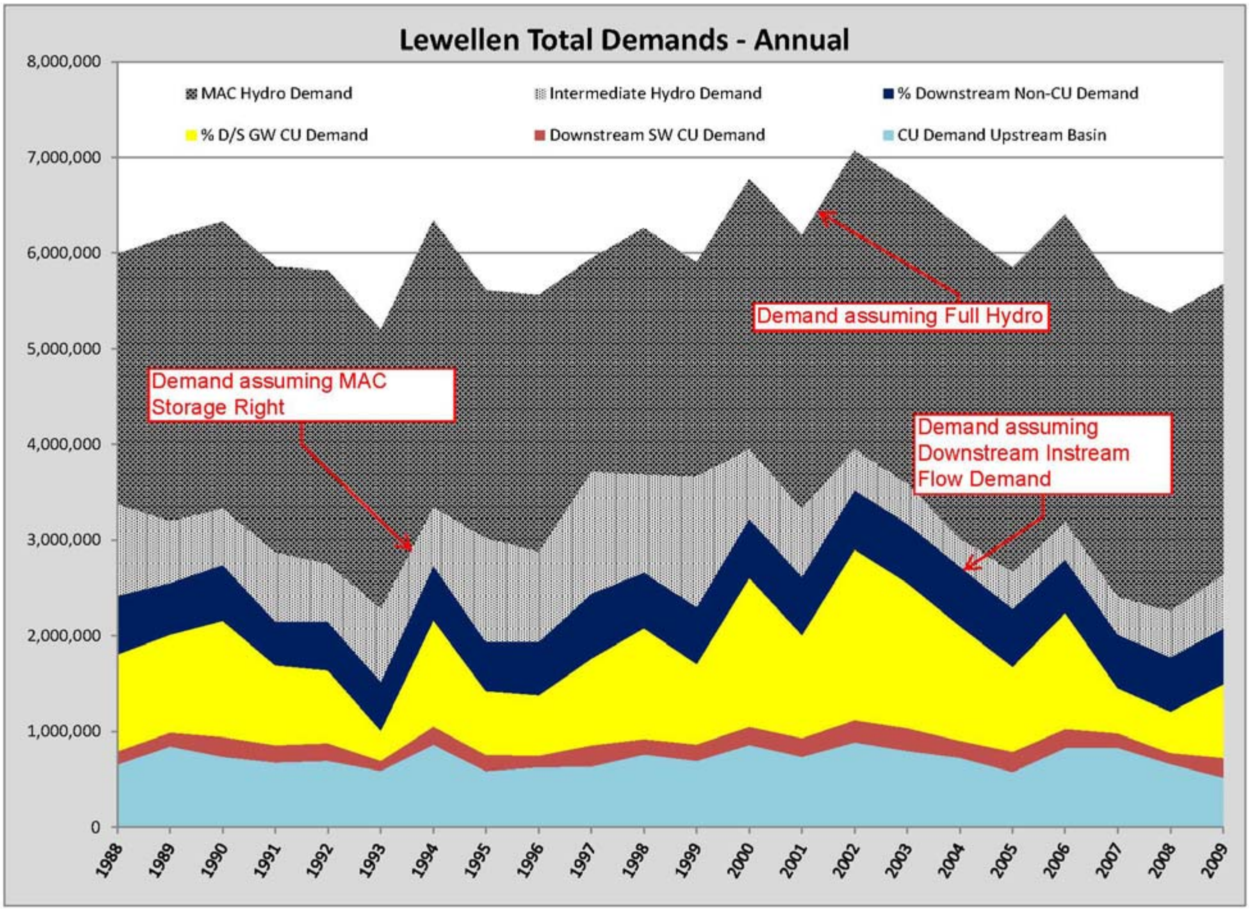
One variation from the methodology test application on the central Platte River involves the representation of upstream non-consumptive use demands. Previously, as described in Sections 9.7.3 and 9.7.4, upstream non-consumptive uses were quantified and included in upstream demands at an analysis point. This upstream non-consumptive use demand was then considered available to meet downstream non-consumptive use demands and accounted for by reducing those downstream demands by the upstream non-consumptive use demand already considered at the analysis point. In the application to the full Platte River, only consumptive use demands of the upstream basin are considered at an analysis point and non-consumptive use demands are included only in the downstream demand on an analysis point (without the reduction previously applied). This reflects the fact that non-consumptive uses are typically tied to supplies from upstream main stem reaches, while consumptive use demands are distributed throughout the basin.

