Appendix I
Technical Memorandum State of Colorado Current and 2050 Agricultural Demands

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Technical Memorandum

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The purpose of this technical memorandum is to update the Statewide Water Supply Initiative (SWSI) Projected 2030 Agricultural Demands. In SWSI, the Colorado Water Conservation Board (CWCB) estimated agricultural demands for the years 2000 and 2030. SWSI also summarized agricultural shortages at the Water District level. It should be noted that the CWCB did not consider the agricultural shortages identified in SWSI as a "gap" that needs to be met in the future across the state.

This technical memorandum provides information about the methodologies utilized to develop a current tally of irrigated acres throughout Colorado and details how 2050 irrigated acres were estimated. In addition, the memorandum provides an overview of existing and 2050 agricultural demands.

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Section 1 – Methodology

This section describes the methods used to estimate the water needed to support Colorado's agriculture, both currently and in 2050. The estimate includes water both for irrigation of crops and for livestock production, on a depletive basis. In other words, the values reported reflect water consumption, rather than water pumped or diverted to agricultural activities. A significant portion of the total diverted amount returns to the stream and therefore is not consumptively used.

Colorado's water needs for irrigation are characterized in this analysis by the Irrigation Water Requirement (IWR), Water Supply Limited Consumptive Use (WSL CU), and the difference between these two numbers. IWR, or irrigation demand, is the volume of irrigation water required to completely satisfy a crop of a specified acreage. The irrigation water requirement for an acre of a given crop is an estimated volume, generally produced by a mathematical model that reflects weather, the growing season, and crop physiology. In Colorado, the water supply available to crops is typically adequate to satisfy IWR during only a part of the growing season; during the rest of the season, the available water supply is less than the amount the crop would consume if given an unlimited supply. Thus on a growing season or annual basis, the actual consumptive use, referred to as the WSL CU, is smaller than IWR and reflects the fact that consumption to the full extent of IWR was not realized. Estimation of WSL CU requires knowledge of both IWR and the irrigation supply accessible to the crop.

The difference between WSL CU and IWR is referred to in this analysis as "shortage." It should be noted that most Colorado farms demonstrate positive shortages; in other words, the shortage is with respect to an idealized supply and maximum crop development, and does not represent an imperative that must be met in order for Colorado agriculture to economically viable. An analysis of shortages by water district can indicate areas where potential infrastructure improvements (e.g., canal improvements, new storage, or dam enlargements) could enable the irrigators to approach their crops' IWR. This analysis can help demonstrate a need and serve as the basis for funding opportunities with CWCB loans for infrastructure improvements. These shortages also indicate that most irrigated farms in Colorado operate under water short conditions for part of the irrigation season and show that farmers have been able to economically survive under less than ideal water supply conditions.

Analysis of current irrigation demand required a balance between relying on a large enough sample of historical diversions and historical climate to make inferences about average conditions; and using only recent and reliable information on location and size of irrigated operations, to represent Colorado's current irrigation practices. The balance was achieved by calculating demand based on the most recent and best information available with respect to number of irrigated acres, crop types, and irrigation efficiency. Consumptive use modeling was executed for these current conditions, using a recent decade of climate and water supply information. The objective was not to simulate what occurred over the past 10 years, but to estimate IWR and WSL CU for today's agricultural conditions and a plausible sample of climate and hydrology, exemplified by the recent decade.

Future irrigation demand was examined by assuming that historical climate conditions will continue. The analysis assumed that agricultural demand is directly and linearly related to the number of acres irrigated. In other words, the future condition did not project changes in crop types or irrigation practices that would affect elements of the analysis such as growing season, crop needs, or irrigation efficiency.

Consistent with the planning nature of this study, IWR, WSL CU, and Shortage are presented on an annual basis, and by Water District. Where data were available to support structure-specific analysis, the Water District summaries are aggregations of structure-specific estimates. Similarly, annual values are summations of monthly time step results.

In addition to the crop consumption described above, Colorado's agricultural demand includes three other types of consumptive use that are associated with agricultural activity: 1) livestock consumptive use, 2) stockpond evaporation, and 3) losses incidental to delivering irrigation water (incidental losses). The Colorado Decision Support System (CDSS) program has developed processes for quantifying these uses in the context of developing basinwide water budgets, water resources planning models, and the Consumptive Uses and Losses Reports required for Colorado River Compact administration on the West Slope. For this analysis, CDSS procedures were used to refresh estimates in those basins where a decision support system (DSS) has been implemented; where a DSS does not exist, the CDSS procedures were generally applied if data were available to support the method.

1.1 Current Irrigated Acres Methodology

The CDSS program has produced irrigated lands mapping and crop consumptive use models in the major basins where it has been implemented. Specifically, a DSS has been implemented in the State's Colorado River tributary basins (Yampa River, White River, Colorado mainstem, Gunnison River, and San Juan River), the Rio Grande basin, and the North and South Platte basins. Feasibility of developing an Arkansas basin DSS is being studied at this time, and a Republican River DSS likewise has not yet been developed. CDSS tools and information were relied on where they were available, but information for the Republican and Arkansas basins had to be gathered from other sources or developed within this project, as described below.

1.1.1 CDSS Basins Irrigated Acres Methodology

As noted above, irrigated lands information for the CDSS basins, developed previously by CWCB, was available. The maps are available as spatial databases, and include crop types, irrigation practices, and association with diversion structures or wells. The structure identifier associated with the irrigated land indicates the location of the headgate that serves the land.

Irrigated acres are assigned to the water district where the diversion is located, which may not be where the irrigated acreage lies. For example, the Redlands Canal serves approximately 3,000 acres on the south side of the Colorado River in Water District 72. But because the demand is exerted on the Gunnison River in Water District 42, the acreage and demand are attributed to Water District 42.

Dates of the irrigated lands information varied with the basins, ranging from 1993 for the Colorado River tributary basins[1], to 2005 for the South Platte. The South Platte acreage reflects reductions in groundwater-supplied acreage that occurred pursuant to administrative changes in 2003, whereby Water Court–approved augmentation plans and supplies became required.

Further detail on the irrigated acres methodology for the CDSS basins is provided in Appendices A, B, and C.

1.1.2 Republican River Basin Irrigated Acres Methodology

Groundwater irrigated acreage for the Republican River basin was obtained from the Republican River Compact Administration (RRCA) accounting spreadsheets for 2007 (http://www.republicanrivercompact.org/). Each year since 2003, when a mediated settlement was reached in Kansas v. Nebraska and Colorado, Colorado prepares and submits to RRCA several spreadsheets that show how much groundwater use occurred. The 2007 spreadsheets were the most recent spreadsheets provided on the website. Most of the irrigation in the Republican River basin is through groundwater pumping but some surface diversions do exist. Most of the few thousand surface water-supplied acres, as of 2003, are being purchased and retired by the Republican River Water Conservancy District, in order to reach compliance with the settlement. Precise information on surface water irrigated lands is not available, but the total amount is believed by the State Engineer's Office (SEO) to be no more than 1,000 acres, and this quantity was included in the irrigated acreage total for the basin. Further detail on the irrigated acres methodology for the Republican River basin is provided in Appendix D.

1.1.3 Arkansas River Basin Irrigated Acres Methodology

The Arkansas basin can be divided into three areas in terms of the irrigated acreage data available: 1) the Lower Arkansas basin, the area covered by the Hydrologic Institutional (HI) model that Colorado must use for compact accounting, pursuant to settlement of the Kansas v. Colorado litigation, comprising irrigated lands under Arkansas River canals from Pueblo Reservoir to the state line; 2) the Purgatoire River Water Conservancy District (PRWCD) in

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[1] While more recent mapping is available for the Colorado River tributaries, the 1993 assessment received the most ground-based review, and is considered most accurate given that irrigation practices and acreage have generally been stable in this part of the state.

Water District 19; and 3) all other irrigated land in the basin, from the mountain valleys of District 11 to the corn fields of the Southern High Plains Designated Basin.

For the Lower Arkansas, Division 2 of the SEO provided its Irrigation Systems Analysis Model (ISAM), a refinement of the HI Model to the individual farm level, which it developed in support of the Arkansas Basin Agricultural Efficiency Rules, proposed in November 2009. ISAM uses irrigated acreage based on 2008 data and historical diversions to estimate IWR and consumptive use. Although it is consistent with the HI model in terms of consumptive use calculations, efficiencies, and irrigation sources, it does not explicitly include five small ditches within the HI Model domain. Acreage for these structures was taken from 2003 imagery associated with the HI Model.

Division 2 recently completed an irrigated lands assessment of the PRWCD. This geographic information system (GIS) product, based on 2008 imagery, is comparable to the irrigated lands mapping available in CDSS basins, and provided data for analysis associated with this part of the Arkansas basin.

For the remainder of the Arkansas basin, multiple scenes spanning the 2009 growing season were obtained from the Landsat 5 Thematic Mapper archive and analyzed. A vegetative index (VI) map was derived, indicating areas of vigorous plant growth. To differentiate between non-agricultural growth, such as riparian areas or irrigated city parks, the VI maps were overlaid with National Land Cover Data coverage, which identified cultivated areas and pasturelands. Lands not included in these use categories were not counted as irrigated, regardless of their VI. This approach applied the method described in the 2002 U.S. Geological Survey (USGS) Water-Resources Investigations Report 02–4236, "Classification of Irrigated Land Using Satellite Imagery, the High Plains Aquifer, Nominal Date 1992", 2002. To establish the VI threshold value, above which lands should be classified as irrigated, candidate values were tested and results compared to the Division 2 2008 irrigated land coverage in the Lower Arkansas and PRWCD.

Further detail on the irrigated acres methodology for the Arkansas River basin is provided in Appendix E.

1.2 2050 Irrigated Acres Methodology

Using the current irrigated acres as defined in the previous section as a baseline, estimates of 2050 irrigated acres where based on the following factors:

- Urbanization of existing irrigated lands
- Agricultural to municipal water transfers
- Water management decisions
- Demographic factors
- Biofuels production

- Climate change
- Farm programs
- Subdivision of agricultural lands and lifestyle farms
- Yield and productivity
- Open space and conservation easements
- Economics of agriculture

The first three factors (urbanization of existing irrigated lands, agricultural to municipal water transfers, and water management decisions) were quantified based on future growth estimates, municipal water demand gaps that will be met by 2050, and interviews with water management agencies across the state. The remaining factors were qualitatively addressed based on discussions with CWCB, the Colorado Department of Agriculture, CDM, and Harvey Economics. These factors were also presented to and discussed with the numerous basin roundtables.

1.2.1 Urbanization of Existing Irrigated Lands Methodology

The urbanization of existing irrigated lands was established using 2050 population projections, estimation of future urban area size, and the current irrigated acres as described in the previous section. As discussed above, current irrigated acres in each administrative Water District were determined from GIS data sources. However, certain types of data (e.g., future population forecasts) were only available on a county basis. Therefore, future losses of irrigated acres were calculated first for each county, and then re-distributed by Water District. The methodology is described in the following paragraphs.

Using municipal boundary GIS data from the Colorado Department of Transportation, the amount of land located within each incorporated municipal boundary was computed and summed by county. Using GIS analyses, irrigated land spatial information were overlaid on the municipal boundaries to determine the amount of irrigated acreage within those incorporated boundaries. From these two quantities, a ratio of irrigated land within municipal boundaries to total municipal land was computed for each county. For counties with no identified irrigated land within municipal boundaries, the statewide average ratio of 0.08 was applied. There were very few counties without irrigated land within municipal boundaries and this assumption was applied as a conservative estimate of urbanization in more rural areas of Colorado. It is assumed for this study that the current ratio will remain constant in the future, i.e., as municipal boundaries expand with future growth, the percentage of irrigated land that becomes enveloped within those boundaries will be consistent. Figure 1 below shows an example of irrigated acres located within the municipal boundary of Longmont, Colorado.

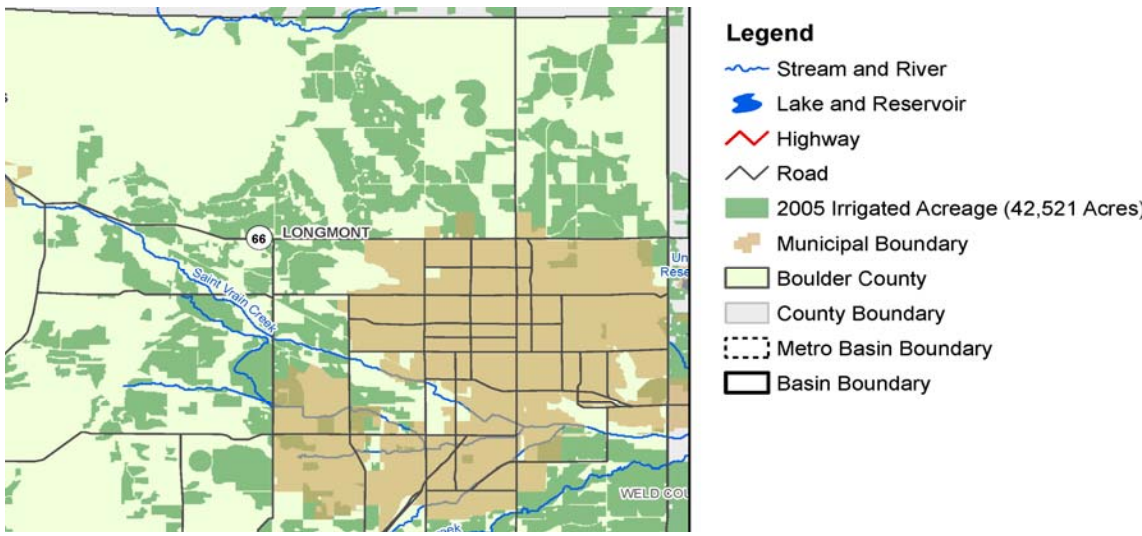

Figure 1. Example of Irrigated Acres Within an Urban Boundary

The equation below summarizes the calculation that was used to estimate the future irrigated acres that may be lost due to urbanization:

Irrigated Acres Urbanized = Change in Population ÷ Population Density x Ratio of Irrigated Lands to Urban Boundary

Harvey Economics developed 2050 county population projections on a low, medium, and high basis based on the Colorado State Demographer's forecast models (CWCB 2010). For this analysis, county density factors were also estimated based on the 2000 Census, which provided population, land area, and density per square mile of land area for population centers. Population centers include cities, towns, and census designated places (CDPs). In order to determine a single factor for each county, the population density per square mile for each population center was weighted according to its percentage of total population for all cities, towns, and CDPs within the county. The weighted densities were then summed to determine the weighed population density for population centers within each county. These densities are assumed to remain constant in the future. In fact, population densities do change slowly over time, depending on market preferences, zoning decisions, and other factors. Over time, updated density assumptions can be factored into the equation above to update urbanized irrigated acreage estimates.

By dividing the 2050 low and high population forecasts by the population density factors, estimates of the low and high land areas required to support future population were computed. The total required land area values were then multiplied by irrigated acres ratio previously described to estimate the future amount of irrigated land that will become urbanized.

After estimating future urbanization of irrigated land, the values were redistributed by Water District. GIS data was used to determine the current irrigated acres in each county by water district in each study basin; many counties have irrigated acreage located in more than one Water District. The percent of total irrigated acres in each Water District was computed for each county. This percentage or ratio was then multiplied by the low/high urbanized acres in each county to estimate the amount of acres that would be lost to urbanization in each Water District.

1.2.2 Agricultural to Municipal Water Transfers Methodology

During the past several months, CWCB has interviewed municipal and industrial (M&I) water providers to assess what projects and methods they will utilize to meet their 2050 water demands. As part of these interviews, M&I water providers have provided details about what portion of their water supply portfolio may consist of agricultural to municipal to transfers. In addition, CWCB is in the process of updating the M&I gap analysis developed in SWSI Phase 1. In SWSI 1, changes in 2030 irrigated acres were related to the M&I gap given the assumption that a large portion of Colorado's future M&I water demands will be met by agricultural to municipal transfers. For this analysis, the preliminary gap analysis was used in assessing the changes in future irrigated acres. For each of Colorado's major river basins, the amount of the M&I gap was summarized in acre-feet per year (AFY) on a low, medium, and high basis. For the purposes of predicting future irrigated acres it was assumed that 70 percent of M&I gap would be met from agricultural to municipal transfers. This is a conservative estimate but this percentage does not take into account the projects or methods that may not be successful in meeting Colorado's future M&I demands that would likely be met by agricultural to municipal transfers. The following equation was used to estimate irrigated acres that would be needed for agricultural to municipal transfers to address M&I gaps:

Irrigated Acres Transferred = M&I Gap ÷ Transferrable Consumptive Use x (1 – Safety Factor)

Again, the M&I gap is based on the recent data collection and analysis efforts completed by CWCB. The transferrable consumptive use was based on work completed to estimate current irrigated agricultural demands at the basin level (described in the Current Agricultural Demand Methodology Section below). A safety factor of 25 percent was applied to account for the additional amount of irrigated acres that may be needed to provide the transferred water on a firm yield basis.

1.2.3 Other Factors and Impacts on Future Irrigated Acres Methodology

CWCB interviewed entities within the South Platte, Rio Grande, and Republican River basins to estimate what changes may occur in irrigated acres due to water management decisions affected by compact compliance or maintain groundwater levels. For the remaining factors (urbanization of existing irrigated lands, agricultural to municipal water transfers, water management decisions, demographic factors, biofuels production, climate change, farm programs, subdivision of agricultural lands and lifestyle farms, yield and productivity, open space and conservation easements, and economics of agriculture), CWCB identified trends that are expected to occur within each area over the next 40 years and then developed a qualitative assessment on whether each factor would cause a negative or positive impact on irrigated agriculture by 2050.

1.3 Current Agricultural Demand Methodology

Current irrigation demand for water in Colorado can be defined as the average amount of water consumptively used by crops on land currently under irrigation. Typically, water supply is plentiful early in the irrigation year, and consumptive use is limited by the crop's capacity for taking up water. As the irrigation season continues, the available water supply generally decreases, becoming less than the crops' uptake capacity, and consumptive use is limited by supply. In order to quantify crop consumptive use, one must have credible estimates or measurements of the crops' average capacity to use irrigation water, referred to as IWR, as well as the average water supply. The minima of these two values over a series of time increments (typically months) is the WSL CU.

For this analysis, both average IWR and average WSL CU are reported. The latter may be the current Agricultural Demand; that is, the water required to sustain current levels of farming. IWR provides perspective on the amount of water that would be used, if it was available. It is an upper limit on consumption by current agriculture, and a reminder that Colorado is a dry state with over-appropriated streams.

IWR estimation requires time series of climate information, particularly precipitation and temperature, over the study period; WSL CU estimation requires information about the time-varying water supply available to the crop. For this analysis, a recent 10-year study period was used in each basin, although the exact decade differed from basin to basin depending on available data. The 10-year period allowed for estimation of average conditions with respect to both climate and hydrology. IWR and WSL CU were calculated assuming that the most current estimate of number of irrigated acres, and most recent information on crop types, prevailed during each year of the study period. The results show demand for "today's" agricultural conditions in Colorado, based on a 10-year sample of climate and hydrology. More specific information about the analysis is provided by basin below.

This section describes the approach taken to estimate non-irrigation water use that is associated with agriculture. Three types of consumptive use are considered: 1) livestock consumptive use, 2) stockpond evaporation, and 3) losses incidental to delivering irrigation water (incidental losses). For this analysis, CDSS procedures were used, as available, to refresh estimates for these uses; where a DSS does not exist, the CDSS procedures were generally applied if data were available to support the method.

1.3.1 Current Irrigation Agricultural Demand Methodology

1.3.1.1 CDSS Basins Agricultural Demand Methodology

StateCU is a modeling package developed by CWCB for estimating potential crop evapotranspiration, irrigation water requirement, and historical consumptive use. StateCU has been implemented in the CDSS basins: Yampa, White, Colorado mainstem, Gunnison, San Juan, Rio Grande, and North and South Platte basins. The model, documentation, and numerous technical memoranda describing development of the basin-specific models are available at the CDSS website (cdss.state.co.us/DNN/Products/tabid/63/Default.aspx).

CDSS StateCU implementations estimate IWR and WSL CU for each diverter or aggregation of small diverters, based on their specific irrigated acreage, estimated system efficiency, crop types, and local climate. For the numerous and diverse input data required, StateCU implementations are integrated with Hydrobase, the State's relational database containing streamflow, diversion, water rights, irrigated acreage, crop, climate, and other data. More specific information about the structure and content of the database, the associated database management interface utilities, and the database/web interface, is available at http://cdss.state.co.us/DNN/ViewData/tabid/60/Default.aspx.

StateCU is capable of using a wide variety of mathematical models for estimating potential crop consumptive use, but this analysis depends on the commonly used Blaney-Criddle method described in the U.S. Soil Conservation Service Technical Report No. 21 (TR21). The method depends on empirical crop coefficients that have been the subject of extensive investigation since TR21 was published. Selection of crop coefficients for the CDSS models is described in technical memos available on the CDSS website (see South Platte Decision Support System (SPDSS) Task Memo 59.1 Develop Locally Calibrated Blaney-Criddle Crop Coefficients at http://cdss.state.co.us/DNN/Products/ConsumptiveUse/tabid/65/Default.aspx.) Elevation adjustment as recommended by *The ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements* (1990) was incorporated, to correct for lower mean temperatures that occur at higher elevations, relative to conditions under which conventional Blaney-Criddle crop coefficients were developed.

Where pasture grass is grown above 6,500 feet, high altitude coefficients developed by Denver Water[2] were used, per recommendations of SPDSS Task 59.1.

Mean monthly temperature is a key parameter for predicting potential crop consumption using the Blaney-Criddle model. Precipitation data are required to estimate IWR, because the irrigation requirement is the crop's need for water that exceeds precipitation. Accordingly, a representative climate station or stations must be assigned to each diversion structure. Under the CDSS program, the level of rigor at which this was done varies from basin to basin. For example, on the West Slope, diversion structures within the same County-HUC are assigned to climate stations based on general understanding of proximity and terrain. In the South Platte basin, spatial analysis tools were used to identify a weighted blend of climate stations for each diversion structure based on proximity, with adjustments made for local topography.

StateCU's IWR calculations use structure-specific crop type, which is stored in HydroBase. WSL CU computations require historical diversion time series and maximum irrigation efficiency values by structure. Historical diversions are read from HydroBase; maximum irrigation efficiency values for flood and sprinkler irrigation have been selected for the CDSS StateCU implementations, based on water commissioner and/or user supplied information. Generally, a selected flood (or sprinkler) irrigation efficiency is applied across Water Districts or basins, but exceptions to the default are incorporated if structure-specific information is available.

The soil moisture reservoir is considered in calculating consumptive use. Excess irrigation water can be stored in the soil reservoir, to be consumed at a later time when irrigation supply is not adequate for the crop's needs. Use of soil water is counted toward the annual consumptive use.

For a more complete description of the Blaney-Criddle model, see CDSS StateCU Documentation, Section 4.0, available in the StateCU application download package at http://cdss.state.co.us/DNN/Products/ConsumptiveUse/tabid/65/Default.aspx. Further detail on the irrigation demand methodology for the CDSS basins is provided in Appendices A, B, and C.

1.3.1.2 Republican River Basin Agricultural Demand Methodology
RRCA groundwater modeling and accounting was used for calculations of IWR for the period 1998 through 2007. RRCA spreadsheets report "annual Net IWR" in feet of water, by county. Use of the Hargreaves evapotranspiration equation calibrated to the Penman-Monteith equation for this calculation is specified in the interstate settlement agreement in *Kansas v.*

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[2] Walter, I.A., Siemer, J.P., Quinlan and Burman, R.D. (1990). "Evapotranspiration and Agronomic Responses in Formerly Irrigated Mountain Meadows, South Park, Colorado", Report for the Board of Water Commissioners, City and County of Denver, CO. March 1, 1990.

Nebraska and Colorado. Each county was assigned a single climate station to provide the needed climate time series. Annual Net IWR multiplied by irrigated acreage for the county is conceptually equivalent to "IWR" estimated by StateCU. Like the StateCU values, it does not include water available to the plant because of precipitation. It also excludes 2.0 inches of crop water requirement that are typically met by the accumulation of soil moisture over the winter.

Pumping records of sufficient reliability were not available on a widespread basis for RRCA to calculate WSL CU directly for each well. However, in 2002, Colorado investigated 150 Republican River basin water right change cases that were supported by collection of pumping data. Calculations showed that on average, irrigators pump sufficient water to supply 75 percent of IWR at their farm efficiency. Accordingly, WSL CU for both groundwater and surface water supplied lands was estimated as 75 percent of IWR. This approach is both consistent with RRCA accounting, and supported by water rights engineering executed at sufficient detail for Water Court.

Further detail on the irrigation demand methodology for the Republican River Basin is provided in Appendix D.

1.3.1.3 Arkansas River Basin Agricultural Demand Methodology

Lower Arkansas—IWR and WSL CU from surface and groundwater supplies were provided by the ISAM model, described above, that the Division 2 office provided. The analysis is on the level of the individual farm, with results aggregated to the Water District where the water is diverted. IWR, WSL CU by surface water, WSL CU by groundwater, and shortages for the five Lower Arkansas ditches not included in ISAM (4 percent of Lower Arkansas irrigated lands) are estimated using average results from ISAM by Water District.

PRWCD—Analysis for this area was very similar to the analysis executed for CDSS basins. A StateCU scenario was developed at the individual structure level to estimate IWR and WSL CU, given historical diversions available in HydroBase. In accordance with CDSS protocol, the analysis used the modified Blaney-Criddle method with elevation adjustment, but without high altitude crop coefficients, as all irrigated lands are below 6,500 feet.

Maximum system efficiencies for PRWCD ditches were provided by the general manager of the conservancy district. Climate data were provided by two stations at or near Trinidad.

Other irrigated lands—To estimate IWR, StateCU was executed on a Water District level, because information associating specific irrigated parcels with diversion structures and crop types does not exist in a data-centered form that is available for the basins with a DSS. Each Water District was assigned a total irrigated acreage as determined through the procedure described above. The composite crop blend from PRWCD mapping was used for crop type in Water Districts 15, 16, 18, 19, and 79. The Colorado and National Agricultural Statistics from

2006 (the most recent year for which data appears to be reliably complete) were used to assign a blend of typical crops to other districts.

Based on proximity and general understanding of terrain, a climate station or stations was selected to represent conditions in each Water District. The Modified Blaney-Criddle method, with elevation adjustment, was used everywhere other than Water Districts 11, 13, and 15. In these districts, the Original Blaney-Criddle method with high altitude coefficients for pasture grass was used, because the elevation of the majority of lands was over 6,500 feet. These selections are consistent with CDSS consumptive use modeling standards.

WSL CU could not be easily modeled or calculated, given the lack of structure-specific data. In the absence of the level of information typical of CDSS basins, WSL CU or shortage percentages were transferred from areas where knowledge or quantitative indication of shortages is available to other areas. The extrapolation is reasonable, given constraints of data availability and general understanding of the basin, but it is subject to error because conditions in the "known" areas may not be identical to those in the "unknown" areas.

Decrees for recent change cases in Water Districts 11, 12, and 13 were researched to find an average or typical annual shortage in historical consumptive use, relative to full IWR, for these mountainous areas. Case 98CW137A changes use out of eight ditches on two ranches in Lake County. The composite historical shortage percentage for these ditches, per the decree, was applied to IWR in Water Districts 11, 12, and 13, to estimate WSL CU.

Water Districts 15, 79, 16, 18, and 19 were grouped together for the purpose of consumptive use computations. Lacking any decrees that adequately described shortages or IWR in these districts, it was assumed that the average WSL CU factor derived from StateCU analysis of the PRWCD was applicable in these south side tributary basins.

WSL CU factors estimated from the HI and ISAM analysis for Water Districts 14, 17, and 67 were applied to irrigation in these districts outside the HI model domain. In addition, the Water District 14 shortage factor was applied to Water District 10, and the Water District 67 shortage factor was adopted for Water District 66. Conversations with the groundwater commissioner from this area and personnel at the Eastern Cheyenne Groundwater Management District indicated that water supply is generally short along Colorado's southeastern border, and probably by more than 25 percent. This information was consistent with the assumptions made in order to estimate WSL CU for Water Districts 66 and 67.

Table 1 summarizes the data sources and methods used to estimate shortages for Other Lands in the Arkansas River basin, by Water District.

Table 1. Method for Estimating Shortages for Other Lands

Water District	Estimation Method
10	Apply shortage factor (WSL CU/IWR) for WD14 structures in ISAM model to WD10 IWR, as calculated by StateCU
11	Calculate shortage factor from historical consumptive use per acre in Case 98CW137A, and StateCU-generated irrigation demand rate for WD 11; apply factor to WD11-wide IWR as estimated by StateCU
12	Calculate shortage factor from historical consumptive use per acre in Case 98CW137A, and StateCU-generated irrigation demand rate for WD 11; apply factor to WD12-wide IWR as estimated by StateCU
13	Calculate shortage factor from historical consumptive use per acre in Case 98CW137A, and StateCU-generated irrigation demand rate for WD 11; apply factor to WD11-wide IWR as estimated by StateCU
14	Apply shortage factor for WD14 structures in ISAM model to IWR for irrigated lands outside ISAM model domain
15	Apply shortage factor from StateCU model of PRWCD to WD15 IWR, as calculated by StateCU
16	Apply shortage factor from StateCU model of PRWCD to WD16 IWR, as calculated by StateCU
17	Apply shortage factor from StateCU model of PRWCD to WD17 IWR, as calculated by StateCU
18	Apply shortage factor from StateCU model of PRWCD to WD18 IWR, as calculated by StateCU
19	Apply shortage factor from StateCU model of PRWCD to WD19 IWR, as calculated by StateCU
66	Apply shortage factor for WD67 structures in ISAM model to WD66 IWR, as calculated by StateCU
67	Apply shortage factor for WD67 structures in ISAM model to IWR for irrigated lands outside ISAM model domain
79	Apply shortage factor from StateCU model of PRWCD to WD79 IWR, as calculated by StateCU

Further detail on the irrigation demand methodology for the Arkansas River basin is provided in Appendix E.

1.3.2 Current Non-Irrigation Agricultural Demand Methodology

1.3.2.1 Stock Watering Demands Methodology

Livestock consumptive use is estimated by multiplying the number of cattle, sheep, and hogs located within the basin by their corresponding per capita consumptive use. Annual agricultural inventory data for counties in Colorado are developed by the National Agricultural Statistical Service and are stored in HydroBase. Quantification of livestock inventory in the CDSS basins has been performed in support of various CDSS or CWCB projects in the past, and documentation is available on the CDSS website[3]. Using the same methodology, basinwide livestock inventories were developed for the Republican River and Arkansas River, and the inventory for the Rio Grande basin was updated to include recent data.

Livestock inventories are available on a county rather than Water District basis. To be consistent with the Water District analysis for irrigation demand, basinwide livestock information was redistributed to a Water District level based on the percent of Water District

[3] SPDSS *Task 84 – South Platte River Basin Water Budget Procedures and Results Memo* (ftp://dwrftp.state.co.us/cdss/wtb/tm/SPDSSTask84_SouthPlatte.pdf); *Colorado River Basin Consumptive Uses and Losses Report - Other (non-agricultural) Uses Procedures,* currently (5/28/2010) not on CDSS website.

land area in each basin. This simplified approach is appropriate given the minimal livestock consumptive use compared to other uses.

For per capita consumption rates, the analysis relied on U.S. Environmental Protection Agency's (EPA's) *Manual of Individual and Non-Public Water Supply Systems, May 1991*. The manual indicates rates of 10 gallons per day (gpd) for cattle; 2 gpd for sheep; and 3 gpd for hogs. These consumptive use rates were used in previous CDSS efforts.

1.3.2.2 Stockpond Evaporation Methodology

Stockpond evaporation is based on net evaporation rates and stock pond surface area estimates. Details differ among the basins[4], but in general, the method estimates net reservoir evaporation by subtracting average effective monthly precipitation from the estimated gross monthly free water surface evaporation. Effective precipitation values are taken directly from key climate stations or using area-weighted averages for stations within a Water District or basin. Annual estimates of gross free water surface evaporation are taken from the National Oceanic and Atmospheric Administration (NOAA) Technical Report NWS 33, based on the 1956 – 1970 time period. The SEO has developed two monthly distributions of the annual evaporation—one applicable to sites above 6,500 feet and the other for sites below 6,500 feet, which it uses routinely in water administration (presented by Wolfe and Stenzel at a 1995 ET and Irrigation Efficiency Seminar and summarized in a paper titled 'Evaporation'). These distribution factors were applied to NWS annual evaporation rates to get monthly evaporation rates applicable to stockponds.

Surface area for stockponds is not generally available, but in previous CDSS efforts, capacity or decreed capacity has been collected and summed over Water District or basin, either via HydroBase or the SEO, and divided by a hypothetical 10-foot depth to get surface area[5]. The approach followed in SPDSS for the North and South Platte basins was applied to the Arkansas basin, for which there is currently no DSS. Under RRCA, capacities and surface

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4 The western slope DSS basins' net evaporation rates are documented in the basin's Water Resources Planning Model User's Manual. The Platte basins' net evaporation rates are documented in SPDSS *Task 53.3 – Assign Climate Information to Irrigated Acreage and Reservoirs* memorandum. Net evaporation rates for the Rio Grande basin are documented in the RGDSS *Task 6.8 – Prepare Reservoir Files*. Evaporation rates for the Republican River basin were based on gross evaporation information and recommended precipitation station as provided by the State of Colorado, as developed in accordance with the Republican River Compact Administration Accounting. As there has not been a DSS developed in the Arkansas River basin, evaporation rates were developed under this project using the standard DSS procedure.

5 The process for developing the capacities for the western slope basins is documented in five basin-specific CRDSS Non-Irrigation (Other Uses) Consumptive Use and Losses technical memoranda (Tasks 1.14-23, 2.09-10, 2.09-11, 2.09-12, 2.09-13); for the Rio Grande basin see RGDSS *Task 7.2 – Aggregate Reservoirs and Stock Ponds;* for the North and South Platte basins, see *SPDSS Task 69 – Estimate Reservoir and Stock Pond Evaporation*.

areas for specific Republican River basin stockponds are accounted for annually. These values were provided by the State of Colorado, such that estimates of evaporation presented here are in accordance with Republican River compact accounting.

1.3.2.3 Incidental Losses Methodology

Incidental losses may include, but are not limited to, vegetative consumptive use that occurs along canals and in tailwater areas. The CDSS program, in preparing Consumptive Uses and Losses (CU&L) reports for the state, has adopted 10 percent as the factor for computing incidental losses associated with irrigation consumptive use. The value is in the middle of the range of factors (5 percent to 29 percent) used by the U.S. Bureau of Reclamation (Bureau) in their parallel CU&L accounting throughout the upper basin states. According to the Bureau, their factors are based on comprehensive framework studies of incidental losses carried out at a sample of Colorado basin sites[6].

The West Slope CDSS StateCU models do not recognize or identify any groundwater irrigation, so incidental losses in these basins' Water Districts is estimated as 10 percent of total WSL CU. The Rio Grande and South Platte CDSS StateCU analyses rigorously identified surface vs. groundwater-related consumptive use. The incidental loss factor was applied only to the surface water component of WSL CU for these basins.

Surface water irrigation in the Republican River basin is an insignificant portion of the total basin's irrigation; incidental losses in this basin are considered negligible and were not reported.

In the Arkansas basin, the HI-Model includes estimates of incidental loss determined as a model calibration factor. Incidental loss is termed 'SEV' or secondary evapotranspiration. For irrigated lands included in the HI-Model, SEV is used directly as an estimate of incidental loss. All irrigation within PRWCD is by surface water, so 10 percent was applied to total WSL CU for PRWCD. Based on information gathered in the exercise to estimate irrigated acreage outside the HI Model and PRWCD in the Arkansas basin, it was assumed that:

- All "Other Lands" in Water Districts 17, 66, and 67 were groundwater irrigated
- All "Other Lands" in Water Districts 11, 12, 13, 14, 15, 16, 18, 19, and 79 were surface water irrigated
- Based on spatial analysis of irrigated lands within and outside of the Upper Black Squirrel Designated Groundwater Basin, 52 percent of irrigated acreage is surface water irrigated, and 48 percent is groundwater irrigated.

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[6] U.S. Bureau of Reclamation, COLORADO RIVER SYSTEM CONSUMPTIVE USES AND LOSSES REPORT, 1996-2000, February, 2004.

Incidental losses were calculated for Other Lands by multiplying the assumed surface water component by 10 percent.

Further detail on the non-irrigation demand methodology is provided in Appendix F.

1.4 2050 Agricultural Demand Methodology

Following the techniques described in the section "2050 Irrigated Acres Methodology" above, changes in numbers of acres irrigated have been developed for each Water District. Since this study intentionally avoids identifying specific water rights or ditches for change of use, there is no basis for calculating the structure-specific consumptive use by which a Water District's irrigation demand will change. Consumptive use per irrigated acre varies from structure to structure, and depends on available supply, seniority of a water right, and system efficiency. Instead, irrigation demand was considered directly proportional to number of acres irrigated. To derive future irrigation demand, current irrigation demand for each Water District was scaled by the ratio of future irrigated acreage to current irrigated acreage.

Similarly, non-irrigation demand was estimated as being in proportion to irrigated acres. The relationship between losses incidental to irrigation and number of acres irrigated is proportional. With respect to stockponds and stock watering, it is assumed that predicted changes in irrigated acreage will be accompanied by similar changes in stock raising activities. To derive future non-irrigation demand, current non-irrigation demand was scaled by the ratio of future irrigated acreage to current irrigated acreage.

Section 2 – Results

2.1 Current Irrigated Acres Results

Information developed for this effort was generated at the Water District level. Figure 2 shows the locations of Colorado's Water Districts, and the spatial distribution of irrigated acres in Colorado based on the methods presented previously. Spatial information was not available for the Republican River Water Districts so the number of irrigated acres in these districts are noted in Figure 3. Table 2 presents the number of irrigated acres in each river basin. The irrigated acres in each Water District are presented in Appendices A, B, C, D, and E.

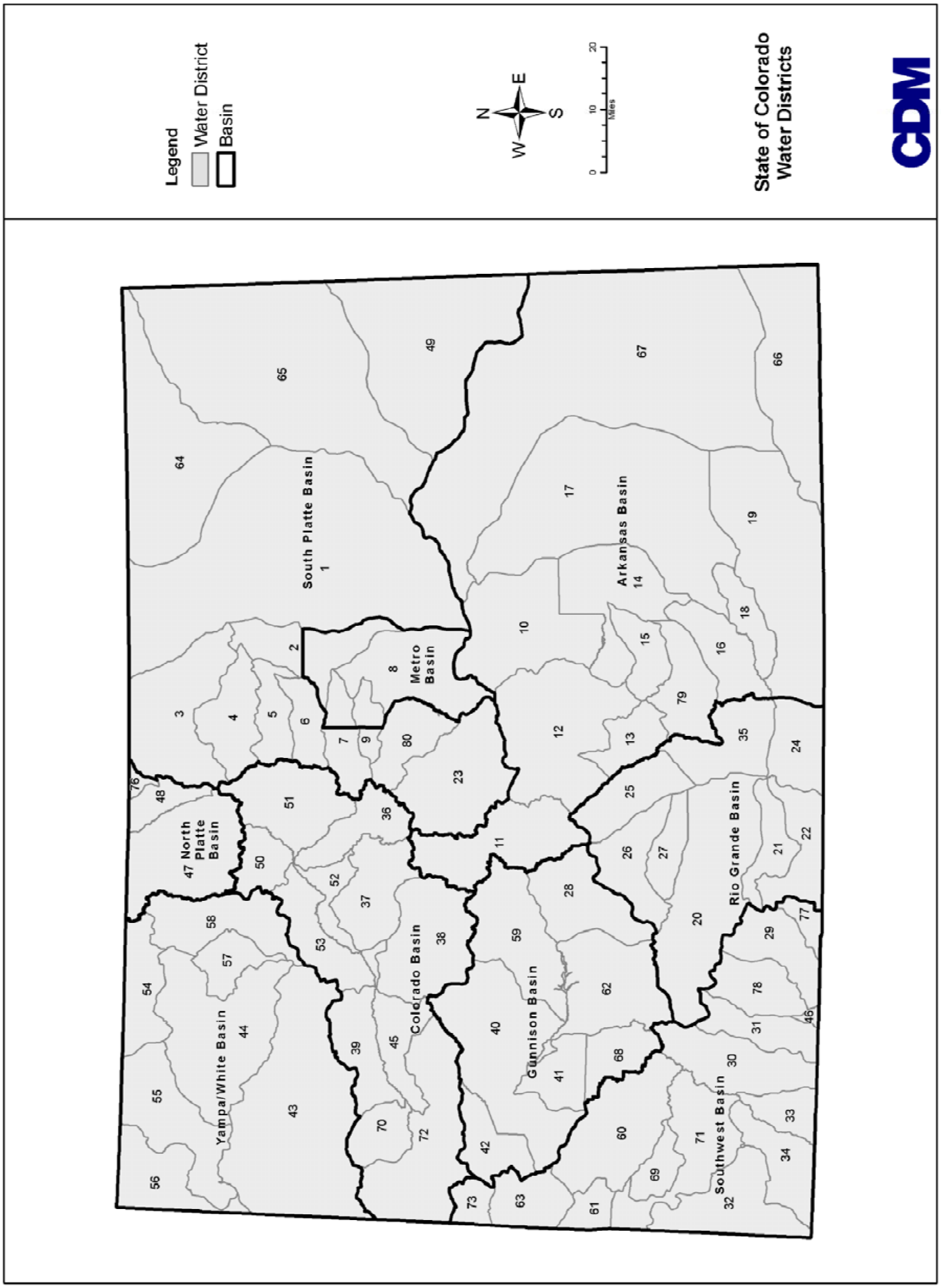

Figure 2. Water Districts

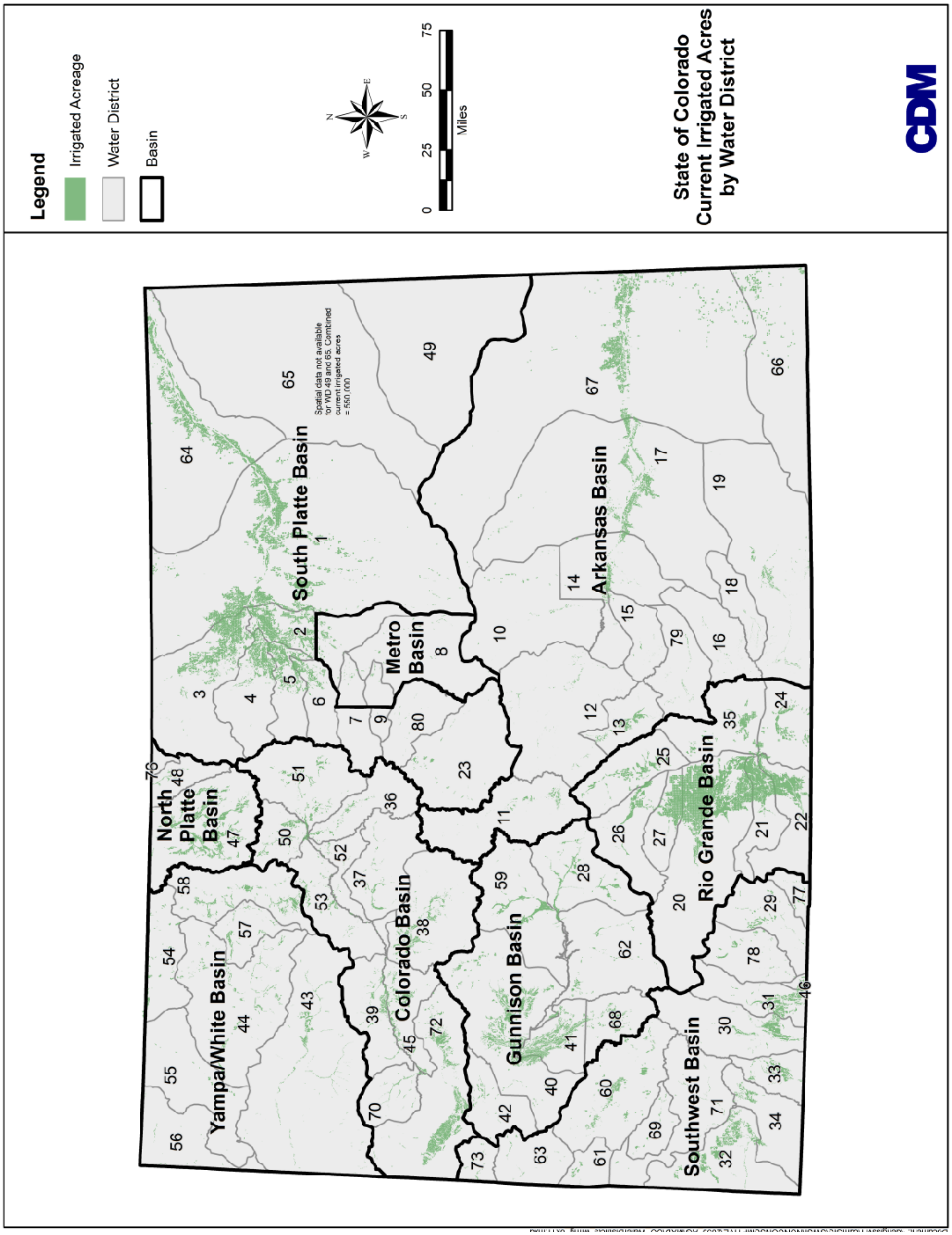

Figure 3. Water Districts with Irrigated Acreage

Table 2. Current Irrigated Acres by River Basin

Basin	Irrigated Acres	Percentage of Colorado's Irrigated Acres
Arkansas	428,000	12%
Colorado	268,000	8%
Gunnison	272,000	8%
North Platte	117,000	3%
Republican	550,000	16%
Rio Grande	622,000	18%
South Platte	831,000	24%
Southwest	259,000	7%
Yampa-White	119,000	3%
Statewide Total	**3,466,000**	**100%**

Colorado currently has 3,466,000 million acres of irrigated farmland across the state. The Metro and South Platte basins have the highest percentage of irrigated acres followed by the Rio Grande basin and the Republican basin.

2.2 Future Irrigated Acre Results

Table 3 shows the results of future irrigated acres analysis. Future irrigated acres in Colorado may decrease by 115,000 to 155,000 acres due to urbanization alone, under low and high population growth scenarios, respectively. The basins with largest expected loss of irrigated acres due to urbanization are the South Platte, Colorado, and Gunnison basins. Table 3 also shows the potential loss of irrigated acres due to other reasons. The South Platte, Republican, and Rio Grande basins are expected to lose irrigated acres due to a variety of factors.

For the South Platte basin, up to 14,000 irrigated acres have been taken out of production in the last 5 years because the Central Colorado Water Conservancy District's water augmentation was not approved by the Department of Water Resources in 2006. Irrigated acres in the district without surface water augmentation total nearly 8000 acres. Lands with groundwater and surface water irrigated acres totaled just over 12,000 acres and approximately 50 percent of these lands were taken out of production (6,000 acres) for a total of 14,000 acres.

Table3. Future Irrigated Acres by River Basin

Basin	Current Irrigated Acres	Decrease in Irrigated Acres Due to Urbanization		Decreases in Irrigated Acres Due to Other Reasons	Decreases in Irrigated Acres from Planned Agricultural to Municipal Transfers	Decreases in Irrigated Acres from Agricultural to Municipal Transfers to Address M&I Gap		Estimated 2050 Irrigated Acres	
		Low	High			Low	High	Low	High
Arkansas	428,000	2,000	3,000	—	7,000	26,000	63,000	355,000	393,000
Colorado	268,000	40,000	58,000	—	200	11,000	19,000	190,800	216,800
Gunnison	272,000	20,000	26,000	—	—	1,000	2,000	244,000	251,000
North Platte	117,000	—	—	—	—	—	—	117,000	117,000
Republican	550,000	300	600	109,000	—	—	—	440,400	440,700
Rio Grande	622,000	800	1,000	80,000	—	2,000	3,000	538,000	539,200
South Platte	831,000	47,000	58,000	14,000	19,000	100,000	176,000	564,000	651,000
Southwest	259,000	4,000	6,000	—	—	3,000	7,000	246,000	252,000
Yampa-White[7]	119,000	1,000	2,000	—	—	3,000	64,000	53,000	115,000
Statewide Total	**3,466,000**	**115,100**	**154,600**	**203,000**	**26,200**	**146,000**	**334,000**	**2,748,200**	**2,975,700**

[7] Upon completion, results of the Yampa-White Basin Roundtable Agricultural Needs Study will be incorporated in the results shown here.

Information available from the Republican River Water Conservation District (RRWCD) on its web site (http://www.republicanriver.com) indicate that the acres removed from irrigation through conservation programs, EQUIP and CREP, removed a total of 35,297 acres from irrigation by 2009. In a report by Slattery Engineering LLC, 10-11-07, to the RRWCD, it was estimated that by 2032 the acres where the saturated thickness of the Ogallala aquifer would be 50 feet or less, would be 64,196 acres. This analysis was based on the assumption that pumping would continue at the current levels. It certainly would appear likely that by 2050 these acres would not be able to be irrigated by pumping at all since the water table will continue to decline and therefore, the acres irrigated by groundwater would be reduced to at least 451,706 acres if pumping continues at the current levels. In addition, the RRWCD is proposing to construct a Compact Compliance Pipeline to pump up to 15,000 acre-feet (AF) of water annually from an area north of the North Fork of the Republican River to the Stateline for assisting Colorado in meeting its obligations under the Republican River Compact. This would require the dry-up of 10,000 acres of land currently irrigated by groundwater in District 65. This project is currently in non-binding arbitration before an arbitrator selected in accordance with the 2002 Settlement Agreement.