11.7.2 Downstream Demands

A portion of downstream demands are met by flows passing through upstream reaches. To recognize and account for this in the evaluation, that portion of flow at each gage required to meet downstream demands is estimated and applied at the upstream gage. To facilitate the allocation of downstream demands, main stem appropriations are determined by reach and season with non-consumptive and consumptive uses considered separately. The allocation of downstream demands using the ratio of virgin natural flows is consistent with the process described in Section 9.7.4.

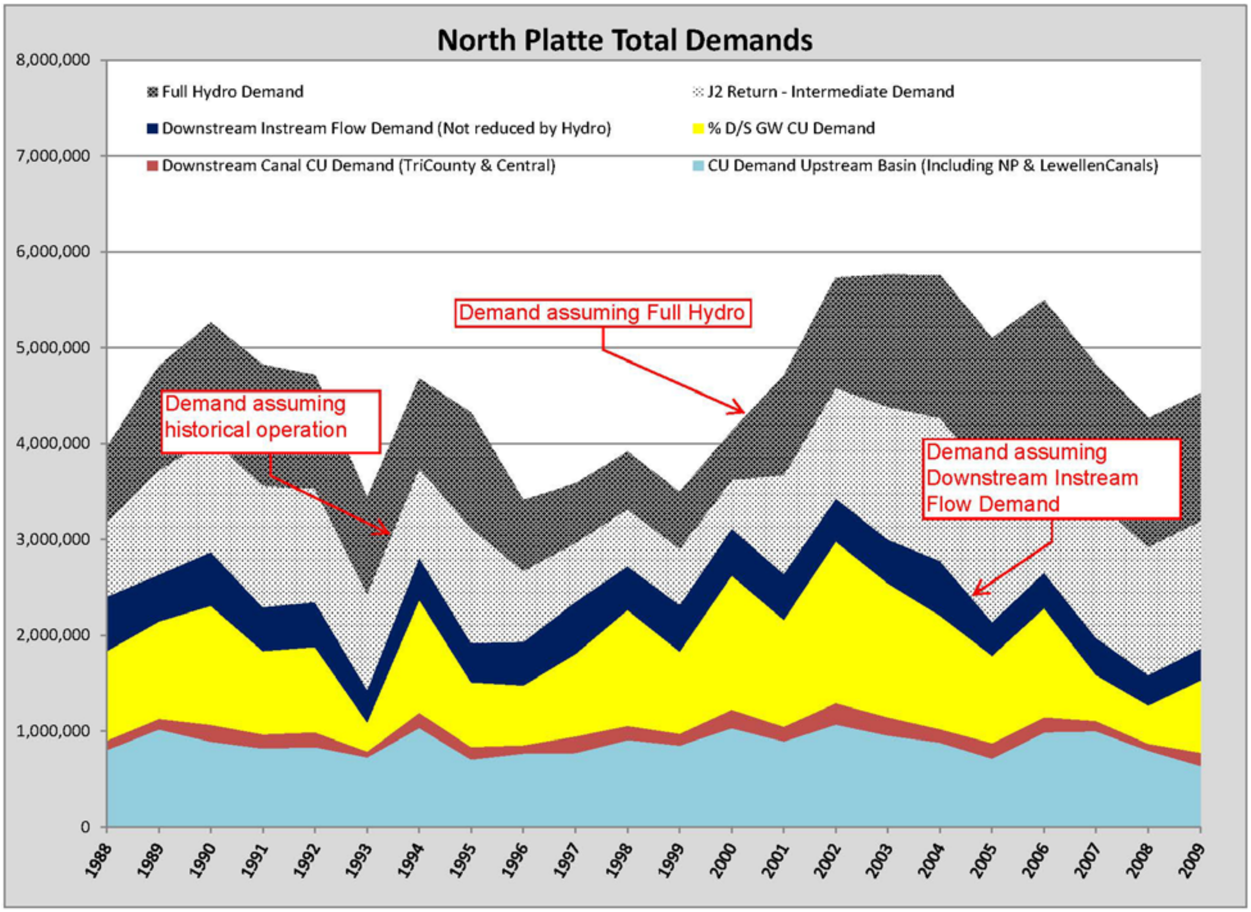
The key difference between the central Platte analysis and the full Platte analysis is the presence of Lake McConaughy on the main stem of the North Platte River. Consistent with the approach, the demand of Lake McConaughy is applied on the North Platte River basin above Lewellen. A range of Lake McConaughy demands have been considered in this analysis. The full McConaughy hydropower demand (5,270 cfs) is considered the “upper” limit. In addition, “intermediate” and “lower” demand scenarios were also considered for the analysis of the Lewellen basin. The intermediate demand considered the Lake McConaughy storage right (500,000 AF) in addition to the historic flow recorded at the Lewellen gage. The lower demand does not explicitly consider a Lake McConaughy demand and considers the downstream instream flow demands using the same procedures as that applied at all other analysis points. In each of these three Lake McConaughy demand scenarios, the upstream and downstream consumptive uses were also included to derive the total demand at Lewellen.

Figure 11.17. Demands, North Platte River at Lewellen



A similar scenario was considered for the CNPPID system demands to be applied at the North Platte River at North Platte and the South Platte River at North Platte. The upper “full hydro” demand considered the greater of the full Jeffrey, Johnson, and J2 hydropower demands (not cumulative). The intermediate demand considered the historic J2 Return flow which is representative of historic operation of the hydropower only conditions. The lower limit considered only the downstream instream flow demand. In each of these three scenarios, the upstream and downstream consumptive uses were also included to derive the total demand for the analysis points. Figure 11.18 represents these demands for the North Platte River at North Platte.

Figure 11.18. Demands, North Platte River at North Platte



Once below the Tri-County diversion, the need for the multiple demand scenarios is no longer needed and non-consumptive uses are considered as described in Sections 9.7.3 and 9.7.4. It is noted that the Kearney hydropower facility demand is applied at the Odessa analysis point.

11.7.3 North Platte versus South Platte Allocations

The South Platte River contributes approximately 27% of the total flow in the Platte River while the North Platte River contributes approximately 73%. Therefore, 73% of downstream demands were assigned to the North Platte River basin supply while 27% were assigned to the South Platte basin supply. The ratio of virgin natural flow methodology was used to further allocate downstream demands to the individual basins.

11.7.4 Municipal and Industrial Demands

Municipal and industrial demands for this analysis included the MUD (City of Omaha and surrounding areas) and City of Lincoln well fields. It is noted that several communities use the Platte River and its alluvial aquifer as their primary municipal and industrial water source. For purposes of testing the methodology, the MUD and City of Lincoln well fields were used because they are both relatively large demands and data on past and anticipated pumping were readily available. These demands were treated the same as other consumptive use demands in that the estimated historic consumptive use is considered in developing the virgin water supply, while the future consumptive use is considered in the demand.

Similar to the supply build plots, the different components that comprise the basin demand are represented within a build plot. In this way, it is easy to visually analyze the relative magnitude of the components that create the basin demand as well as any trends that may exist within the datasets. See Figures 11.19 through 11.26 for examples of the supply build plots.