In the Rio Grande basin, the estimated decline in irrigated acres (80,000 acres) shown in Table 3 is related to the protection of the water table and senior water rights in the Rio Grande Valley. To bring about the reduction, Groundwater Management Subdistricts would have to be established. Subdistrict 1 has been created for the closed basin in District 20. The water management plan that has been created for this subdistrict is currently under Water Court review and the outcome is uncertain at this time. The Trinchera Water Conservancy District has established a subdistrict for its area in Water District 35 but no management plan has been developed. The SEO is expected to issue rules this summer for the Rio Grande basin that facilitate well owners in the other districts to move forward with getting subdistricts established and management plans approved.

Finally, Table 3 address potential future decreases in irrigated acres due to agricultural to municipal transfers as identified by water providers across the state. Table 3 shows that water providers have identified approximately 26,000 acres to be transferred to meet future M&I needs. As discussed previously in the "Agricultural to Municipal Water Transfers Methodology," a portion of the M&I gap is expected to be met by agricultural to municipal transfers. Table 3 shows that the amount of irrigated acres may decrease by 160,000 to 334,000 acres to meet future municipal demands. Basins with largest decreases in irrigated acres to meet municipal demands include the South Platte and Metro basins, Arkansas basin, Colorado basin, and Yampa-White basin.

As discussed in the "2050 Irrigated Acres Methodology" section above, other factors were considered by CWCB in examining expected trends in irrigated agriculture over the next 40 years. For each factor, CWCB examined what may cause potential changes and identified the direction and qualitative magnitude of the change. The additional factors considered included in addition to loss of irrigated acres due to urbanization, agricultural to municipal transfers and water management considerations include:

- Demographic factors
- Biofuels production
- Climate change
- Farm programs
- Subdivision of agricultural lands and lifestyle farms
- Yield and productivity
- Open space and conservation easements
- Economics of agriculture

Each of these factors is summarized below. The data and information sources that contributed to the evaluation of each factor are found in Appendix G. In the aggregate, these factors will likely provide a slight positive pressure to keep Colorado's agricultural economy viable and irrigated acres in production in the future.

2.2.1 Demographic Factors Results

The major demographic trend considered was the aging of the typical Colorado farmer. The majority of household farms across the state are led and operated by Baby Boomers. Due to a variety of factors, the next generation is less interested in continuing to farm or the farm can only support a subset of the future generation. However, irrigated farming in Colorado continues to be profitable and these demographic trends may not lead to large-scale sell off of farmland across the state. The assumption for this factor is that farmers will sell to neighbors or corporate operators, but operation will continue in some form. However, demographic factors will contribute to agricultural to municipal transfers and easements in the future as the market allows. It is assumed for the purpose of this analysis that there will be negligible effect on irrigated acres from this factor in the future above what was presented in the agricultural to municipal transfers described previously.

2.2.2 Biofuels Production Results

Biofuels will remain part of the agricultural economy in that ethanol will remain the leading biofuel for the near and intermediate future (2030) if government support remains at levels present today. Although it will not affect irrigated acreage, cellulosic and algae biofuels are a long-term possibility in Colorado and might benefit Colorado agricultural processing sectors. Pressure to produce biofuels should positively impact the corn market and with Colorado's livestock demand, there will be pressure to maintain or increase corn acres. However, this increase to produce corn may result in a trade-off with other crops. Overall, there is a slight positive increase in irrigated acres expected across the state for this factor.

2.2.3 Climate Change Results

Climate change is projected to increase the frequency of drought events in Colorado, and, as a result of increasing temperatures, water yields will in general decrease. Warmer temperatures will likely result in precipitation occurring as rain rather than snow, an earlier spring melt, more intense precipitation events, and increased evapotranspiration (CWCB 2008, CWCB 2010, Knowles et al., 2006, Mote 2006, Saunders 2005, Udall 2007). Consequently, runoff will start earlier and reservoirs will fill earlier. The water that cannot be stored in the spring and early summer will be spilled when agricultural demands are not as great as they are later in the summer. Decreased runoff in the summer will result in additional reservoir drawdown and many studies agree that higher temperatures and lower precipitation during summer months will further increase agricultural demands, thus causing even more stress on reservoir storage (CWCB 2008, CWCB 2010).

2.2.4 Farm Programs Results

With respect to farm programs providing assistance to farmers, the programs have historically changed frequently but they have always been available in some form. It is recognized that food production is a national strategic resource and there is little evidence that significant change in farm programs will occur in the future. For this analysis, it was assumed that this factor will have no net effect on the number of irrigated acres in Colorado in the future.

2.2.5 Subdivision of Agricultural Lands and Lifestyle Farms Results

Input on this factor was received from the Basin Roundtables. It is assumed that subdivision of agricultural land and an increase in lifestyle farms will preserve irrigated farmland from urbanization or agricultural to municipal transfers. In addition, with lifestyle farms, there may be less focus on beneficial uses of water and therefore less intensive usage and less actual irrigation. It is difficult to determine the net effect that this factor may have on future irrigated acres, but it is assumed to be negligible.

2.2.6 Yield and Productivity Results

With respect to yield and productivity, there have been historic gains for agriculture since the 1950s. Technological improvements have been gradual but continuous for both agricultural equipment and processes. It is assumed that continued gradual improvements will occur over time and that Colorado farms will produce more per acre in the long-term. Whereas productivity gains will make Colorado agriculture more resilient, it is unlikely that this factor will increase the amount of irrigated acres across the state in the future.

2.2.7 Open Space and Conservation Easements Results

In Colorado, there is a wide variety of open space and easement types. The landowners and motivations of those landowners seeking open space and easements vary as well. Many cities and counties have been more active in acquiring open space in the 1990s and early 2000s. The net effect of open space acquisition within urban growth boundaries has been increased development outside of urban planning areas and in some cases onto irrigated lands. Some conservation easements protect irrigated acres, help farm viability, and deter development. However, conservation easement activity is closely tied to tax breaks and incentives that might not be available in the future. It is assumed that the recent rush to purchase open space and assign easements has led to a transition to lower, more sustainable levels of conversion to open space and easements. It is expected that even though open space and conservation easements will continue to be a factor in the future, there will be a modest amount of irrigated acres impacted.

2.2.8 Economics of Agriculture

As part of the 2050 population projections recently completed by Harvey Economics (2010), there was a range of assumptions that related the agricultural economy to population growth. These assumptions included:

- World food demand increasing from developing countries
- Acceptance and crop enhancement from genetic modification
- Trends toward locally produced foods
- Prices generally more firm with usual periodic oscillation
- Costs keeping pace with firmer prices, so net income stable

Based on these economic factors, farming, especially irrigated agriculture, will remain a resilient economic sector. Without incentives to reduce this activity, irrigated acreage will remain steady.

2.2.9 Summary

For historical perspective, Table 4 shows historical trends in statewide total farmland and irrigated acres during the last 20 years. Between 1987 and 2007, Colorado has lost approximately 10 percent of it irrigated acres statewide according to information generated by U.S. Department of Agriculture (USDA).

Table 4. Historical Trends in Colorado Farmland and Irrigated Acres

Year	Total Land in Farms		Total Irrigated Acres	
	Millions of Acres	Percent Change from Previous Period	Millions of Acres	Percent Change from Previous Period
1987	NA	NA	3.0	NA
1992	34.0	NA	3.2	6.7
1997	32.6	-4.1	3.4	6.3
2002	31.1	-4.6	2.6	-23.5
2007	31.6	1.6	2.9	11.5
Percent change for 1992-2007 period		**-7.0**		**-10.0**

Source: USDA Census of Agriculture, selected years

Overall, the future irrigated analysis has shown that Colorado may lose between 517,000 and 714,000 acres, or 15 to 20 percent, of its irrigated acres by 2050. Figure 4 shows the potential changes by basin.

2.3 Current Agricultural Demand Results

Table 5 summarizes results of the average annual Current Agricultural Demand by basin. It shows irrigated acres, IWR, WSL CU, and Shortage (difference between IWR and WSL CU). Non-Irrigation Demand is also shown by basin. The information is presented by Water District in Appendices A, B, C, D, E, and F. Figures 5 and 6 show the WSL CU and shortages amounts by basin. Basins with the highest agricultural water demand include the Metro/South Platte, Rio Grande, and Republican.

Table 5. Estimated Current Agricultural Demand by Basin

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)	Non-Irrigation Demand (AFY)
Arkansas	428,000	995,000	542,000	453,000	56,000
Colorado	268,000	584,000	485,000	100,000	51,000
Gunnison	272,000	633,000	505,000	128,000	54,000
North Platte	117,000	202,000	113,000	89,000	12,000
Republican	550,000	802,000	602,000	200,000	67,000
Rio Grande	622,000	1,283,000	855,000	428,000	45,000
South Platte	831,000	1,496,000	1,117,000	379,000	115,000
Southwest	259,000	580,000	382,000	198,000	46,000
Yampa-White[8]	119,000	235,000	181,000	54,000	24,000
Statewide Total	**3,466,000**	**6,819,000**	**4,791,000**	**2,028,000**	**470,000**

[8] Upon completion, results of the Yampa-White Basin Roundtable Agricultural Needs Study will be included in the results presented here.

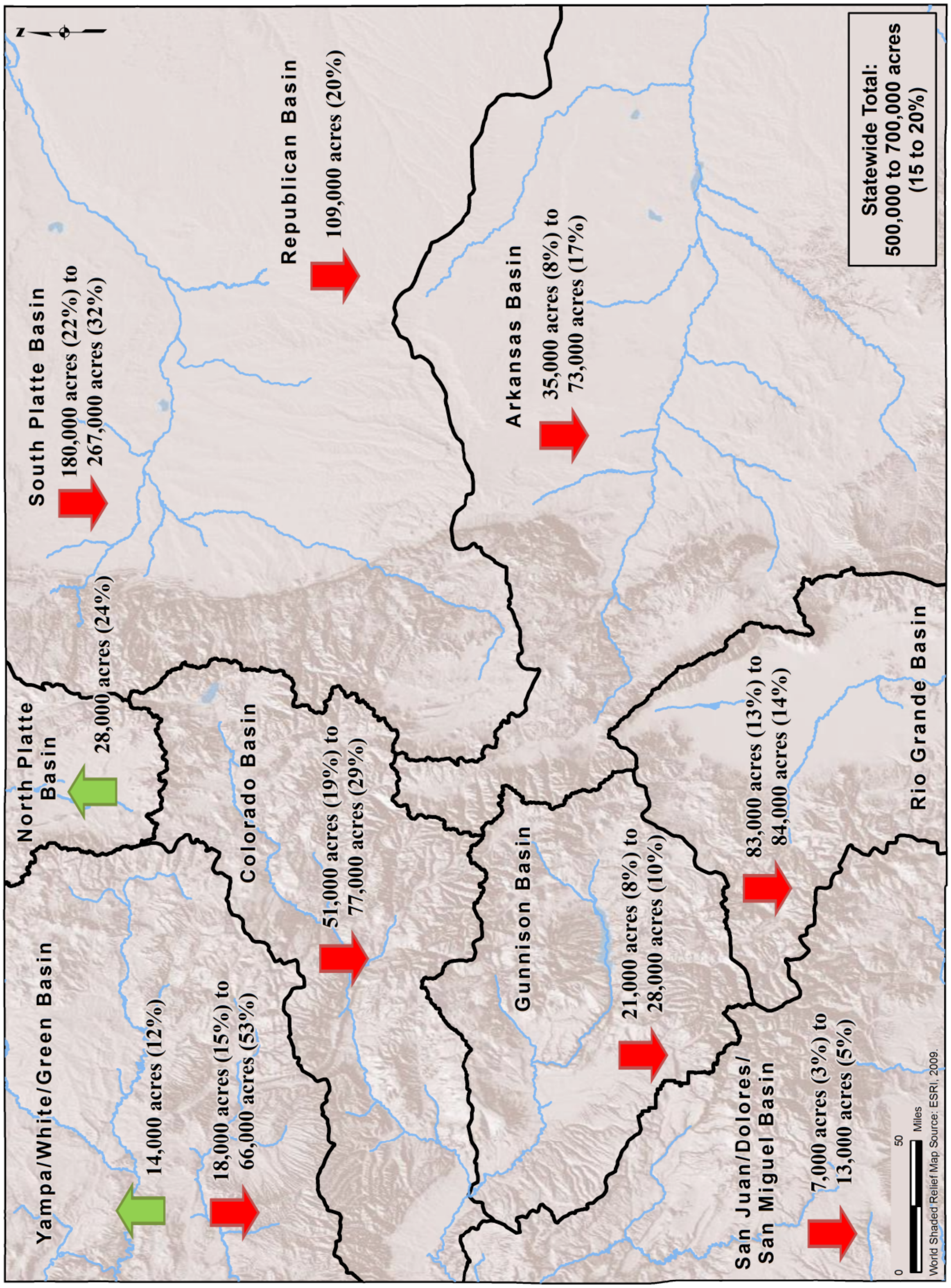

Figure 4. Potential Changes by Basin

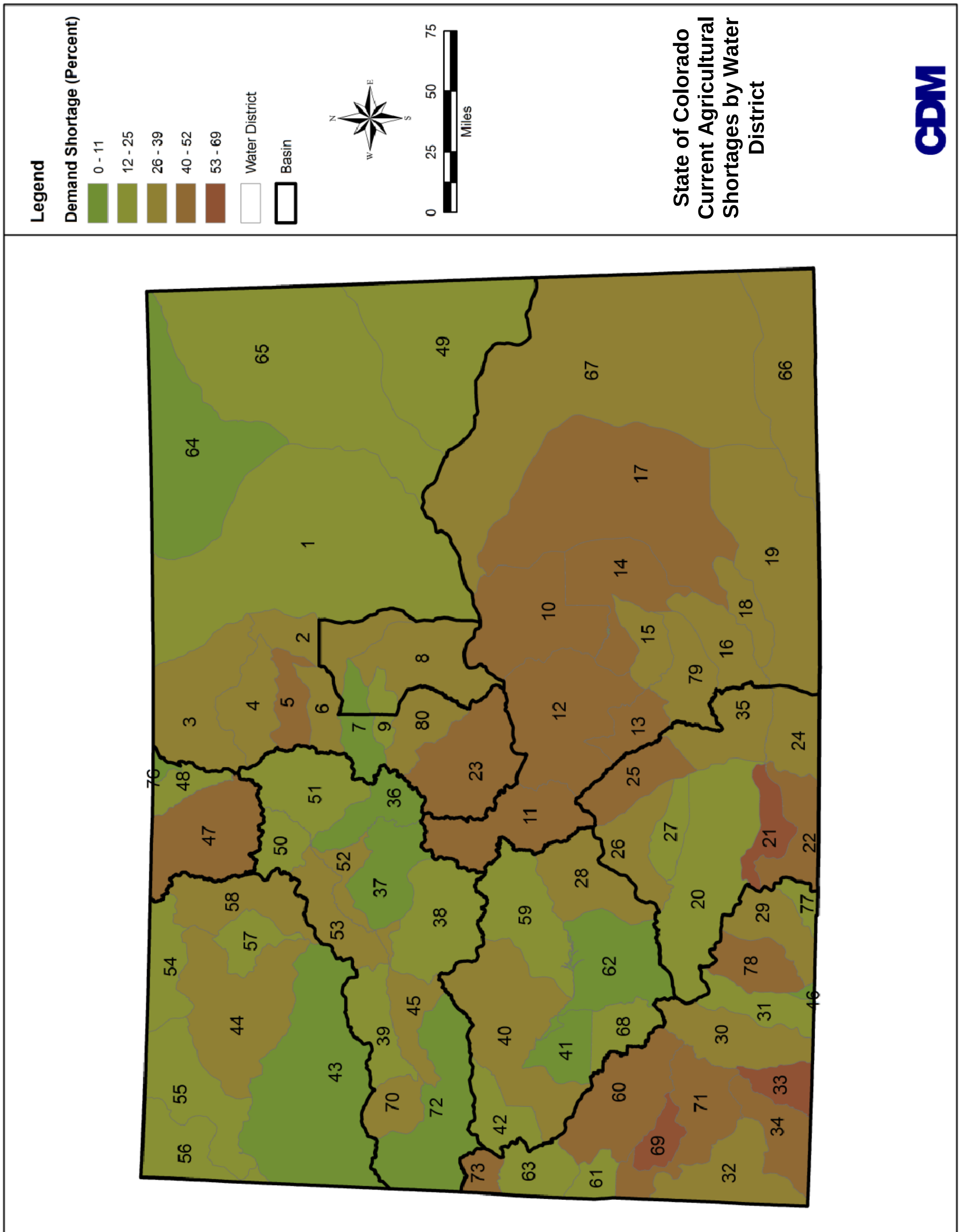

Figure 5. Agricultural Shortages by Water District

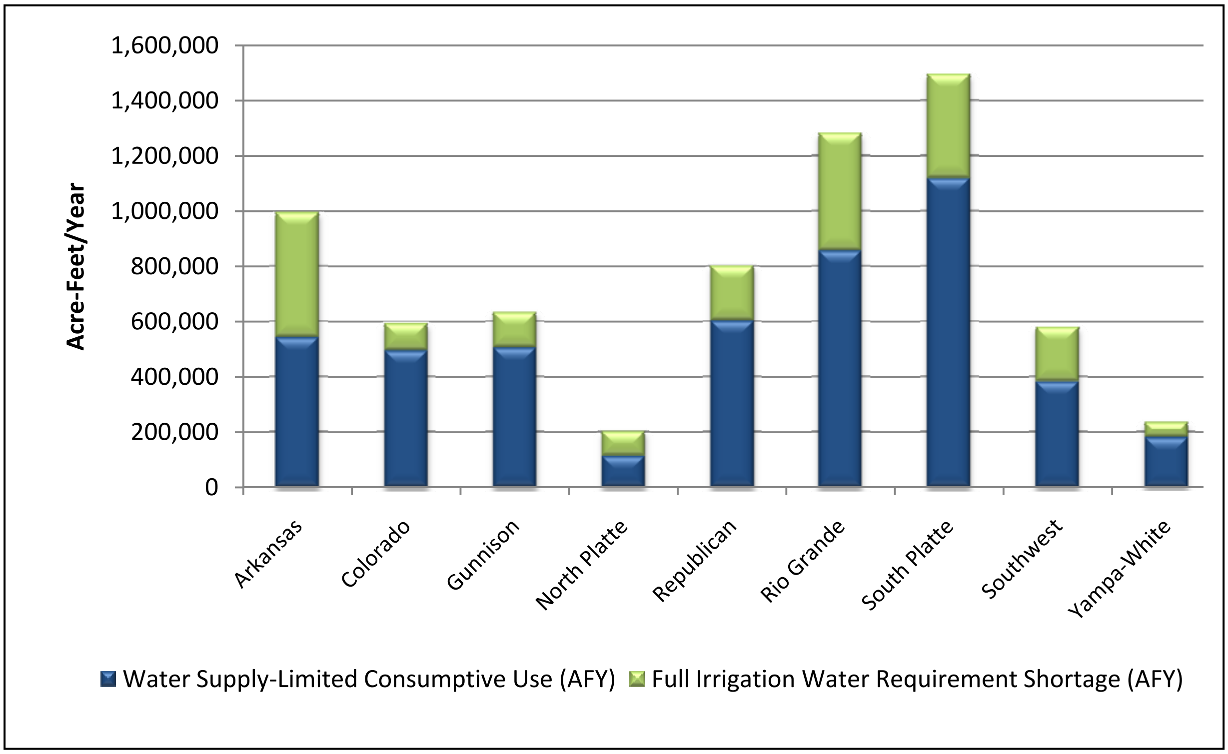

Figure 6. Current Agricultural Demands and Shortages

2.4 Future Agricultural Demand Results

Table 6 summarizes results of the average annual 2050 Agricultural Demand by basin, assuming that historical climate and hydrology continue into the future. It shows irrigated acres, IWR, WSL CU, and Shortage (difference between IWR and WSL CU). Finally Non-Irrigation Demand is also shown by basin. Figure 7 shows the WSL CU and shortages by basin for the estimated 2050 irrigated acres.

Table 6. Estimated 2050 Agricultural Demand by Basin

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)	Non-Irrigation Demand (AFY)
Arkansas	373,000	862,000	476,000	386,000	49,000
Colorado	204,000	443,000	366,000	77,000	38,000
Gunnison	219,000	573,000	457,000	116,000	48,000
North Platte	117,000	202,000	113,000	89,000	12,000
Republican	441,000	640,000	480,000	160,000	5,000
Rio Grande	537,000	1,108,000	739,000	369,000	38,000
South Platte	607,000	1,094,000	820,000	274,000	84,000
Southwest	249,000	558,000	367,000	191,000	44,000
Yampa-White[9]	85,000	209,000	170,000	39,000	13,000
Statewide Total	**2,832,000**	**5,689,000**	**3,988,000**	**1,701,000**	**331,000**

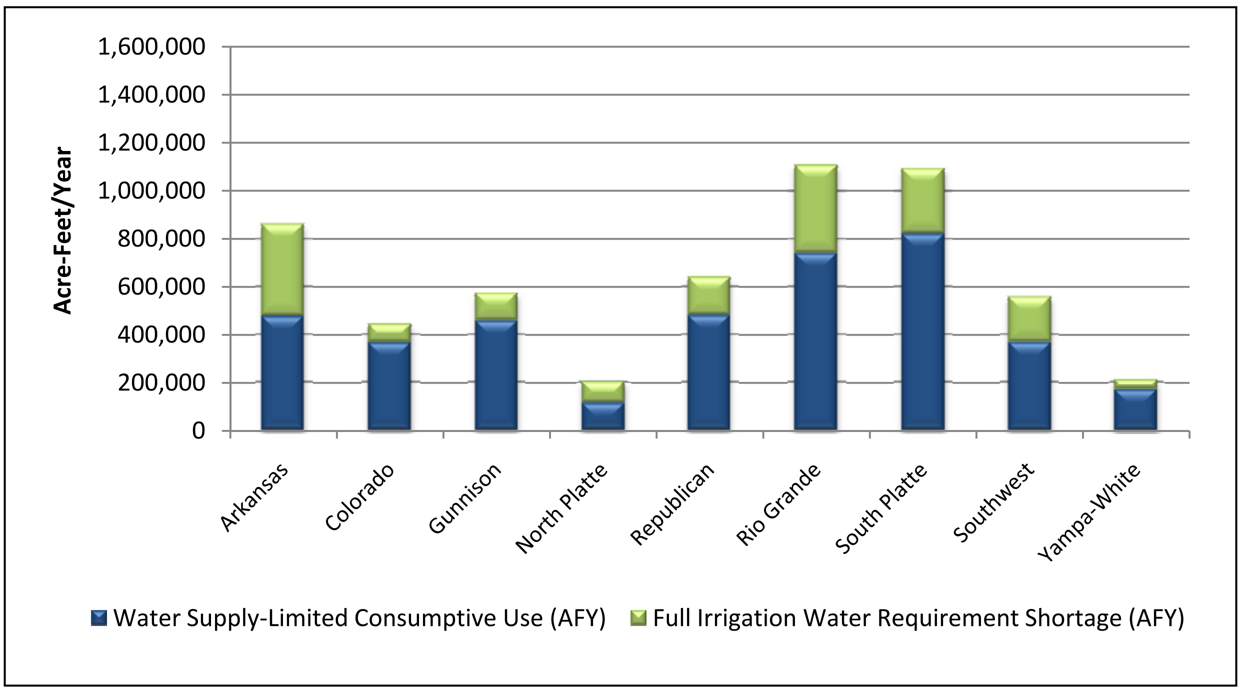

Figure 7. 2050 Agricultural Demands and Shortages

[9] Upon completion, results of the Yampa-White Basin Roundtable Agricultural Needs Study will be included in the above results.

Section 3 – Summary and Conclusions

Figure 8 shows the comparison between current and 2050 irrigated acres results as described in this technical memorandum. The basins with the largest expected decreases in irrigated acres by 2050 include the Yampa-White, South Platte and Colorado Basins. Statewide, irrigated acres are projected to decrease between 15 and 20 percent between now and 2050.

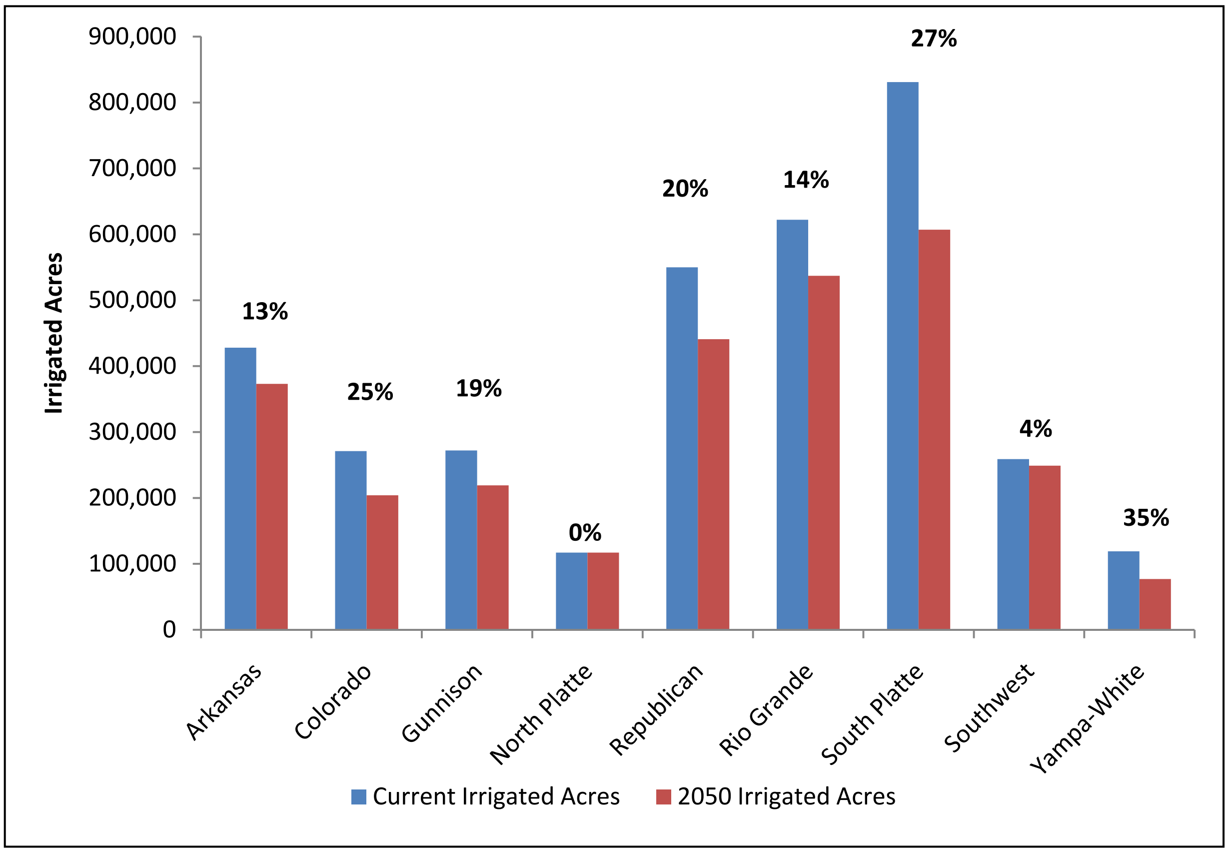

Figure 8. Comparison of Current and 2050 Irrigated Acres

Section 4 – References

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Appendix A
West Slope Agricultural Demands Methodology

Memorandum

Date:	March 19, 2010
To:	Nicole Rowan, CDM
From:	Meg Frantz, AECOM
Subject:	West Slope Basins Current Agricultural Demand – Methods

Distribution:	Todd Doherty, CWCB

Purpose

This memorandum documents the methods AECOM used to produce Irrigated Acreage, Irrigation Water Requirement (the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage, for the west slope river basins. The values are tabulated in spreadsheet workbooks Gunnison.xlsx, SanJuan.xlsx, UpperColorado.xlsx, White.xlsx, and Yampa.xlsx.

Background

During fall 2009, as part of the Colorado Water Availability Study, AECOM and Leonard Rice Engineers updated the CDSS Water Resources Planning Models (the Statemod models) in each of the five west slope basins. The update was directed at improving representations where, for instance, additional information had become available in recent years, conditions were known to have changed, or limitations were recognized incidental to applying the model to other projects. The Basin Round Tables were solicited for their ideas and prioritization of the potential model improvements. Extending the models' study periods was not a high priority item. By November 2009, an updated StateMod model data set was completed for each basin.

Supporting each one of the StateMod models, and integral to the StateMod input data set, is a StateCU model for each basin. StateCU calculates the irrigation demand for each diversion structure in the StateMod model. The modeled diversion structures were developed with the specific objective of representing 100 percent of the agricultural consumptive use in each basin. Diversion structure characteristics such as irrigated area, crop type, and irrigation practices were developed under CDSS. Another key input to StateMod is a time series file of historical diversions, for which missing data are filled.

Method and Assumptions

1. AECOM relied on the recently updated StateCU and StateMod model data sets for this effort. The models included the requisite information on irrigated lands, relevant climate stations, crop types and irrigation practices, and historical water supply. StateCU was executed to produce irrigation water requirement, water-supply limited consumptive use, and shortage.

2. Study period varies with each basin, depending on the study period of the CDSS products for each basin. In each case however, the StateCU model was executed for the most recent 10 years of the CDSS model period. This approach allows for incorporation of climate variability, but confines the study to current conditions in terms of the available water supply. For example, storage water might be available recently that was not available in earlier decades. If a study period of several decades was used, shortage might be overstated, influenced by the pre-storage condition.

3. All models used irrigated lands information based on 1993 aerial photography. Changes in irrigated lands in this part of the state have been minor, and the coverage is considered valid for this level of planning.

4. The Blaney-Criddle method (SCS Publication TR-21) is used for estimating potential evapotranspiration and effective precipitation. Elevation adjustment as recommended by The ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990) is incorporated, to correct for lower mean temperatures that occur at higher elevations, relative to conditions under which the conventional Blaney-Criddle crop coefficients were developed. Where pasture grass is grown above 6,500 feet, high altitude coefficients developed by Denver Water are used.

5. The soil moisture reservoir is considered in calculating consumptive use. Excess irrigation water can enter the reservoir, to be consumed at a later time when irrigation supply is not adequate for the crop's needs. Use of soil water is counted toward the annual consumptive use.

Summary Agricultural Demand Tables

Table 1. Gunnison Basin 10-year Average Agricultural Demands

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD28	28,441	63,753	43,898	19,855
WD40	90,238	228,765	153,636	75,128
WD41	79,796	175,688	172,757	2,931
WD42	8,263	24,923	18,650	6,273
WD59	33,786	73,072	58,557	14,514
WD62	16,503	34,726	31,927	2,800
WD68	14,926	31,816	25,915	5,902

Table 2. San Juan Basin 10-year Average Agricultural Demands

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD29	12,922	28,316	17,683	10,633
WD30	32,193	74,431	53,817	20,614

WD31	46,755	103,096	90,515	12,581
WD32	72,463	157,219	110,571	46,648
WD33	21,305	44,493	14,286	30,207
WD34	11,617	31,560	16,060	15,499
WD60	32,879	71,167	37,396	33,770
WD61	3,403	6,950	5,370	1,580
WD63	2,864	8,522	7,065	1,457
WD69	2,832	6,591	2,021	4,571
WD71	7,128	18,419	9,501	8,917
WD73	3,070	8,246	4,094	4,153
WD77	2,919	6,377	4,914	1,463
WD78	7,074	14,839	8,595	6,244

Table 3. Upper Colorado Basin 10-year Average Agricultural Demands

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD36	8,569	19,787	17,888	1,899
WD37	11,781	28,712	27,025	1,688
WD38	33,587	78,391	66,937	11,454
WD39	16,854	38,058	32,085	5,974
WD45	30,370	68,375	43,777	24,598
WD50	19,094	39,669	29,707	9,962
WD51	25,406	52,333	41,440	10,893
WD52	4,171	8,585	5,276	3,308
WD53	13,591	27,933	19,273	8,660
WD70	6,250	12,312	7,931	4,381
WD72	101,175	218,993	202,301	16,692

Table 4. White Basin 10-year Average Agricultural Demands

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD43	26,593	46,208	41,166	5,042

Table 5. Yampa Basin 10-year Average Agricultural Demands

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
Wyoming	12,830	32,666	29,333	3,333
WD58	34,551	73,001	53,358	19,644

WD57	10,537	17,137	13,565	3,572
WD44	29,069	55,892	39,292	16,600
WD54	14,678	35,317	28,195	7,122
WD55	1,789	3,161	2,674	486
WD56	2,173	3,879	2,969	910

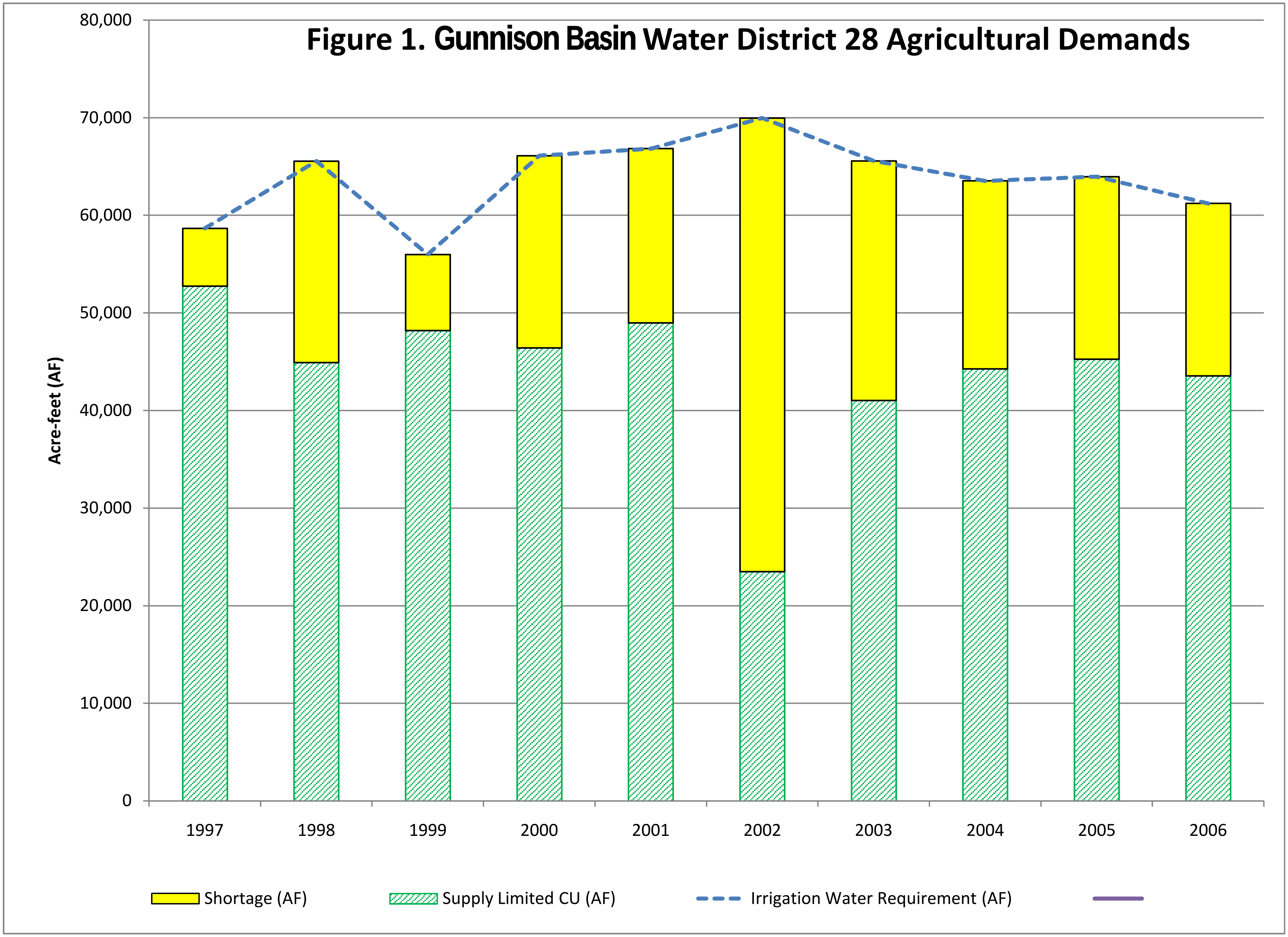


Figure 1. Gunnison Basin Water District 28 Agricultural Demands
Acre-feet (AF)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

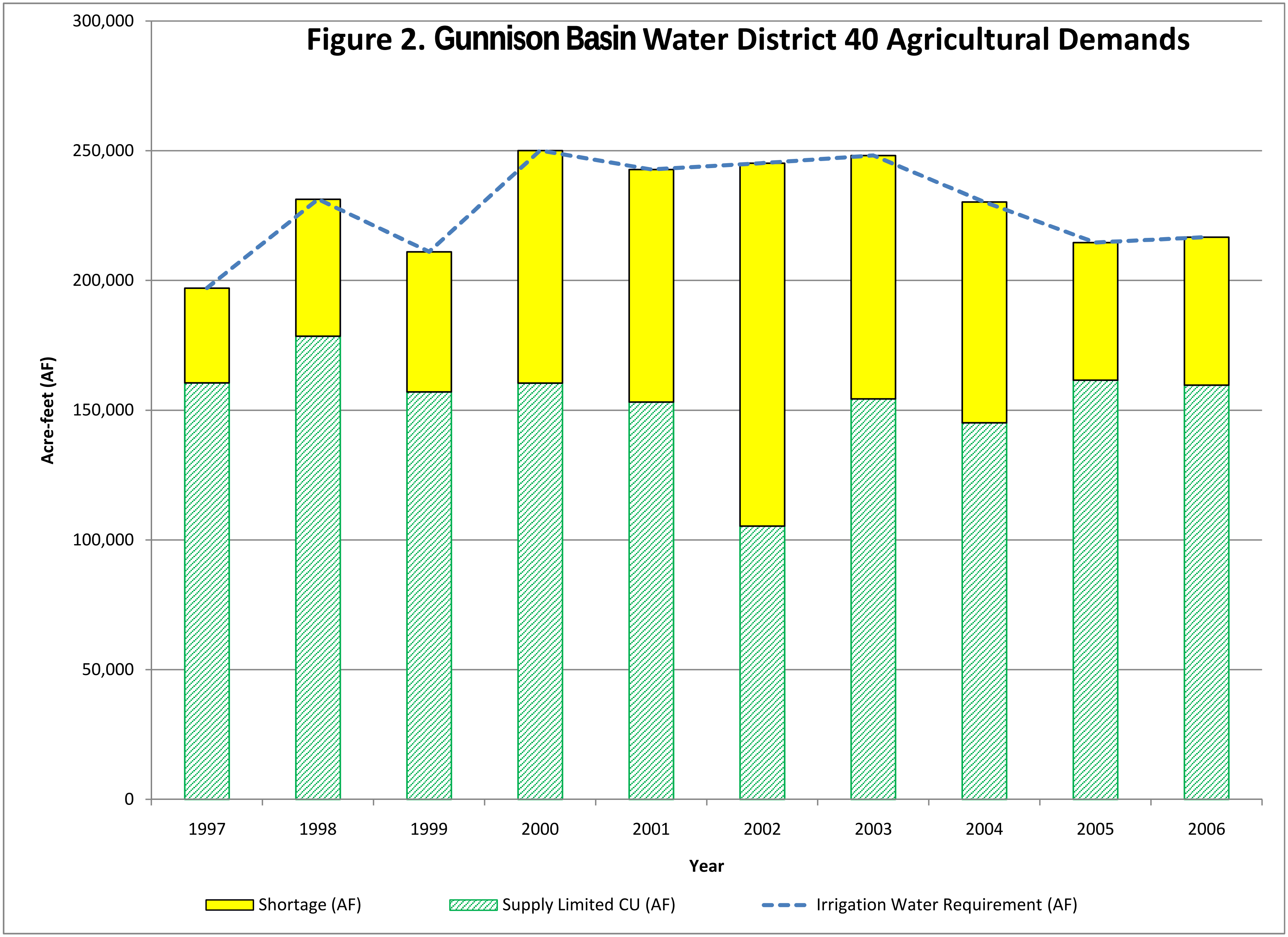


Figure 2. Gunnison Basin Water District 40 Agricultural Demands
Acre-feet (AF)
300,000
250,000
200,000
150,000
100,000
50,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

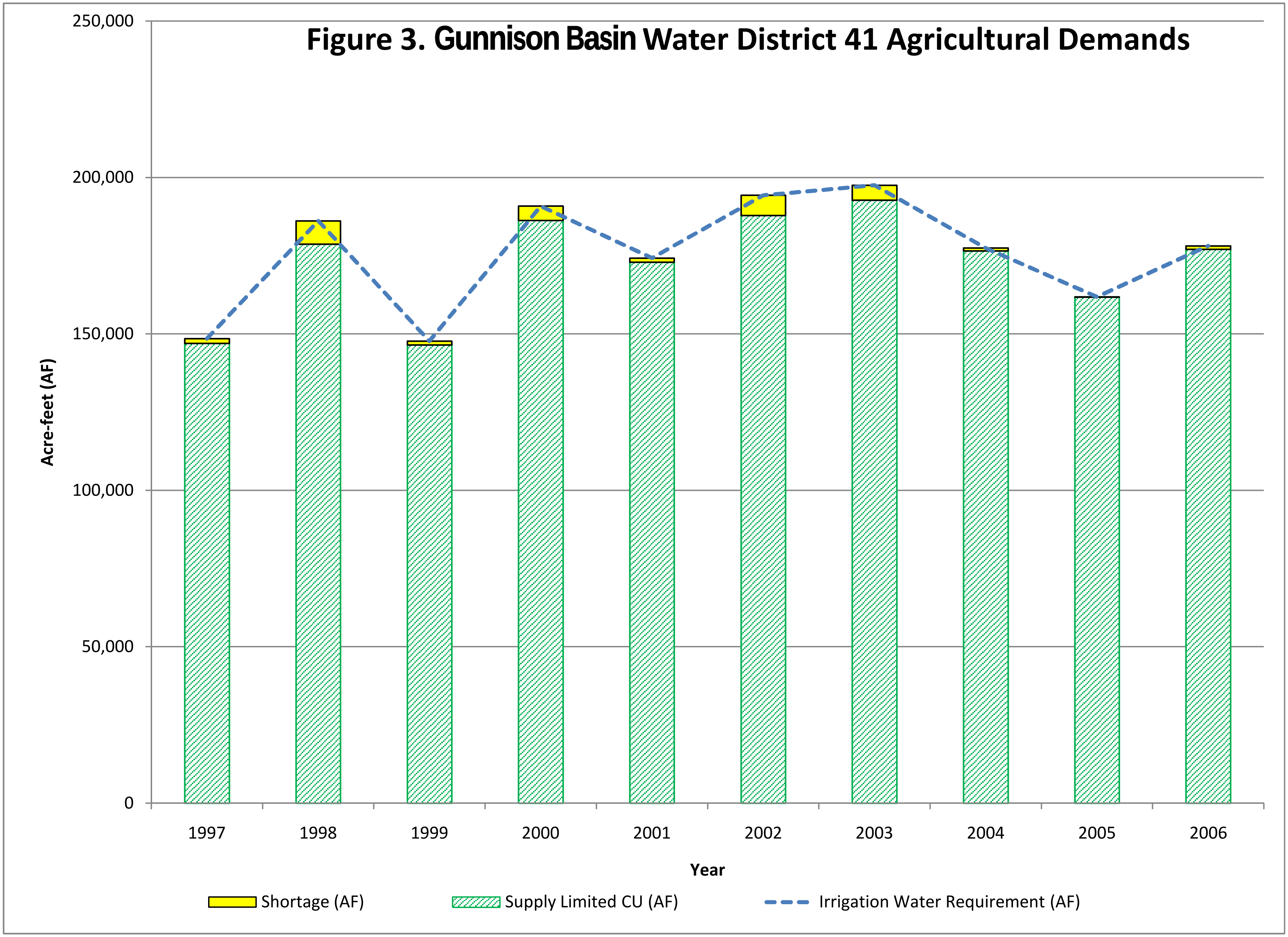


Figure 3. Gunnison Basin Water District 41 Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

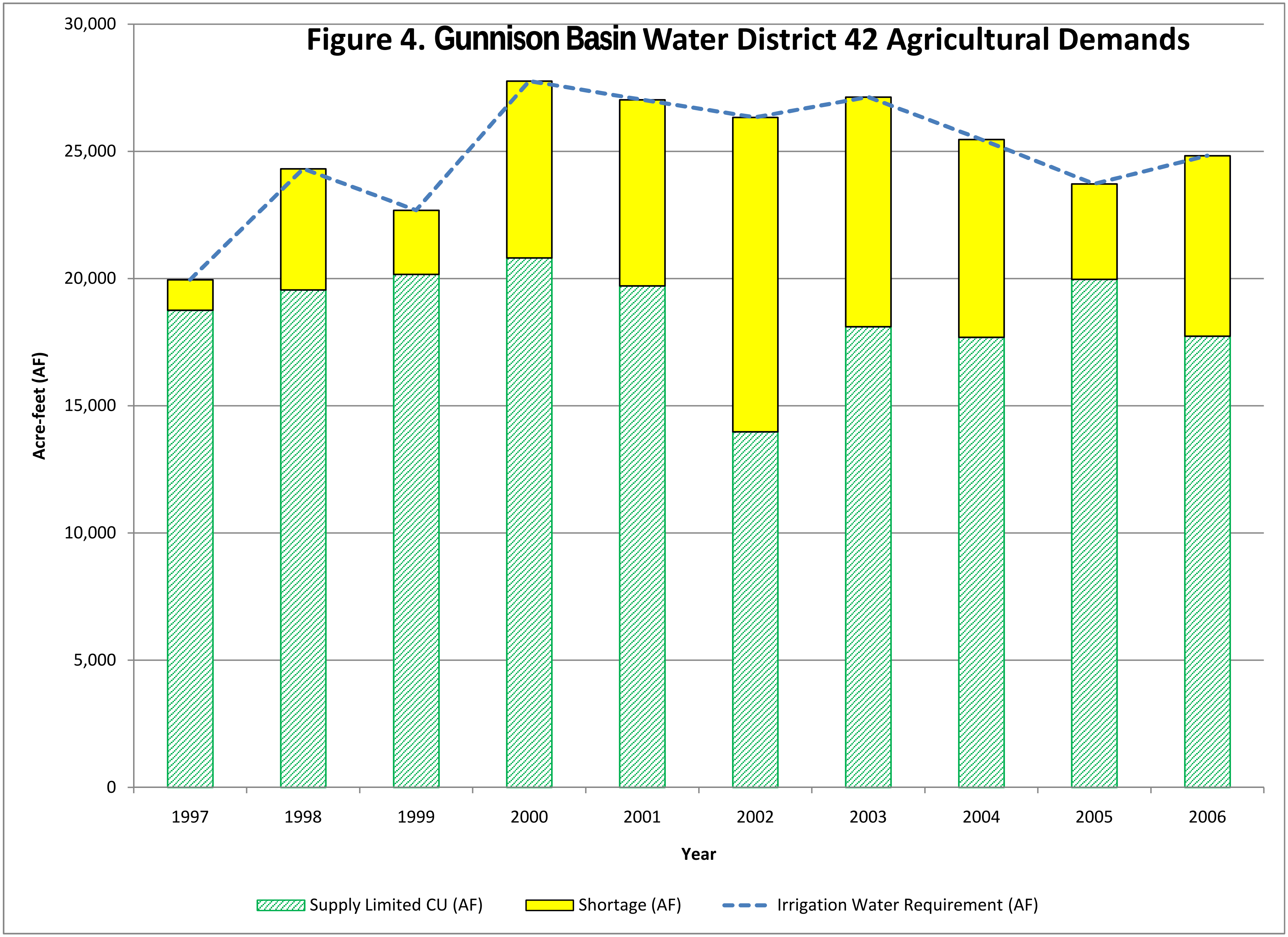


Figure 4. Gunnison Basin Water District 42 Agricultural Demands
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