Figure 11.19. Demands, South Platte River at North Platte

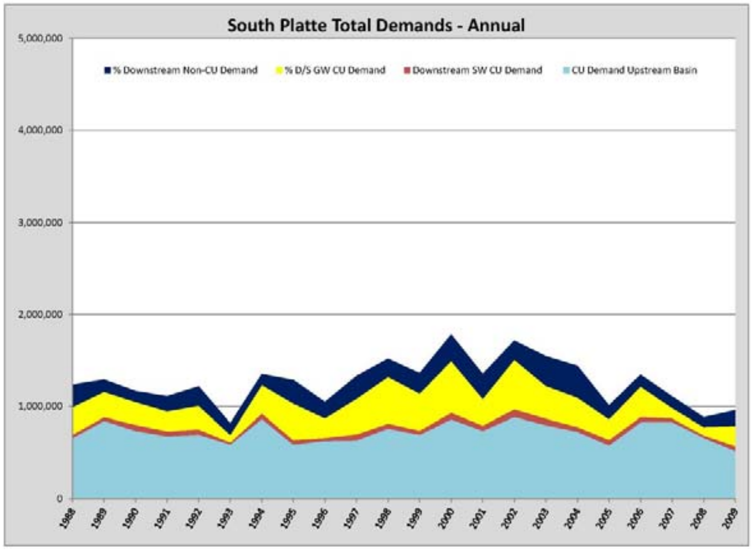


Figure 11.20. Demands, Platte River at Brady

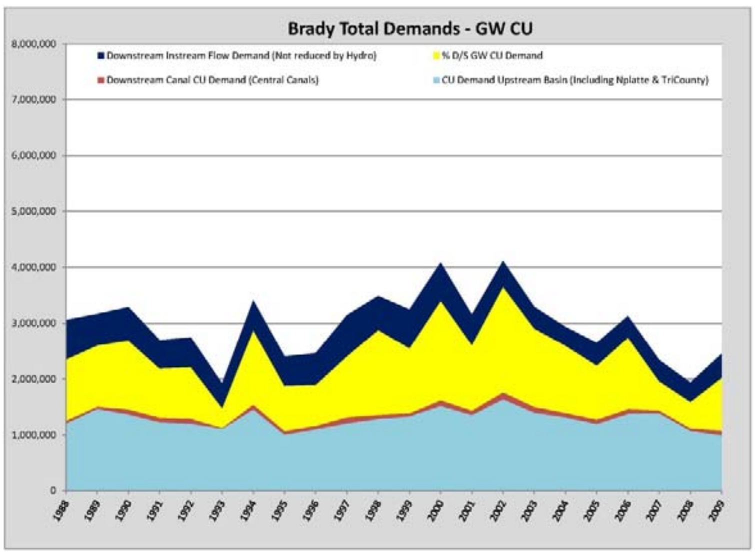


Figure 11.21. Demands, Platte River at Odessa

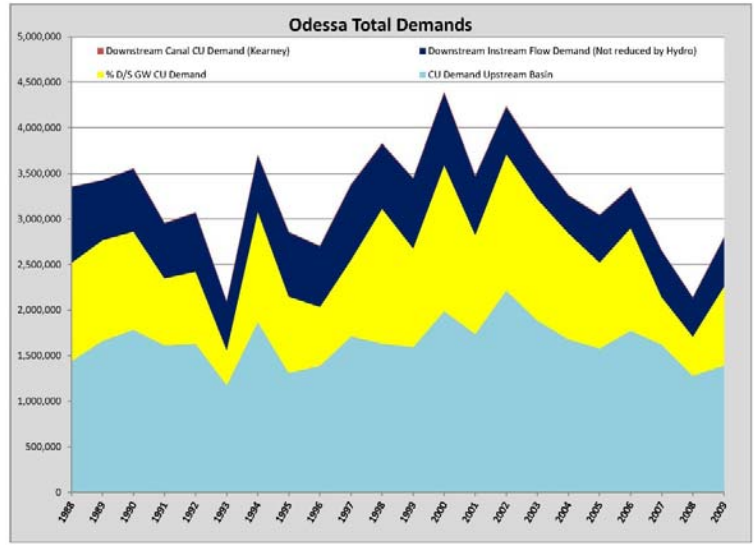


Figure 11.22. Demands, Platte River at Grand Island

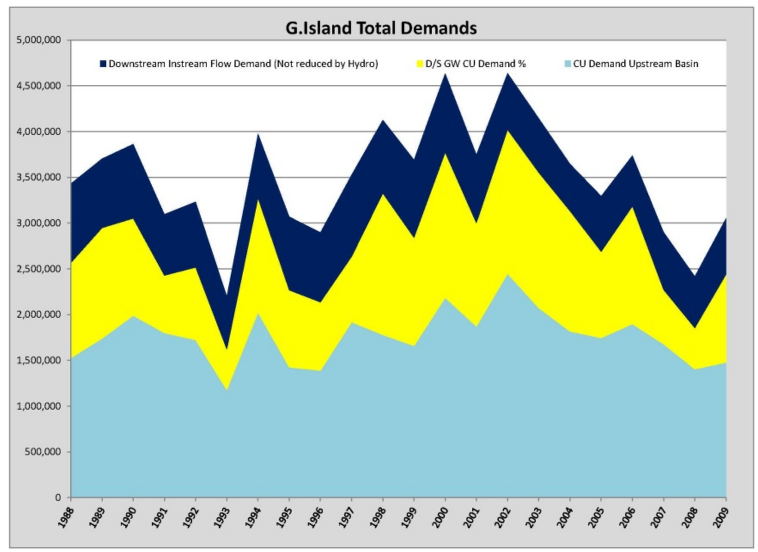


Figure 11.23. Demands, Platte River at Duncan

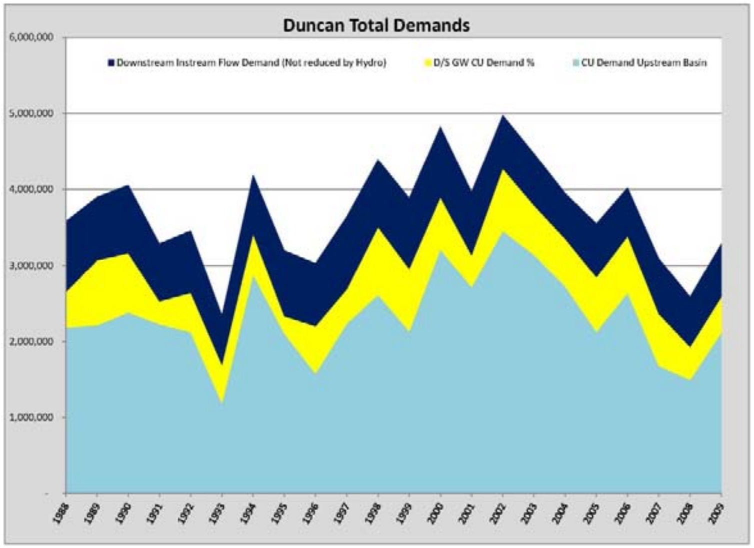


Figure 11.25. Demands, Platte River at Ashland

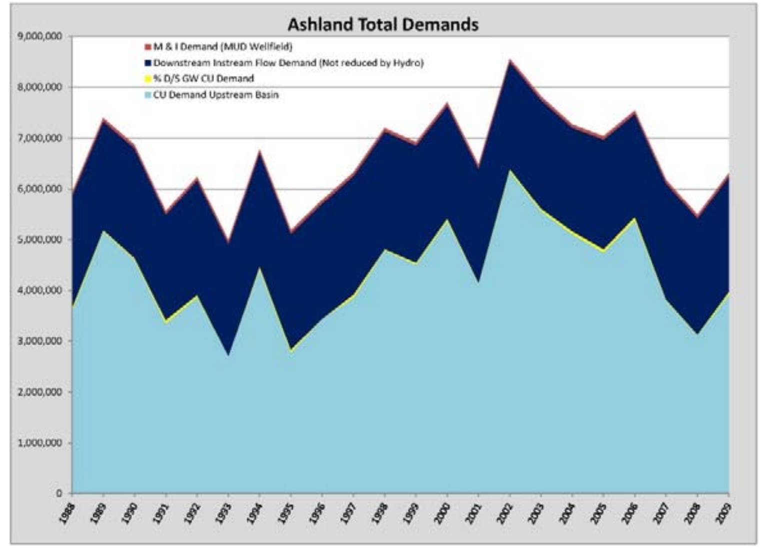


Figure 11.24. Demands, Platte River at North Bend

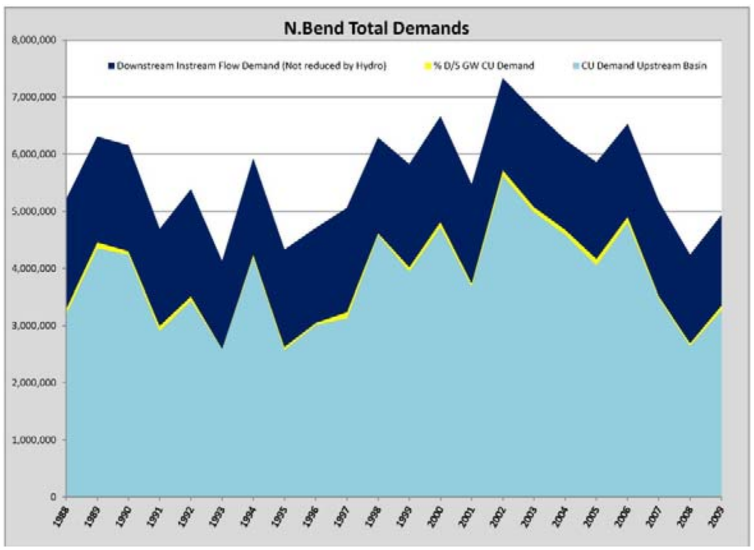
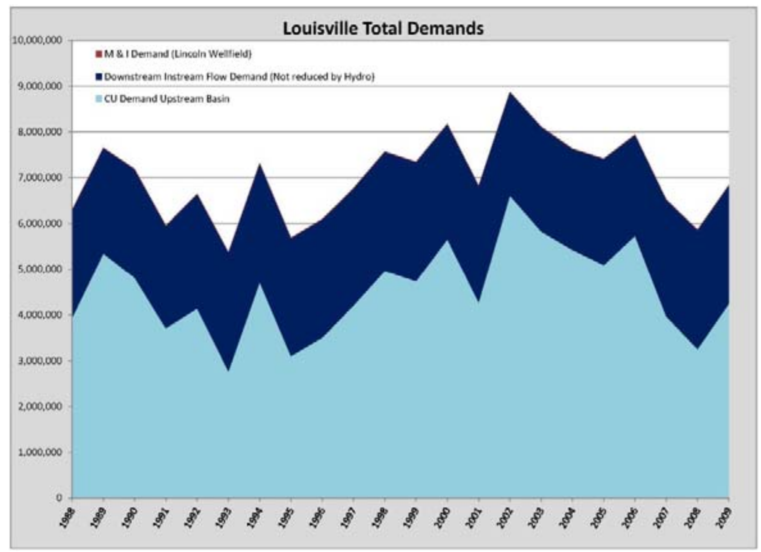