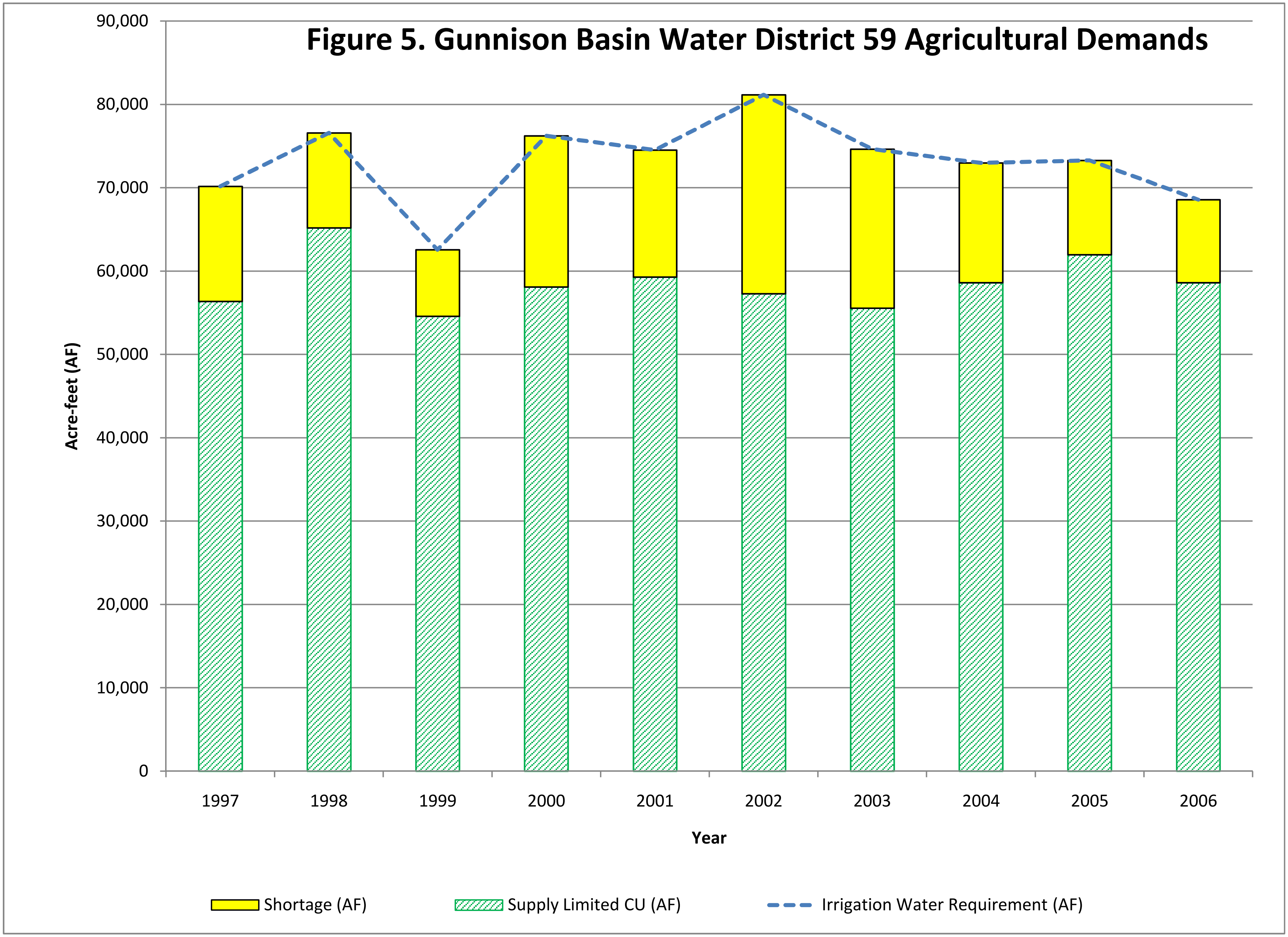


Figure 5. Gunnison Basin Water District 59 Agricultural Demands
Acre-feet (AF)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

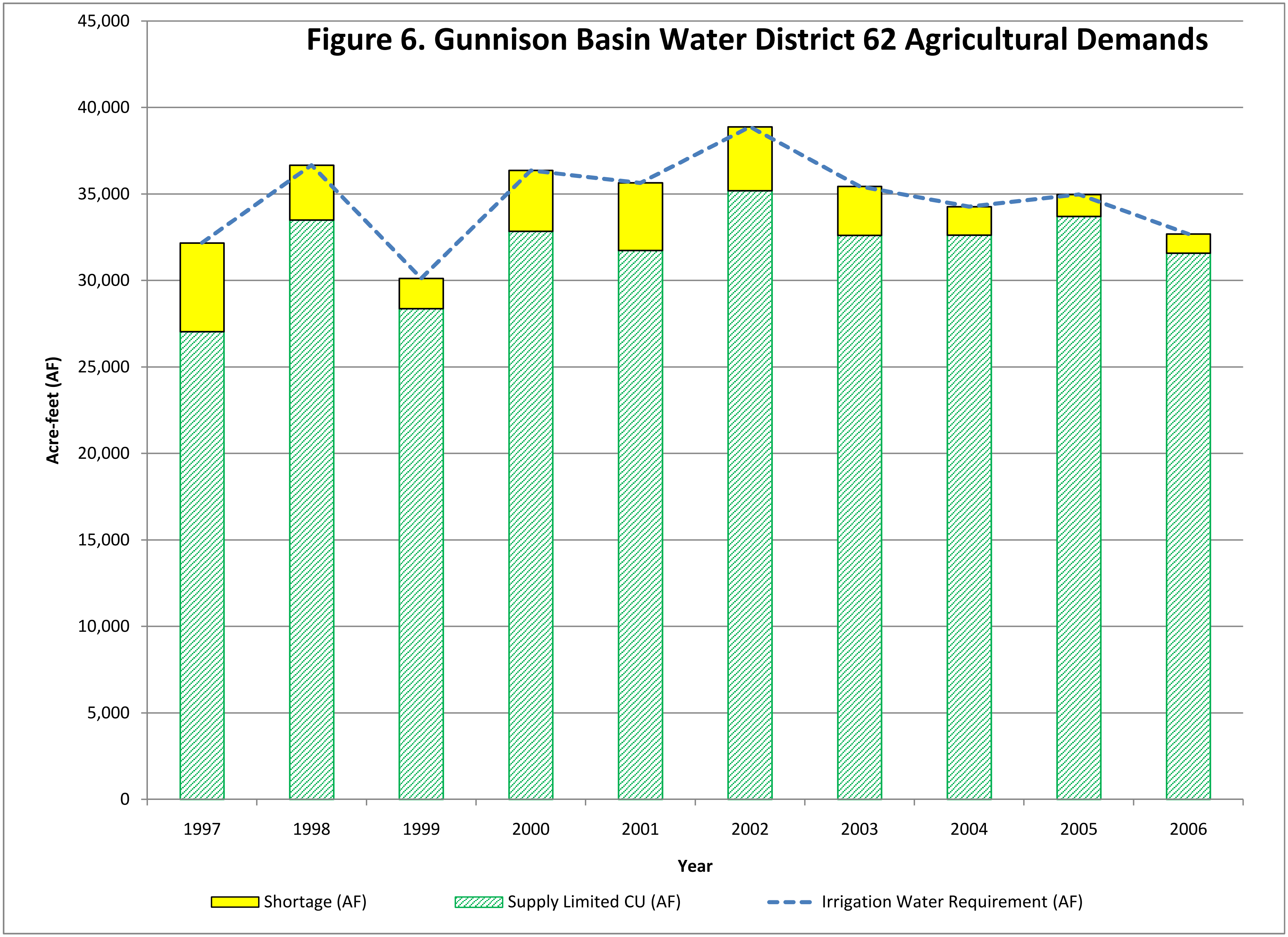


Figure 6. Gunnison Basin Water District 62 Agricultural Demands
Acre-feet (AF)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

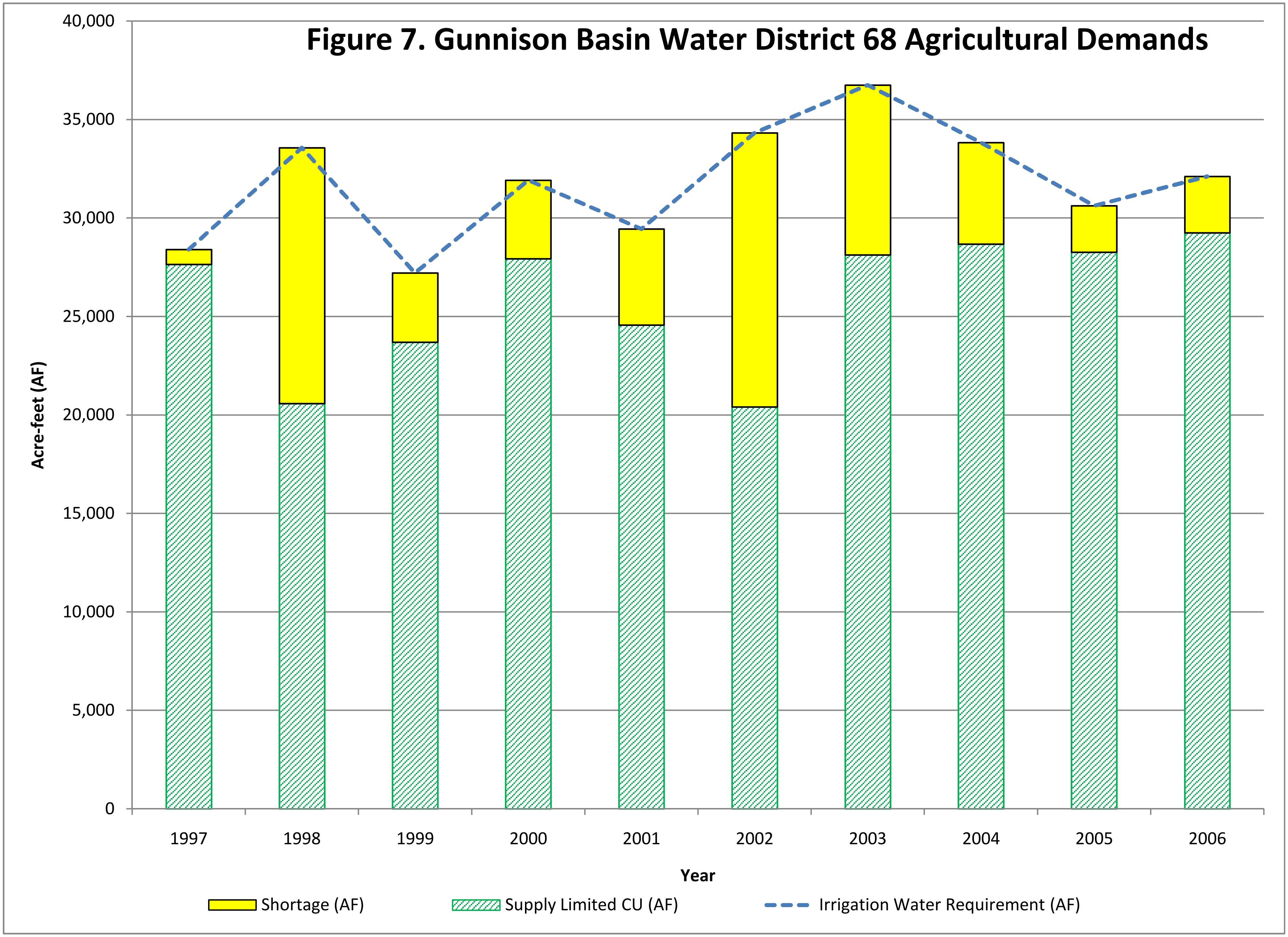


Figure 7. Gunnison Basin Water District 68 Agricultural Demands
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

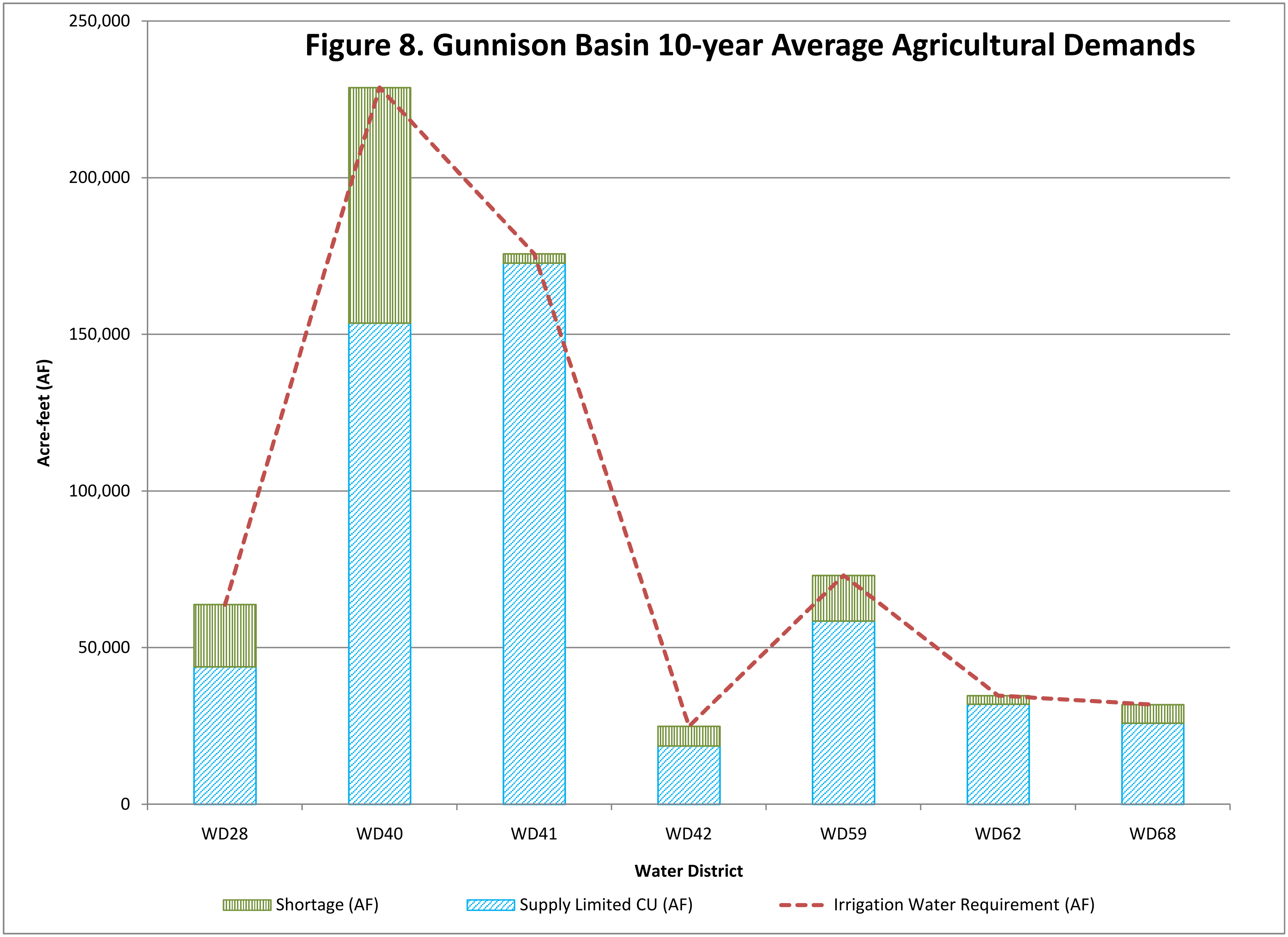


Figure 8. Gunnison Basin 10-year Average Agricultural Demands
Acre-feet (AF)
250,000
200,000
150,000
100,000
50,000
0
WD28
WD40
WD41
WD42
WD59
WD62
WD68
Water District
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

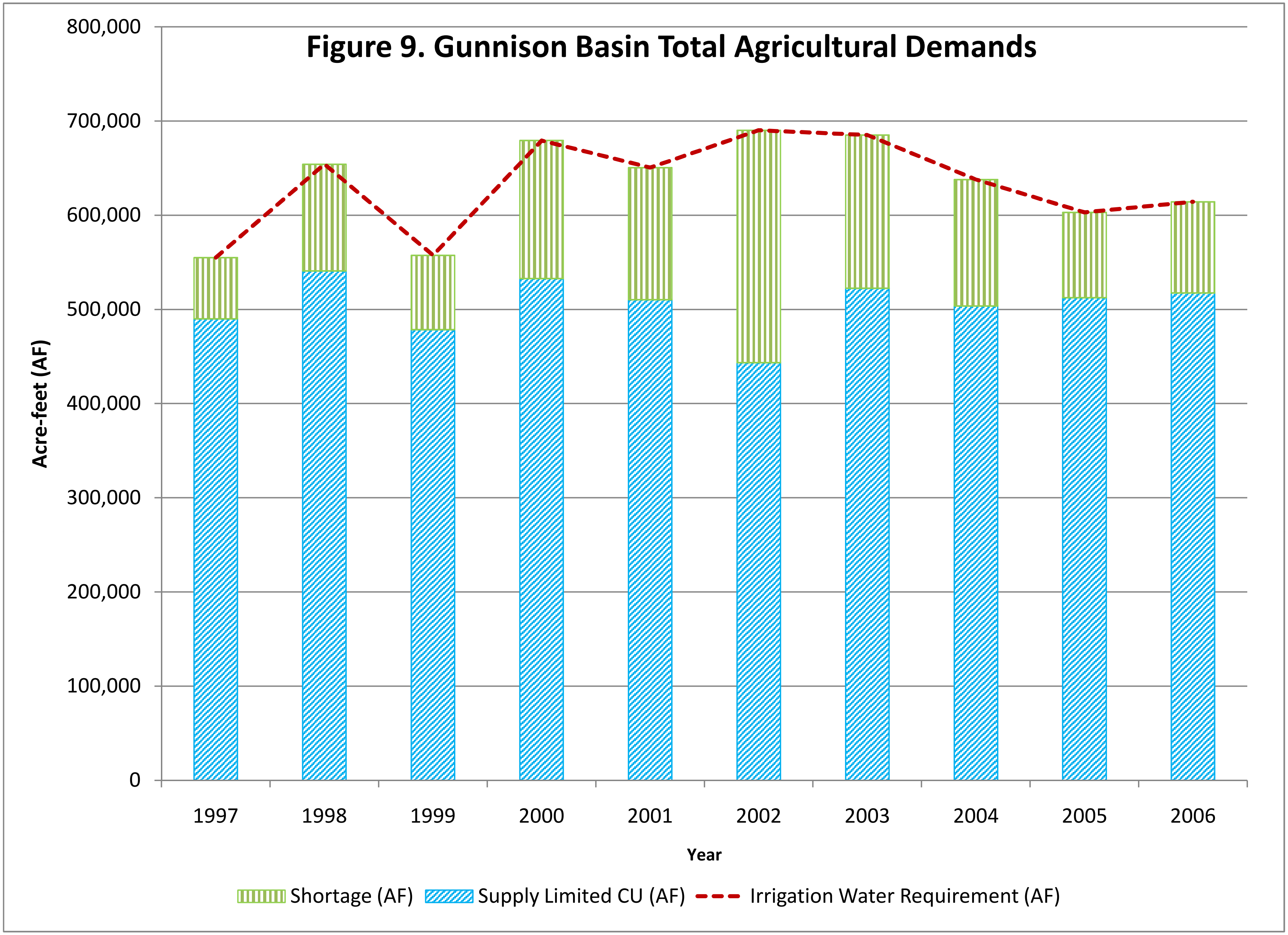


Figure 9. Gunnison Basin Total Agricultural Demands
Acre-feet (AF)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

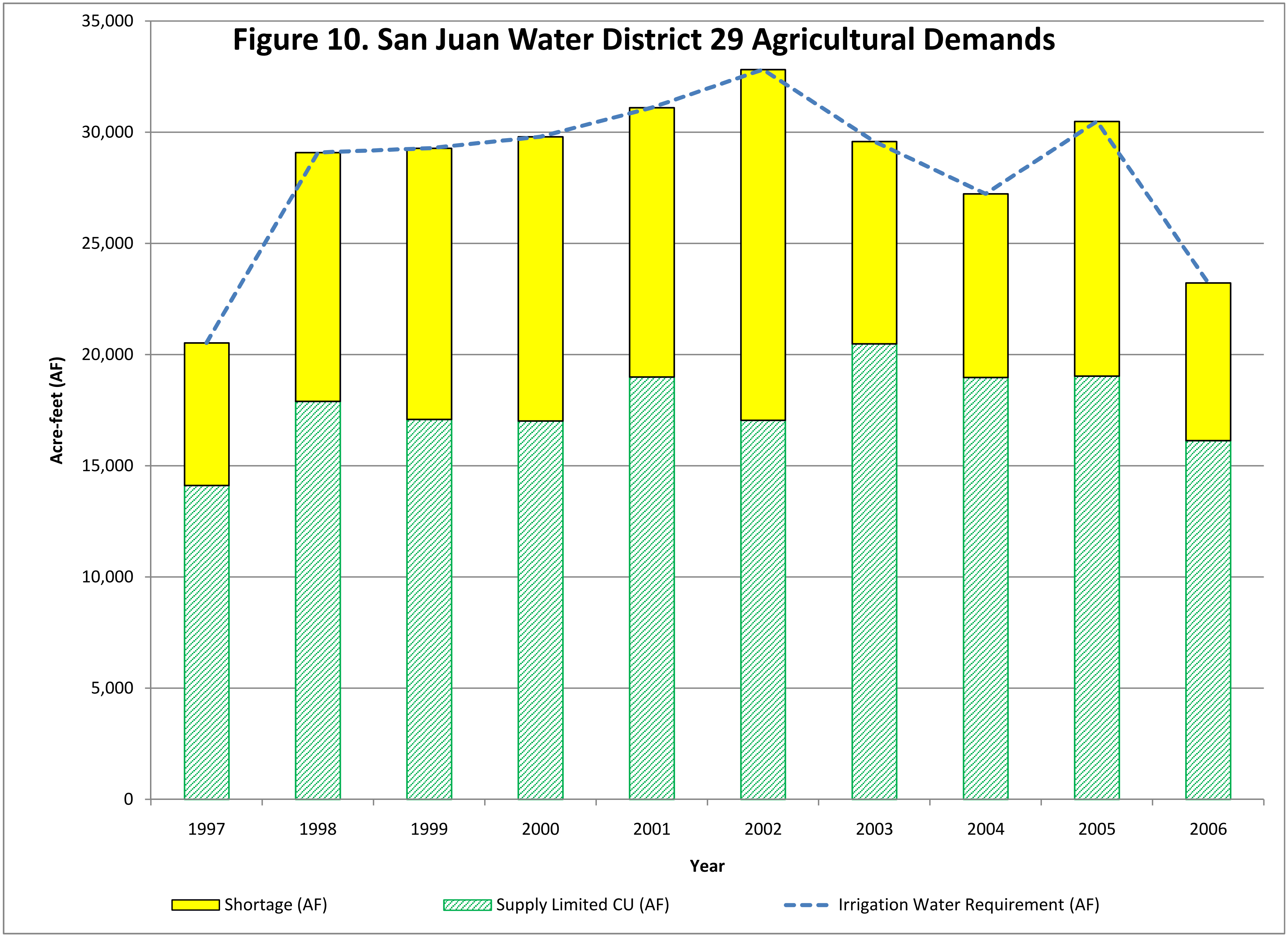


Figure 10. San Juan Water District 29 Agricultural Demands
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

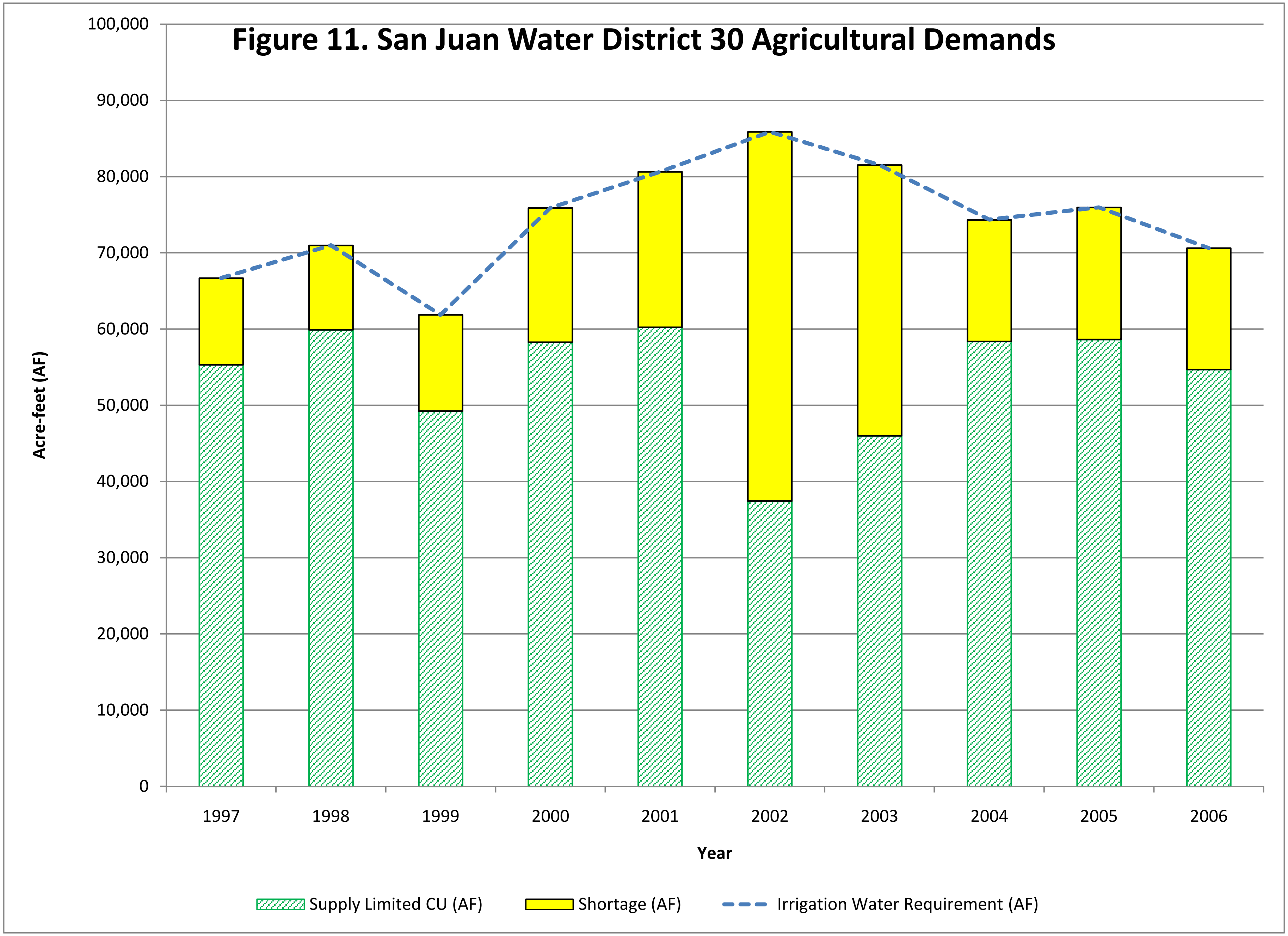


Figure 11. San Juan Water District 30 Agricultural Demands
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

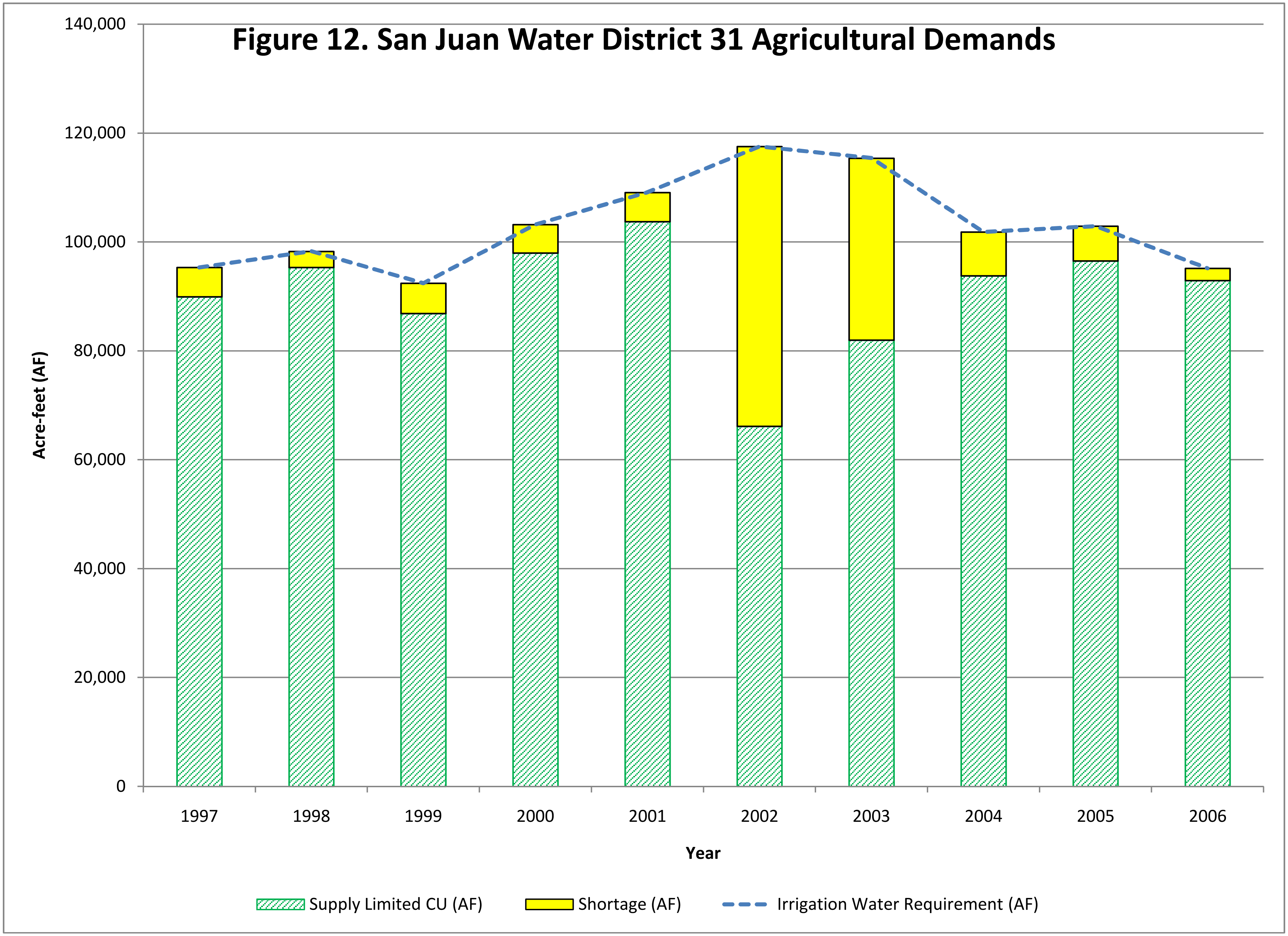


Figure 12. San Juan Water District 31 Agricultural Demands
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

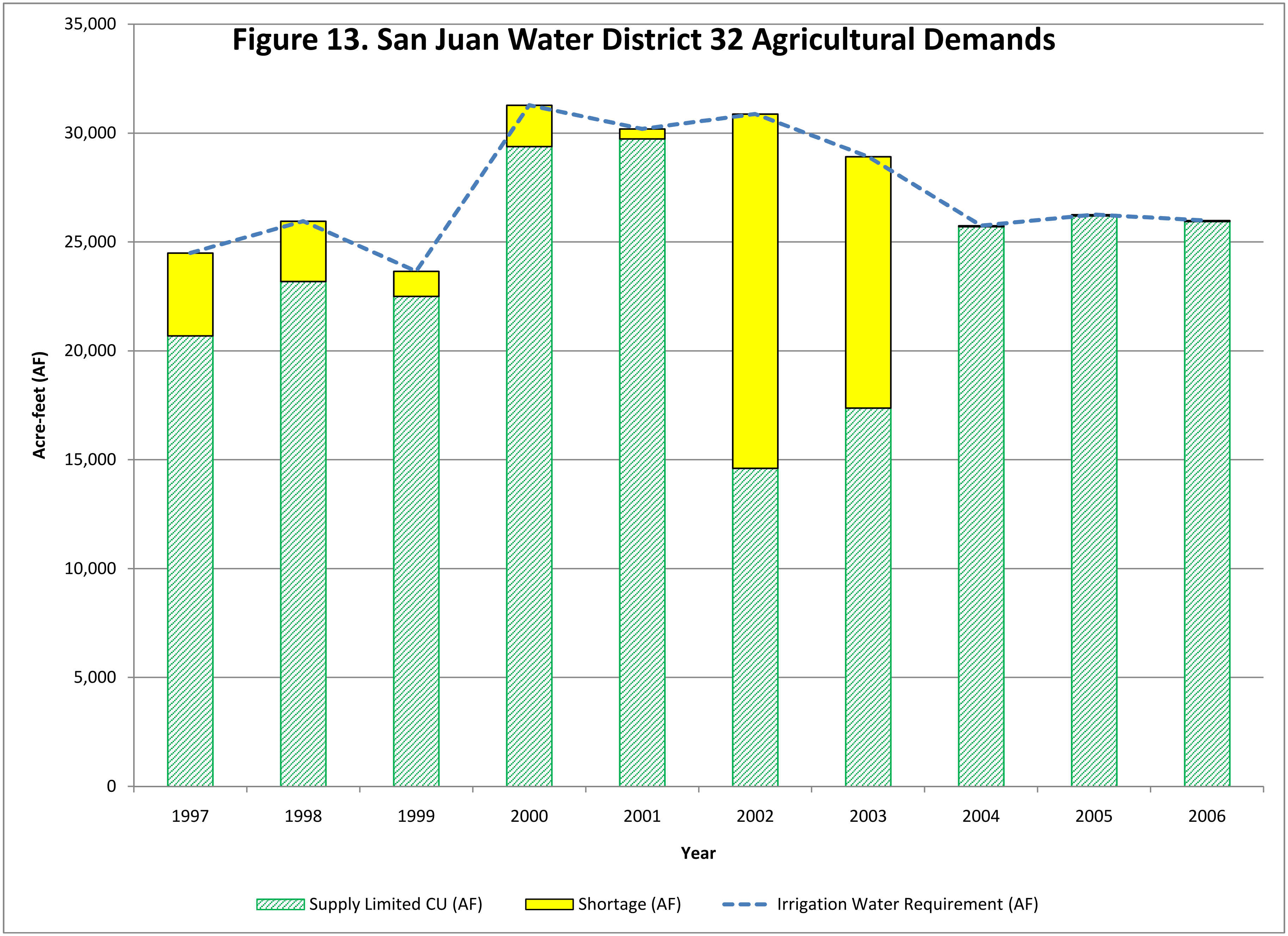


Figure 13. San Juan Water District 32 Agricultural Demands
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

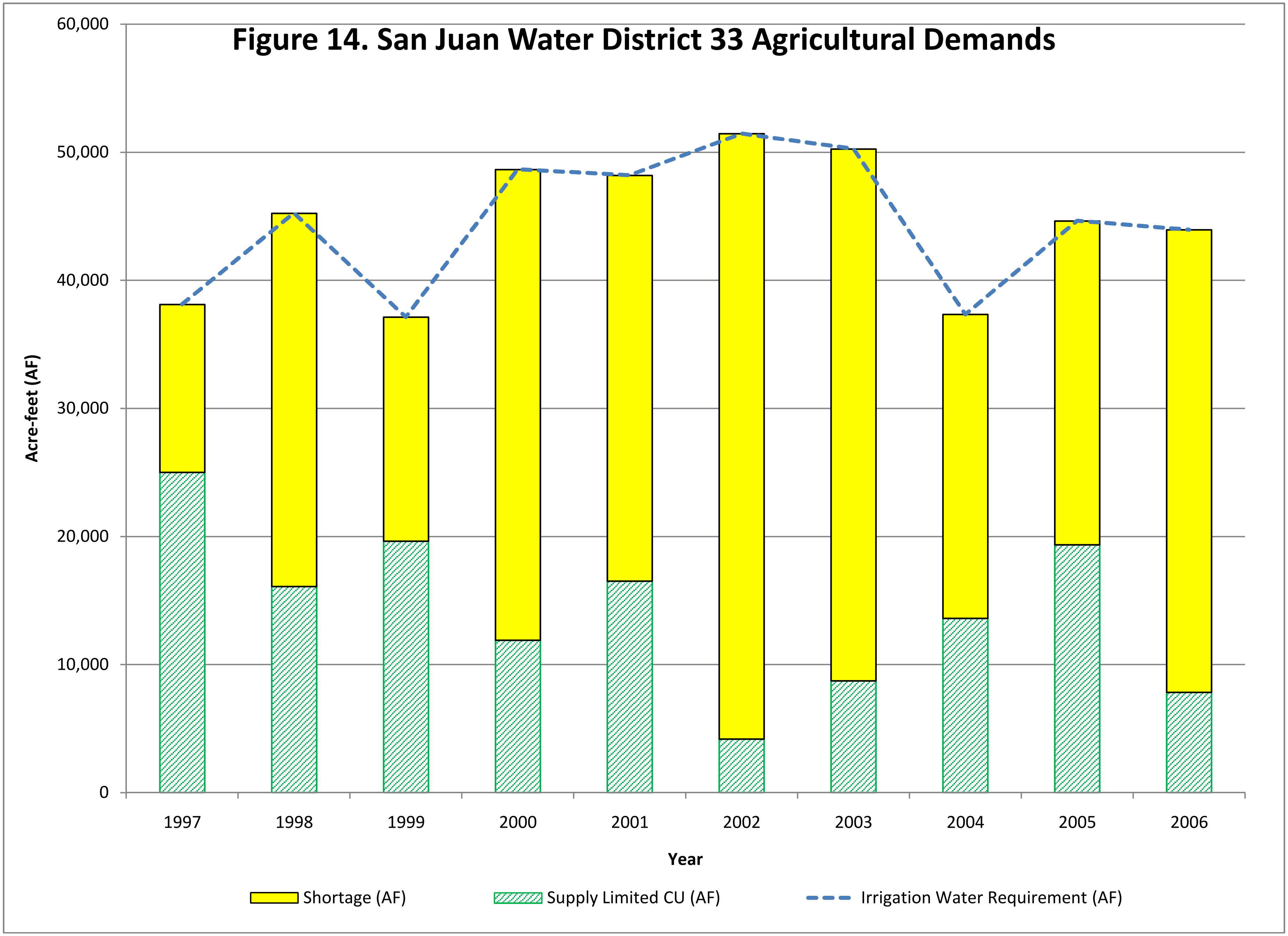


Figure 14. San Juan Water District 33 Agricultural Demands
Acre-feet (AF)
60,000
50,000
40,000
30,000
20,000
10,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

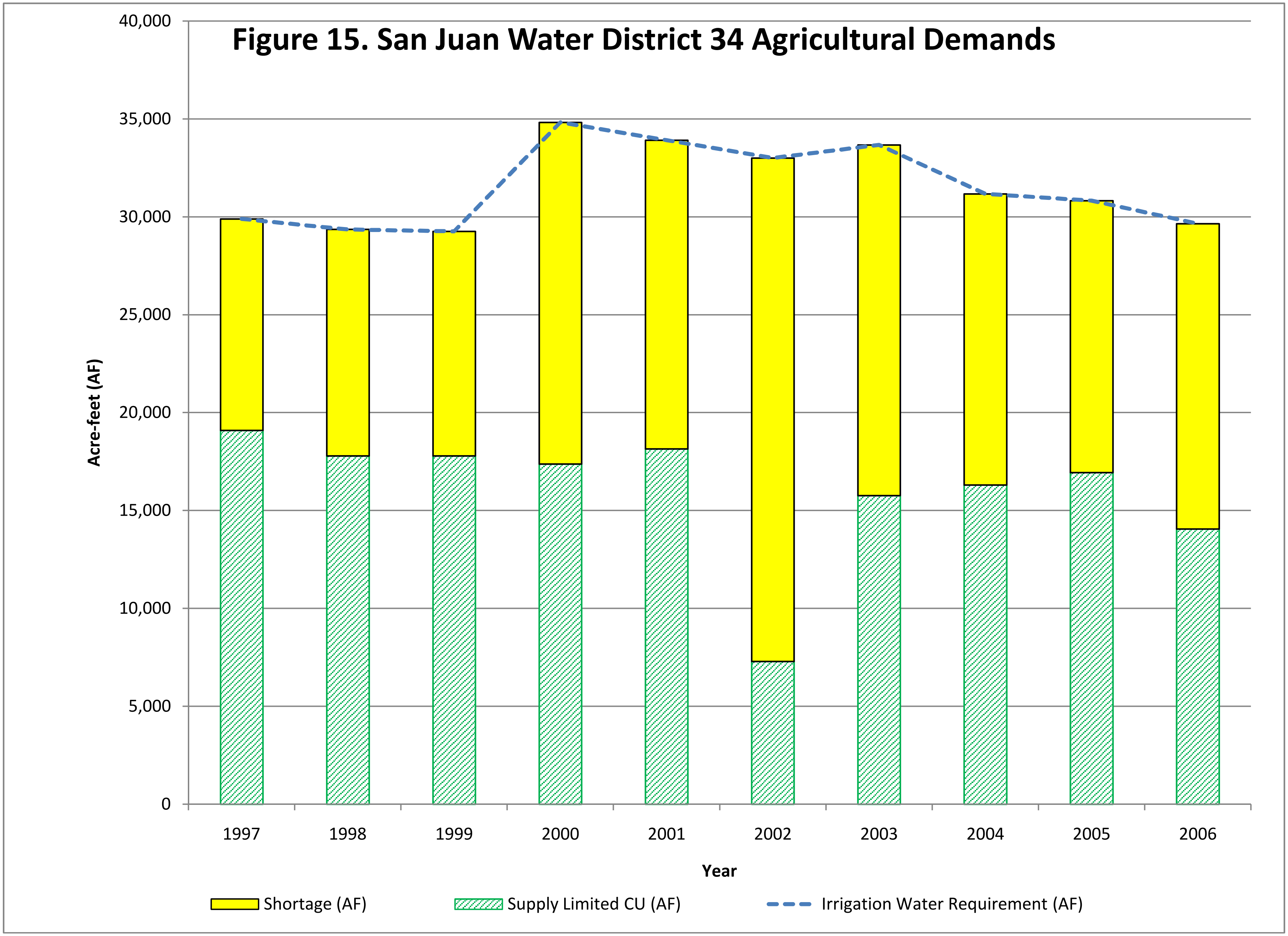


Figure 15. San Juan Water District 34 Agricultural Demands
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

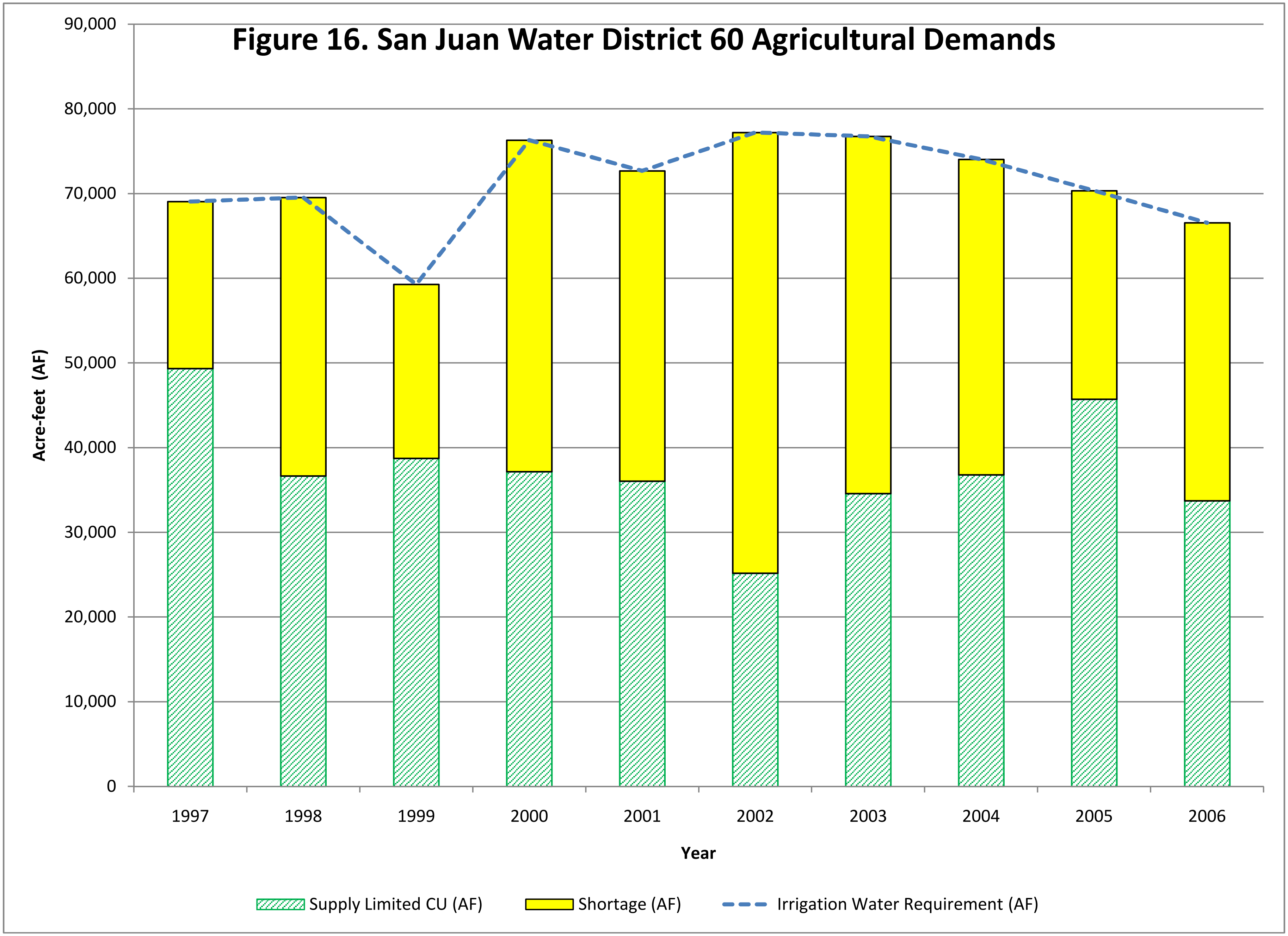


Figure 16. San Juan Water District 60 Agricultural Demands
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

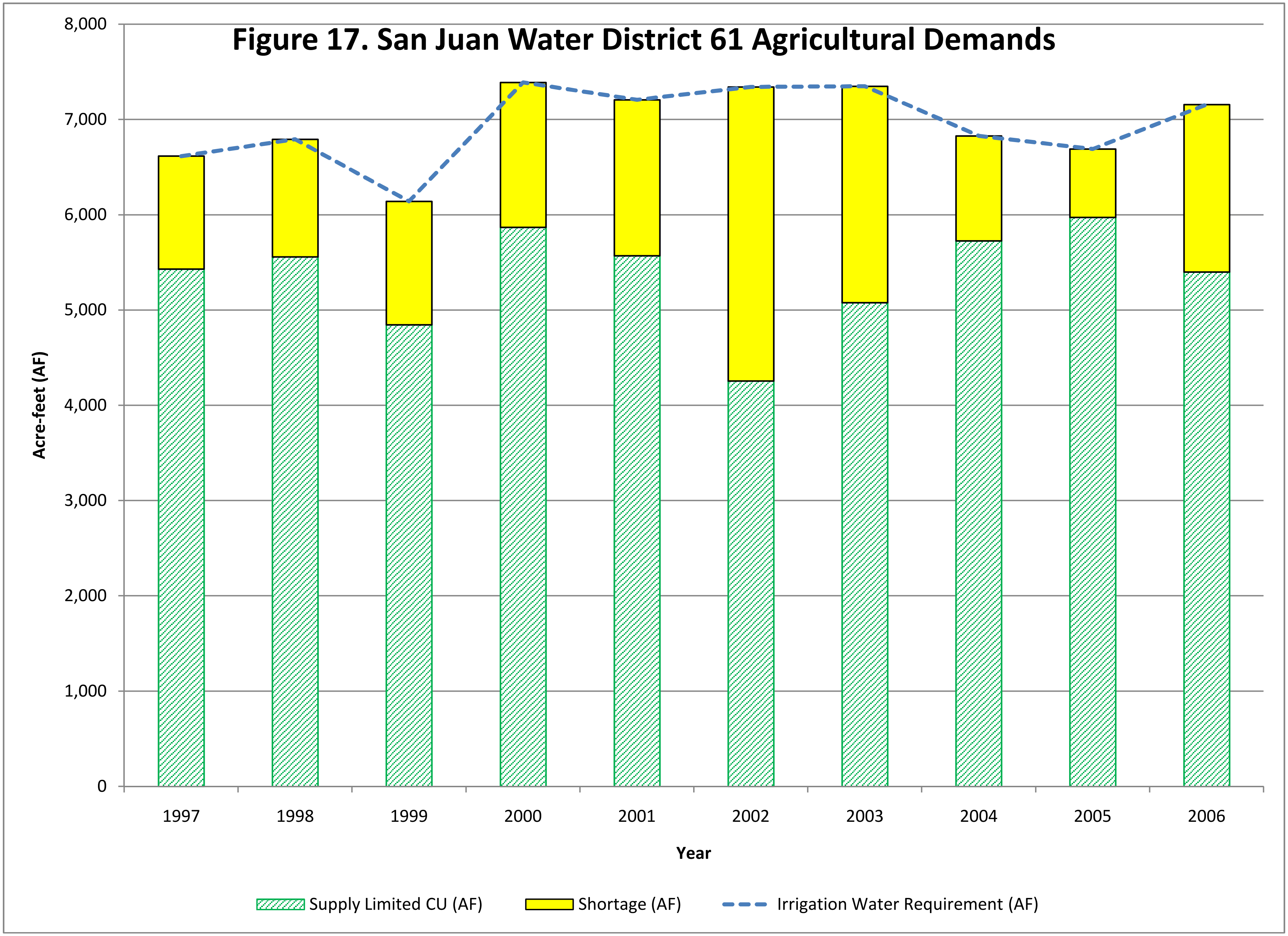


Figure 17. San Juan Water District 61 Agricultural Demands
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