Figure 11.26. Demands, Platte River at Louisville



11.8 Instream Flow Test

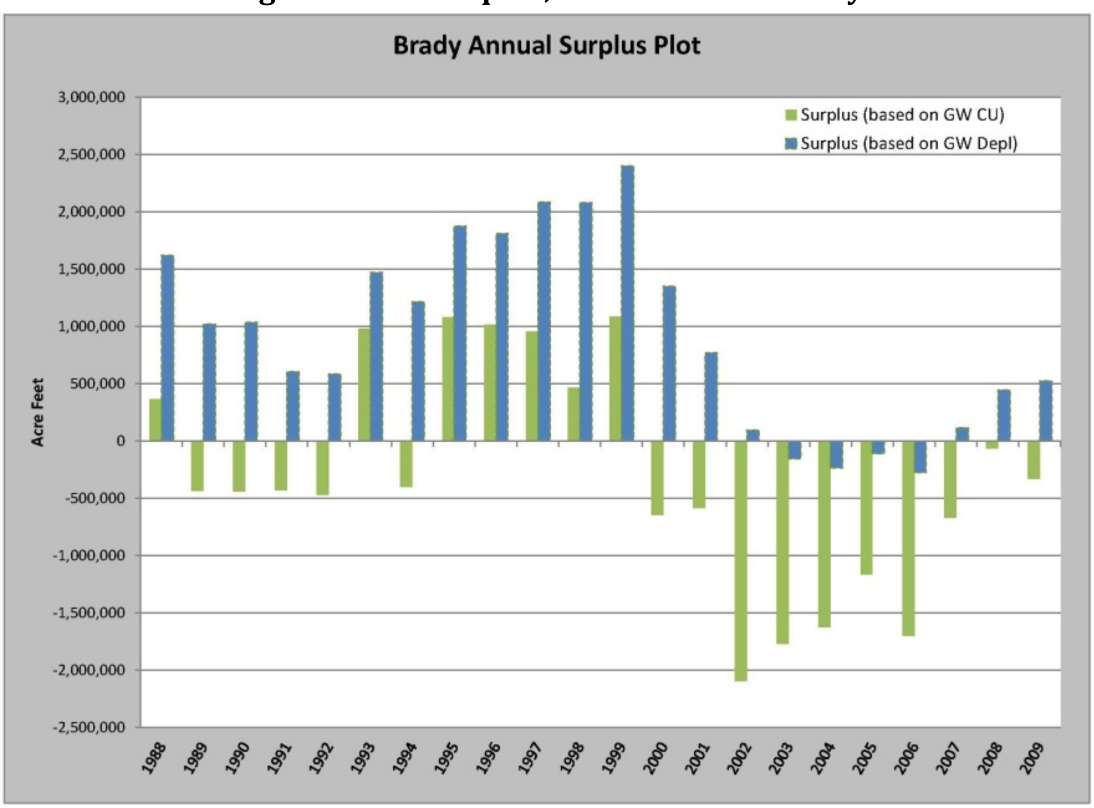
The instream flow test methodology remains unchanged from the central Platte River application, described in Section 9.9.

11.9 Result and Surplus Plots

The use of surplus plots continues to be an effective way to view the total supply compared to total demands through the analysis period. The first plot is a bar chart of the surplus (equal to supply less demands) versus time. In this way, one could easily see how the surplus varies on an annual basis for the analysis period.

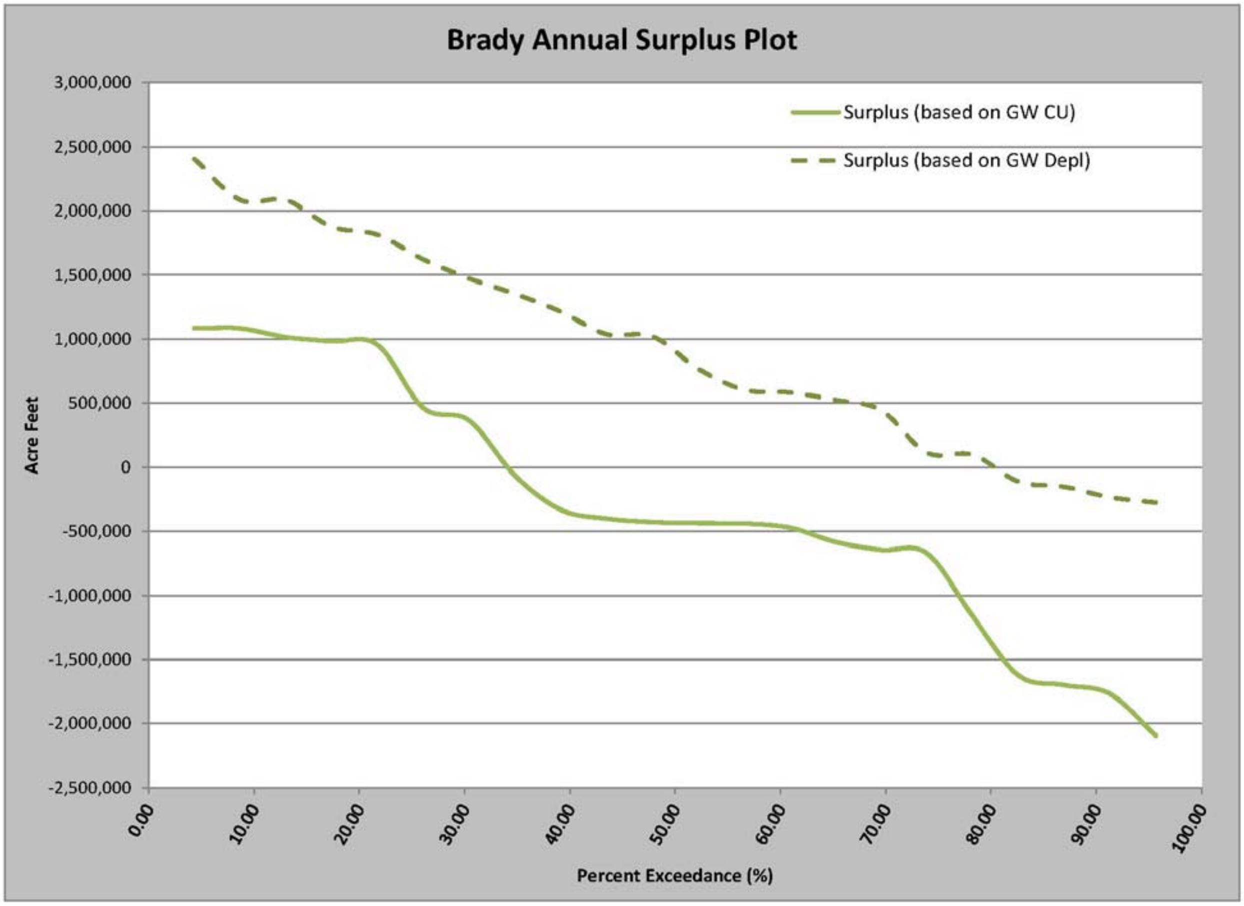
As described in Section 7.9.3, Groundwater usage demand may be represented as either the full consumptive use of groundwater irrigated acreage or the groundwater depletions due to pumping. Using the groundwater consumptive use is similar to applying the lag test included in the current methodology and is useful in projecting the full impacts of current levels of development not yet observed on current supply estimates. Using the depletions as the groundwater usage demand illustrates the current impacts of groundwater usage on current supply estimates. The two approaches bookend the groundwater irrigation usage demands. This approach is represented in the surplus plot shown in Figure 11.27 below and the differences in annual surplus when considering full groundwater consumptive use compared to considering groundwater depletions is readily apparent.

Figure 11.27. Surplus, Platte River at Brady



The second type of plot that has utility is a percent exceedance plot of the surplus values. In this way, the user can readily determine the relative probability of surplus and deficit conditions occurring at an analysis point. Again, and the differences in surplus when considering full groundwater consumptive use compared to considering groundwater depletions is readily apparent, and useful in informing the planning process.

Figure 11.28. Surplus, Platte River at Brady



12.0 Final Recommendations

Based on application of the concepts to the Niobrara, Lower Platte and Full Platte River case studies described herein, the following recommendations regarding the proposed fully appropriated methodology are made:

Supply

1. Virgin Natural Flow – The use of virgin natural flow to represent water supplies is an appropriate approach for the evaluation. For purposes of this discussion and recommendation, virgin natural flow is defined as estimated supplies undepleted by the activities of man.
2. Statistical Testing – The use of statistical tests, specifically the Kendall Tau and autocorrelation tests, on virgin natural flow estimates are recommended in determining an appropriate period of analysis that represents the cyclical nature of supplies and uses without bias. In the event that every time period evaluated in the Kendall Tau test has a statistically significant trend, the Kendall Tau value can be used to determine the degree of the trend. For values close to 0 (approximately +0.25 to -0.25, for example) the trend may be negligible to the analysis, especially when it is coupled with the autocorrelation test. If a strong enough trend exists (greater than +0.25 or less than -0.25, for example) it is recommended that the statistical analyses be performed on the individual components comprising the virgin natural flow to determine the component(s) causing the trend. The remaining component(s) can then be used to determine the period of analysis in conjunction with the autocorrelation test.
3. Discrete Supply Components – Representation of each discrete component of the computed virgin natural flow provides insight into the relative magnitude of supply components and trends and should be employed. It also provides useful information on the importance of assumptions utilized in building the supply and can serve as a guide on future efforts to refine estimates.
4. Reservoir Storage – For reservoirs with the potential for large carryover storage volumes, supply should incorporate both the total available storage for use as well as change in storage in the analysis.
5. State Line Inflows – For basins with headwaters that originate outside of the State's boundaries, inflows should be estimated using the closest available main stem gage in addition to flows from tributary basins or canals that are not captured by the main stem.