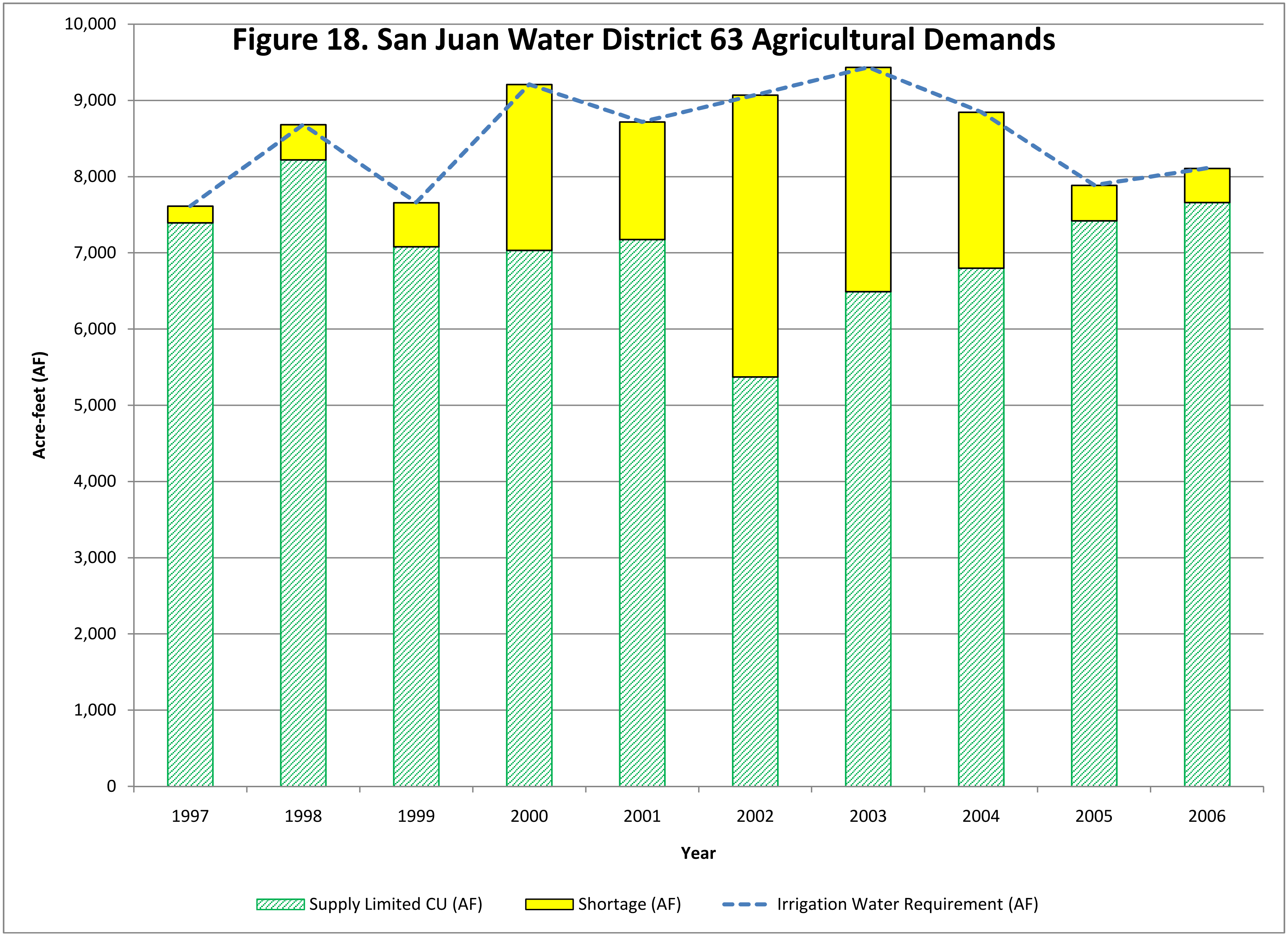


Figure 18. San Juan Water District 63 Agricultural Demands
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

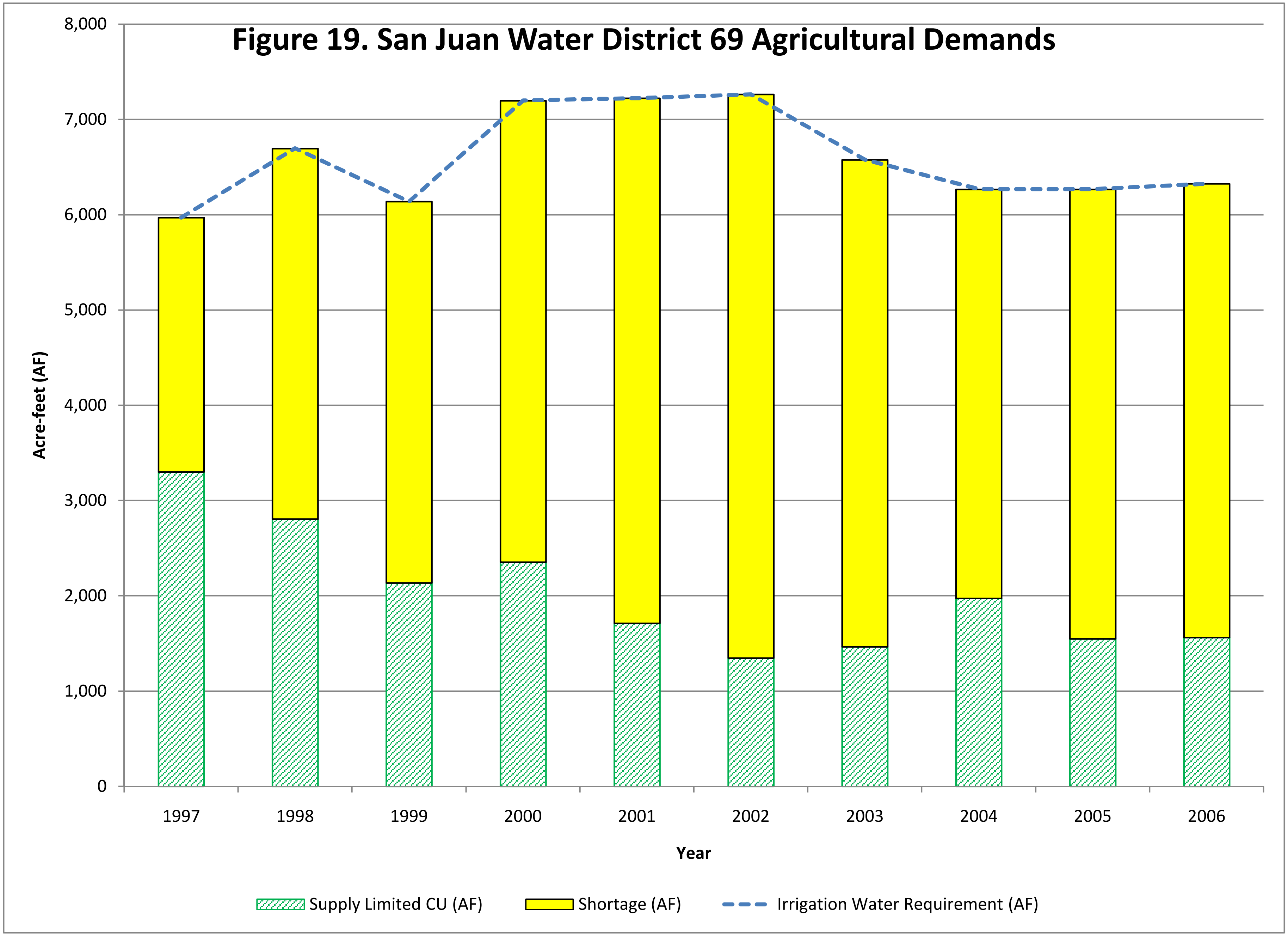


Figure 19. San Juan Water District 69 Agricultural Demands
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

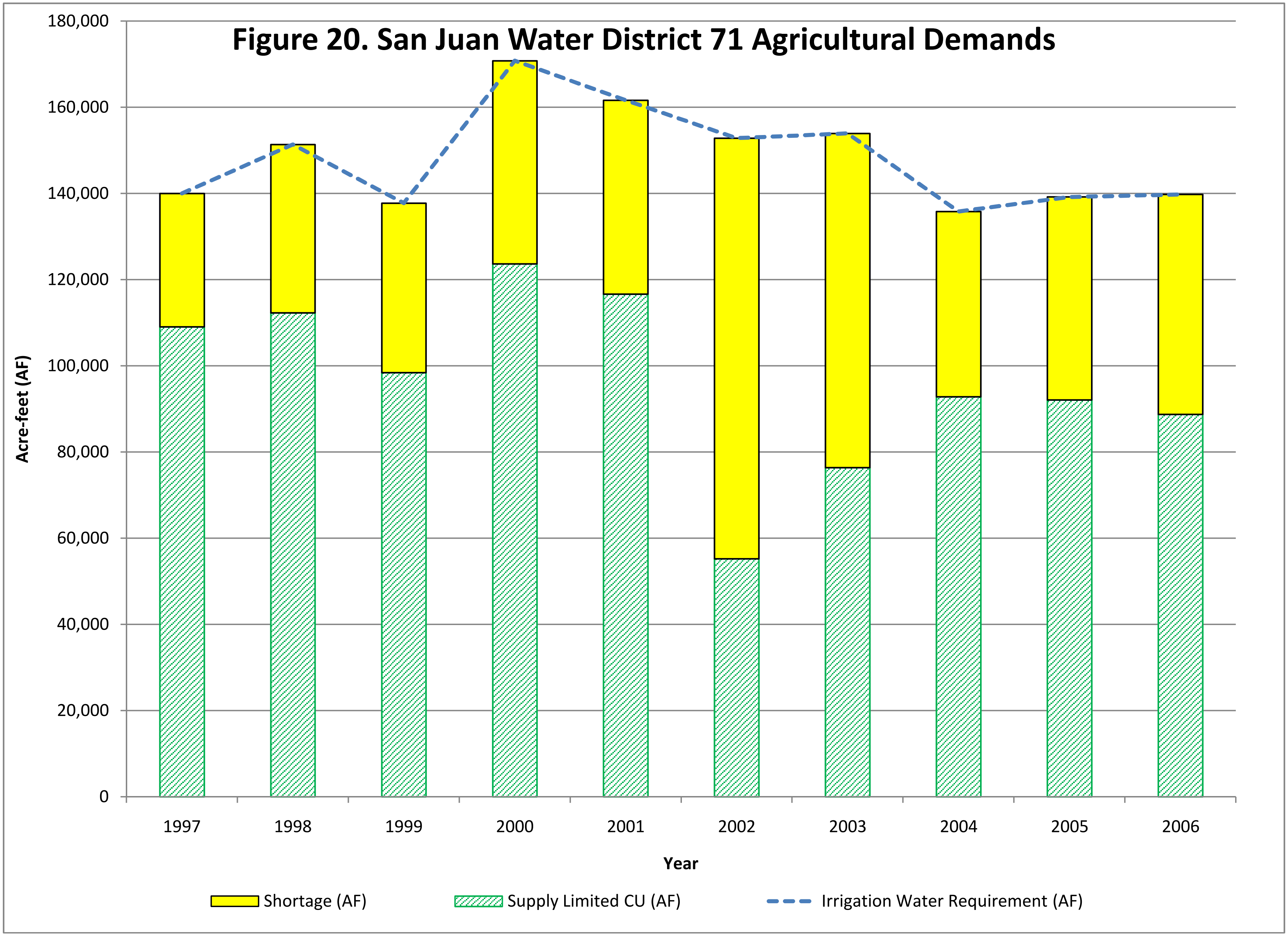


Figure 20. San Juan Water District 71 Agricultural Demands
Acre-feet (AF)
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

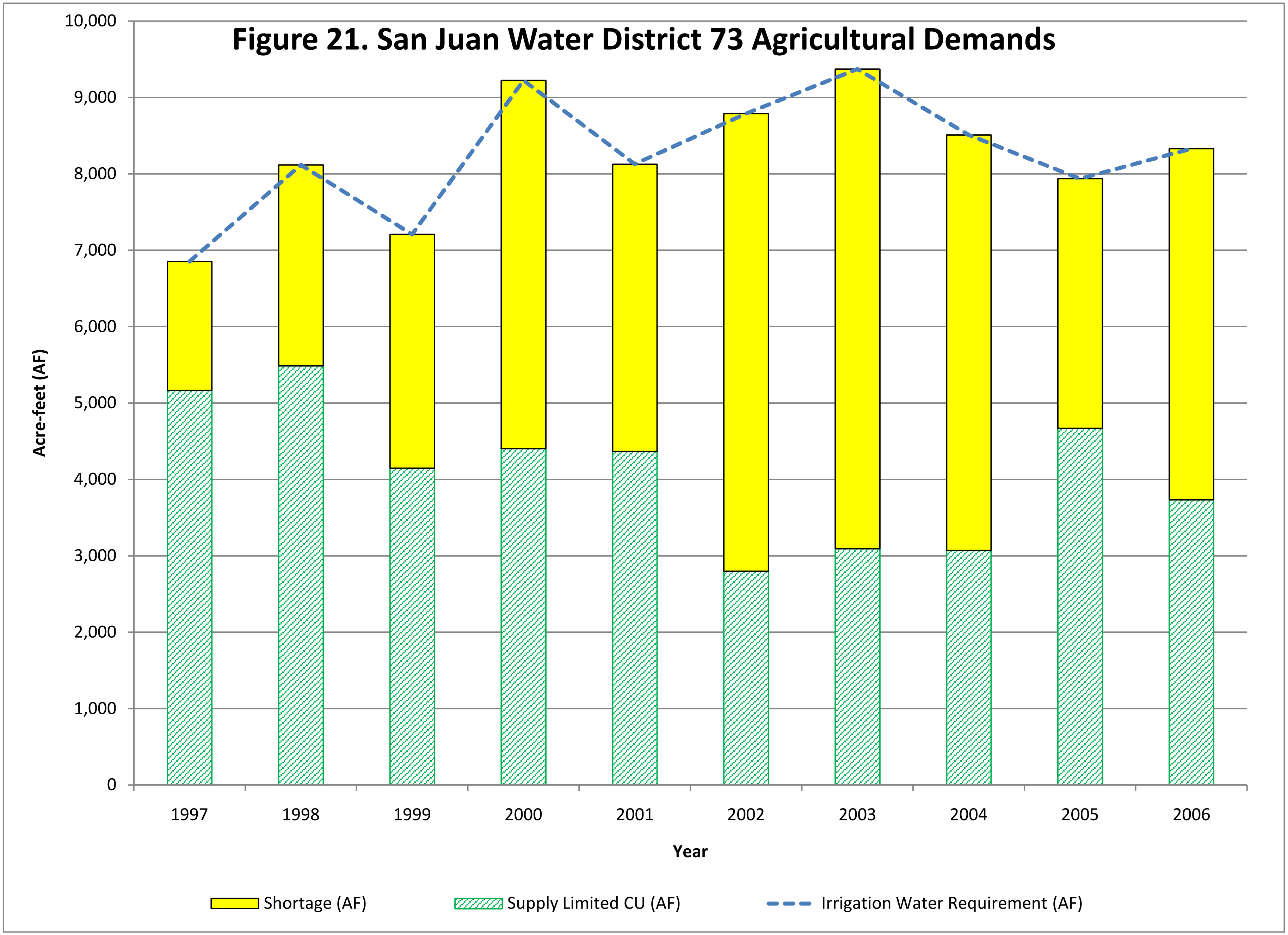


Figure 21. San Juan Water District 73 Agricultural Demands
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

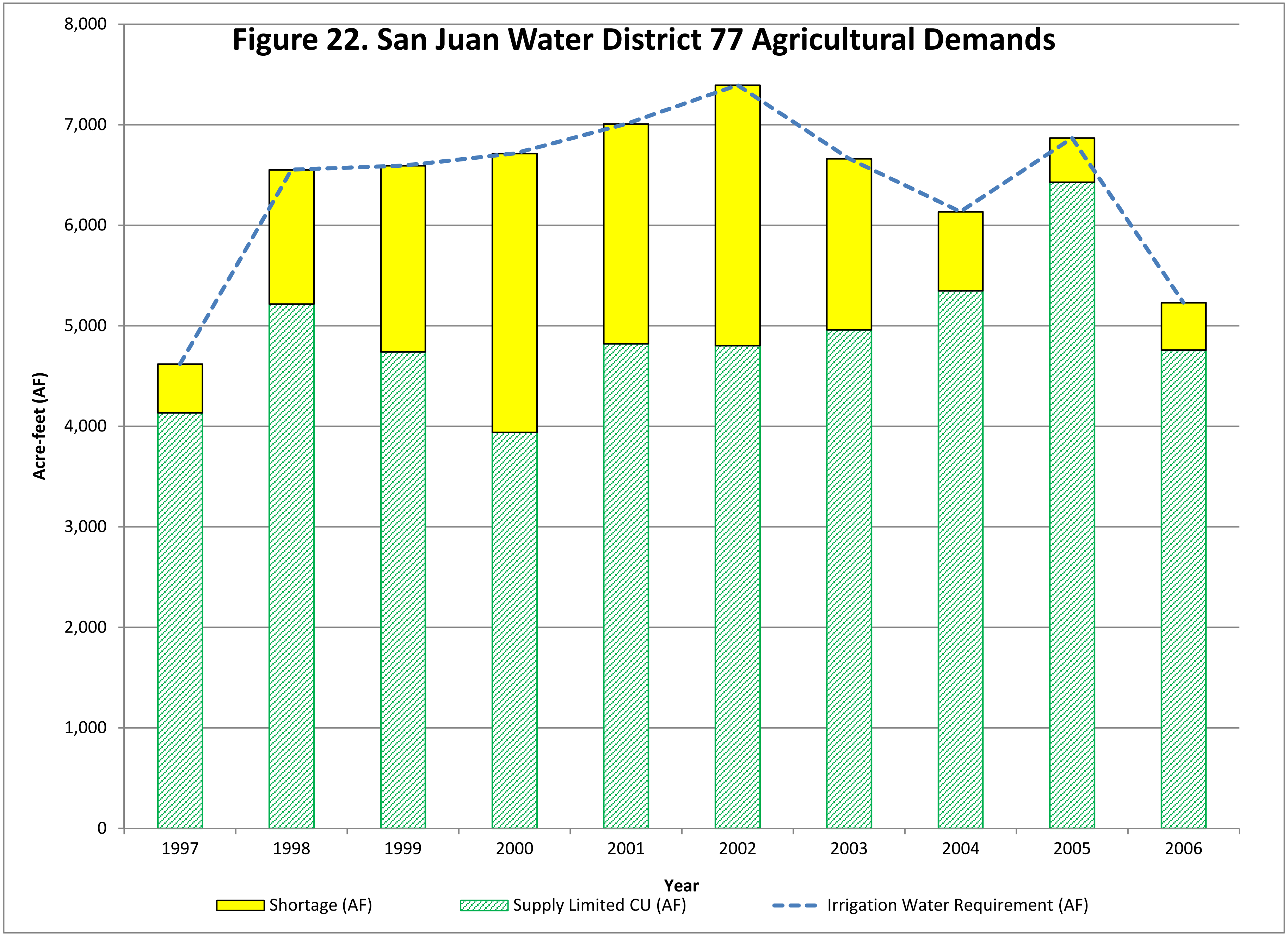


Figure 22. San Juan Water District 77 Agricultural Demands
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

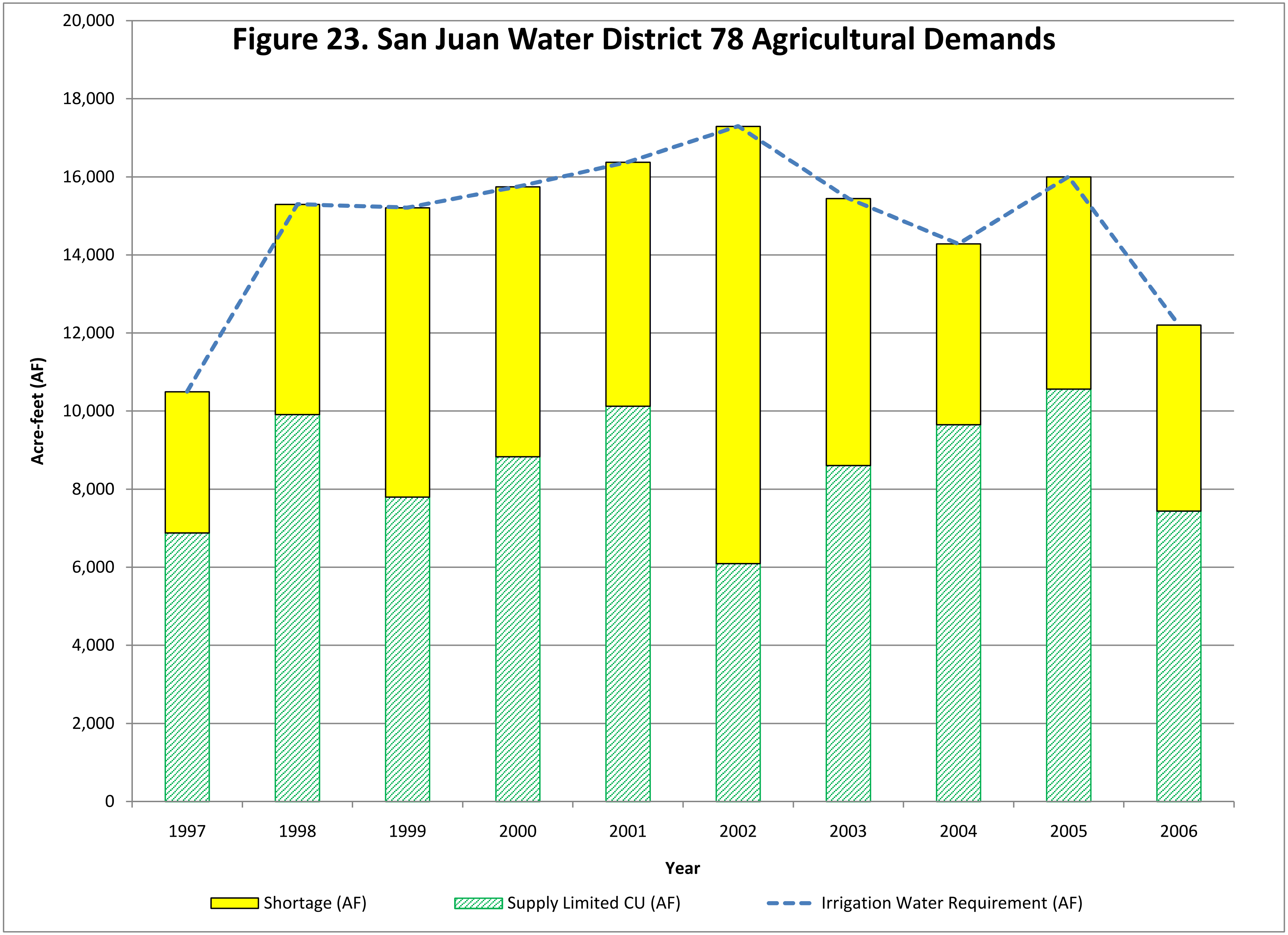


Figure 23. San Juan Water District 78 Agricultural Demands
Acre-feet (AF)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

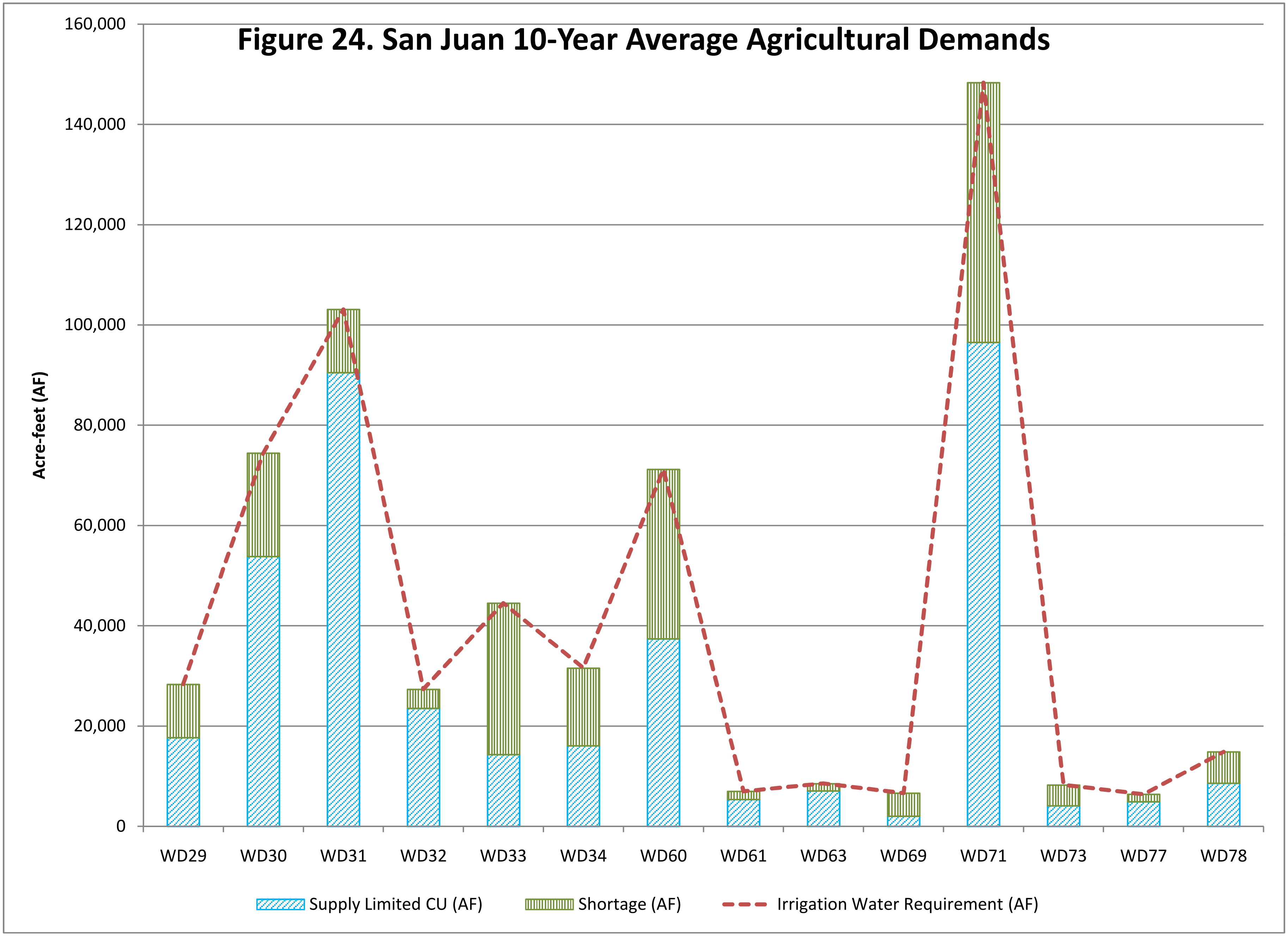


Figure 24. San Juan 10-Year Average Agricultural Demands
Acre-feet (AF)
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
WD29
WD30
WD31
WD32
WD33
WD34
WD60
WD61
WD63
WD69
WD71
WD73
WD77
WD78
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

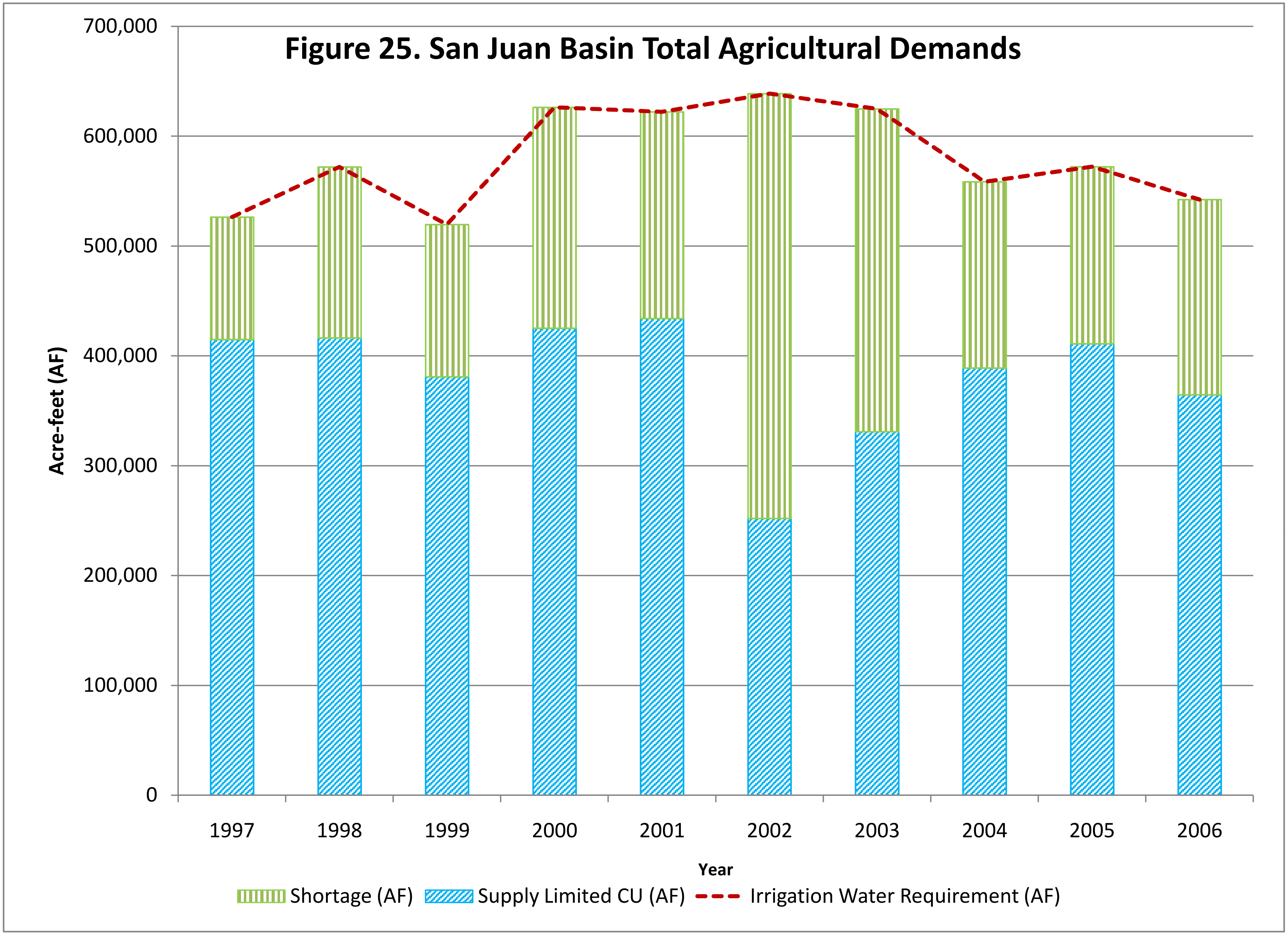


Figure 25. San Juan Basin Total Agricultural Demands
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

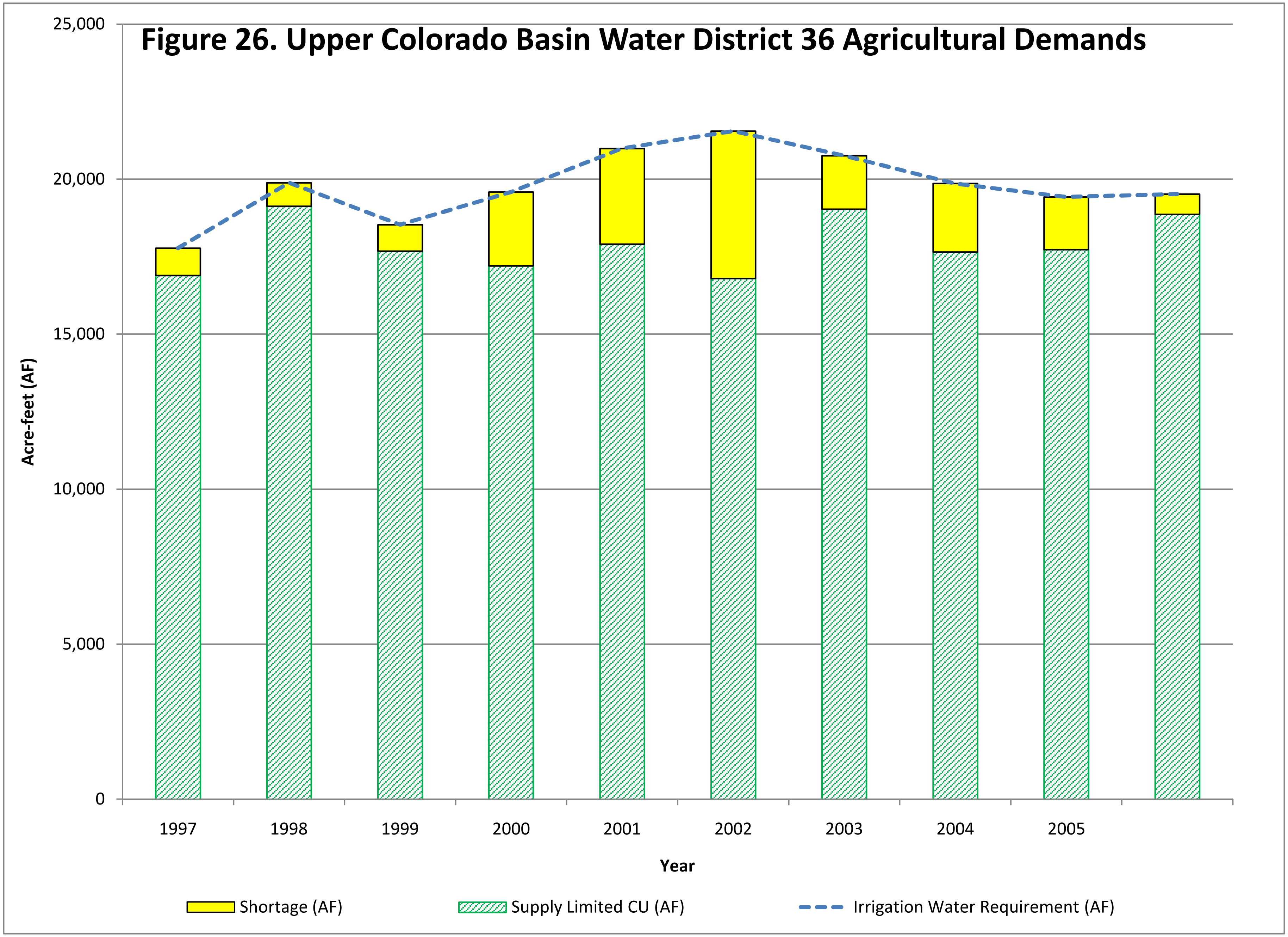
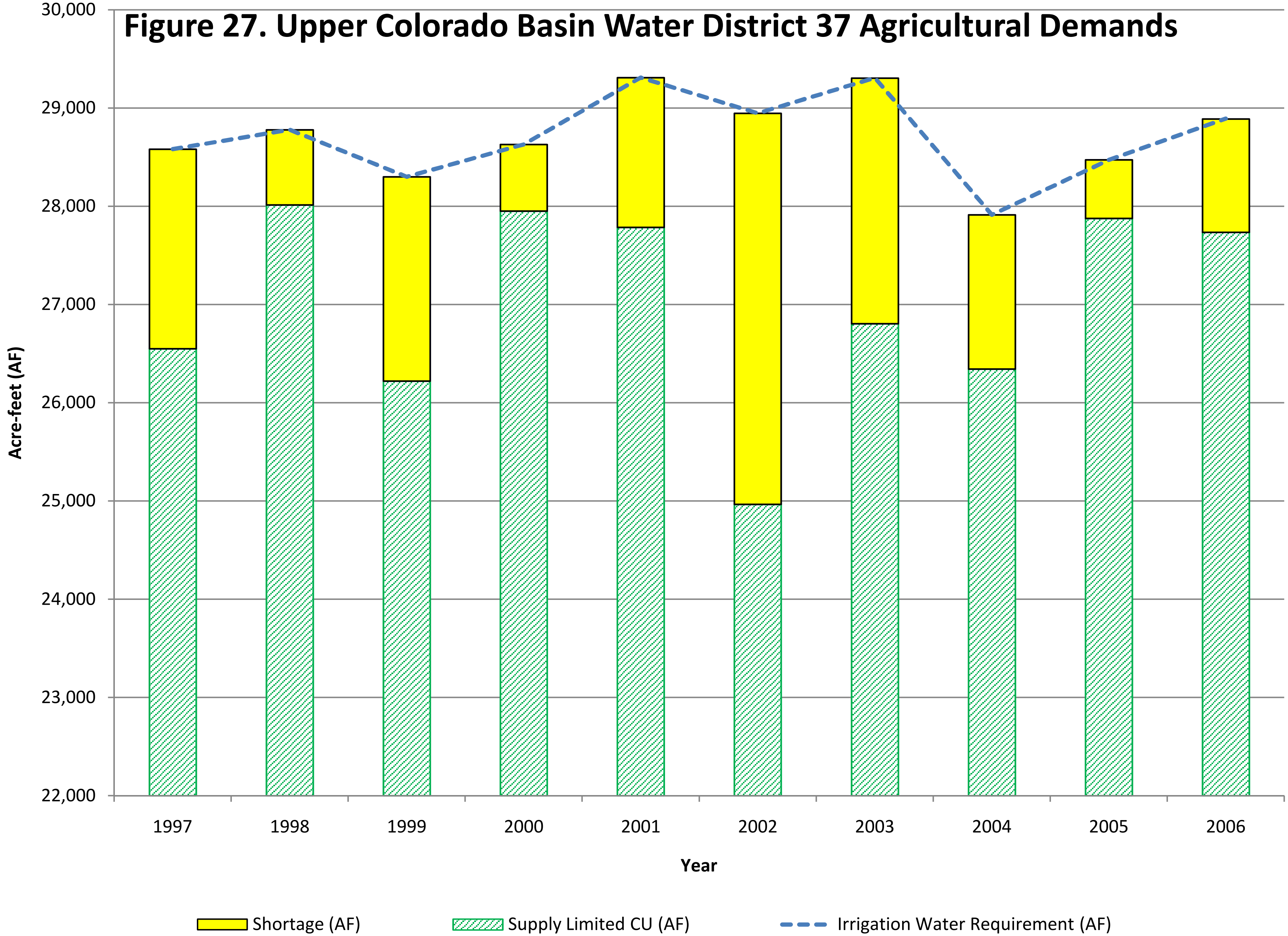


Figure 26. Upper Colorado Basin Water District 36 Agricultural Demands
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

Figure 27. Upper Colorado Basin Water District 37 Agricultural Demands



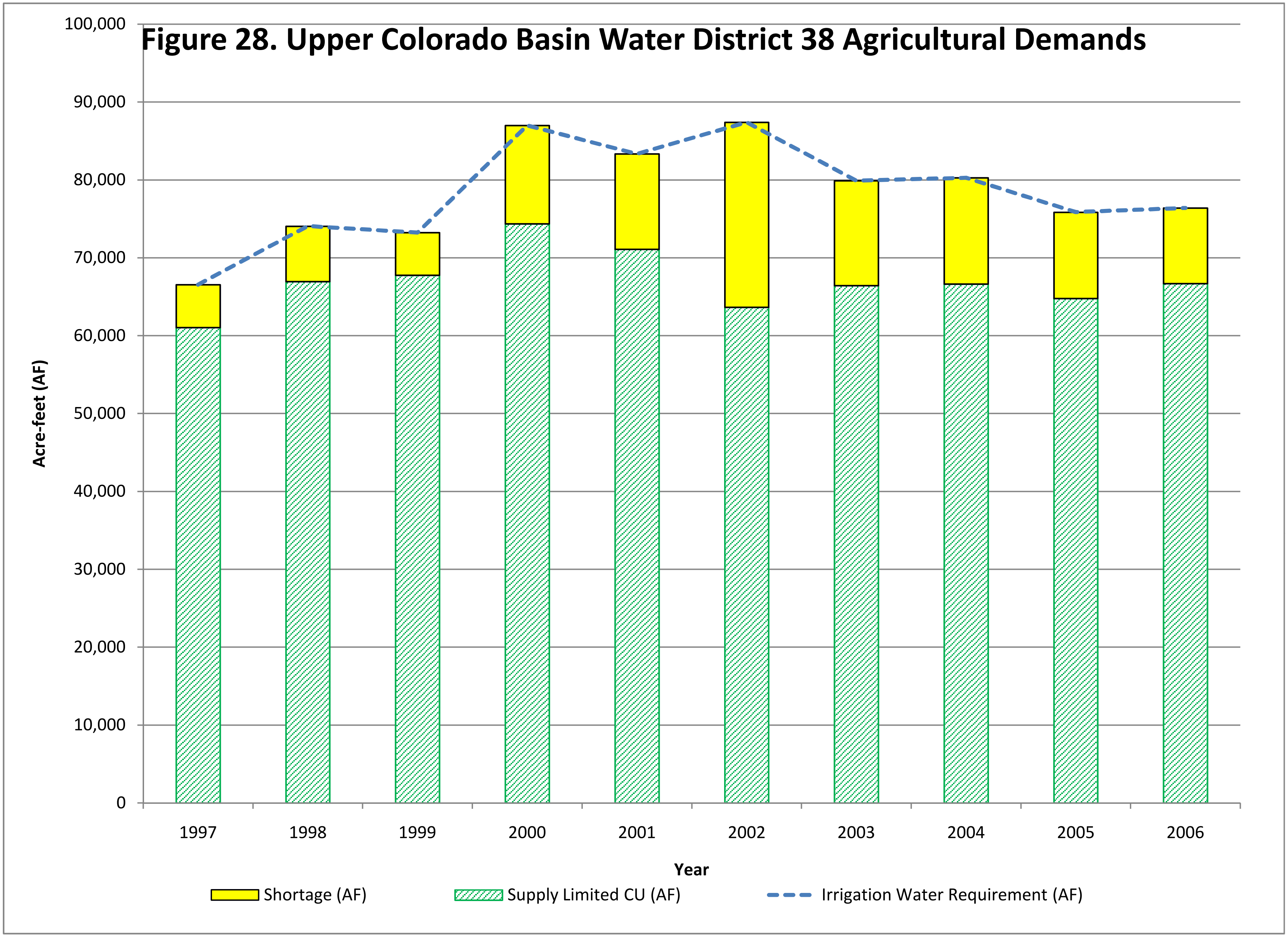


Figure 28. Upper Colorado Basin Water District 38 Agricultural Demands
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

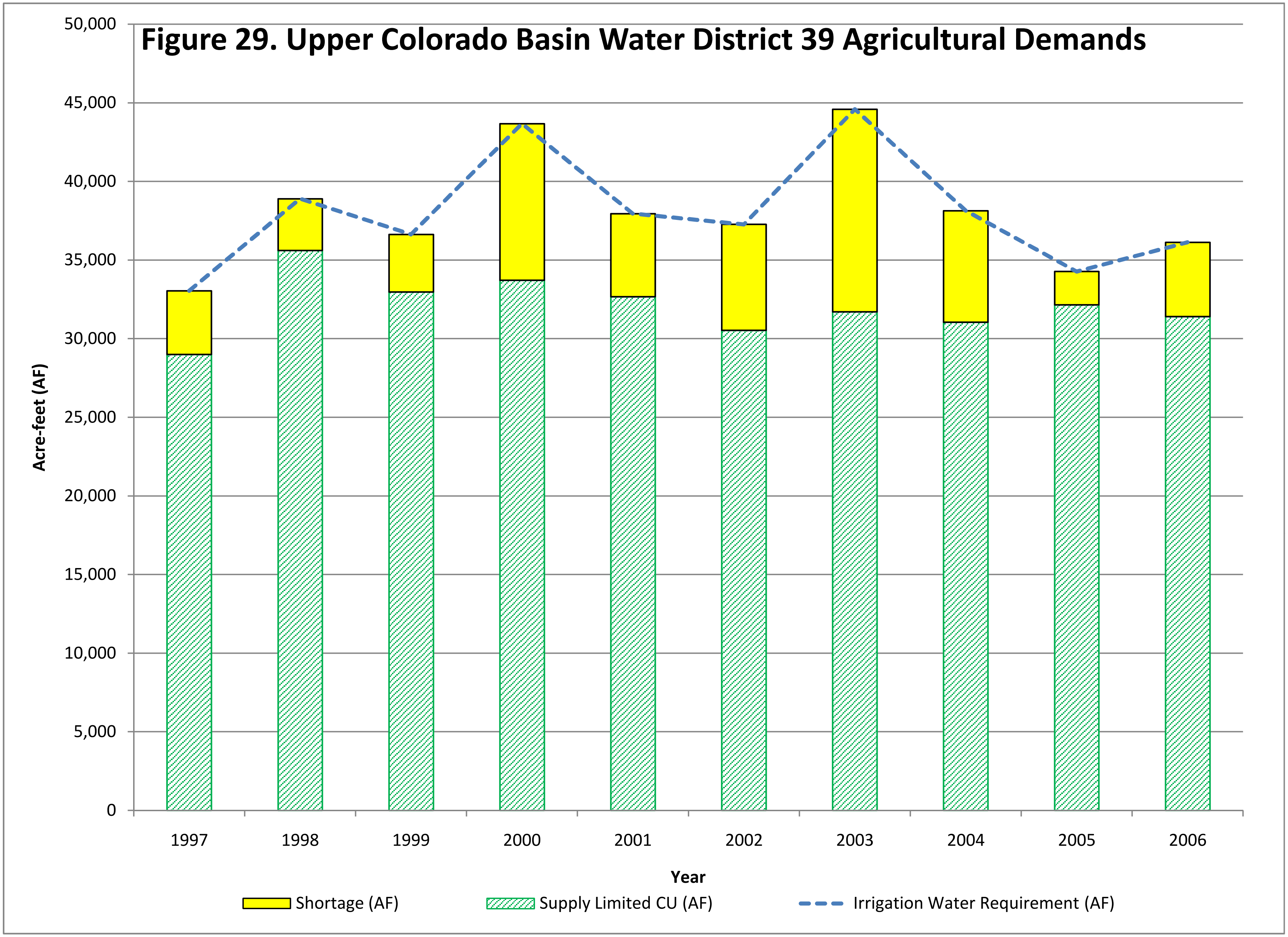


Figure 29. Upper Colorado Basin Water District 39 Agricultural Demands
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

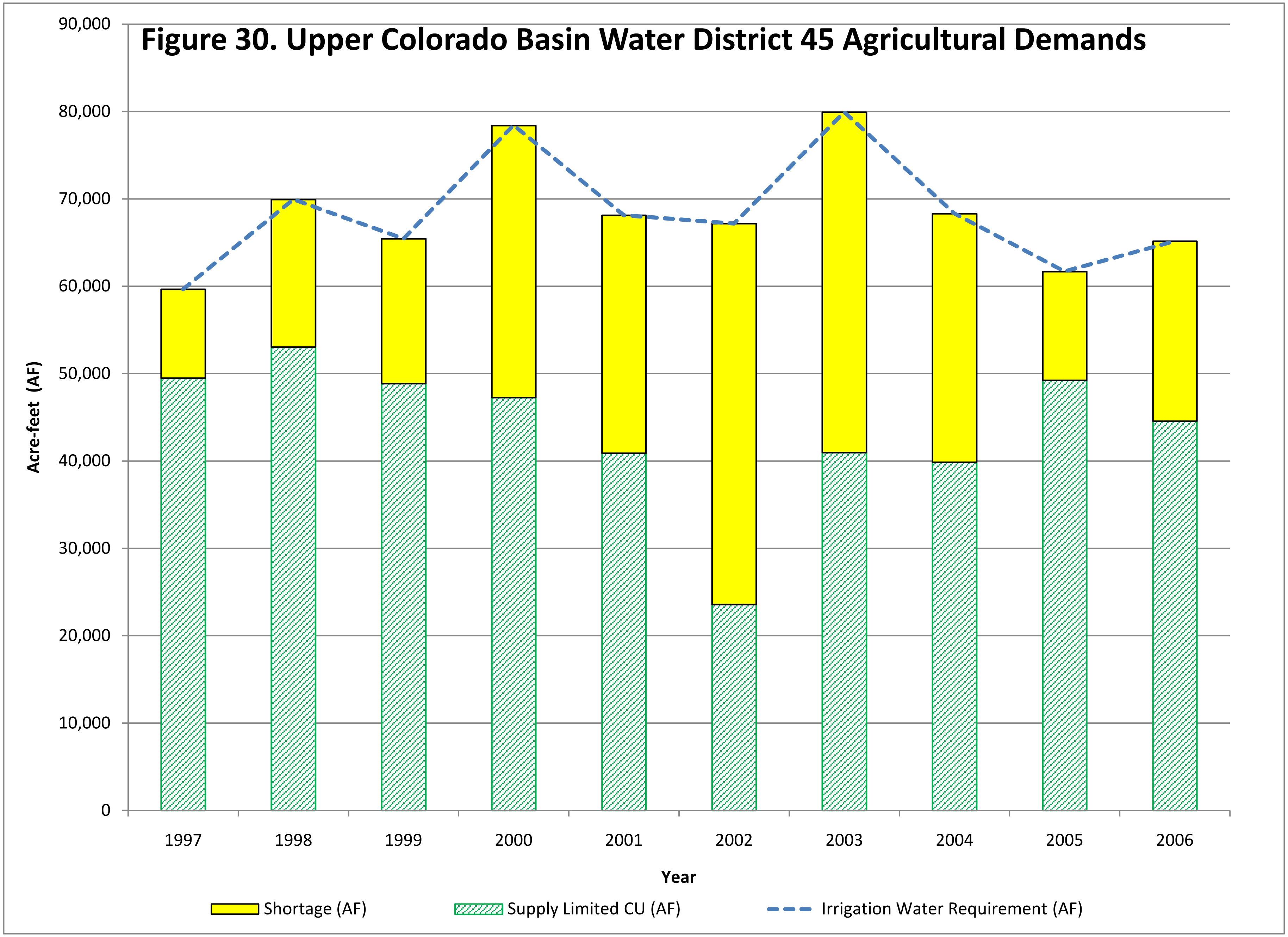


Figure 30. Upper Colorado Basin Water District 45 Agricultural Demands
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