Demand

1. Demand Estimates – Representation of discrete demands, both consumptive and non-consumptive, using the best available information provides a clear picture of water usage, relative magnitude of each demand, and should be employed to the extent possible. The use of 'build' plots that illustrate each component of demand, as well as the cumulative demand, can also be used to consider water use preferences.
2. Consumptive Uses – Primary consumptive uses for consideration in the methodology vary by reach, but include:
    a. Groundwater irrigation consumptive use: Estimates may be made based on well database, irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements.

   b. Surface water irrigation consumptive use: Estimates may be made in a couple of different ways. For those diverters with available historical gaging records, consumptive use may be estimated as a percent of diversions. This approach provides a way to account for water-short years when full irrigation requirements may not be met. Consumptive use estimates may also be made using irrigated acres, cropping patterns, and precipitation-adjusted estimates of crop requirements.
   c. Municipal and Industrial consumptive use: Estimates of consumptive use may be made based on historic groundwater well pumping and wastewater return records. Conversion of total consumptive use to a per capita estimate allows variations in population over time to be represented in the evaluation. Estimates of future usage for municipal and industrial users should be represented in as much as that future usage is accommodated for within their current appropriation.
   d. Reservoir Evaporation: For reservoirs with historic stage data, historic pan evaporation data and reservoir stage/surface area data may be used to estimate evaporation. For the numerous smaller reservoirs throughout the state with permanent pools and no historic data, the Nebraska DNR's dam database may be used to identify locations and estimate pool sizes for estimate evaporative losses.
3. Non-Consumptive Uses – The two primary non-consumptive uses include hydropower and instream flows:
   a. It is recommended that the demand evaluation consider three levels of hydropower demands: 1) no hydropower demand; 2) full hydropower appropriation; and 3) an intermediate demand that may be based on historic hydropower usage, physical capacity of system, adjusted historic flow available at time of granting, etc.
   b. Instream flow demands may be estimated based on the appropriated right, capped to the adjusted historic flow available at the time of granting.
4. Downstream Demands – Evaluation of demands at a particular analysis point on a river or stream should consider downstream demands that are served by flows passing that analysis point. It is recommended that the ratio of virgin natural flows (upstream virgin natural flow to downstream virgin natural flow) be used to allocate these downstream demands to the upstream reach. This approach provides full consideration of demands, as well as a potential means for discrete evaluation of tributary basins.
5. Precipitation-adjusted crop irrigation requirements – Use of this adjustment for annual crop demands allows variations in the hydrologic cycle to be represented in the evaluation.
6. Use of Groundwater Depletions and Consumptive Use as Demands – Representing groundwater usage using both depletions and consumptive use is a useful approach in determining the impacts of historic usage on current water supplies as well as the future impacts on water supplies based on current water usage in the basin. The use of groundwater depletion demands provides an indication of demands based on current levels of depletions. The use of groundwater consumptive use demands provides an indication of demands based on the full depletive effects of current groundwater development. By comparing the two levels of

demands, the relative maturity of groundwater usage in the basin can be assessed and the parameters for management and planning of future uses defined.

7. Canal Losses – While canal losses were not included as a demand represented in the analyses presented in this report, the spatial and temporal discretization used for analyzing water supplies and demands may require that canal losses are represented as demands.

Evaluation

1. Surplus Values – The use of a surplus value (supply less demand) for each time period is recommended as a metric for evaluating appropriated status. Incorporating both supply and demand keeps the data paired and incorporates the flow, demand, and climatic conditions for that time period.
2. Arithmetic Plots – Arithmetic plots of surplus vs. time provide useful information regarding magnitudes of supply, demand, and surplus, as well as potential trends in each term.
3. Frequency Curves – Frequency curves (exceedance curves) are an appropriate and useful tool in assessing surplus probability in annual and seasonal periods over the period of analysis.
4. Three-Step Analysis – The three-step process illustrated in Figure 9.23 for determining a basin's status is an approach that is recommended.
5. Instream Flow Erosion Test – The approach detailed for adjusting historic flow records (prior to granting of instream right) and for adjusting the flow records of the current analysis period is an approach that is recommended and provides a sound basis for evaluating potential erosion of instream flow appropriations.