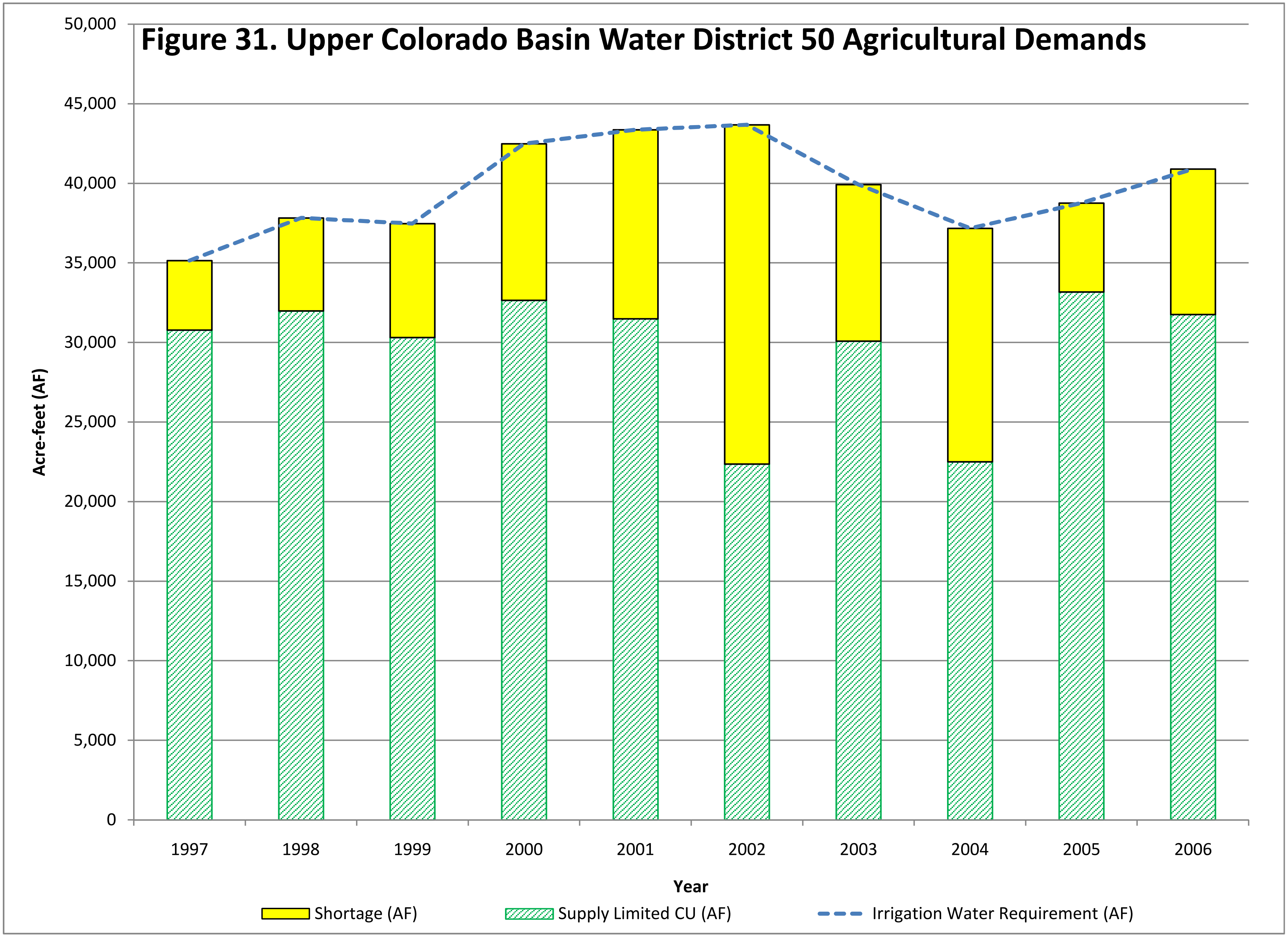


Figure 31. Upper Colorado Basin Water District 50 Agricultural Demands
Acre-feet (AF)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

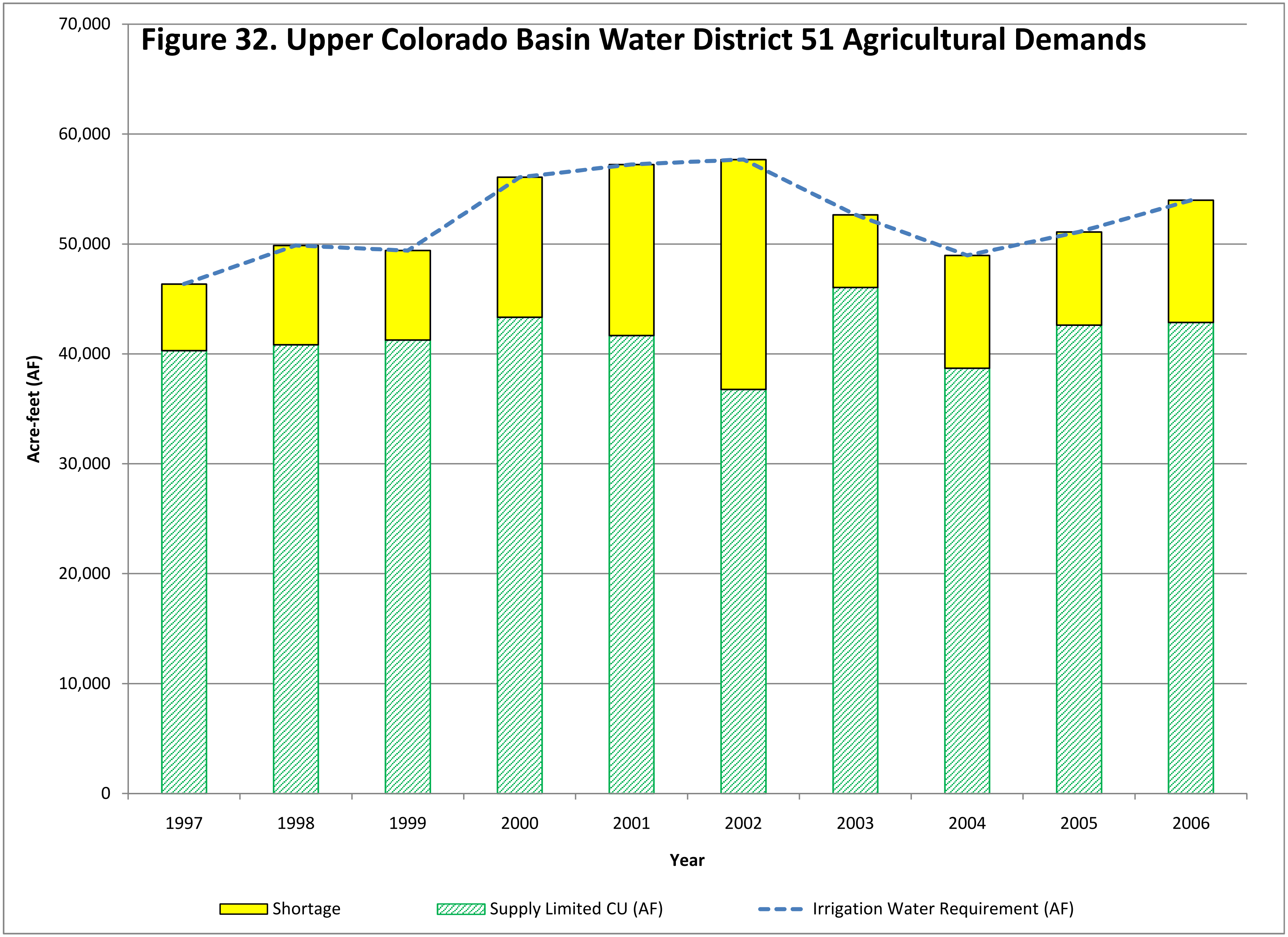


Figure 32. Upper Colorado Basin Water District 51 Agricultural Demands
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

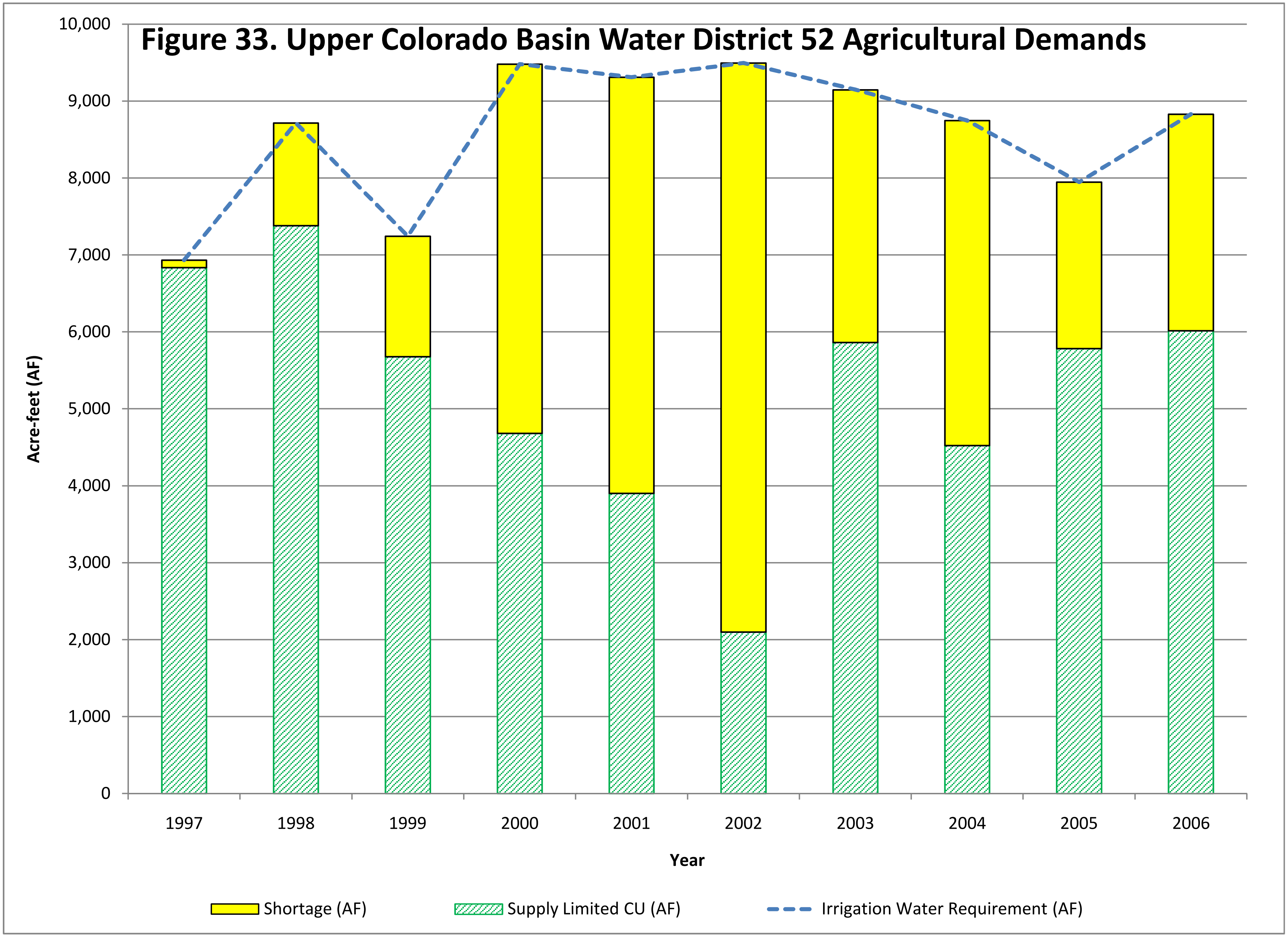


Figure 33. Upper Colorado Basin Water District 52 Agricultural Demands
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

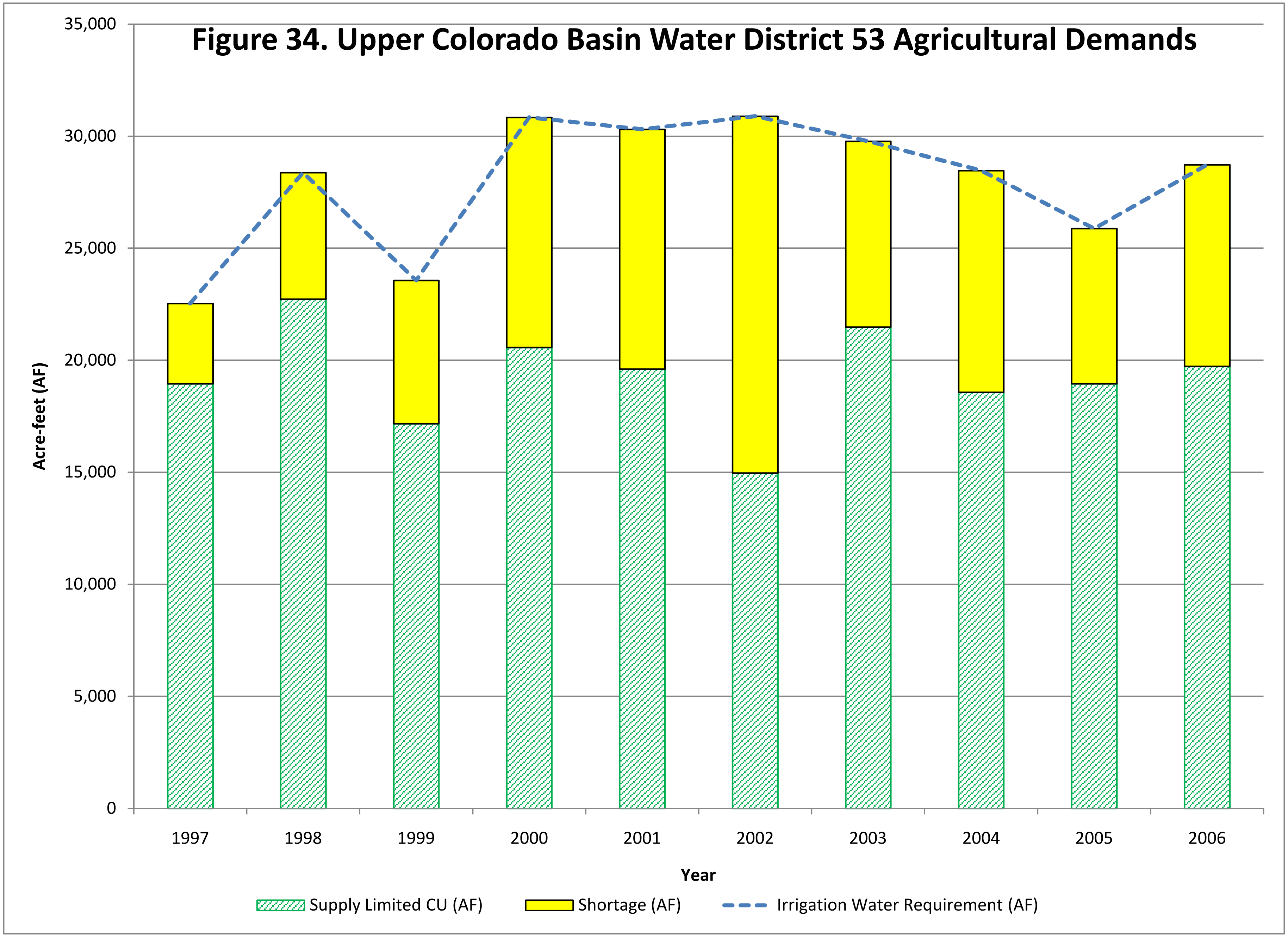


Figure 34. Upper Colorado Basin Water District 53 Agricultural Demands
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

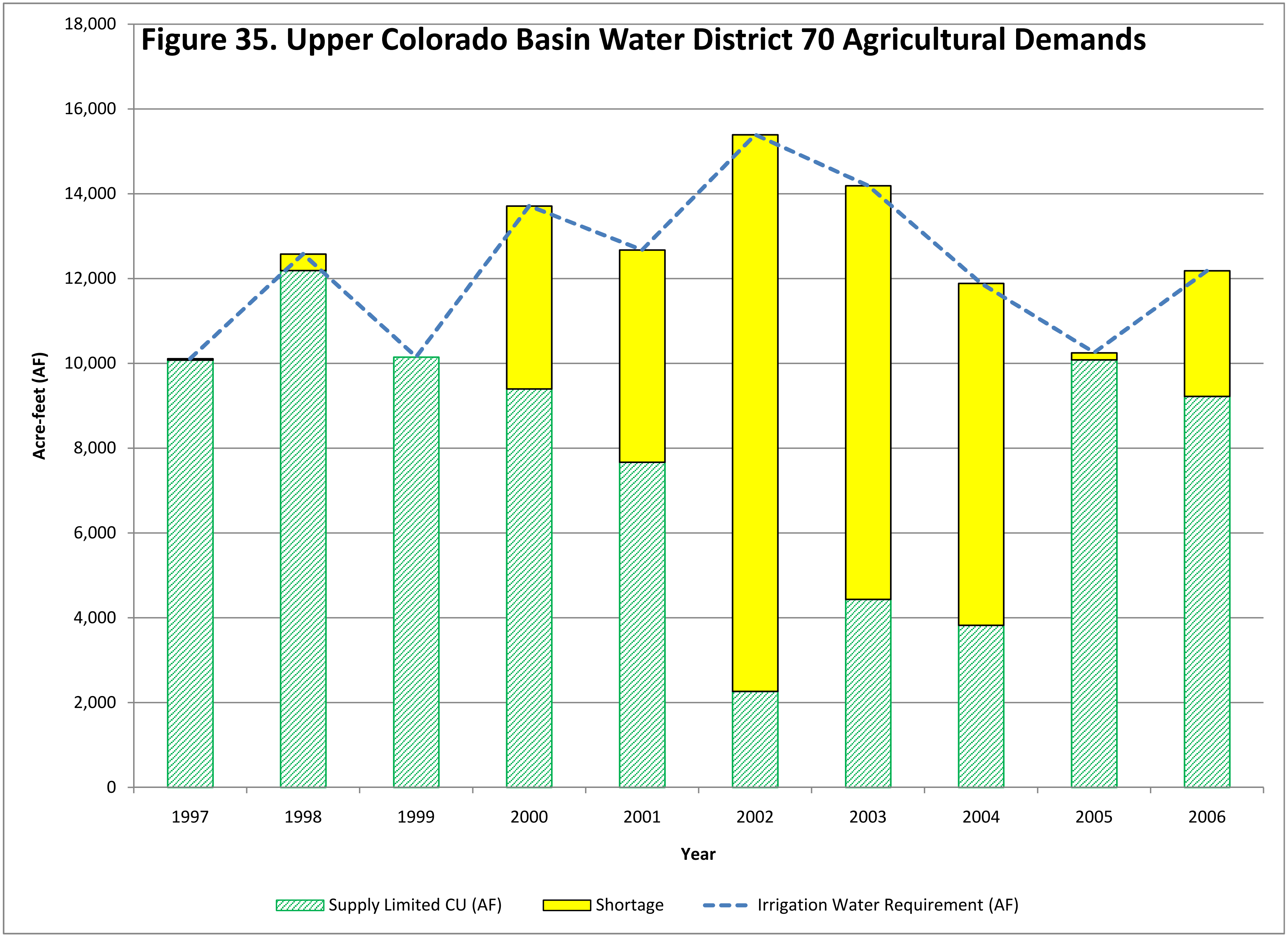
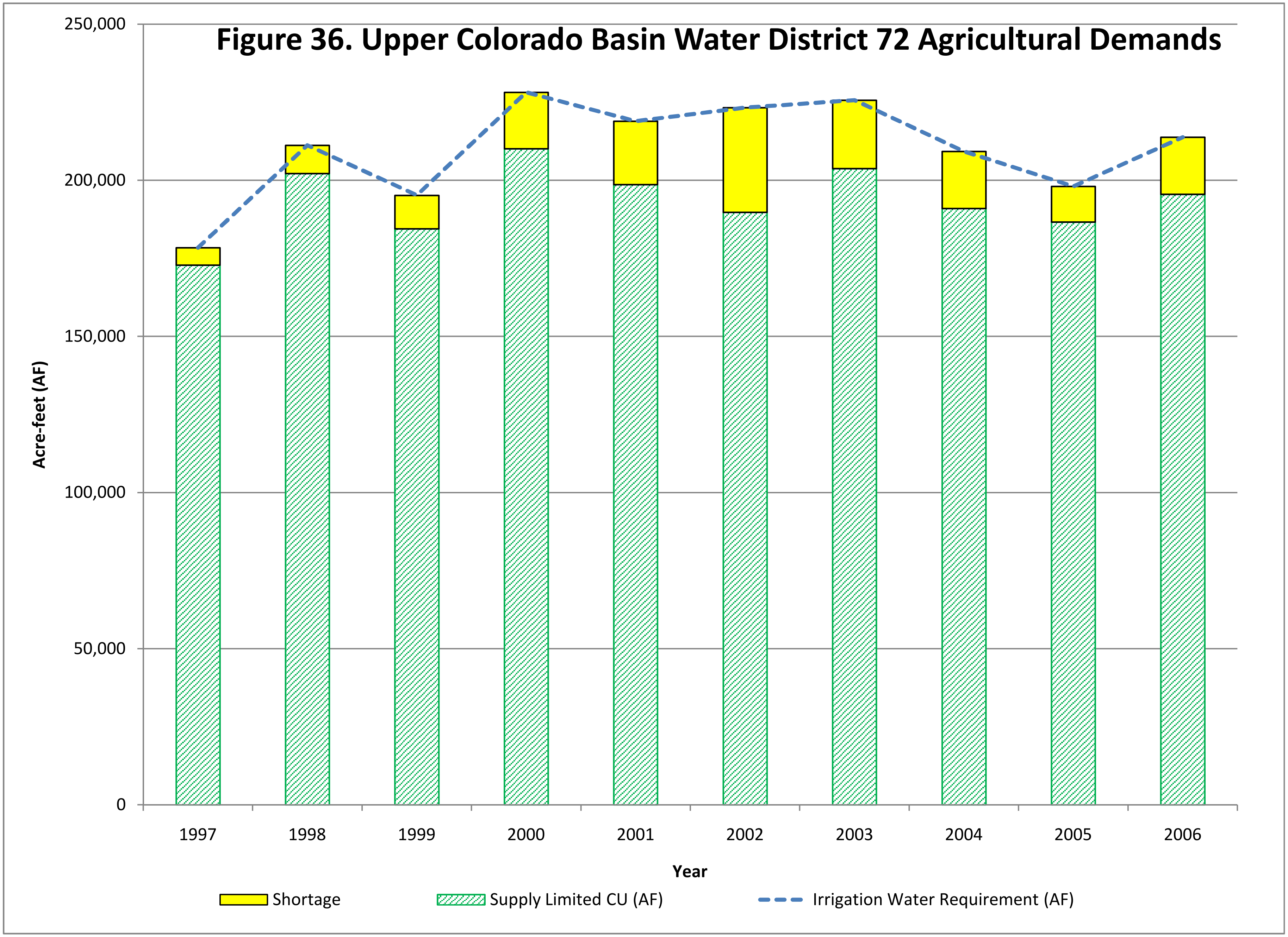


Figure 35. Upper Colorado Basin Water District 70 Agricultural Demands

Figure 36. Upper Colorado Basin Water District 72 Agricultural Demands



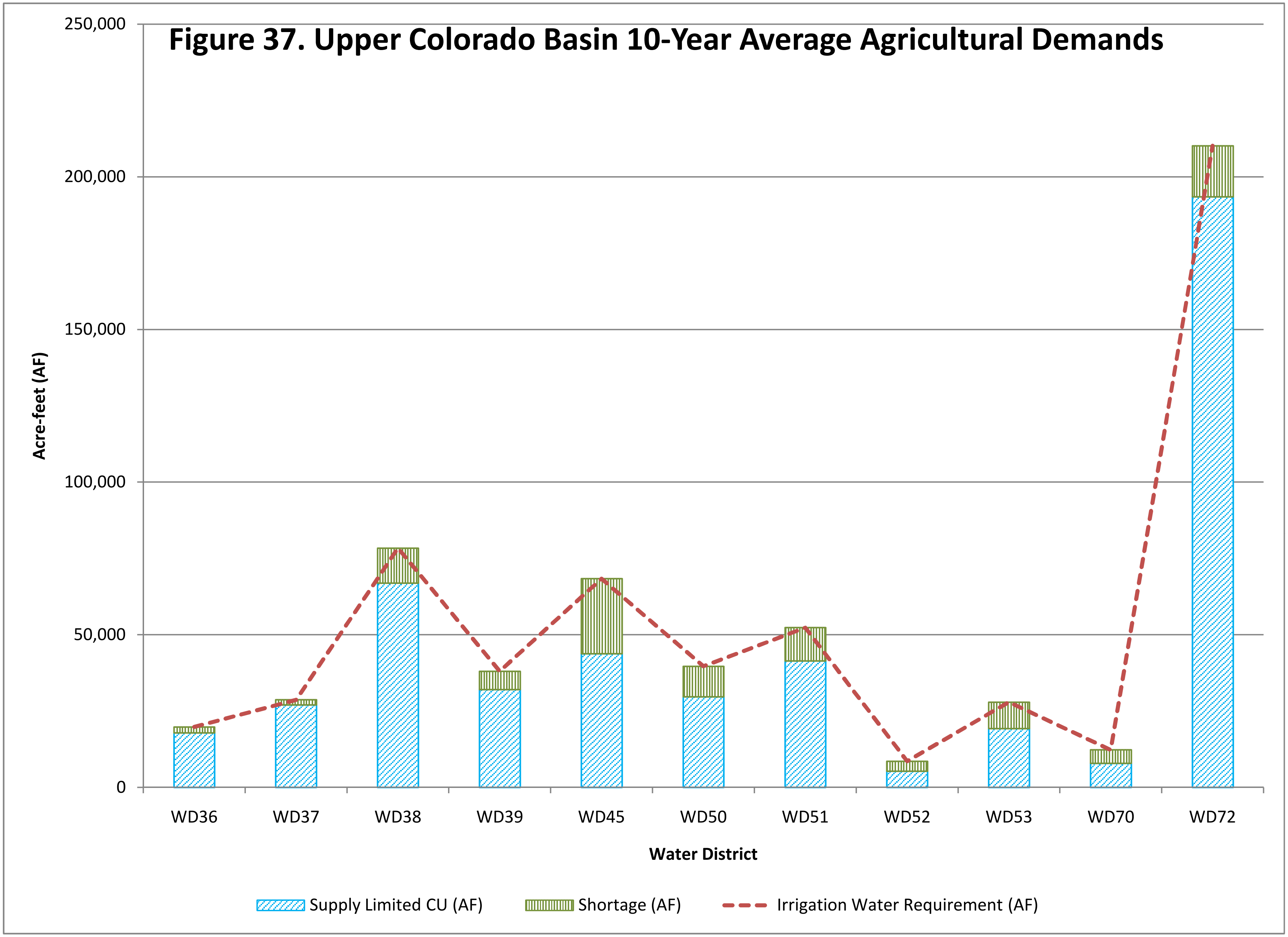


Figure 37. Upper Colorado Basin 10-Year Average Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
WD36
WD37
WD38
WD39
WD45
WD50
WD51
WD52
WD53
WD70
WD72
Water District
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

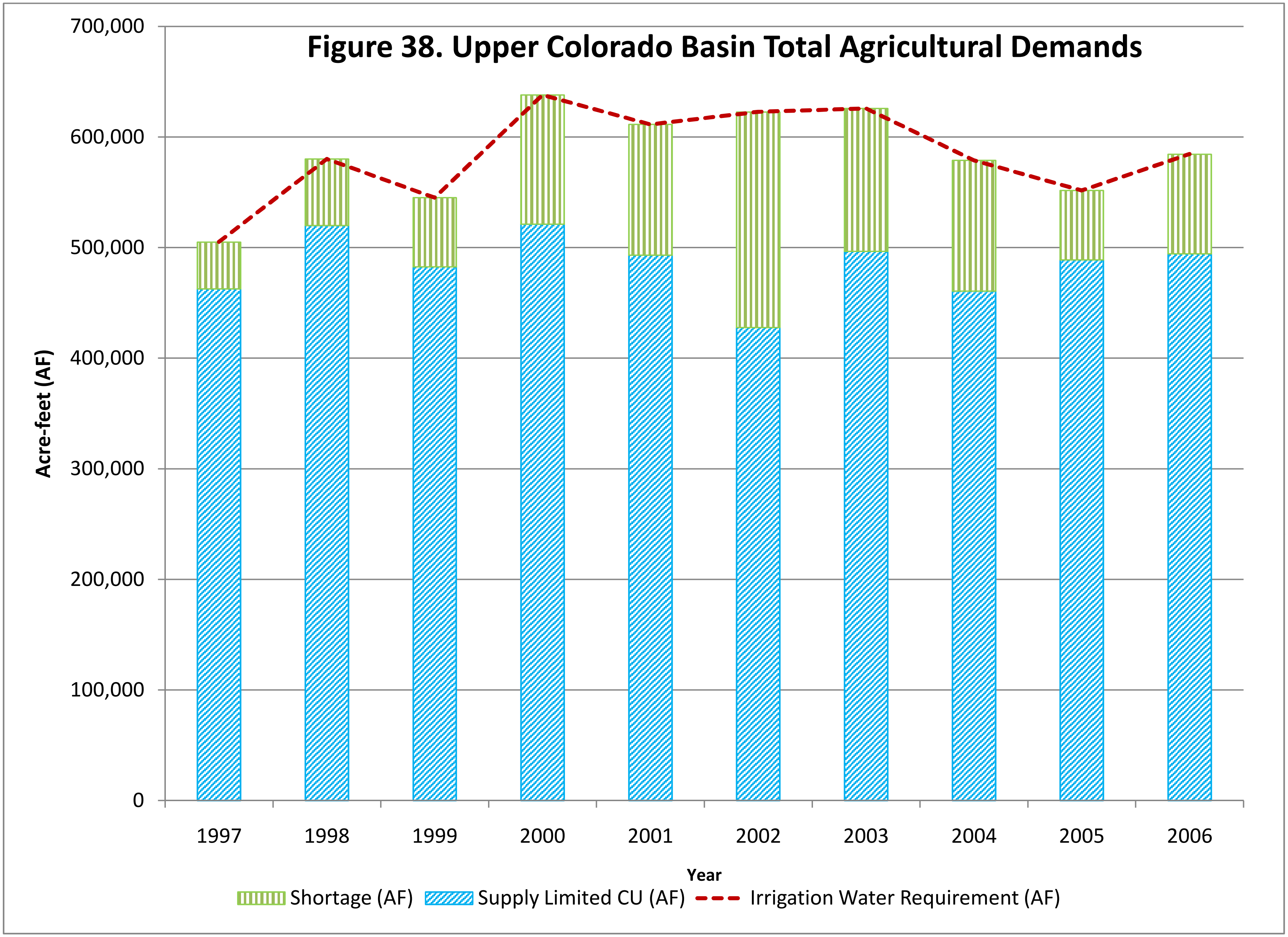


Figure 38. Upper Colorado Basin Total Agricultural Demands
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

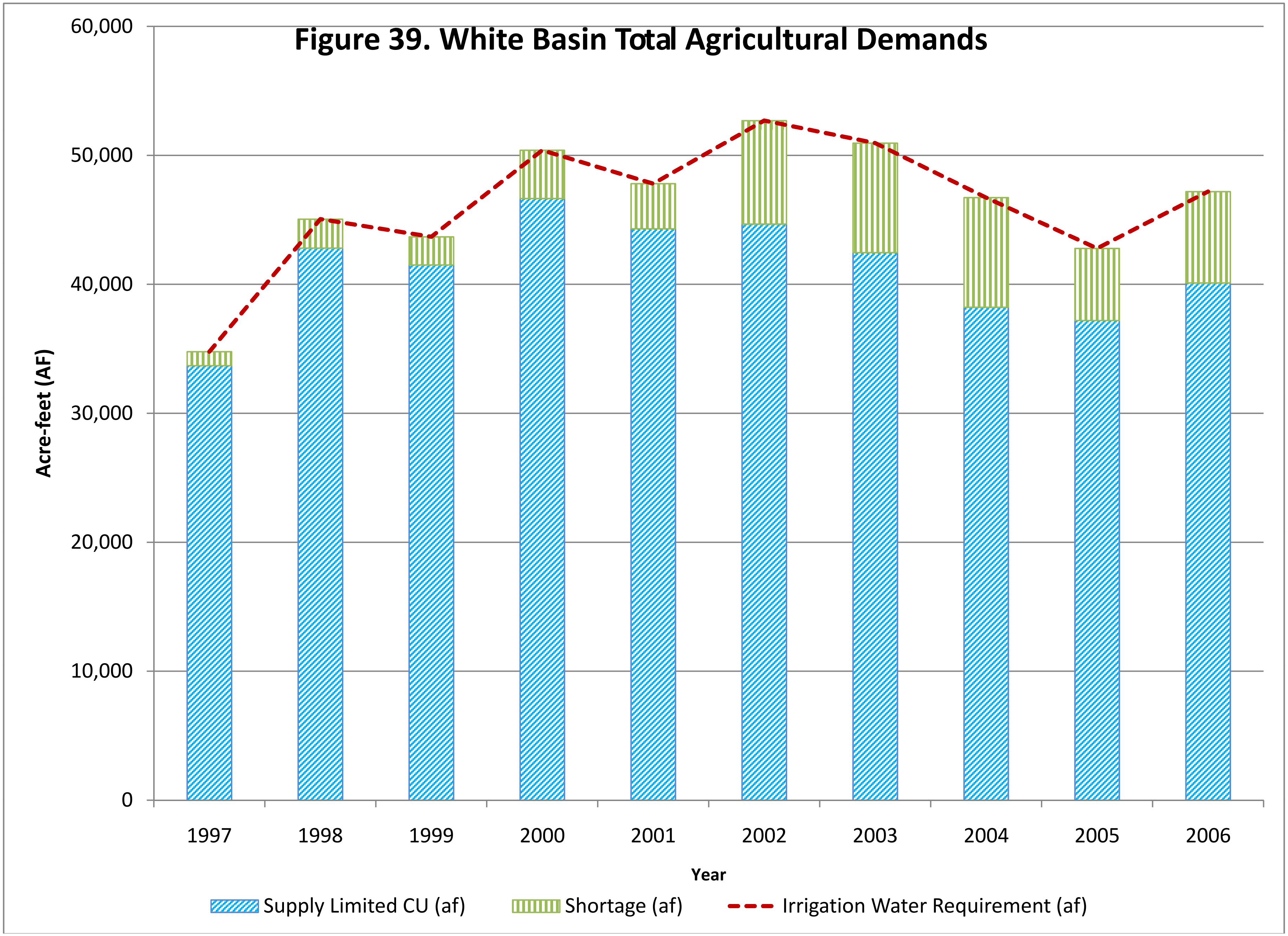


Figure 39. White Basin Total Agricultural Demands
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (af)
Shortage (af)
Irrigation Water Requirement (af)

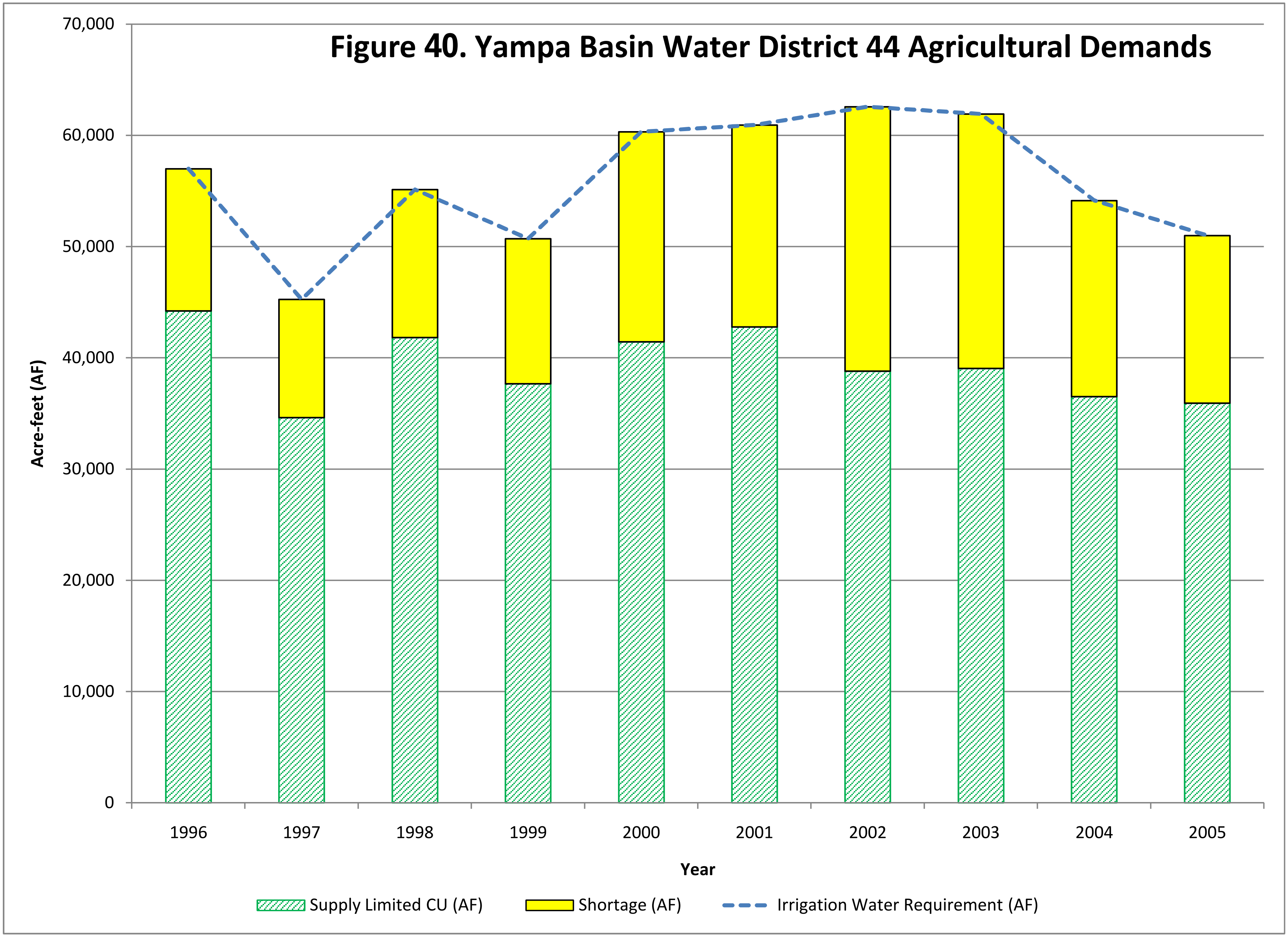


Figure 40. Yampa Basin Water District 44 Agricultural Demands
Acre-feet (AF)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

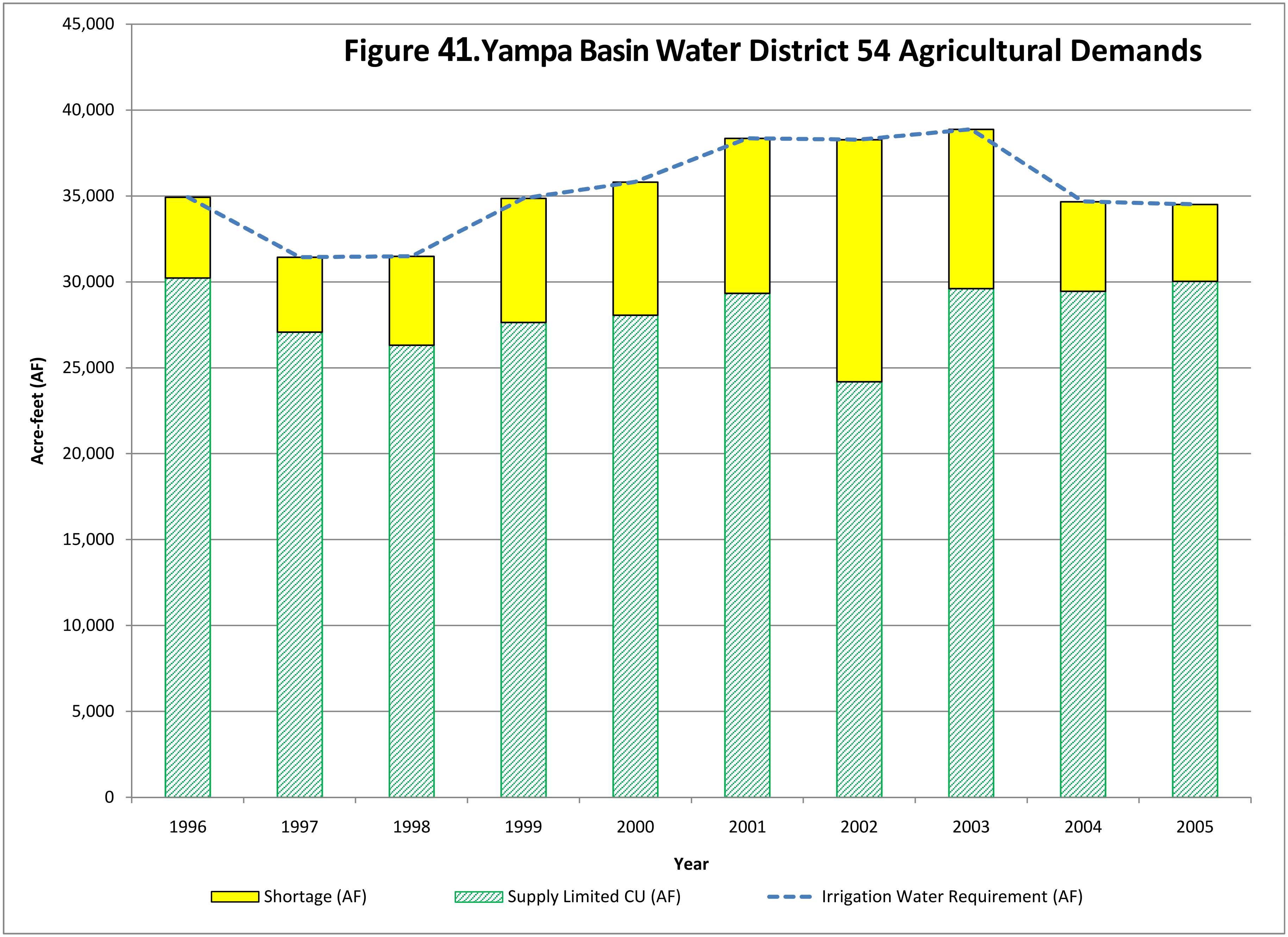


Figure 41.Yampa Basin Water District 54 Agricultural Demands
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

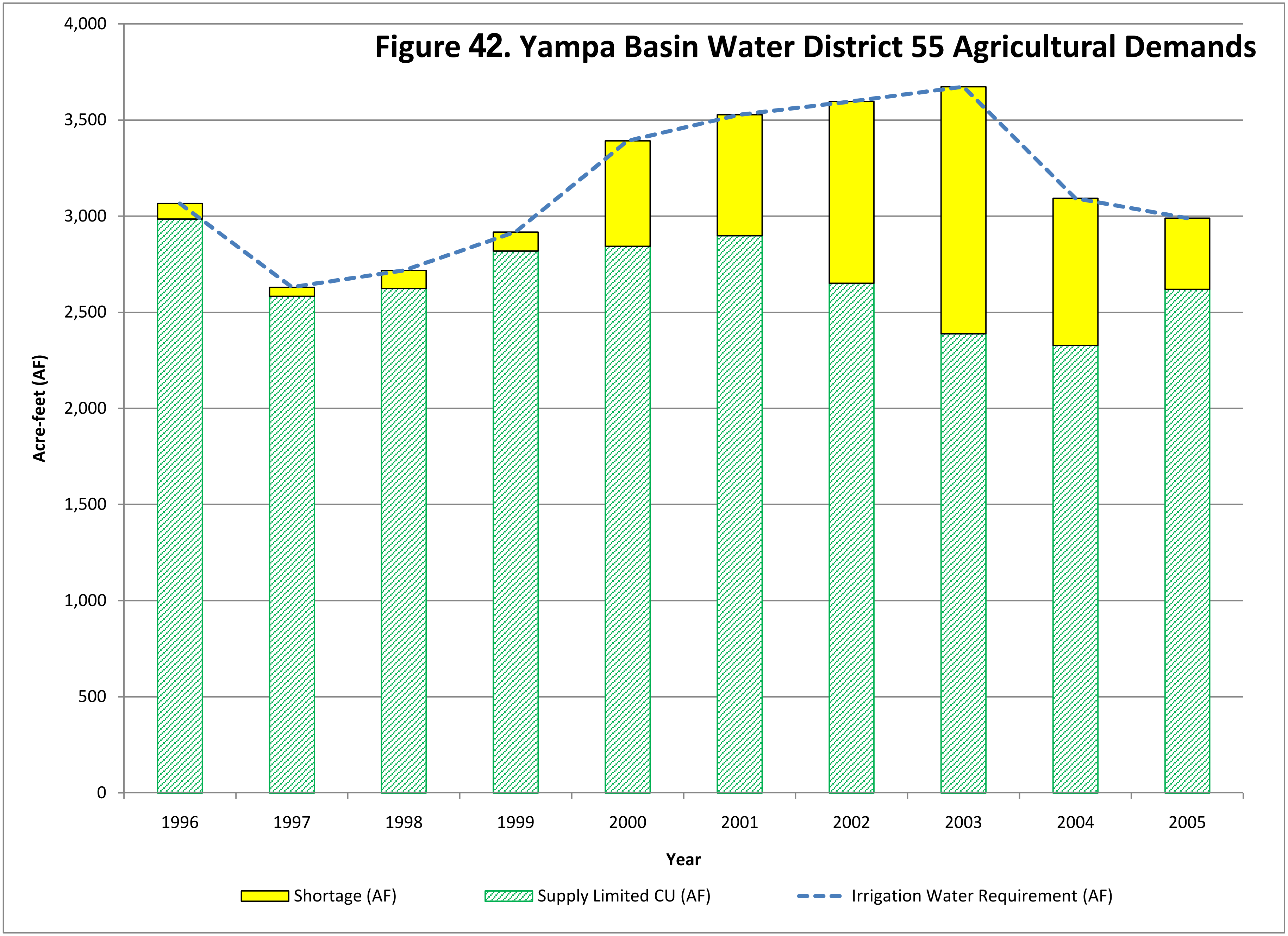


Figure 42. Yampa Basin Water District 55 Agricultural Demands
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

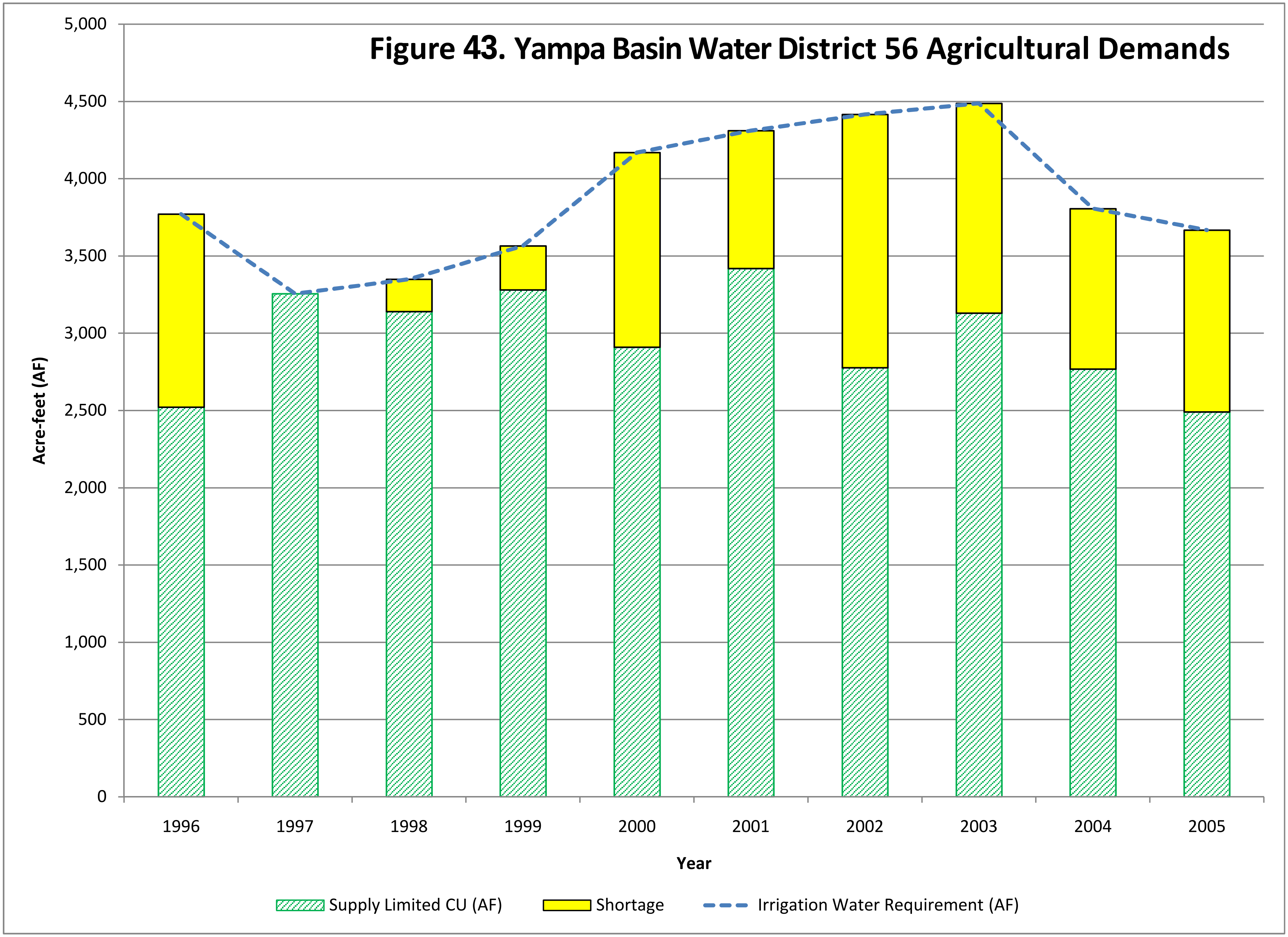


Figure 43. Yampa Basin Water District 56 Agricultural Demands
Acre-feet (AF)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage
Irrigation Water Requirement (AF)

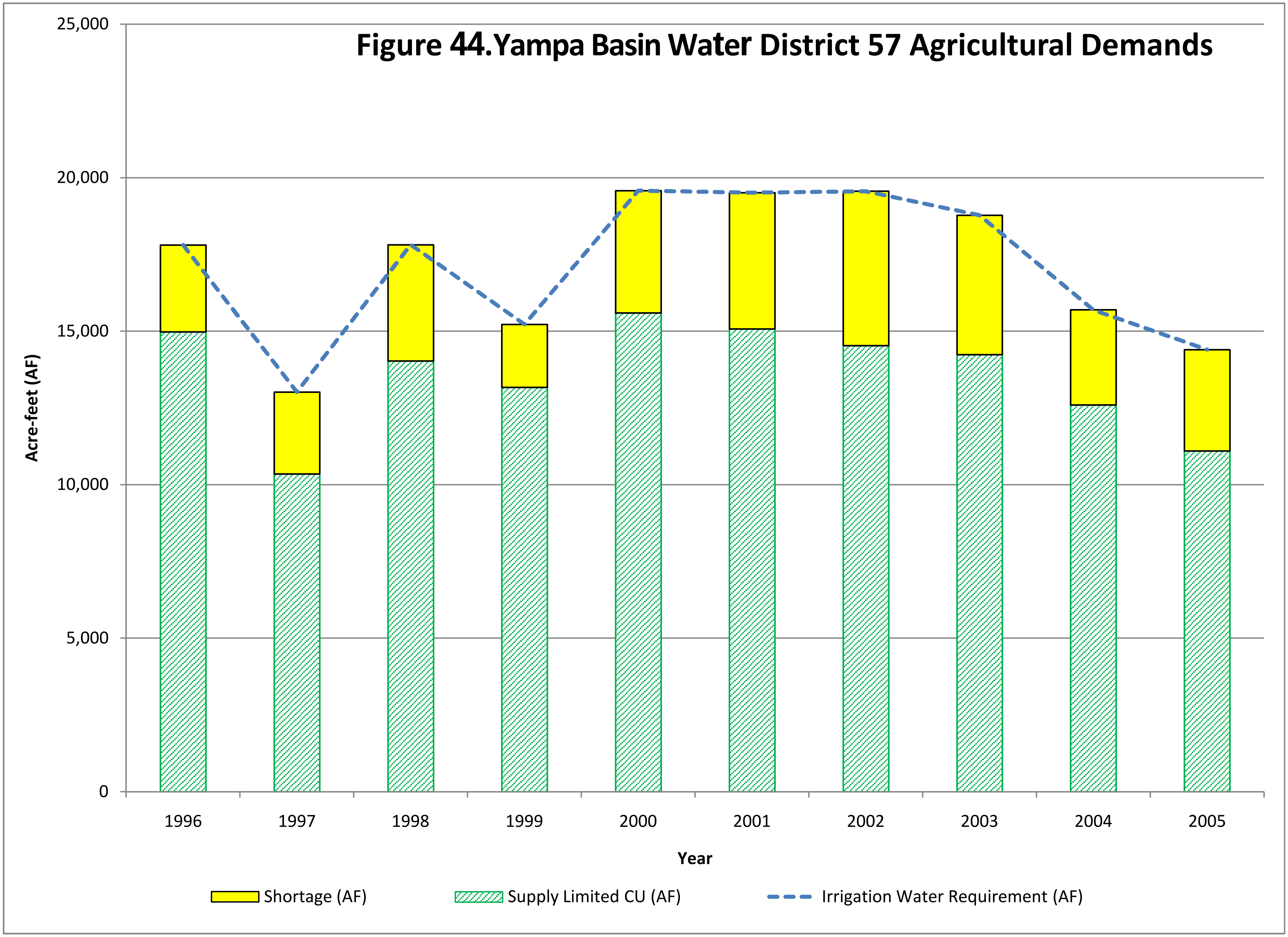


Figure 44.Yampa Basin Water District 57 Agricultural Demands
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

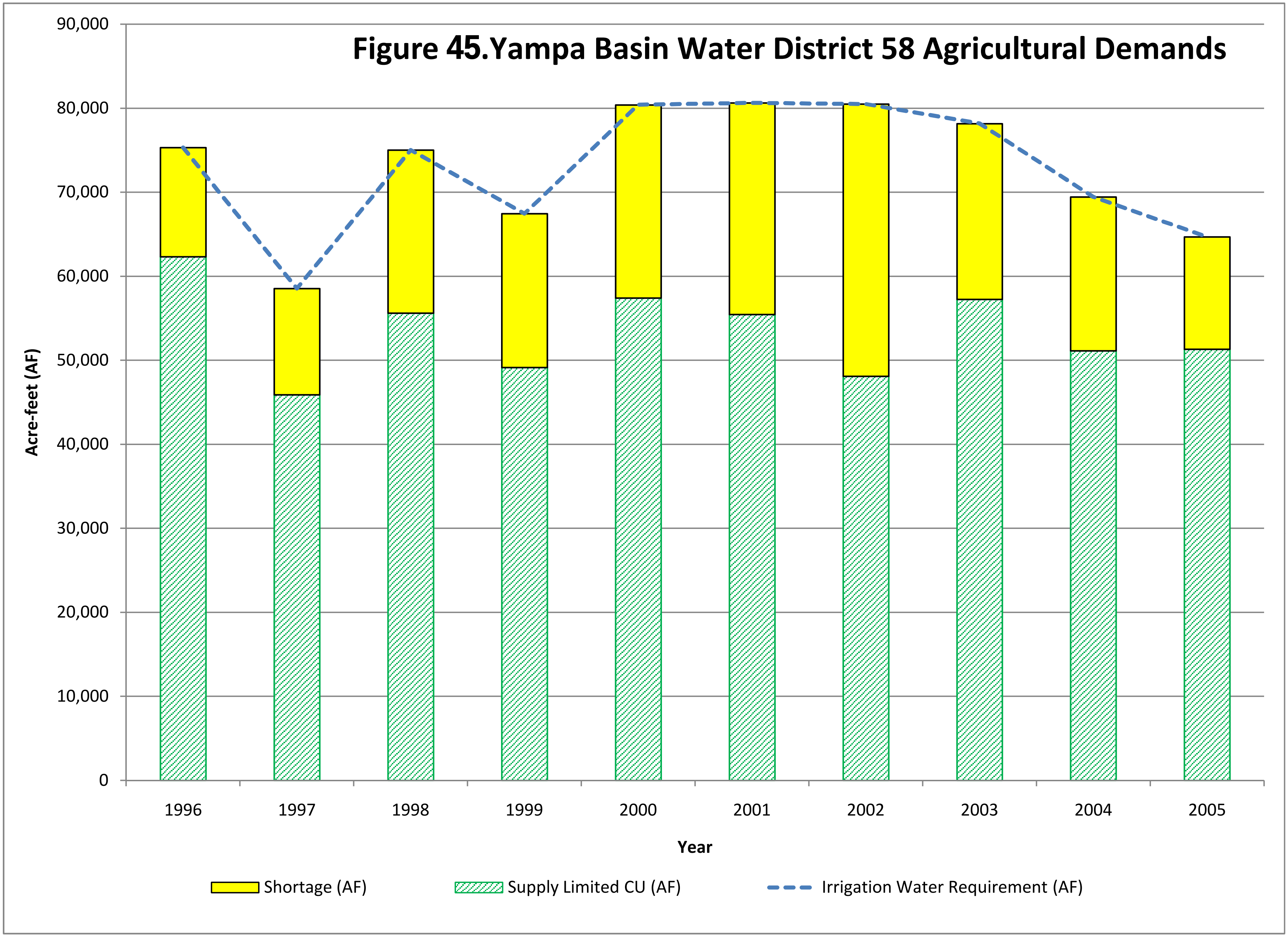


Figure 45.Yampa Basin Water District 58 Agricultural Demands
Acre-feet (AF)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

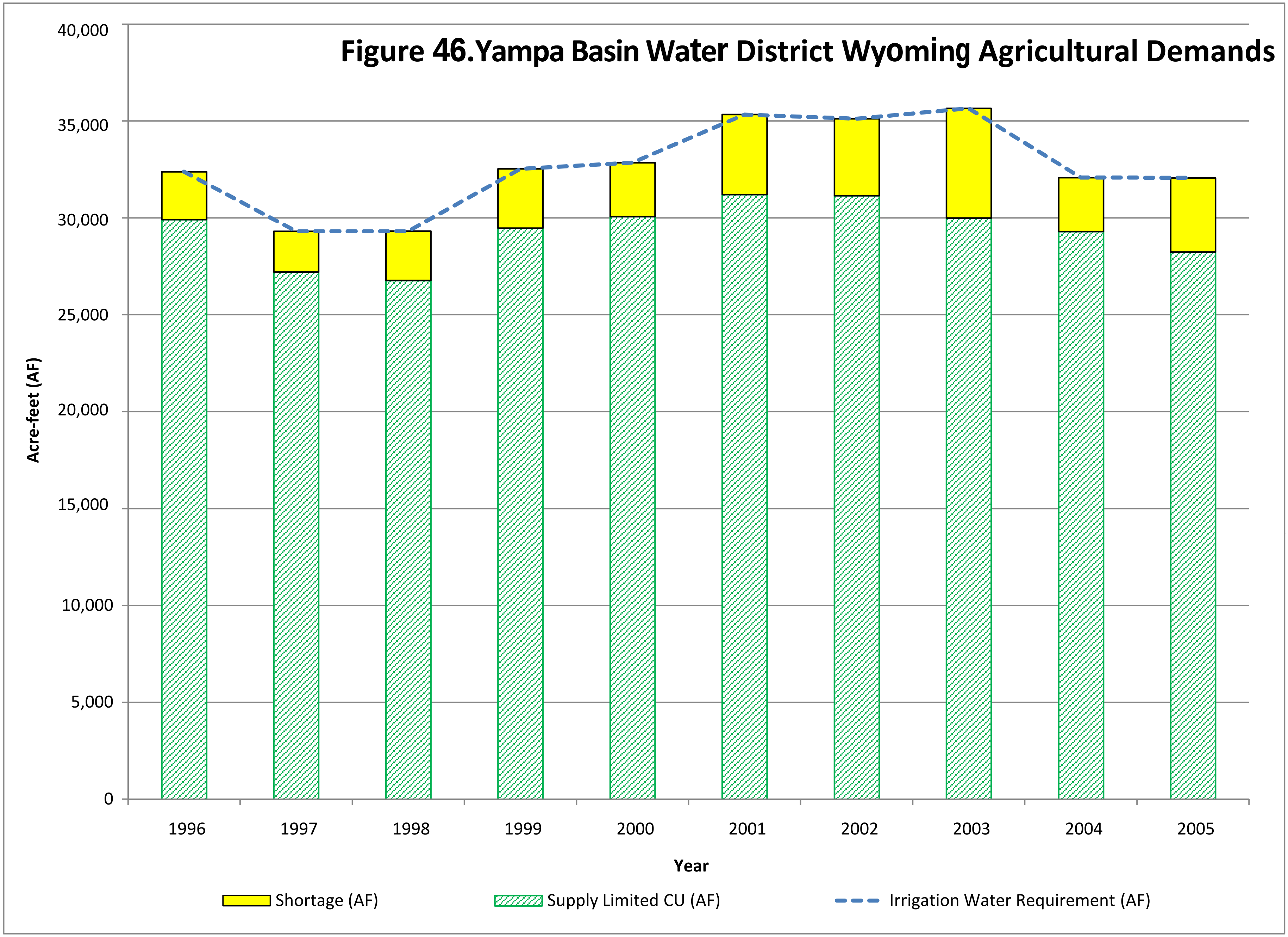


Figure 46.Yampa Basin Water District Wyoming Agricultural Demands
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

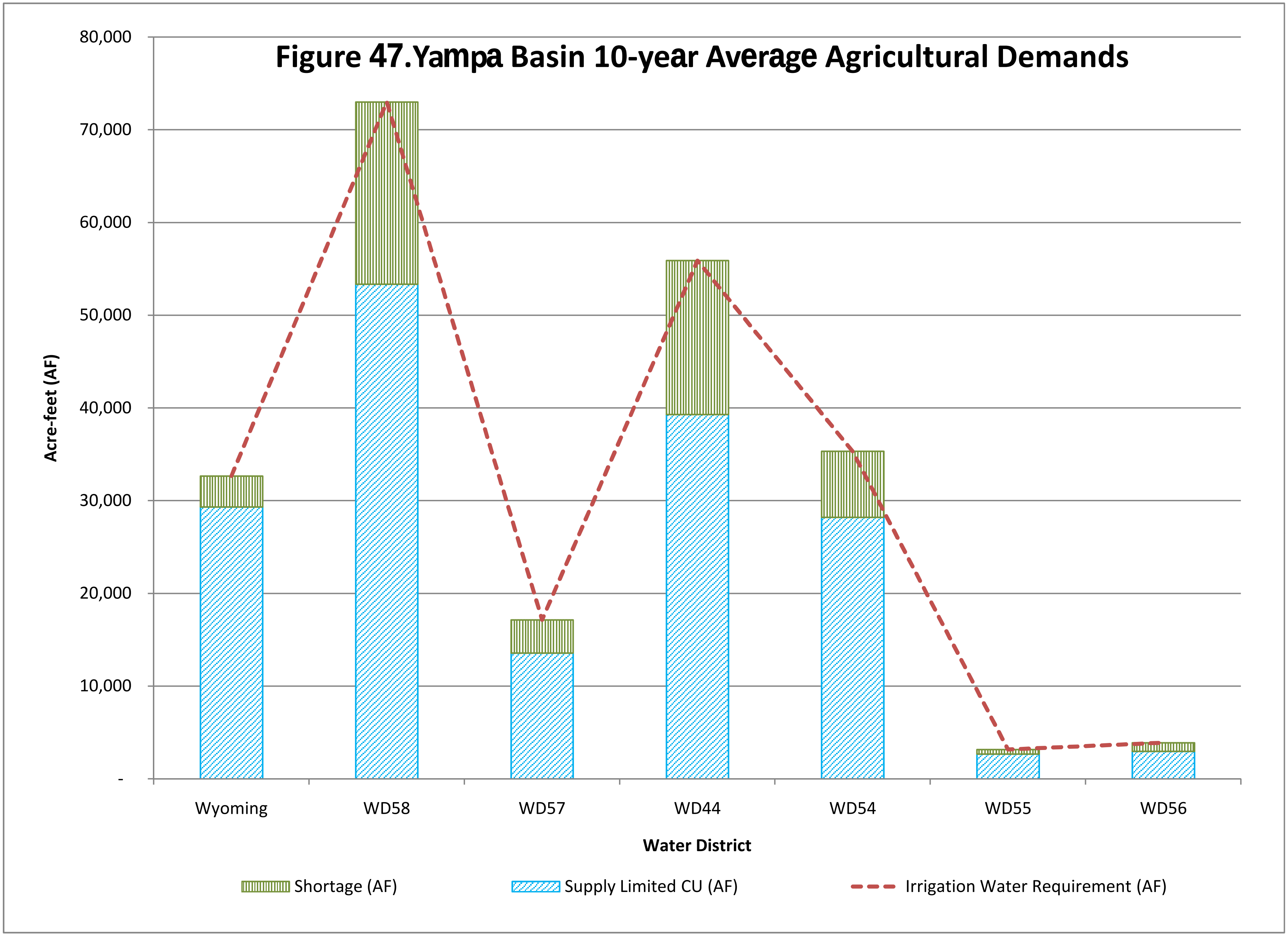


Figure 47. Yampa Basin 10-year Average Agricultural Demands
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
Acre-feet (AF)
Wyoming
WD58
WD57
WD44
WD54
WD55
WD56
Water District
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

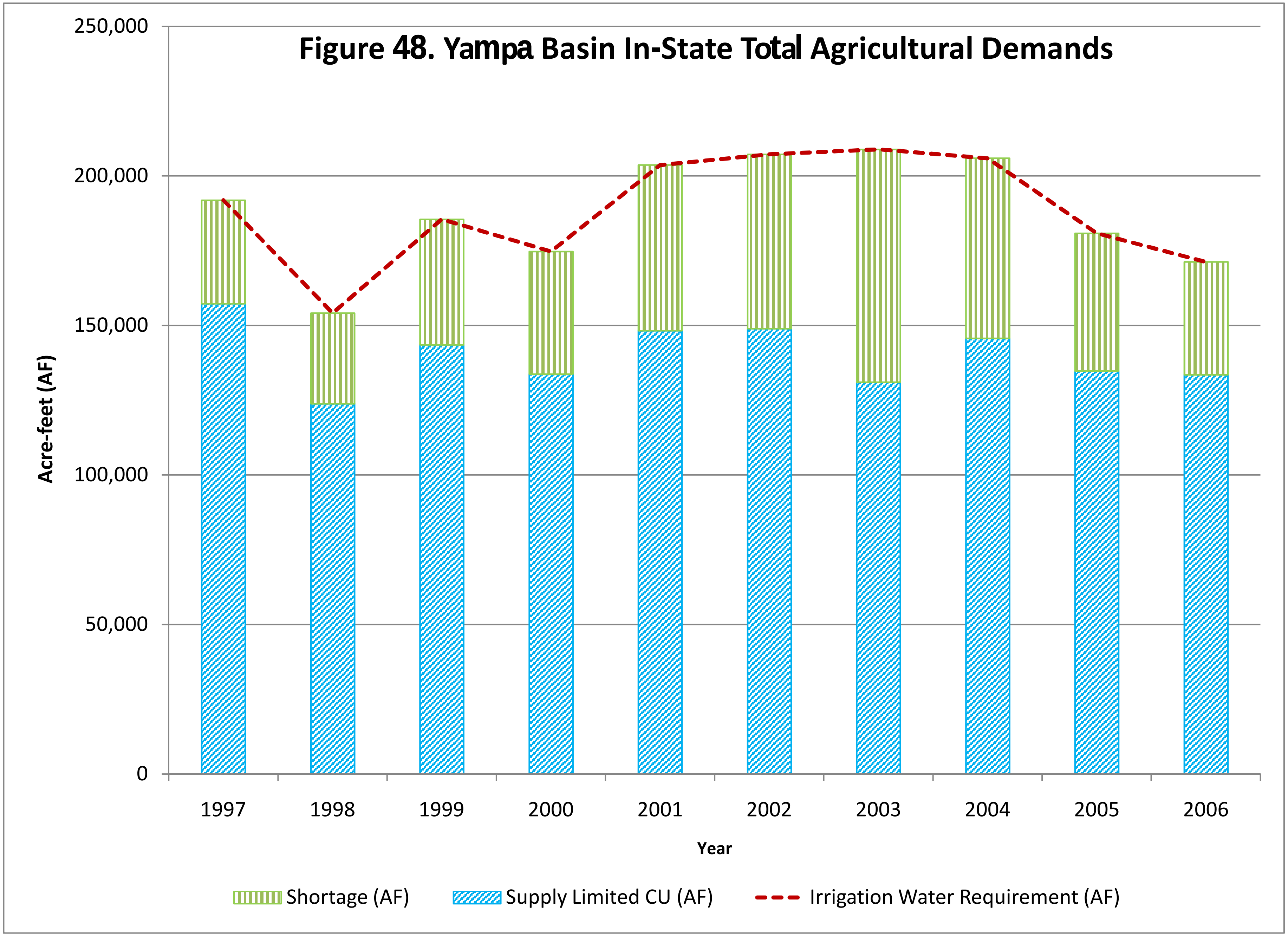


Figure 48. Yampa Basin In-State Total Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

Appendix B
South Platte and Rio Grande Basins Agricultural Demands Methodology

AECOM

Memorandum

Date:	March 26, 2010
To:	Nicole Rowan, CDM
From:	Meg Frantz, AECOM
Subject:	Rio Grande and South Platte Current Agricultural Demand – Methods
Distribution:	Todd Doherty, CWCB

Purpose

This memorandum documents the methods used to produce Irrigated Acreage, Irrigation Water Requirement (the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage, for the Rio Grande and South Platte basins. The values are tabulated in spreadsheet workbooks RioGrande_AgDmd_SupportTable_Mar2010.xlsx and SouthPlatte_AgDmd_SupportTable_Mar2010.xlsx, respectively.

Background

Under the ongoing South Platte Decision Support System (SPDSS) project, Leonard Rice Engineers developed an historical consumptive use model for the South Platte basin using StateCU. Similarly, a model for the Rio Grande basin was developed under the Rio Grande Decision Support System (RGDSS), to support consumptive uses and losses reporting. These models represent 100 percent of the crop consumptive use in the basin.

Method and Assumptions

1. AECOM relied on the SPDSS and RGDSS model data sets for this effort. The models included the requisite information on irrigated lands, relevant climate stations, crop types and irrigation practices, and historical water supply. StateCU was executed to produce irrigation water requirement, water-supply limited consumptive use, and shortage.

2. The StateCU model was executed for the most recent 10 years of the CDSS model period. For the South Platte, the period was 1997 through 2006; for the Rio Grande the period was 1996 through 2005. This approach allows for incorporation of climate variability, but confines the study to current conditions in terms of the available water supply. For example, storage

water might be available recently that was not available in earlier decades. If a study period of several decades was used, shortage might be overstated, influenced by the pre-storage condition.

3. The South Platte analysis uses 2005 irrigated acreage over the entire study. This acreage represents an overall reduction in wells, as wells not included in augmentation plans were no longer allowed to pump by 2005. In addition, recent Central Colorado Water Conservancy District well pumping restrictions were applied over the entire study period. These pumping restrictions have been relatively consistent over the past five years, and best represent current conditions. Wells included under the two Central augmentation plans are modeled with pumping restrictions; wells under the GMS augmentation plan pump a maximum of 50 percent of their irrigation requirements and wells under the WAS augmentation plan do not pump at all. Irrigated lands served by these wells with pumping restrictions reflect the additional shortages imposed by the limited pumping. This approach represents the current agricultural demand, given the administrative changes that have occurred in the lower South Platte in recent years.

4. The Rio Grande analysis uses 1998 irrigated acreage from 1998 through 2005. Acreages for 1996 and 1997 are interpolated numbers “backcast” to the next most recent CDSS irrigated acreage set available, which for the Rio Grande basin, is dated 1936. An irrigated lands assessment for 2005 is currently in process but it was not available in time for this study. Thus the most current reliable information available for irrigated lands was used. We are aware that there will be reductions in irrigated acreage in the near future. In a letter dated November 30, 2009, the Rio Grande Round Table informed CWCB that:

   > *The agricultural community determined it was necessary to manage the Basin’s groundwater, and specifically the unconfined acquifer. The management plan being proposed under the Groundwater Subdistrict is to allow the unconfined acquifer to recover to recent historic levels and to utilize it in a manner that will be sustainable in the future….The actions by the agricultural community are to reduce the overall consumptive use of water by taking historically irrigated land out of production. Plans are underway to attempt to remove approximately 40,000 acres from agricultural production to reduce consumptive use by some 80,000 acre-feet per year.*

   As these reductions have not taken place yet, they are not reflected in the current irrigation demand estimate.

5. The Blaney-Criddle method (SCS Publication TR-21) is used for estimating potential evapotranspiration and effective precipitation. The South Platte analysis uses high altitude crop coefficients for irrigated pasture above 6500 feet in elevation; locally calibrated coefficients for crops below 6500 feet; and elevation adjustment, as recommended by The ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990), for crops other than pasture above 6500 feet. The Rio Grande analysis uses locally calibrated crop coefficients throughout the basin.

6. The soil moisture reservoir is considered in calculating consumptive use. Excess irrigation water can enter the reservoir, to be consumed at a later time when irrigation supply is not adequate for the crop’s needs. Use of soil water is counted toward the annual consumptive use.

Agricultural Demand Summary Tables

Table 1. Rio Grande Basin 10-year Average Agricultural Demand

Water District	Irrigation Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD20	341,193	646,526	486,209	160,316
WD21	53,174	118,419	50,149	68,270
WD22	82,674	196,733	106,303	90,430
WD24	27,875	61,967	43,222	18,745
WD25	34,546	81,786	45,281	36,505
WD26	29,933	71,813	45,895	25,918
WD27	22,101	42,719	35,995	6,724
WD35	30,108	63,383	41,483	21,900

Table 2. South Platte Basin 10-year Average Agricultural Demand

Water District	Irrigation Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD01	231,593	399,426	334,911	64,515
WD02	153,485	285,314	186,577	98,738
WD03	181,574	323,591	233,086	90,505
WD04	60,864	110,614	70,858	39,756
WD05	50,191	92,574	51,918	40,656
WD06	35,011	64,784	43,856	20,928
WD07	4,756	9,392	9,267	125
WD08	3,188	5,471	3,930	1,542
WD09	1,627	3,199	2,830	369
WD23	5,120	8,348	4,570	3,778
WD48	3,977	6,128	4,744	1,384
WD64	98,181	185,372	169,640	15,732
WD80	978	1,419	1,035	385

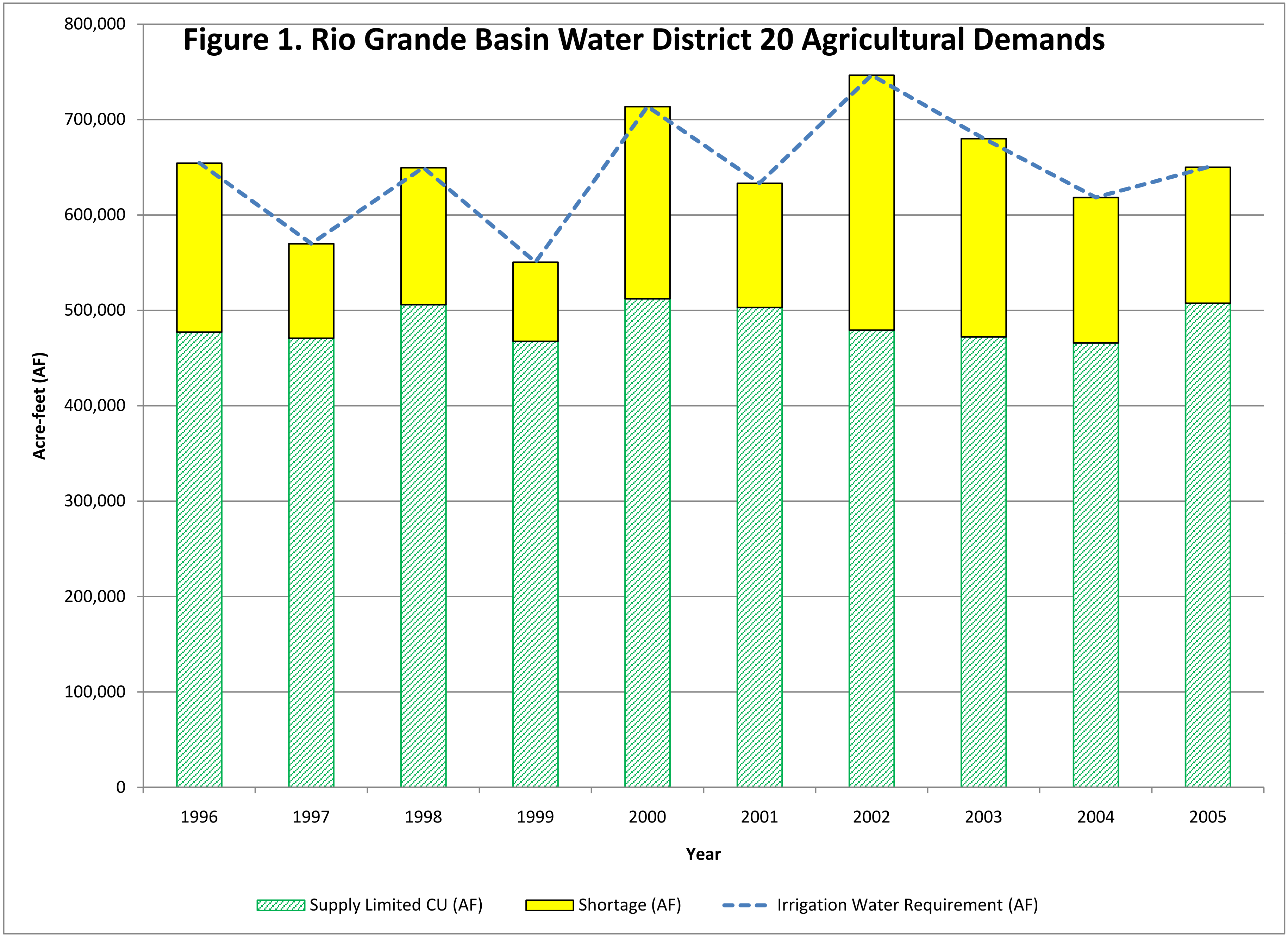


Figure 1. Rio Grande Basin Water District 20 Agricultural Demands
Acre-feet (AF)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

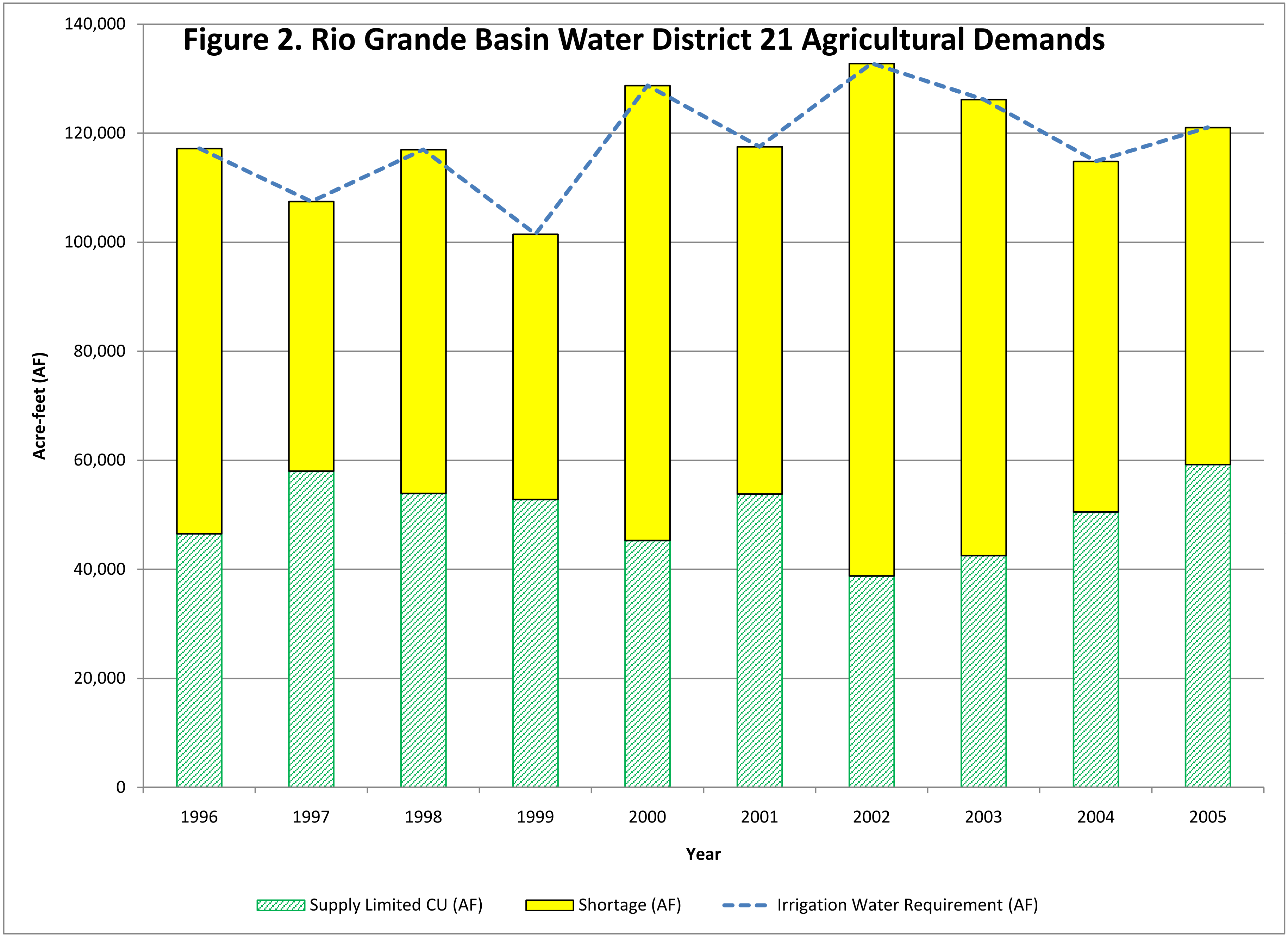


Figure 2. Rio Grande Basin Water District 21 Agricultural Demands
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

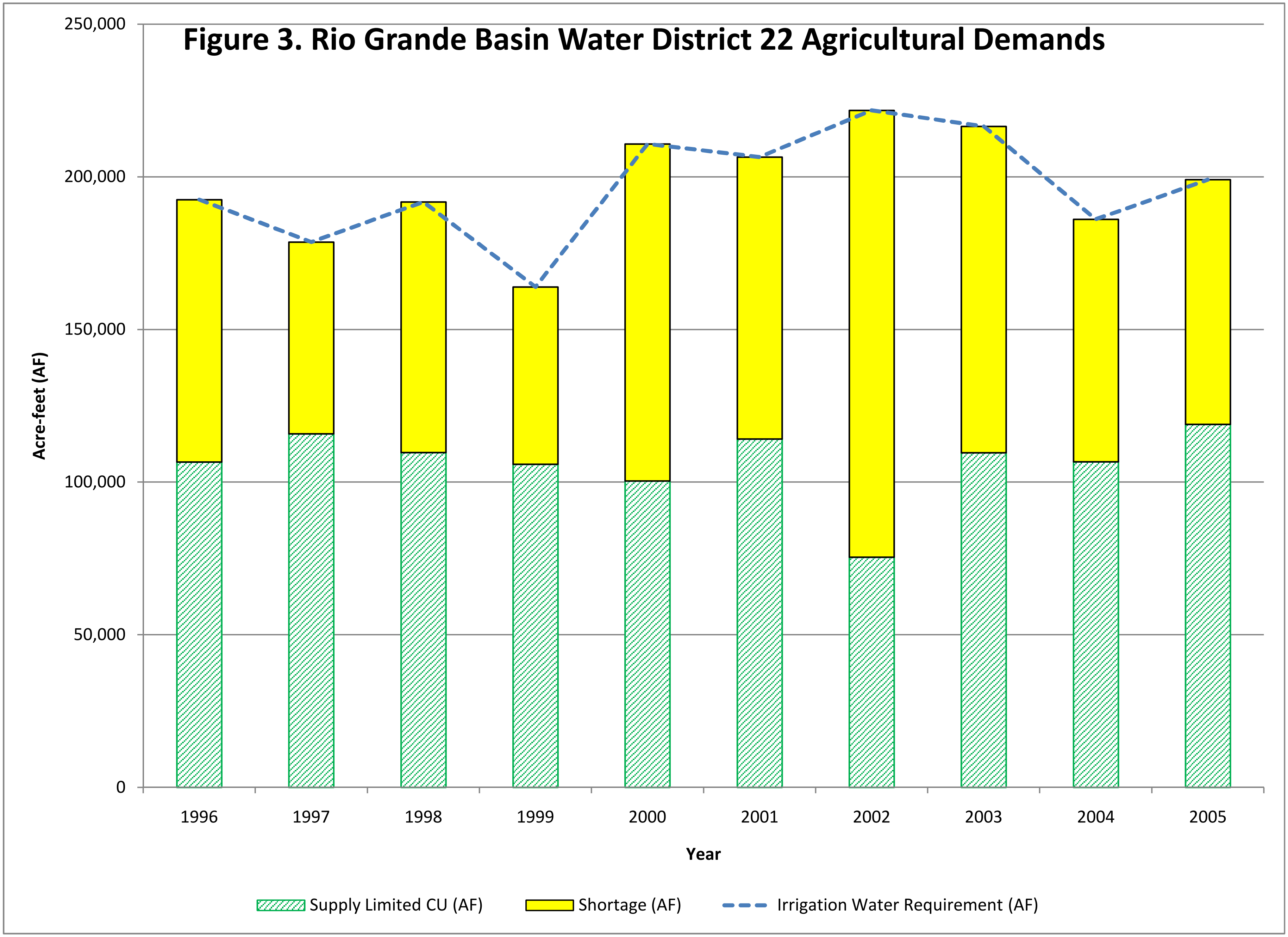


Figure 3. Rio Grande Basin Water District 22 Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

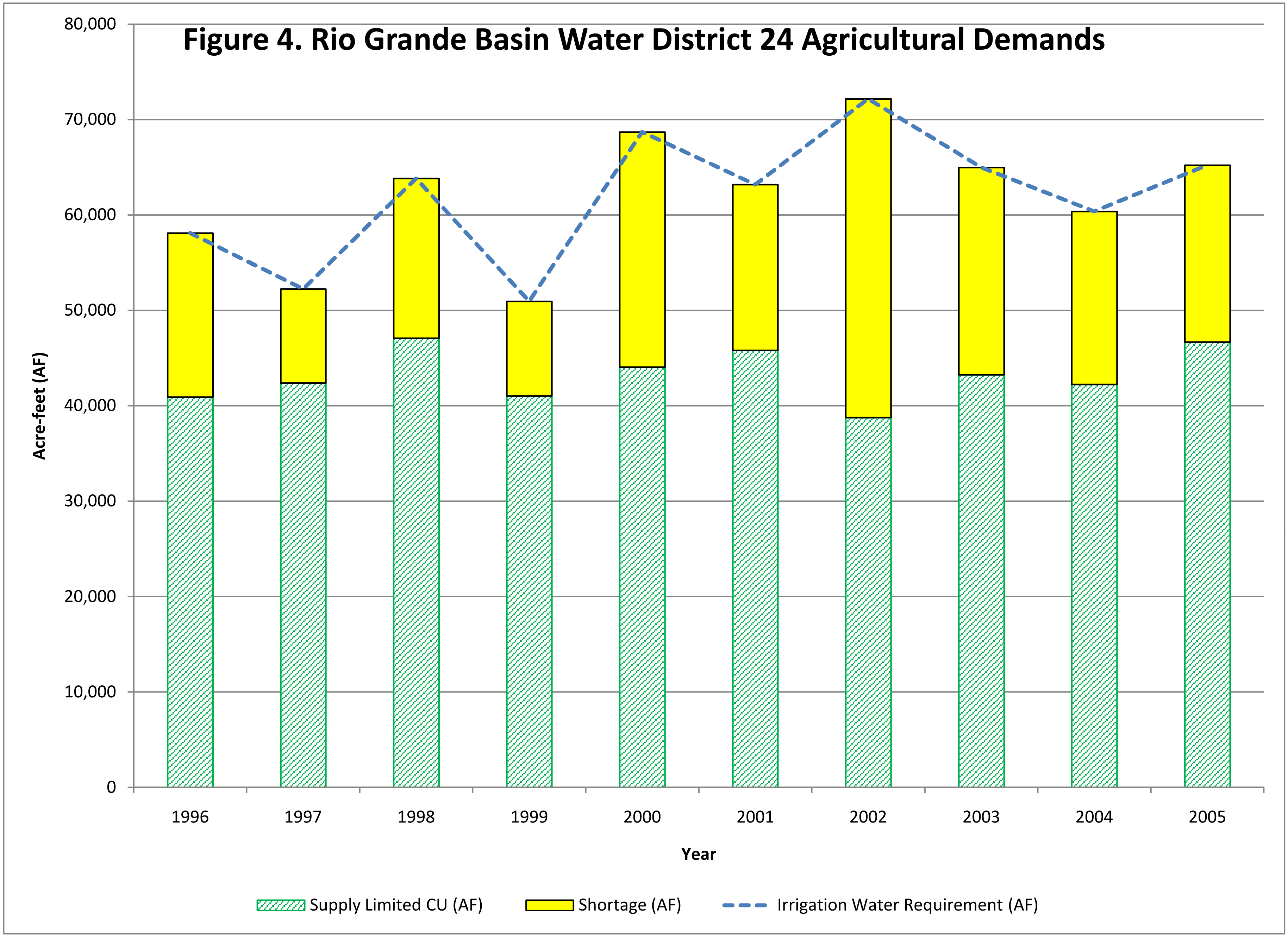


Figure 4. Rio Grande Basin Water District 24 Agricultural Demands
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

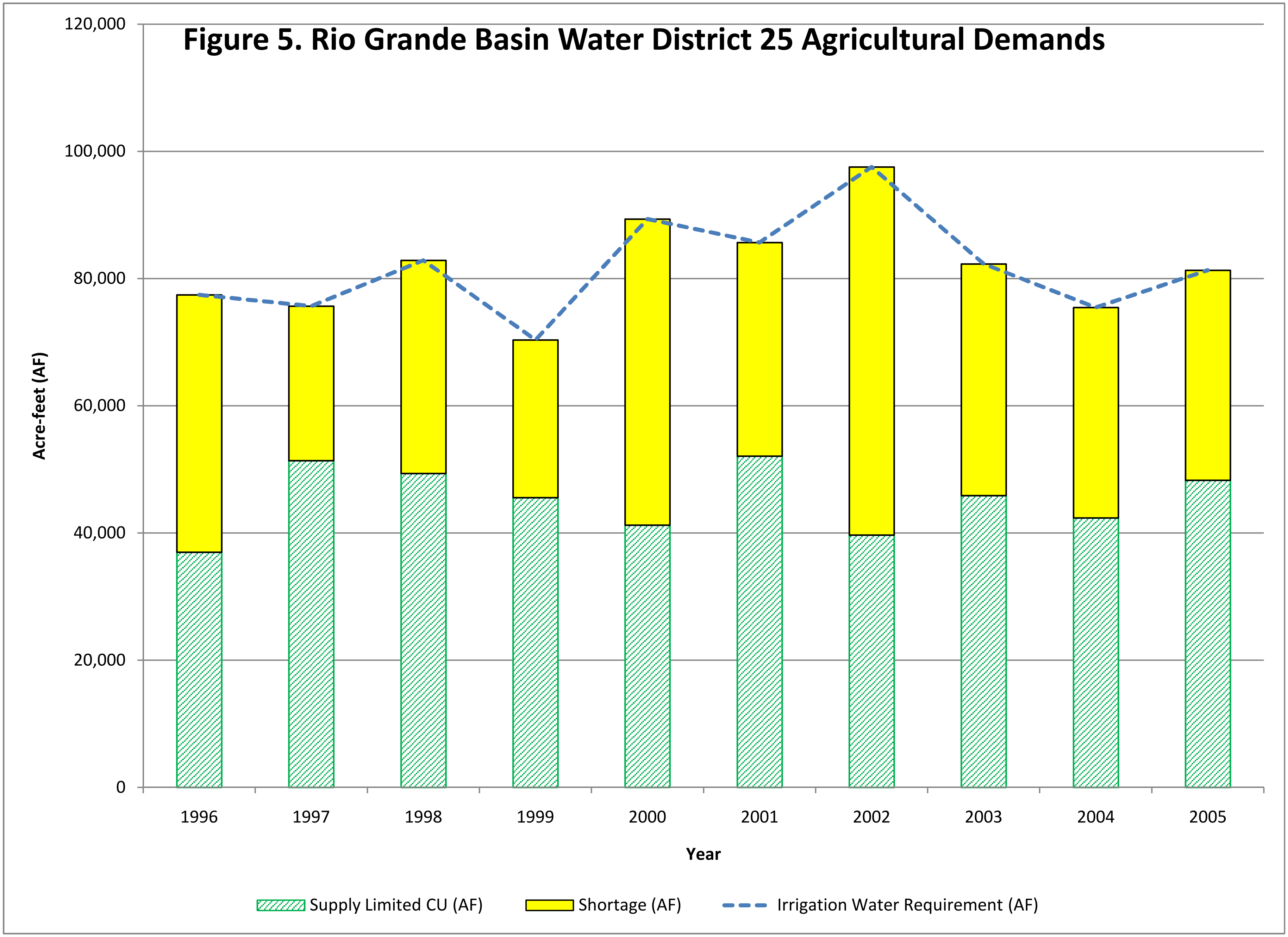


Figure 5. Rio Grande Basin Water District 25 Agricultural Demands
120,000
100,000
80,000
60,000
40,000
20,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

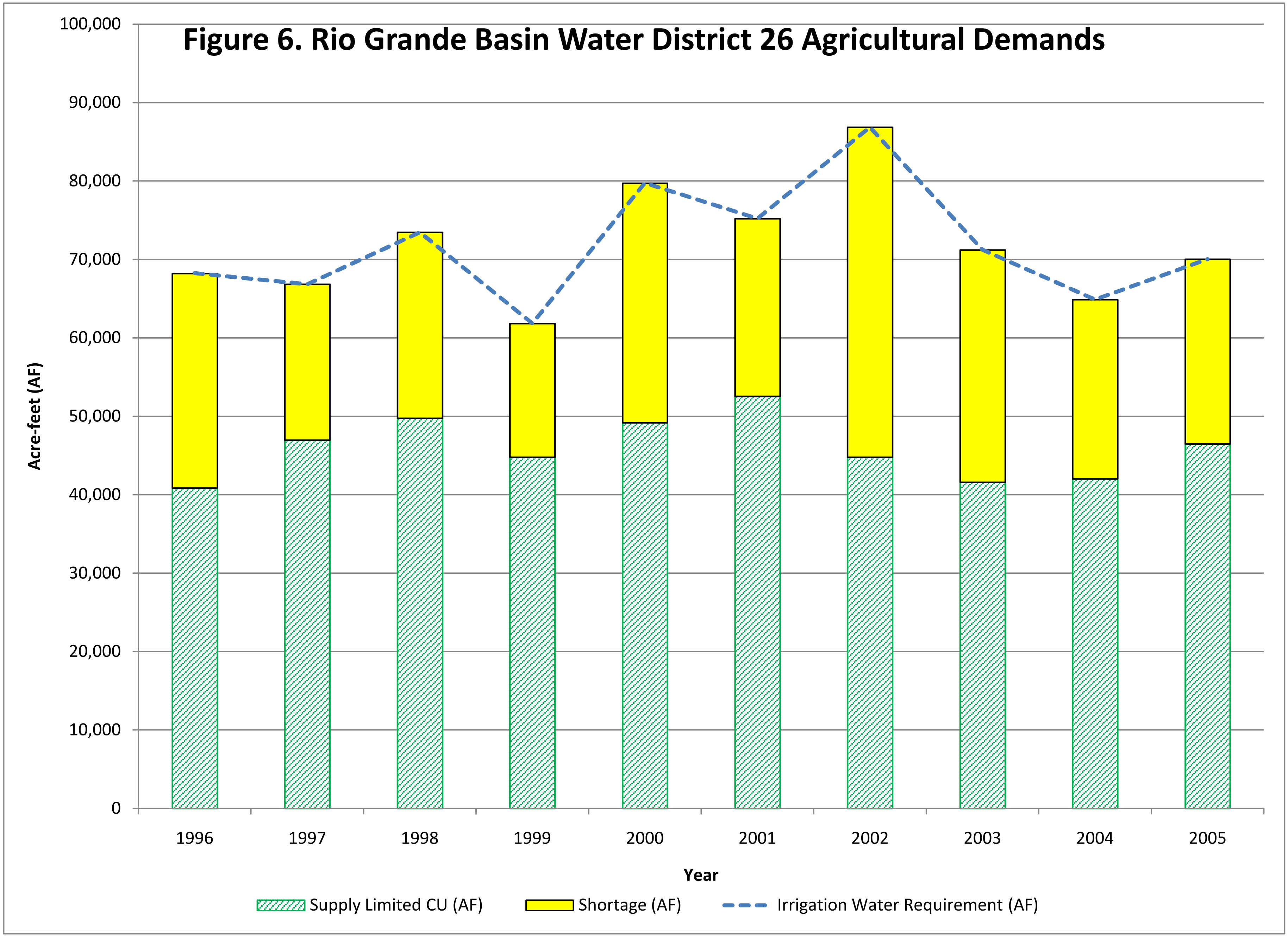


Figure 6. Rio Grande Basin Water District 26 Agricultural Demands
Acre-feet (AF)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

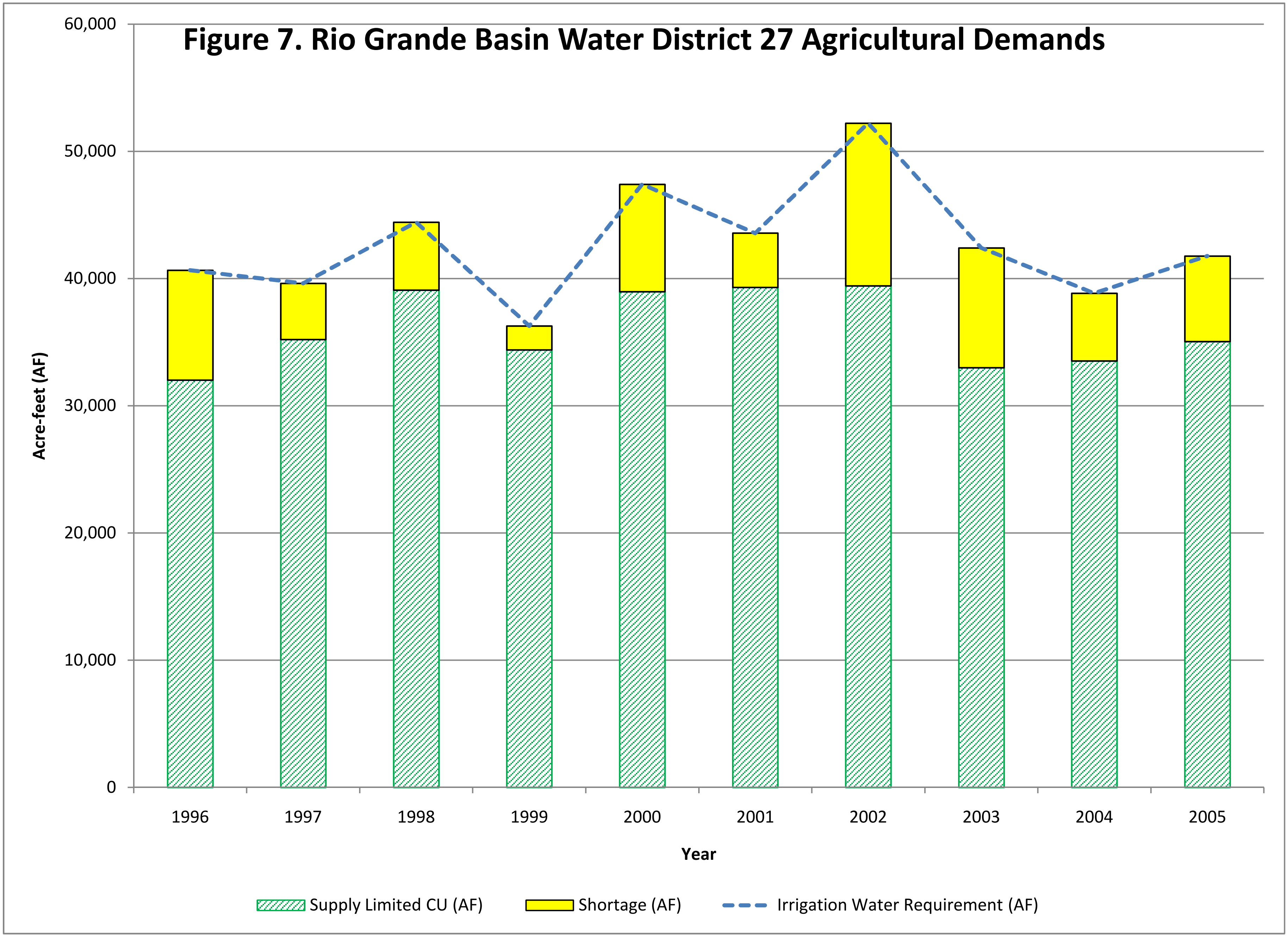


Figure 7. Rio Grande Basin Water District 27 Agricultural Demands
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

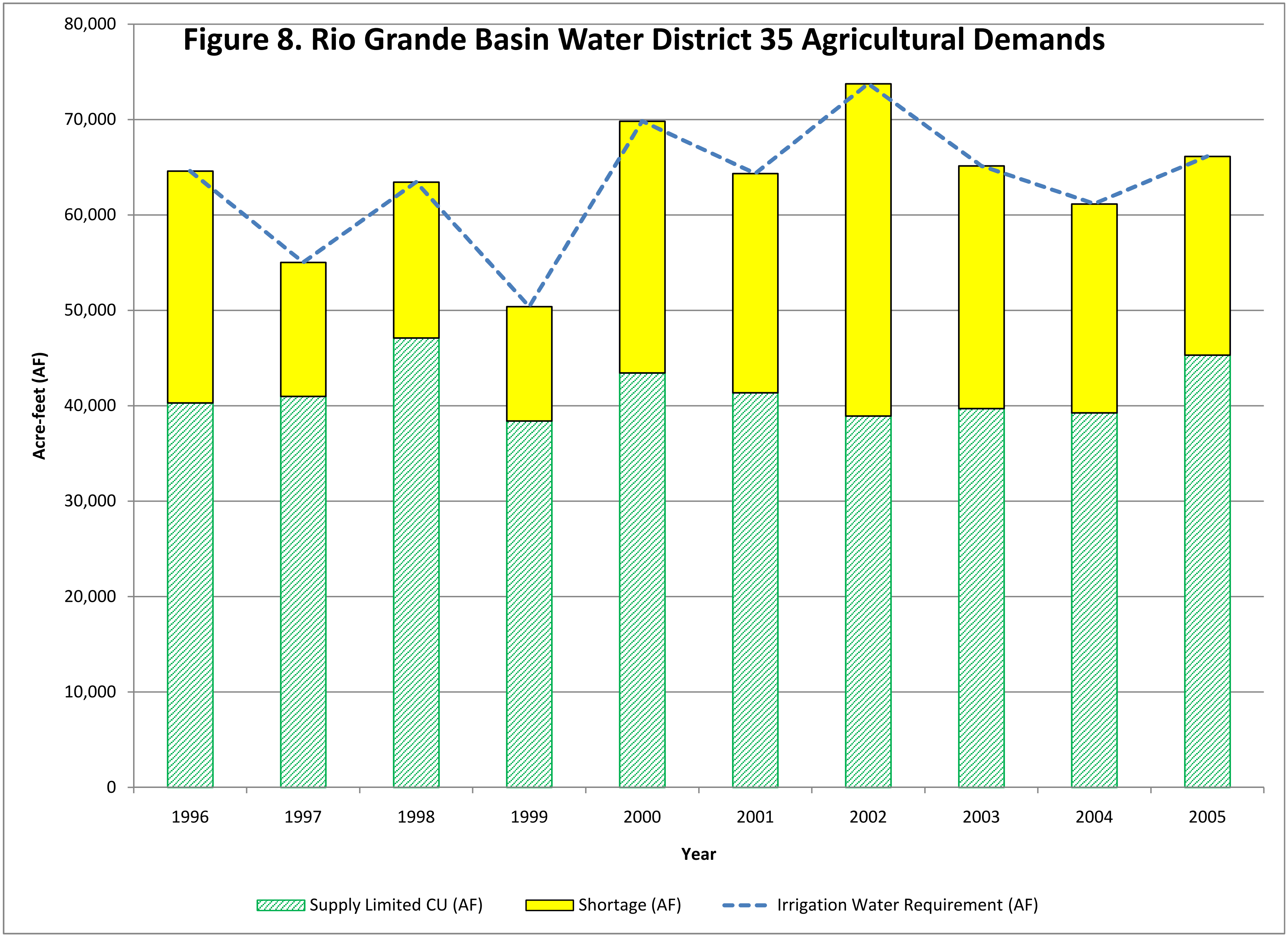


Figure 8. Rio Grande Basin Water District 35 Agricultural Demands
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

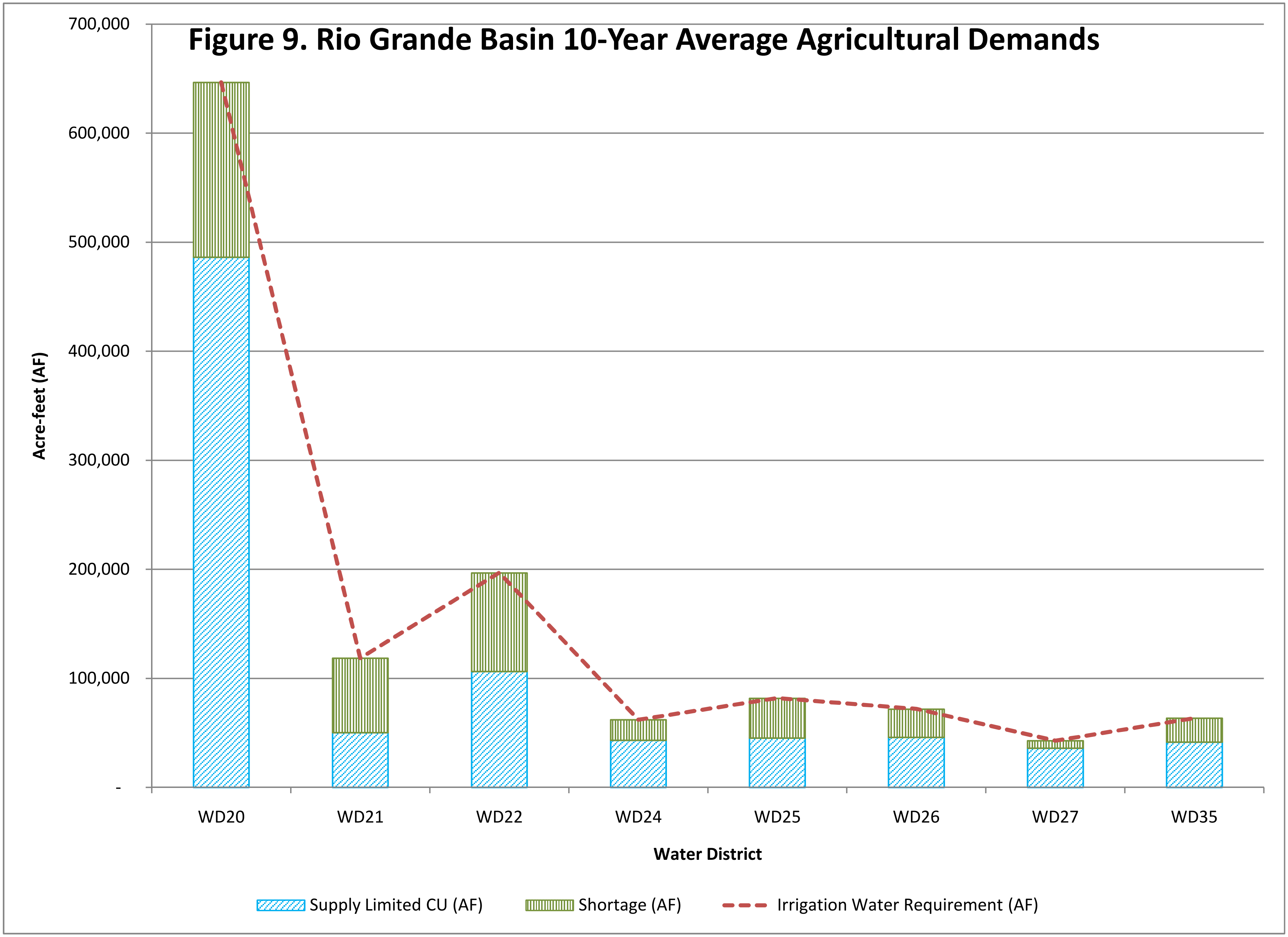


Figure 9. Rio Grande Basin 10-Year Average Agricultural Demands
700,000
600,000
500,000
400,000
300,000
200,000
100,000
-
Acre-feet (AF)
WD20
WD21
WD22
WD24
WD25
WD26
WD27
WD35
Water District
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

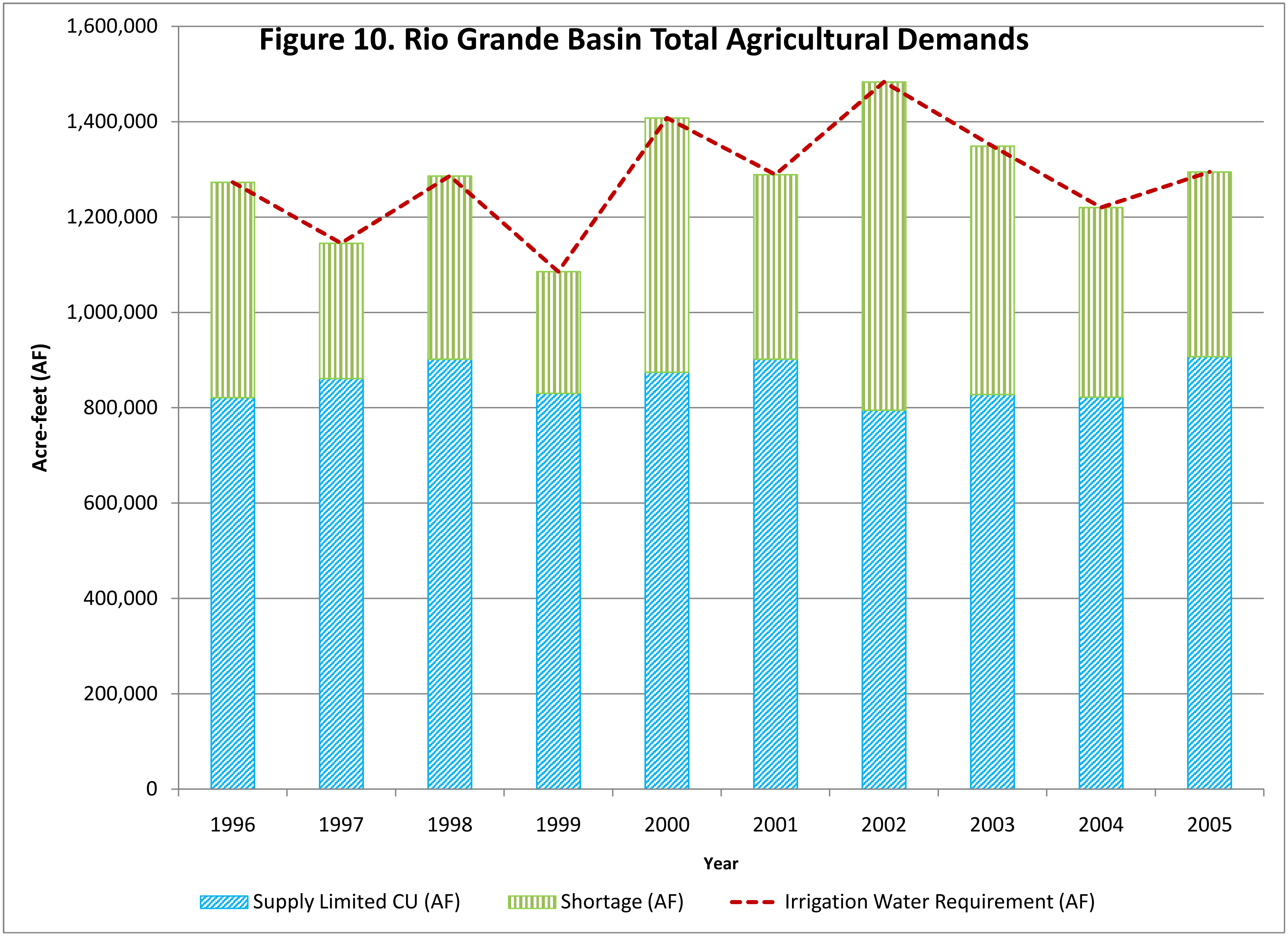


Figure 10. Rio Grande Basin Total Agricultural Demands
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Acre-feet (AF)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

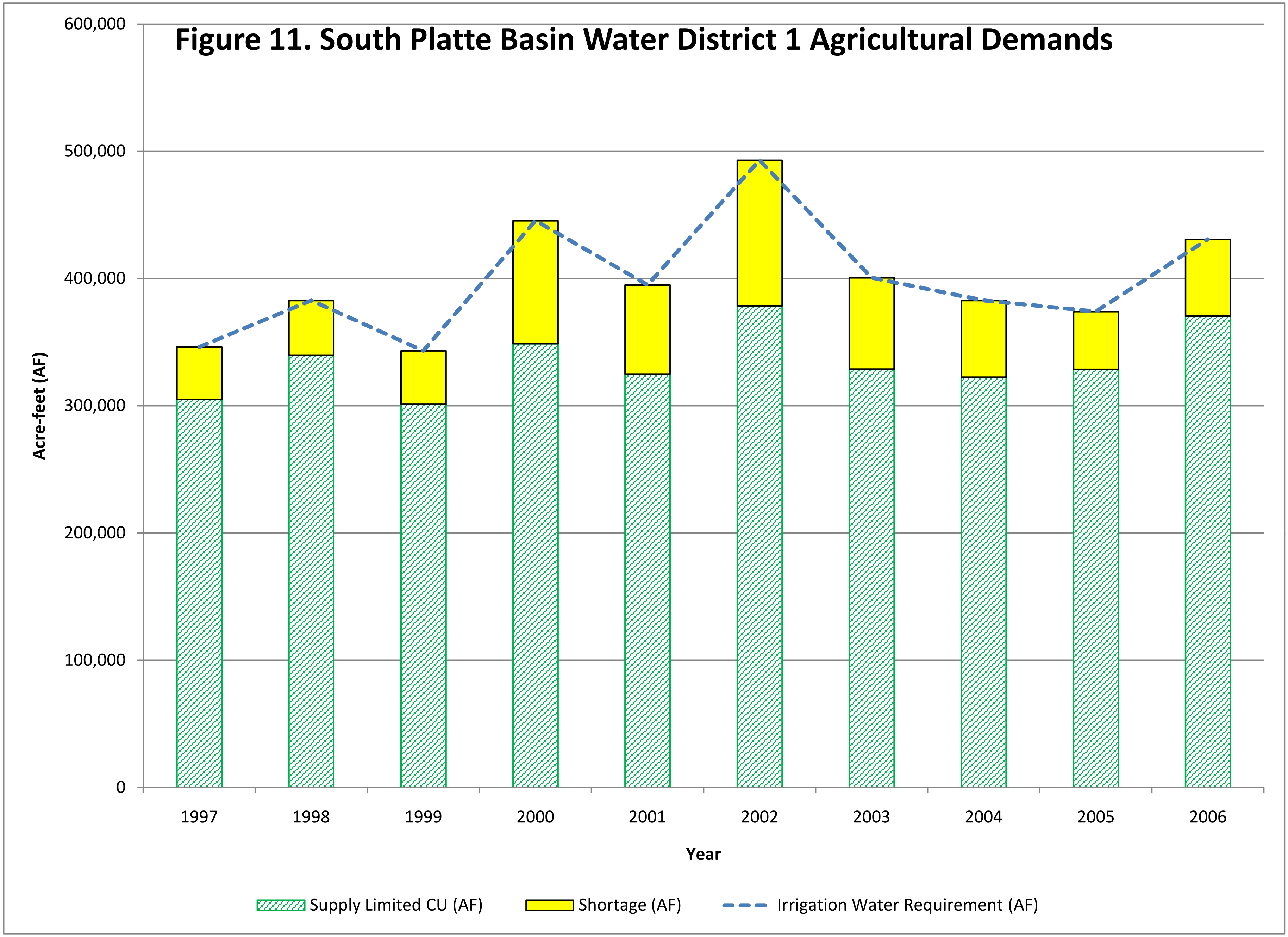


Figure 11. South Platte Basin Water District 1 Agricultural Demands
600,000
500,000
400,000
300,000
200,000
100,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

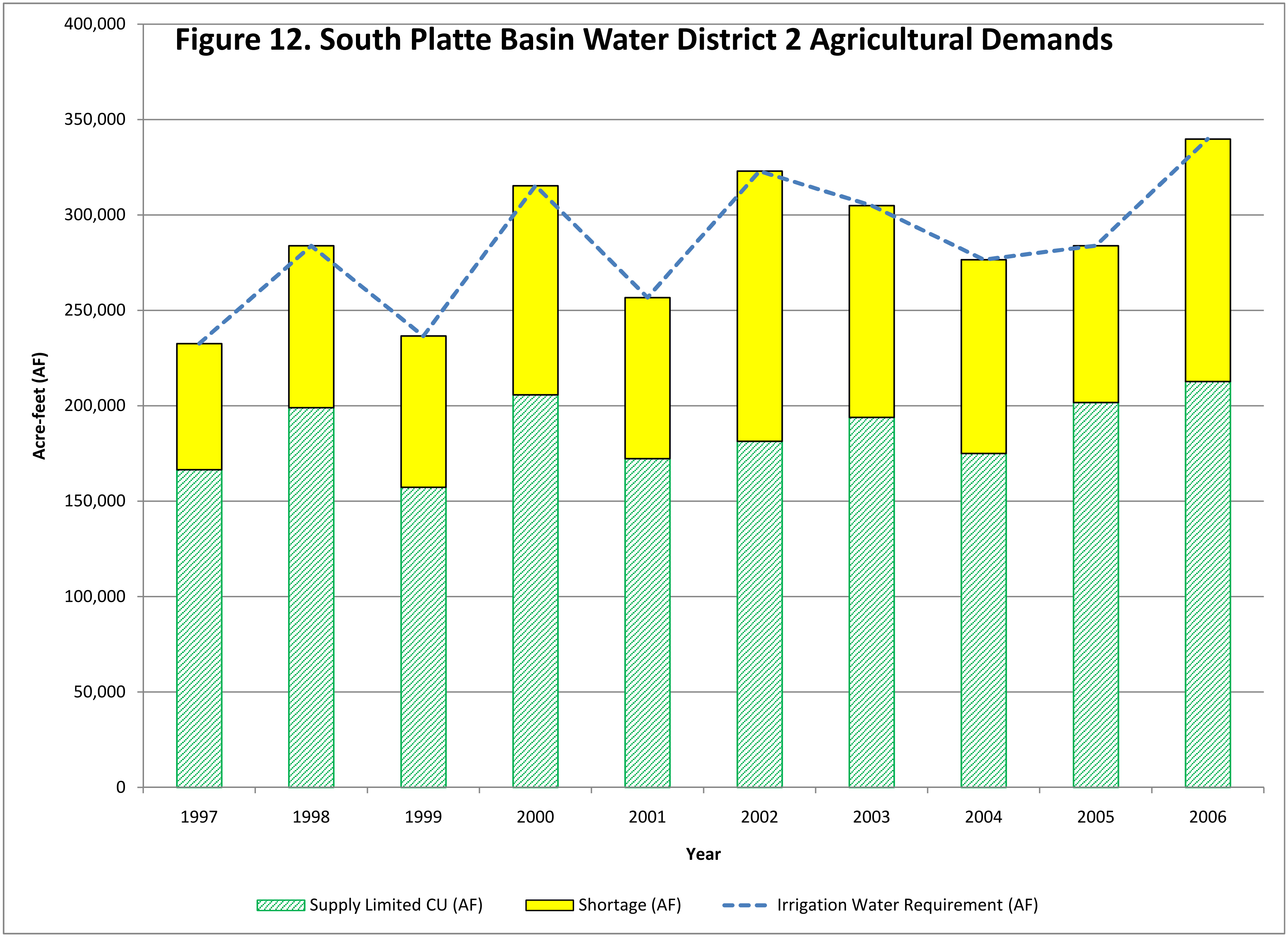


Figure 12. South Platte Basin Water District 2 Agricultural Demands
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

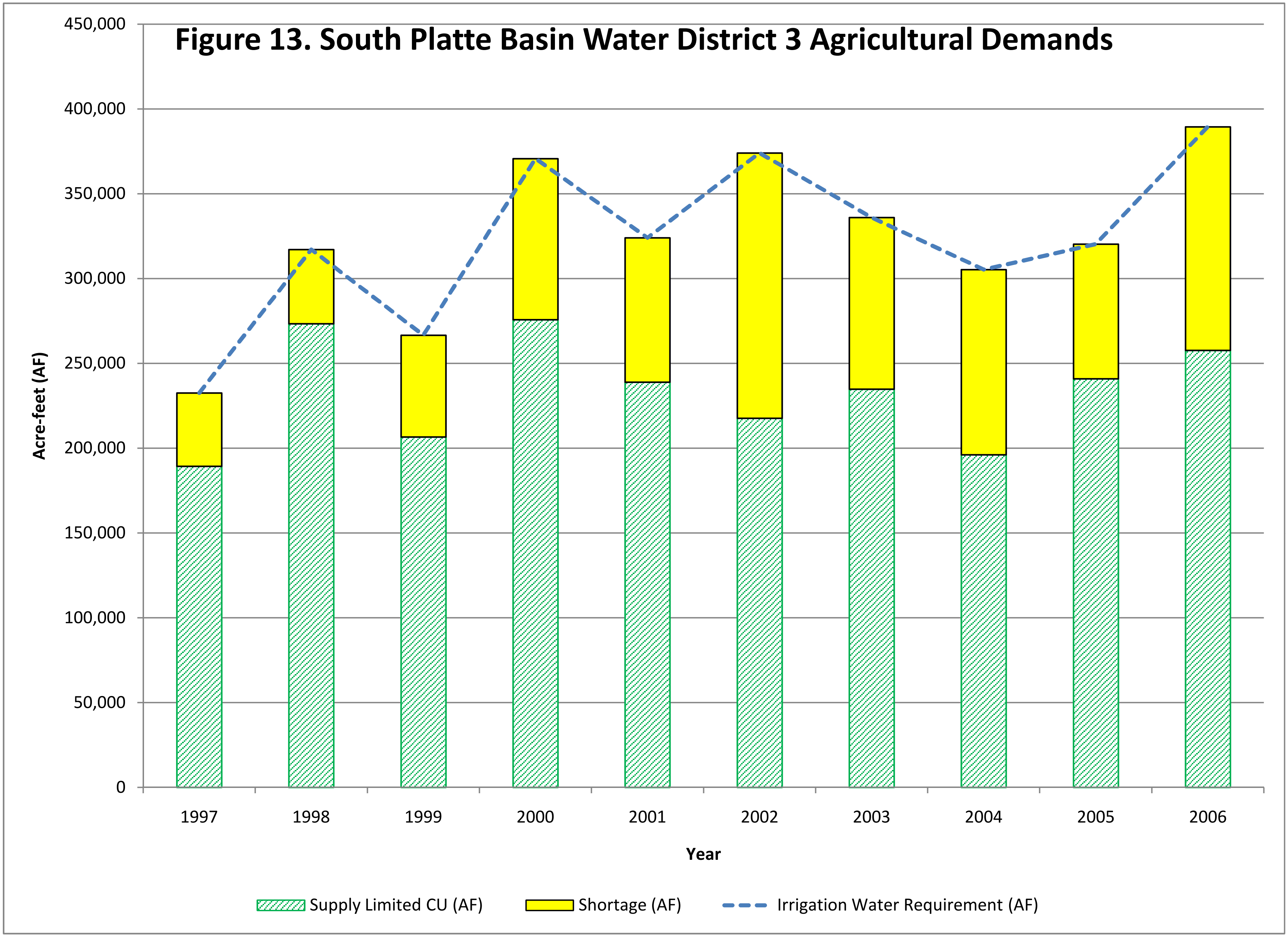


Figure 13. South Platte Basin Water District 3 Agricultural Demands
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

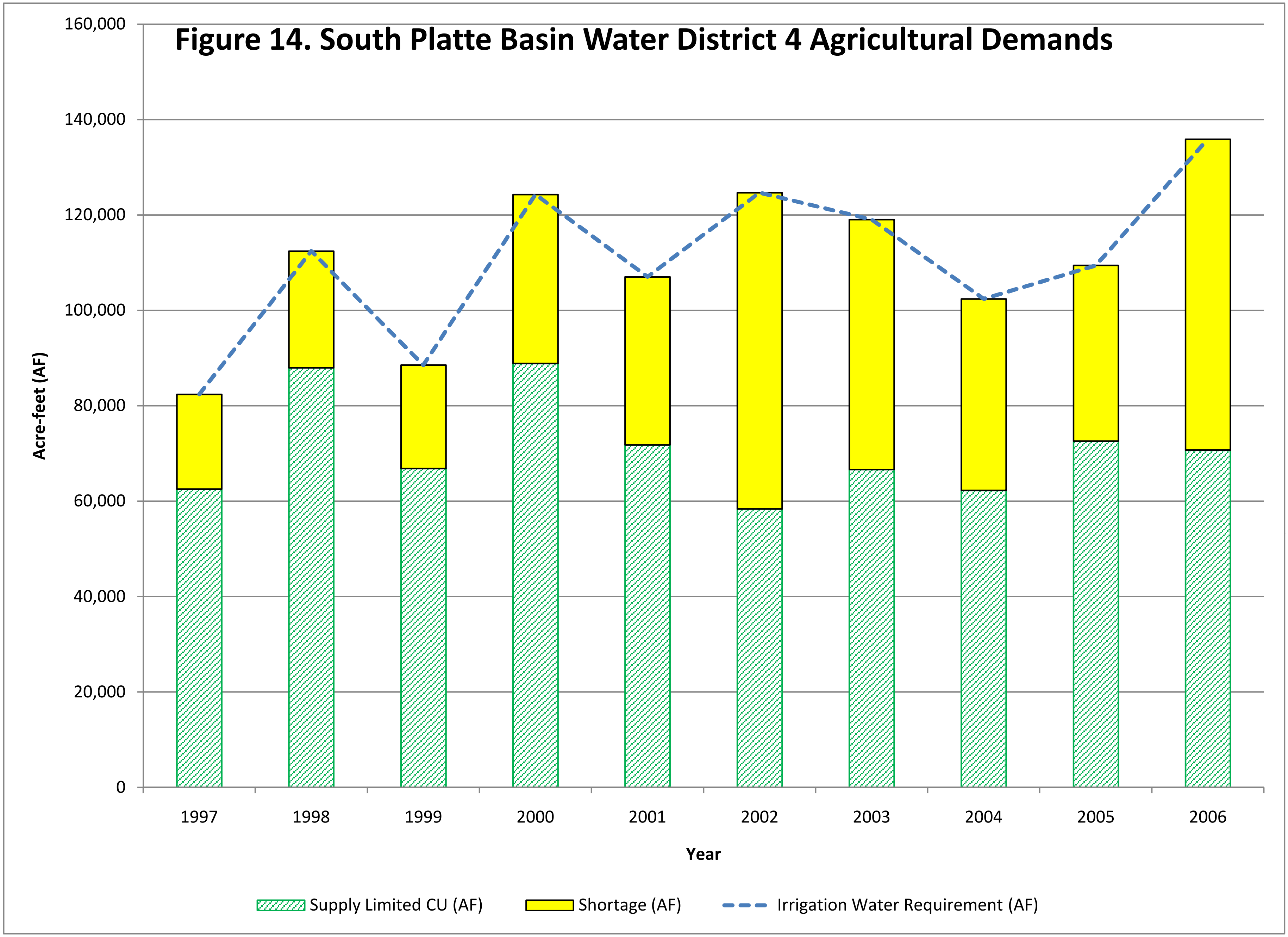


Figure 14. South Platte Basin Water District 4 Agricultural Demands
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

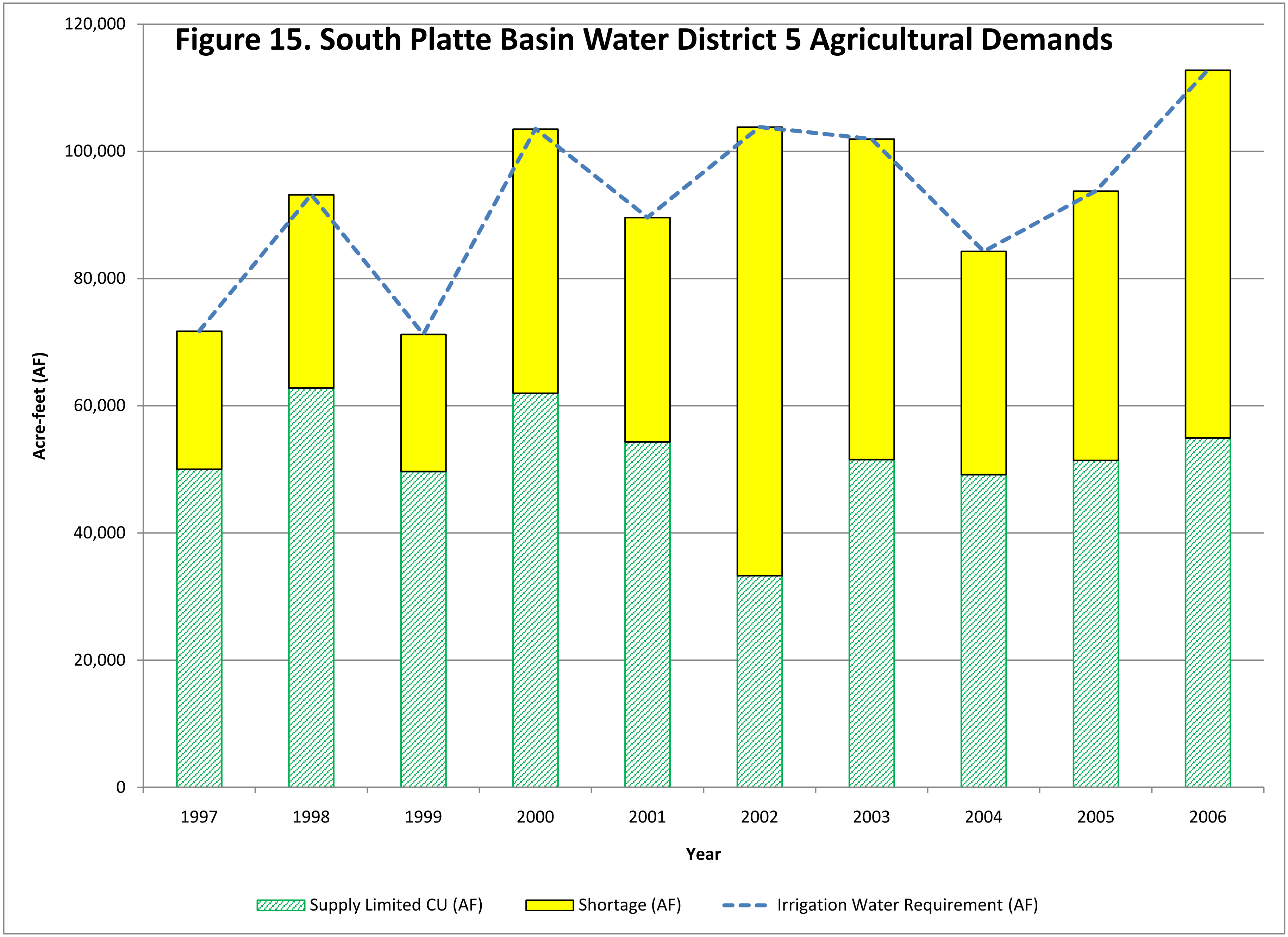


Figure 15. South Platte Basin Water District 5 Agricultural Demands
Acre-feet (AF)
120,000
100,000
80,000
60,000
40,000
20,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

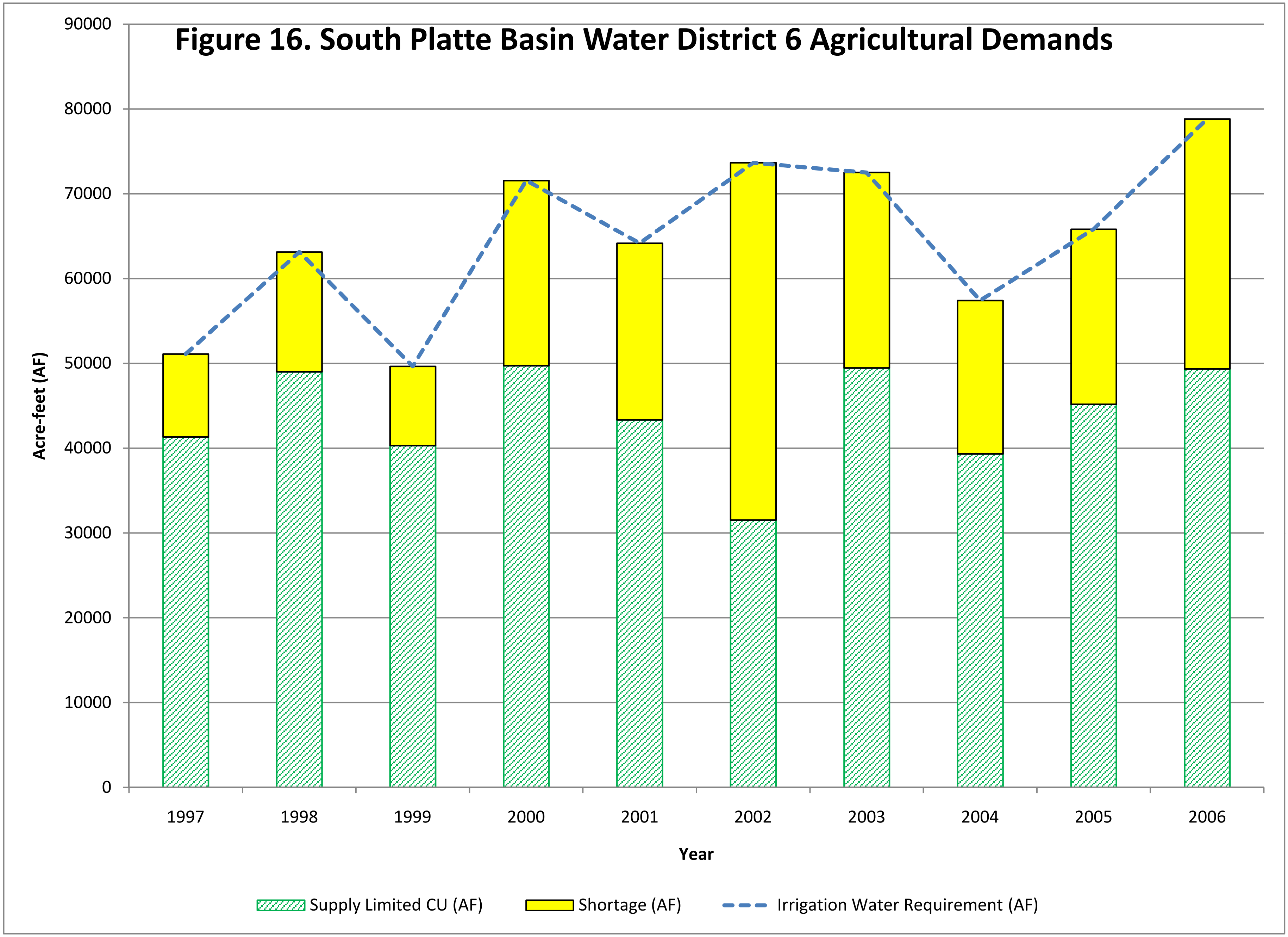


Figure 16. South Platte Basin Water District 6 Agricultural Demands
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

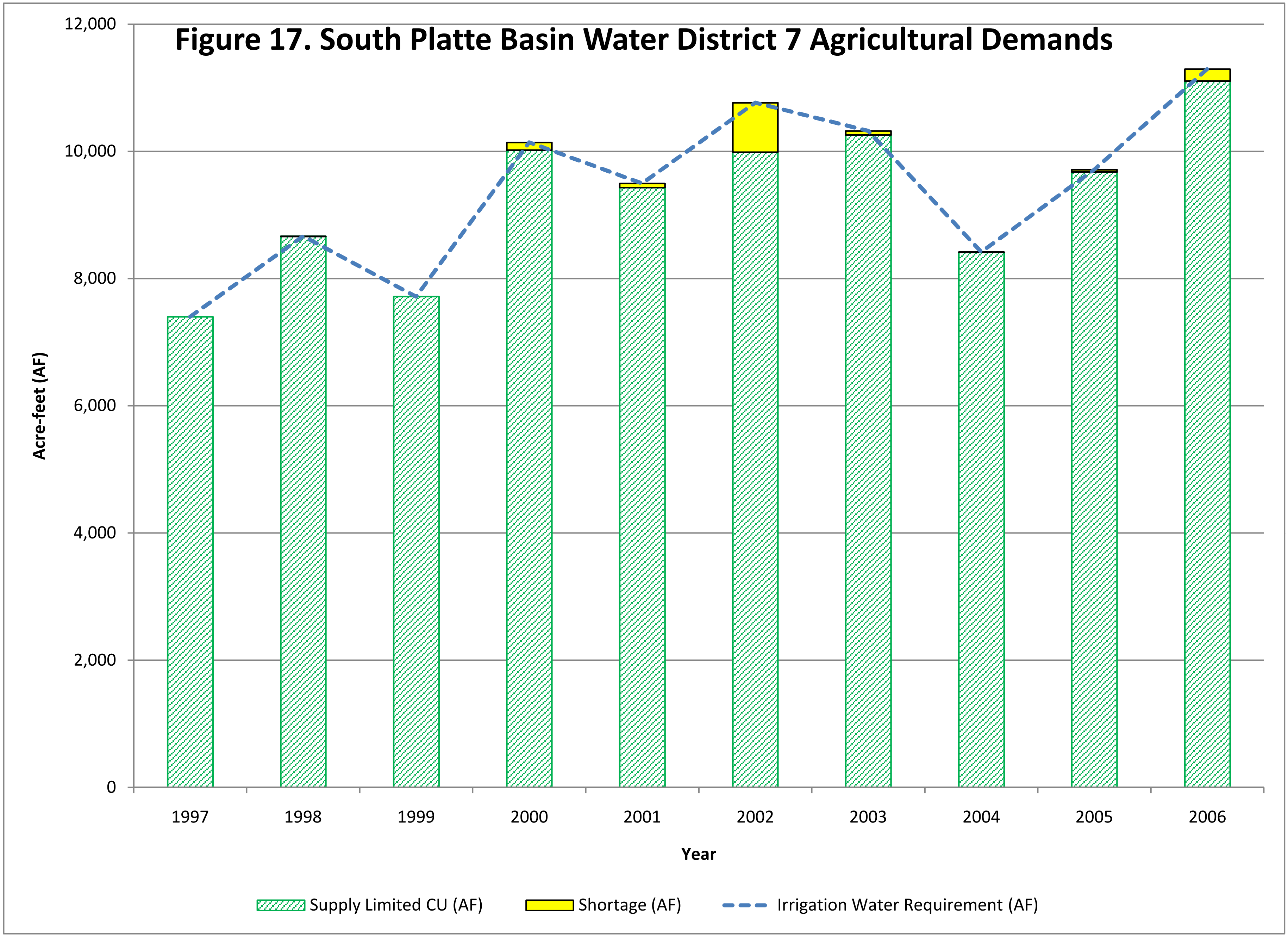


Figure 17. South Platte Basin Water District 7 Agricultural Demands
Acre-feet (AF)
12,000
10,000
8,000
6,000
4,000
2,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

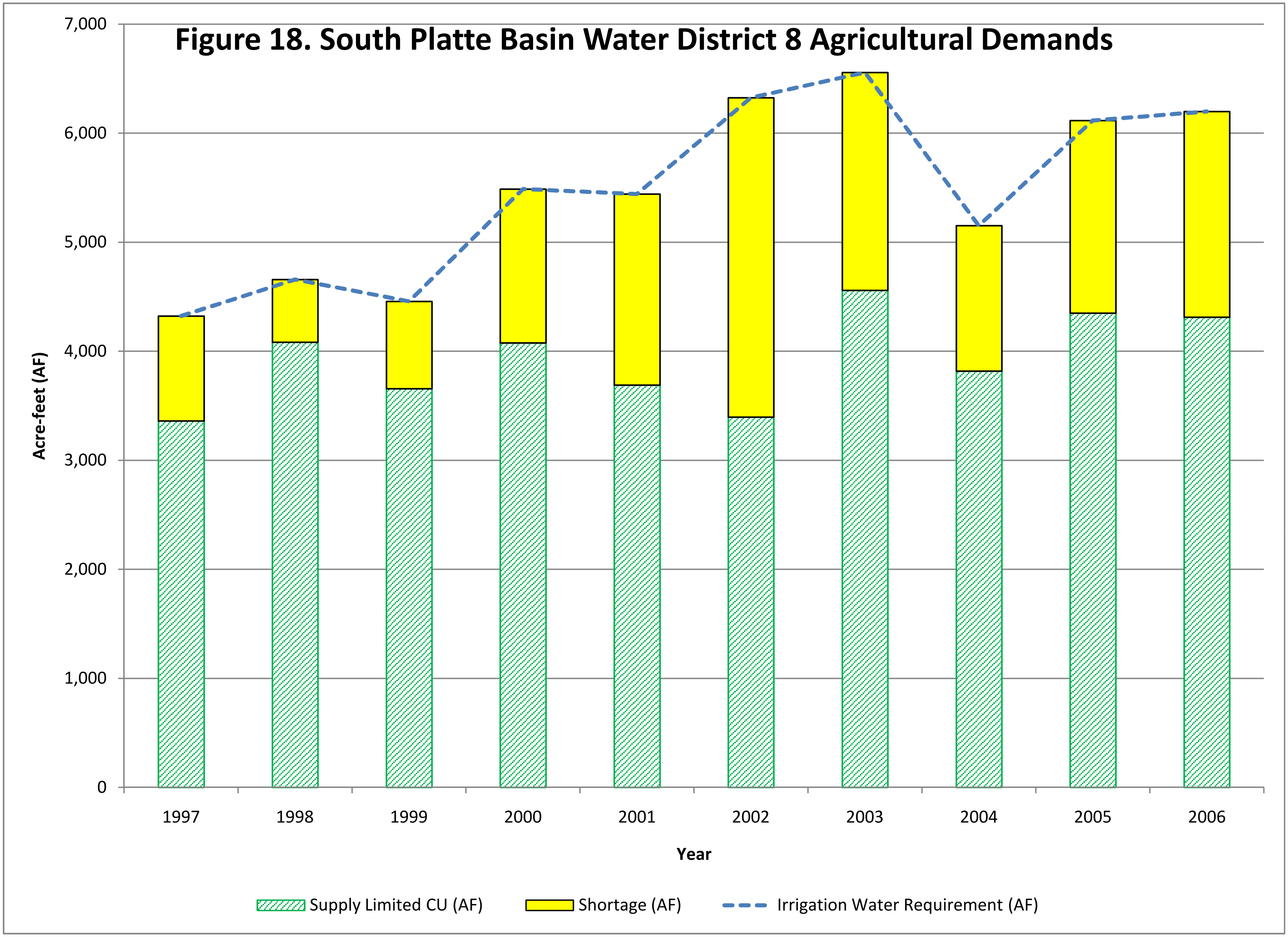


Figure 18. South Platte Basin Water District 8 Agricultural Demands
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

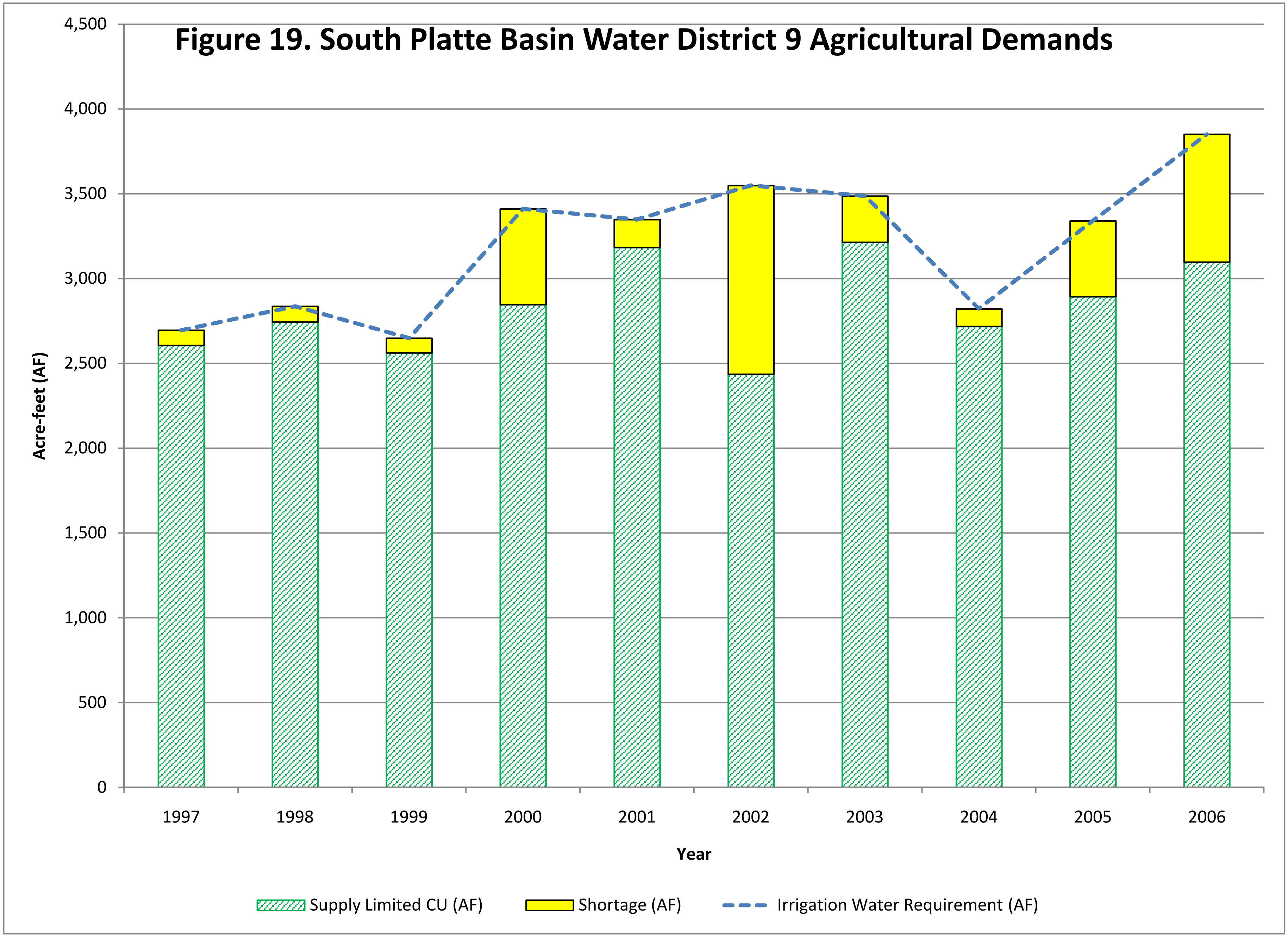


Figure 19. South Platte Basin Water District 9 Agricultural Demands
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

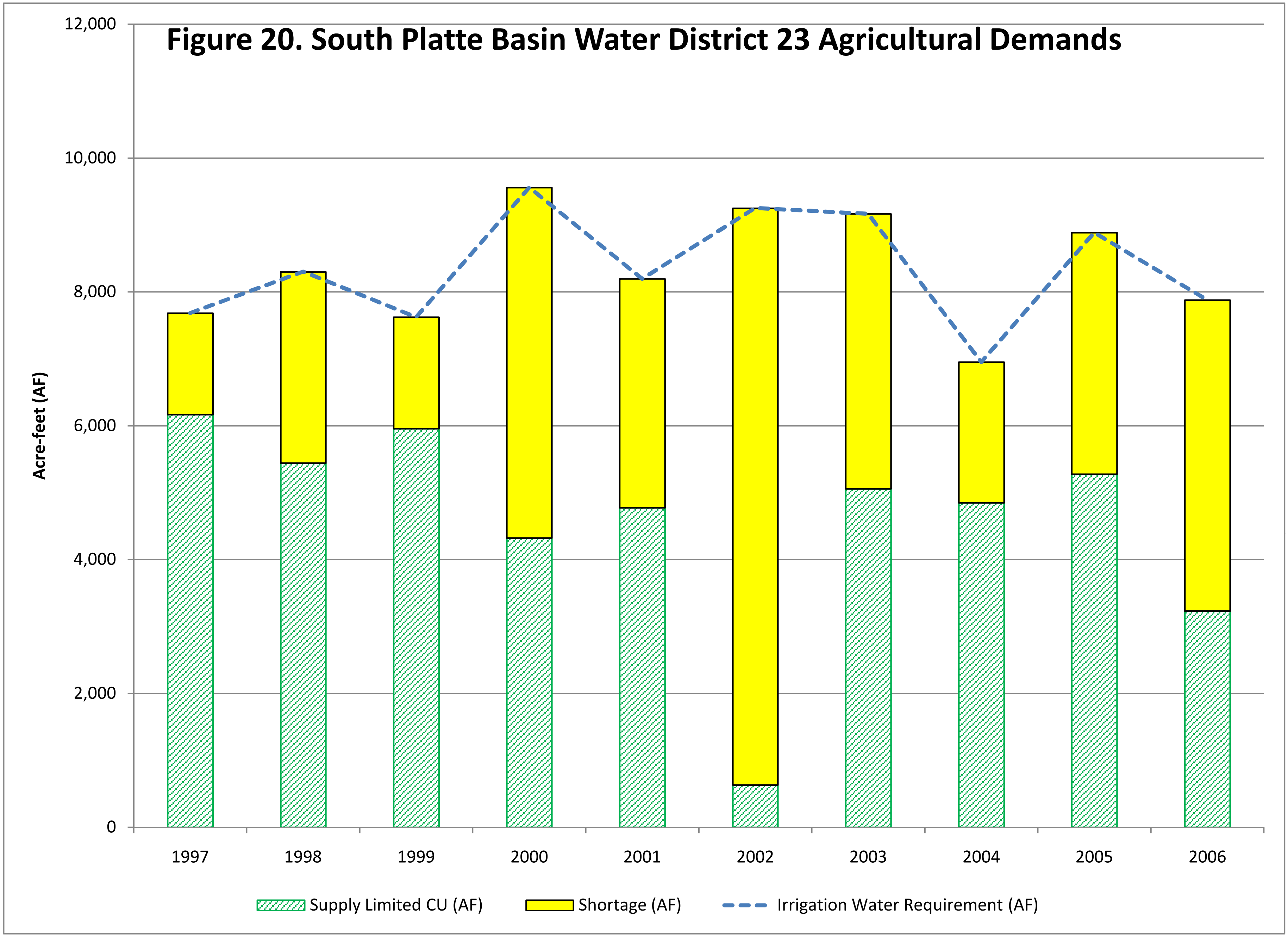


Figure 20. South Platte Basin Water District 23 Agricultural Demands
Acre-feet (AF)
12,000
10,000
8,000
6,000
4,000
2,000
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

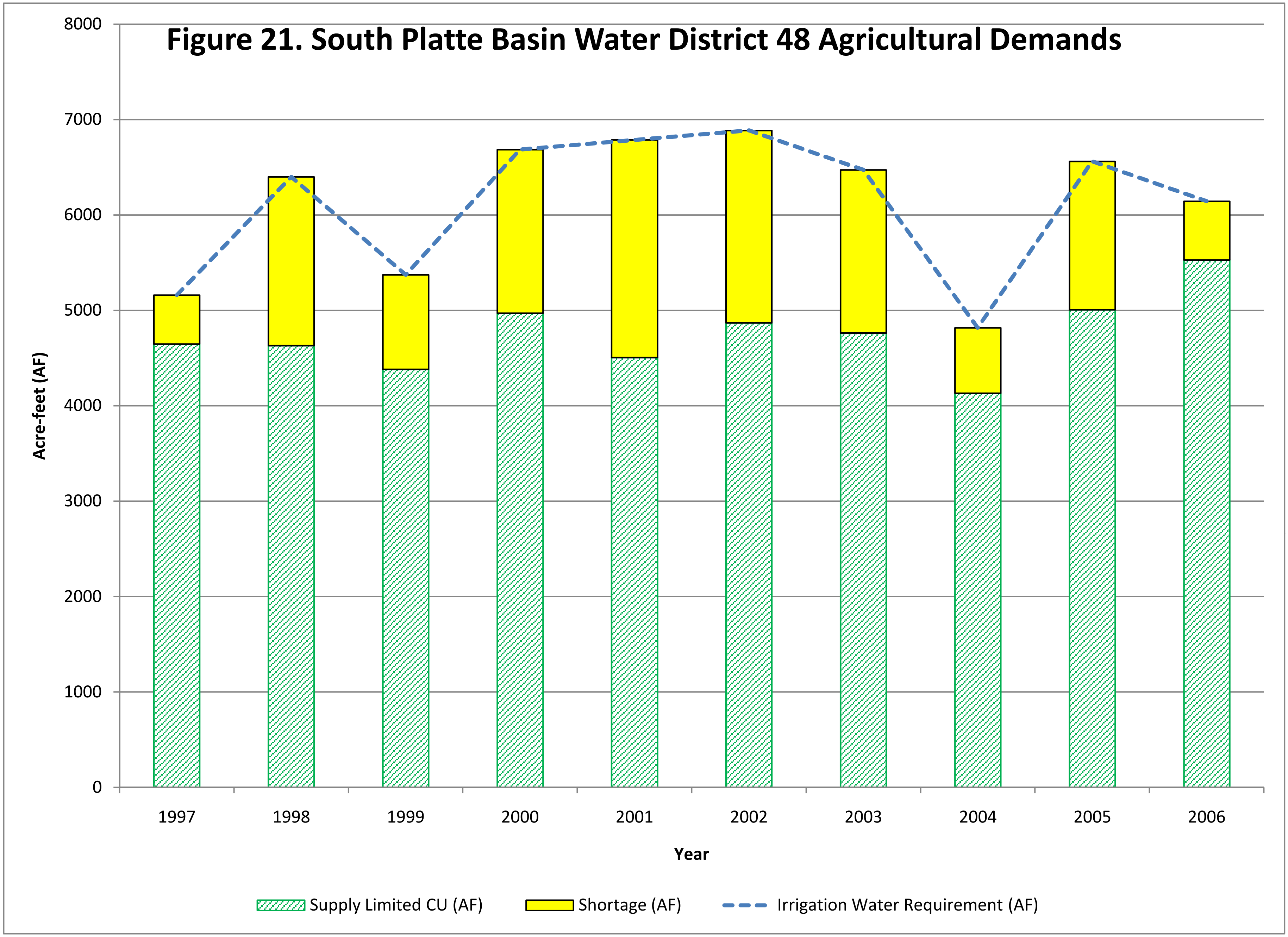


Figure 21. South Platte Basin Water District 48 Agricultural Demands
Acre-feet (AF)
0
1000
2000
3000
4000
5000
6000
7000
8000
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

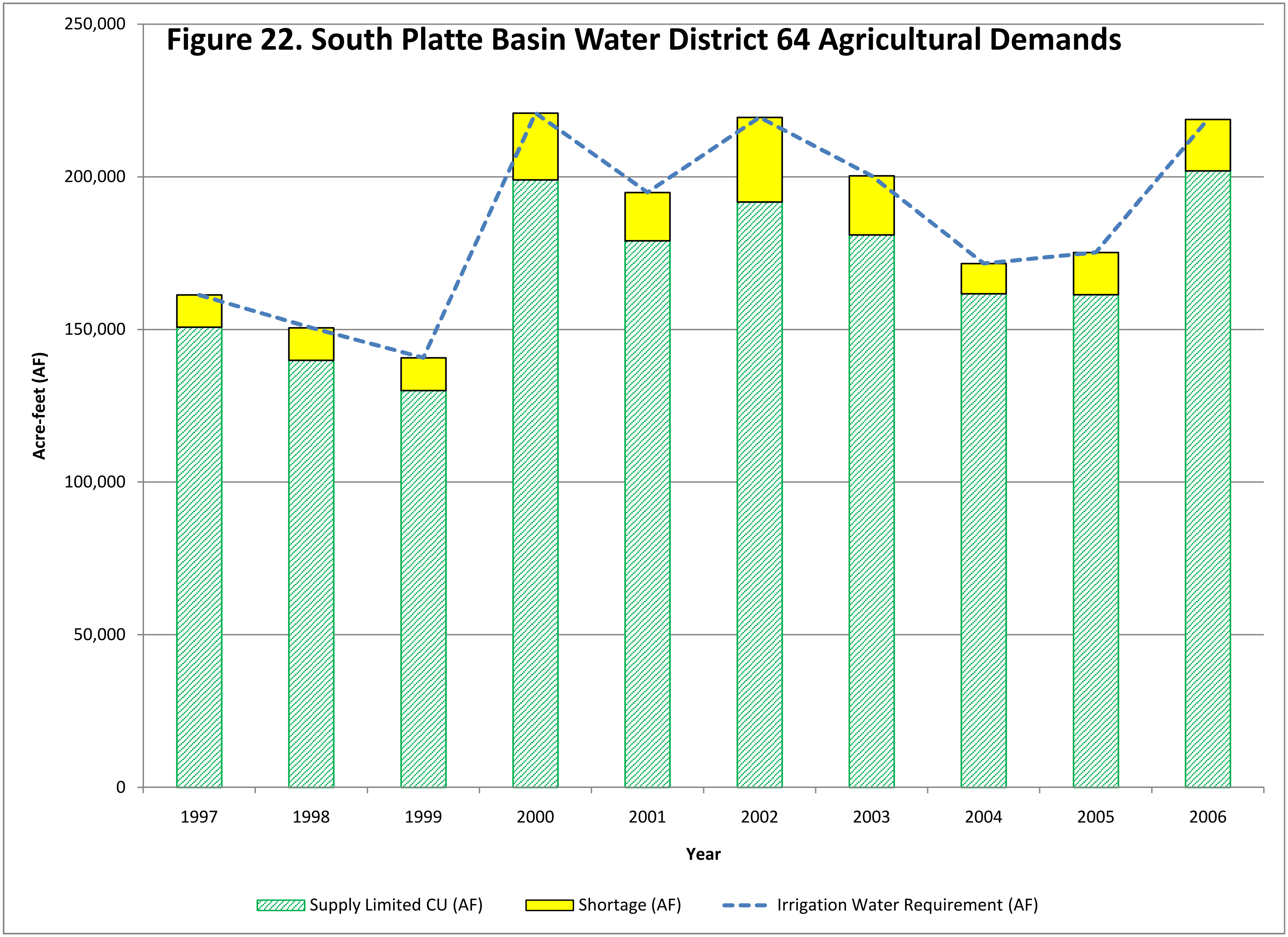


Figure 22. South Platte Basin Water District 64 Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

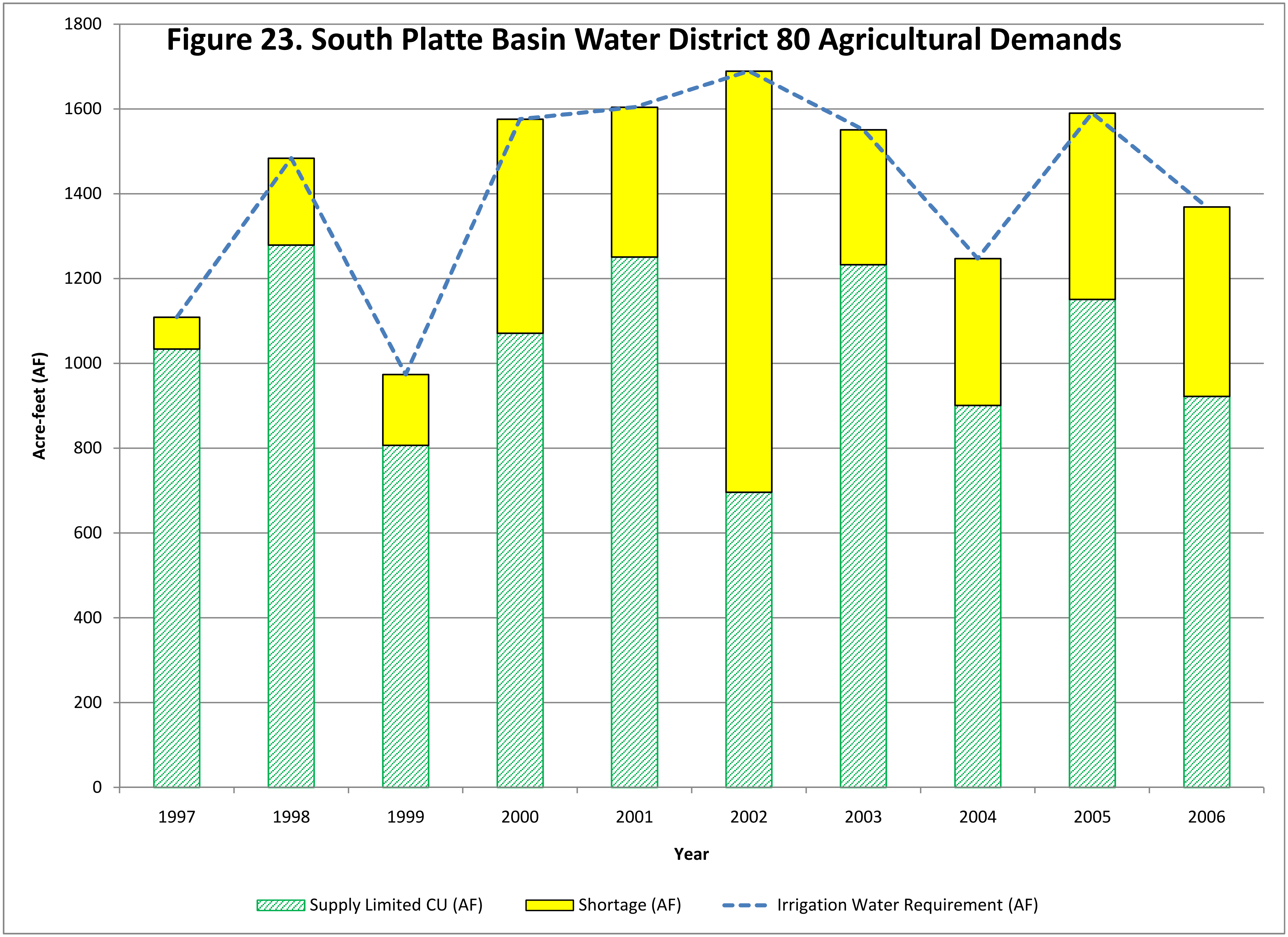


Figure 23. South Platte Basin Water District 80 Agricultural Demands
Acre-feet (AF)
0
200
400
600
800
1000
1200
1400
1600
1800
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

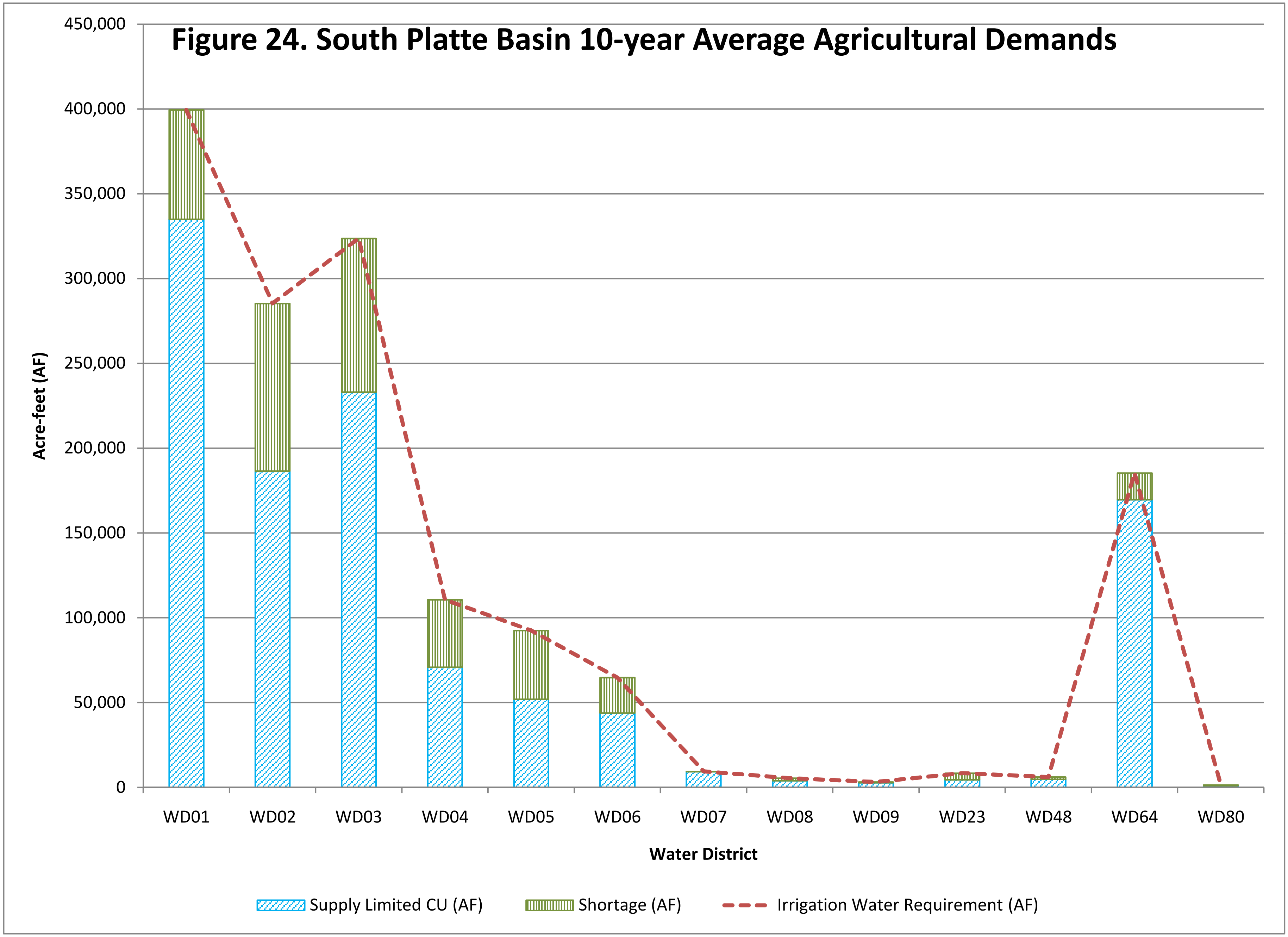


Figure 24. South Platte Basin 10-year Average Agricultural Demands
Acre-feet (AF)
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
WD01
WD02
WD03
WD04
WD05
WD06
WD07
WD08
WD09
WD23
WD48
WD64
WD80
Water District
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

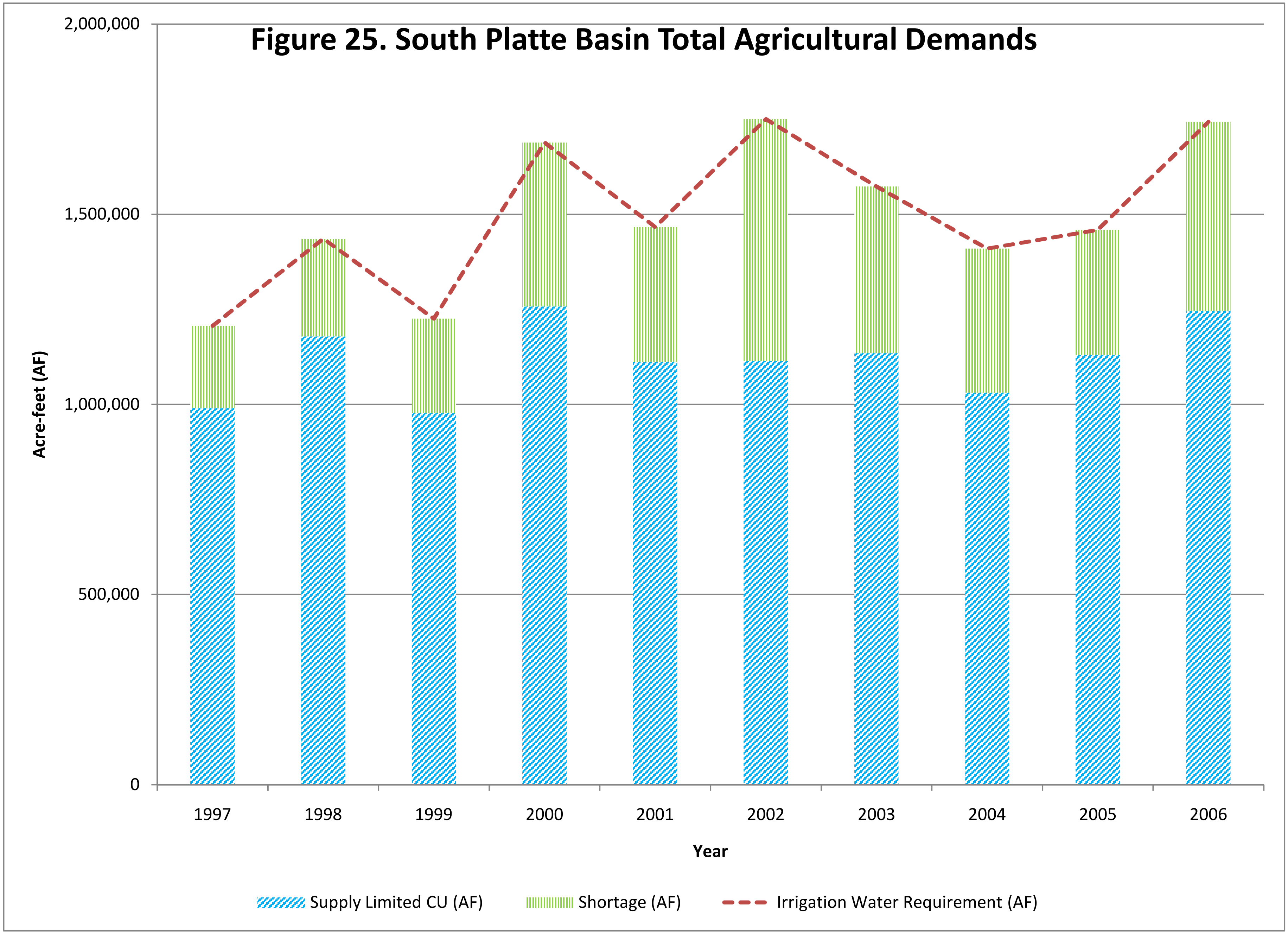


Figure 25. South Platte Basin Total Agricultural Demands
2,000,000
1,500,000
1,000,000
500,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

Appendix C
North Platte Basin Agricultural Demands Methodology

AECOM

Memorandum

Date:	March 22, 2010
To:	Nicole Rowan, CDM
From:	Meg Frantz, AECOM
Subject:	North Platte Basin Current Agricultural Demand – Methods

Distribution:	Todd Doherty, CWCB

Purpose

This memorandum documents the methods used to produce Irrigated Acreage, Irrigation Water Requirement (the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage, for the North Platte basin in Colorado. The values are tabulated in a spreadsheet workbook NorthPlatte.xlsx.

Background

Under the ongoing South Platte Decision Support System (SPDSS) project, Leonard Rice Engineers developed an historical consumptive use model using StateCU, for Water District 47. This District comprises the North Platte River basin within Colorado. The model represents 100 percent of the crop consumptive use in the basin.

Method and Assumptions

1. AECOM relied on the recently completed StateCU data set for this effort. The model included the requisite information on irrigated lands, relevant climate stations, crop types and irrigation practices, and historical water supply. StateCU was executed to produce irrigation water requirement, water-supply limited consumptive use, and shortage.

2. The study period 1997 through 2006, the most recent 10 years of the CDSS model period. This approach is consistent with that taken in the other major basins. It incorporates climate variability, but confines the study to current conditions in terms of the available water supply.

3. The irrigated lands information was based on 2001 imagery supplemented by user information. Changes in irrigated lands in this part of the state have been minor, and the coverage is considered valid for this level of planning.

4. The Blaney-Criddle method (SCS Publication TR-21) is used for estimating potential evapotranspiration and effective precipitation. Irrigated lands in the North Platte basin are all above 6500 feet, and pasture grass is the only irrigated crop. Accordingly, high altitude coefficients developed by Denver Water for pasture grass were used throughout the StateCU model.

5. The soil moisture reservoir is considered in calculating consumptive use. Excess irrigation water can enter the reservoir, to be consumed at a later time when irrigation supply is not adequate for the crop's needs. Use of soil water is counted toward the annual consumptive use.

6. Shortages due to irrigation practice are included in the reported shortages. This is true in all basins, but is pronounced in the North Platte basin. Historically, farmers cease irrigation after one hay crop. After that point, there is a crop irrigation requirement and legally available water, but generally, diversions are not made.

Agricultural Demand Summary Tables

Table 1. North Platte Basin 10-year Average Agricultural Demand

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD47	117,259	201,521	113,216	88,305

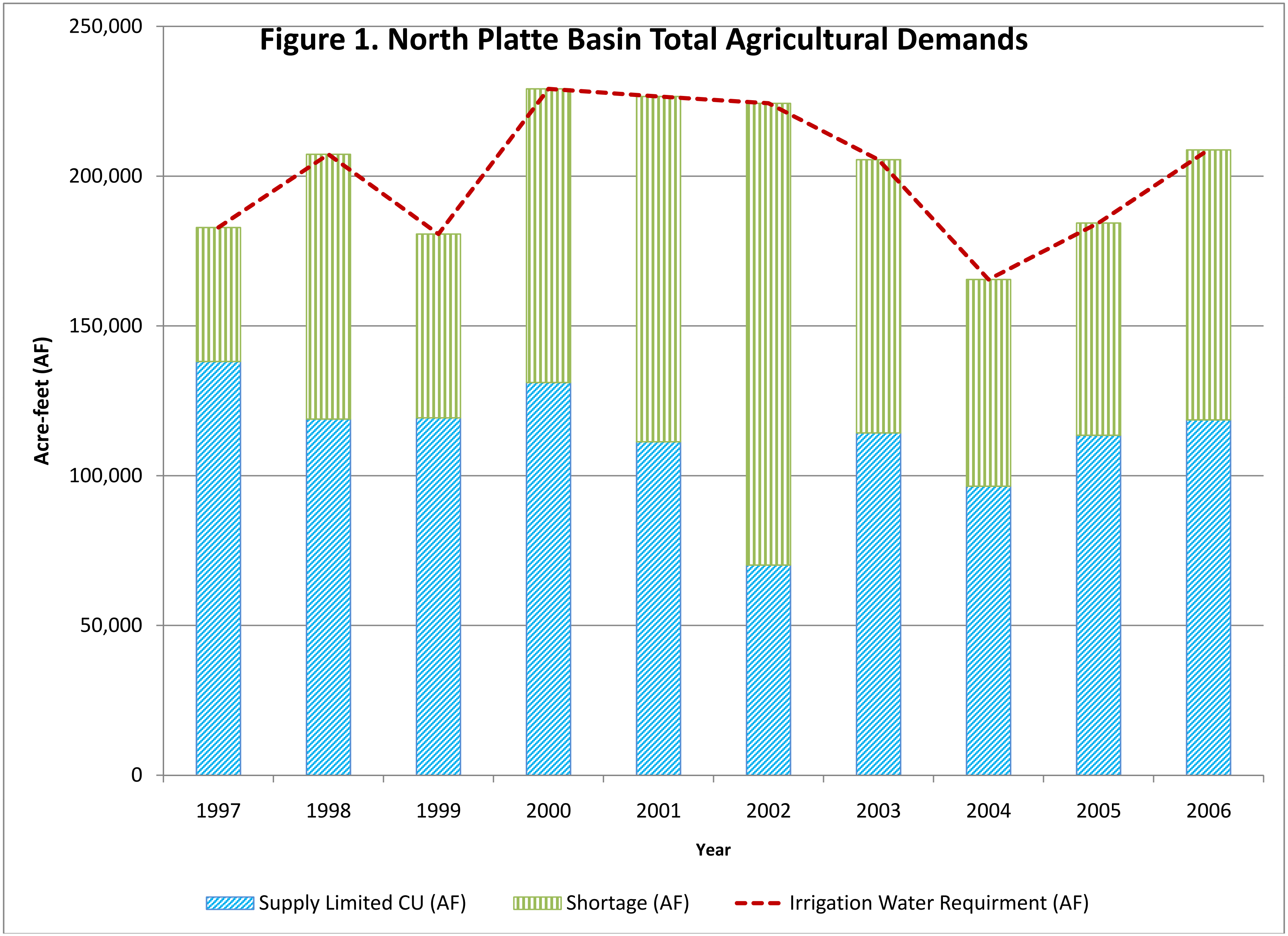


Figure 1. North Platte Basin Total Agricultural Demands
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirment (AF)

Appendix D
Republican Basin Agricultural Demands Methodology

Memorandum

Date:	March 18, 2010
To:	Nicole Rowan, CDM
From:	Meg Frantz, AECOM
Subject:	Republican River Current Agricultural Demand – Methods
Distribution:	Todd Doherty, CWCB

Purpose

This memorandum documents the methods AECOM used to produce the spreadsheet workbook RepublicanSummary.xlsx, which tabulates Irrigated Acreage, Irrigation Water Requirement (the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage. The method was described in a memorandum distributed to the Division of Water Resources on January 19, 2010, and Mike Sullivan of that office indicated that he concurred with the approach and use of data.

Background

AECOM relied on input to The Republican River Compact Administration Ground Water Model (RRCA Model) for data prior to 2000 (i.e, 1998 through 2000), and on the yearly compact accounting for years following 2000 (i.e., 2001 through 2007). The RRCA model was developed collaboratively by the three signatory states to determine the amount, location, and timing of streamflow depletions to the Republican River, attributable to pumping; and to determine streamflow accretions from recharge of water imported from the Platte River into the Republican River basin. Pumping and recharge input to the Colorado portion of the model are driven by Irrigation Water Requirement (IWR), which was estimated for the initial modeling period of 1940 through 2000. Annual accounting for each year since then has required simulation of the current year with updated pumping and return flow information, derived using the current climate, crop mix, and irrigated acreage.

Irrigation Demand - Estimation of irrigated acreage for 1940 through 2000 was the result of considerable effort. It was computed by county, based on County assessor's data for crop mix, irrigated acreage, and irrigation method (flood versus sprinkler). Historical irrigated acreage was adjusted for lands that were temporarily out of production under certain federal programs, but classified as irrigated by the County, per the program guidelines. Surface-water irrigated lands (approximately 1% of the total irrigated area in the basin) were assumed to remain static after groundwater began to be developed in the 1940's.

County assessors' data were used in the incremental annual additions to the RRCA model from 2001 through 2004. In 2005, Colorado developed a more refined procedure for modeling well pumping, beginning with estimation of irrigated acreage from 2005 aerial photography available under the National Agricultural Imagery Program (NAIP). Irrigated acreage identified in this manner was close to the irrigated acreage available from the assessors' data, but the GIS techniques under the new procedure allowed for more accurate spatial placement of the pumping in the model.

Regardless of the method used for determining irrigated acres and crop mix, IWR was estimated for all years using the Hargreaves equation calibrated to the Penman-Monteith equation. Each county was assigned a single climate station to provide the needed climate time series.Net IWR was computed as IWR less effective precipitation, and less 2.0 inches for the accumulation of soil moisture during the non-growing season.

Net IWR multiplied by irrigated acreage is equivalent in concept to the Irrigation Agricultural Demand sought by this study. These two pieces of data are available by county for years up to and including 2000, in Appendixes K and L of the document "Republican River Compact Administration Ground Water Model, June 30, 2003", available at the Compact website. For 2001 through 2007, Net IWR and groundwater-irrigated acreage are available in separate Excel spreadsheets for each year.

Shortage – Apparently, pumping records of sufficient reliability were not available on a widespread basis to calculate water-supply limited consumptive use (and shortage) directly for each well. However, in 2002, Colorado investigated 150 water right change cases which were supported by collection of pumping data. Calculations showed that on average, irrigators pump sufficient water to supply 75 percent of the Net IWR at their farm efficiency. Implicit in the procedure for estimating groundwater recharge due to irrigation, for input to the model, is the assumption that 75 percent of Net IWR is met, meaning that average shortage is 25 percent of irrigation demand.

Method

1. AECOM relied on the "Annual Net IWR" time series (the potential evapotranspiration rate less effective precipitation and winter soil moisture, in inches) by county from Appendix L of the RRCA groundwater model documentation, for 1998 through 2000. Source for Net IWR for 2001 through 2007 was the annual groundwater pumping spreadsheets named *yyyy Republican-CO Pump.xls* where *yyyy* is the year.

2. Based on discussions the January 6th coordination meeting, irrigated acreage in the Republican basin has been dynamic in the last decade. This condition is due to both the interstate settlement and loss of saturated thickness and well productivity. Accordingly, current demand was estimated using 2007 irrigated acreage by county and the annual Net IWR values for 1998 through 2007. This approach incorporates climate variability, but assumes that current amount of irrigated acreage is best represented by the most recently available value for that parameter.

3. Estimate of shortage for groundwater-irrigated acreage is based on the shortage assumptions described above, namely, that 25 percent of the basin's water requirement is not met. This approach is both consistent with RRCA accounting and rooted in an extensive study of "real world" conditions.

4. Surface water irrigation occurs only in Yuma and Kit Carson counties, and is currently being phased out. Based on recommendations from the State's consultant in the Republican River case, we assumed 1000 acres of surface water irrigation, and applied to that figure the Net IWR time series for those two counties. Determining a more precise number of surface water-

irrigated acreage is of little value because the exact number is expected to change soon, and because surface water accounts for a very small percentage of the total Republican basin irrigation use. There is no specific guidance in the accounting that relates to the percentage of demand satisfied by surface water irrigation (i.e., shortages). We used the 75 percent assumption that is described for groundwater.

5. All of the above calculations are on a county basis. Results for Cheyenne, Kit Carson, and 18.8 percent of Lincoln County are attributed to Water District 49. The balance of Lincoln County, plus all of Logan, Phillips, Sedgwick, Washington, and Yuma Counties are attributed to Water District 65. The split for Lincoln County is based on the percent of irrigated acreage in the respective Water Districts, according to the GIS products of the 2005 aerial photography analysis mentioned above.

Agricultural Demand Summary Tables

Table 1. Republican Basin 10-year Average Agricultural Demand

Water District	Irrigated Acres	Irrigation Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD49	154,549	247,652	185,739	61,913
WD65	395,650	554,767	416,075	138,692

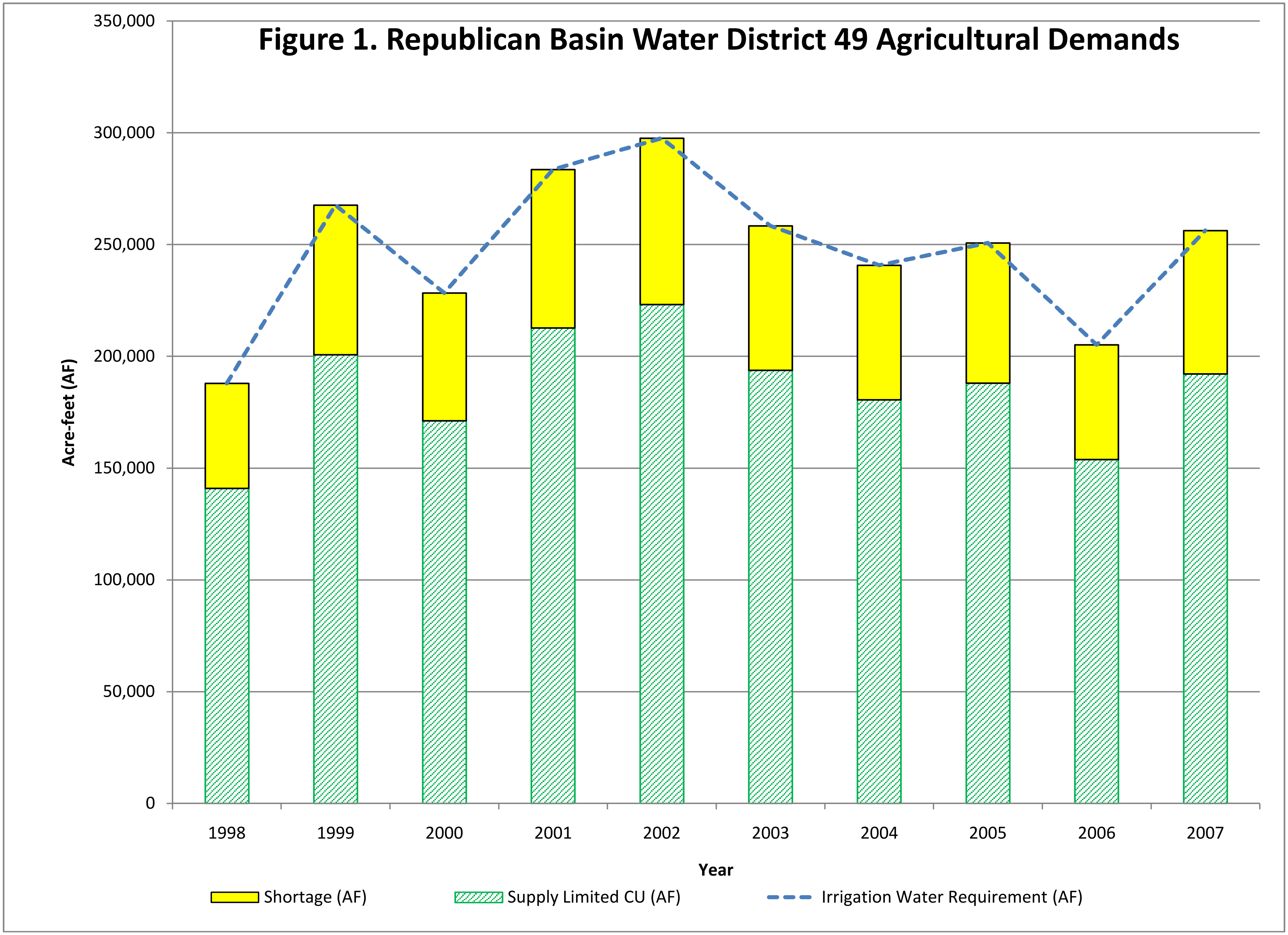


Figure 1. Republican Basin Water District 49 Agricultural Demands
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

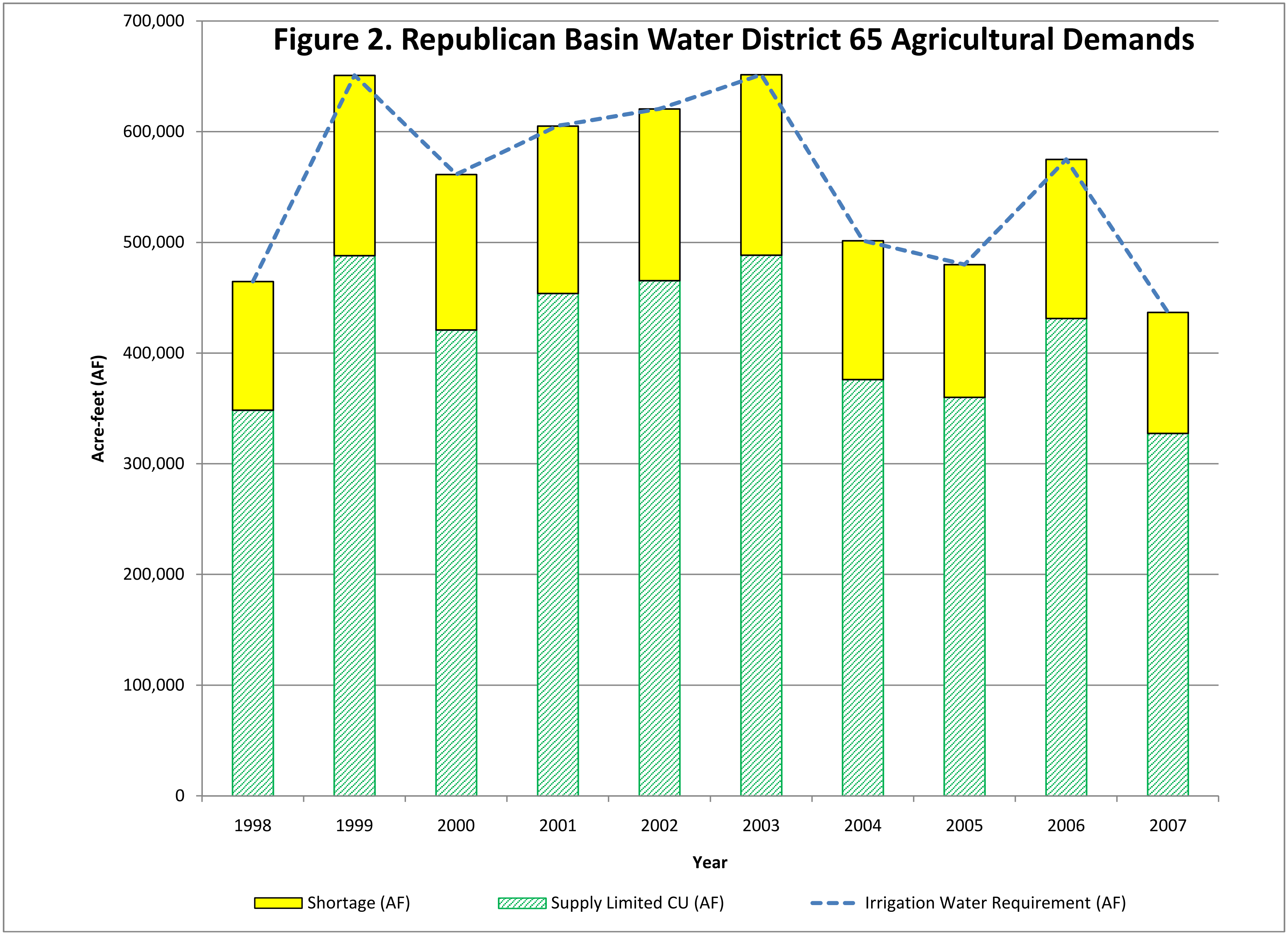


Figure 2. Republican Basin Water District 65 Agricultural Demands
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Acre-feet (AF)
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Year
Shortage (AF)
Supply Limited CU (AF)
Irrigation Water Requirement (AF)

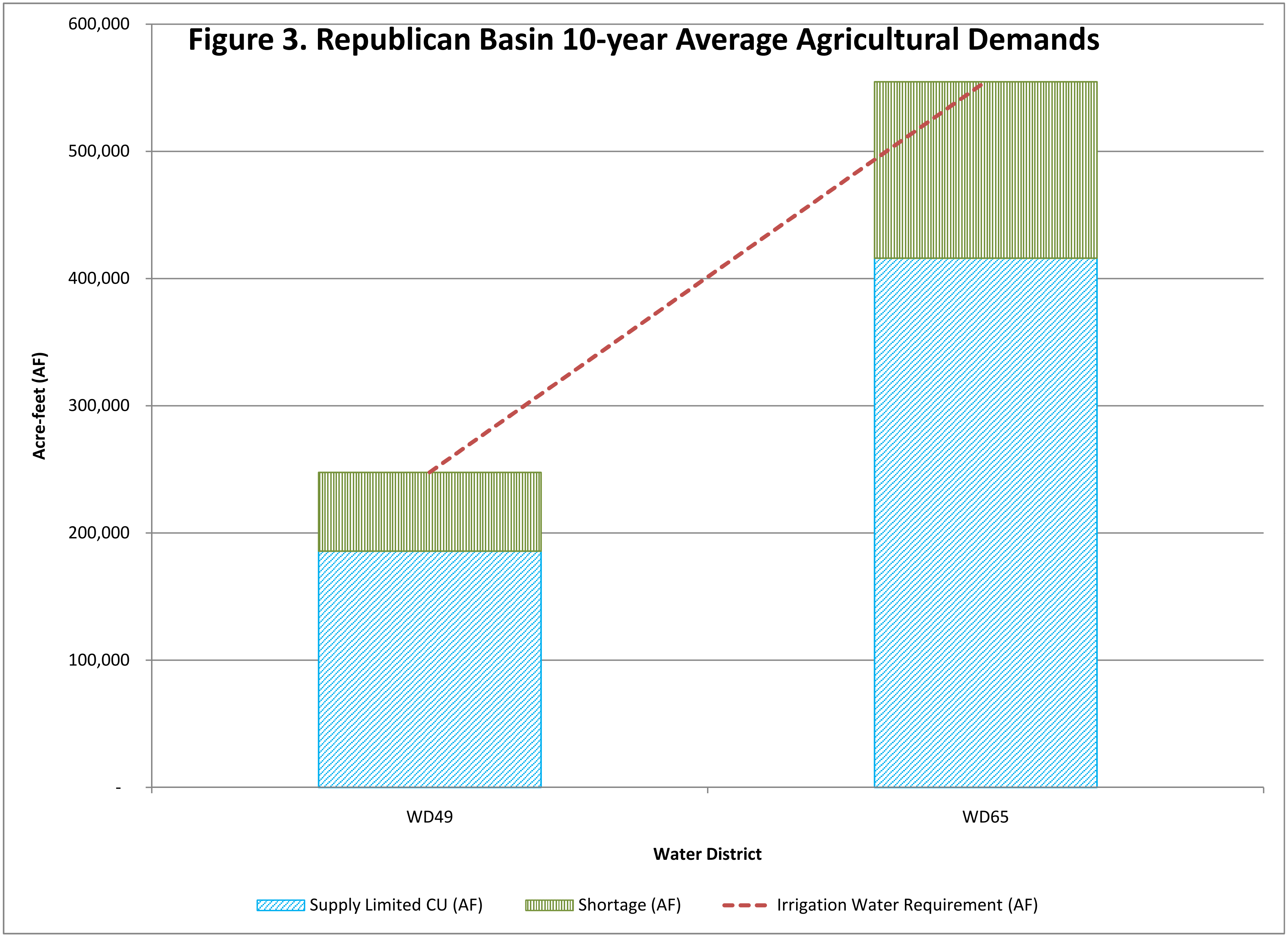


Figure 3. Republican Basin 10-year Average Agricultural Demands
600,000
500,000
400,000
300,000
200,000
100,000
-
Acre-feet (AF)
WD49
WD65
Water District
Supply Limited CU (AF)
Shortage (AF)
Irrigation Water Requirement (AF)

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Memorandum

To	Nicole Rowan, CDM	Page	1
CC	Todd Doherty, CWCB		
Subject	Current Ag Demand, Arkansas Basin		
From	Enrique Triana and Meg Frantz, AECOM Kara Sobieski and Adam Kremers, LRE		
Date	5/13/2010		

Purpose

This memorandum documents the methods AECOM and Leonard Rice Engineers used to produce the spreadsheet workbook ArkansasSummary.xlsx, which tabulates Irrigated Acreage, Irrigation Water Requirement (IWR, the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage. This task proceeded without the benefit of an existing CDSS component for the basin; therefore, many data types that are available in other basins have not been collected, processed or analyzed for the entire basin.

Introduction

The Arkansas basin can be divided into three areas, in terms of the data available and approach taken for this analysis. The first is the Lower Arkansas basin, the area covered by the Hydrologic Institutional (HI) model that Colorado must use for compact accounting, pursuant to settlement of the *Kansas v. Colorado* litigation. This area consists of irrigated lands under Arkansas River canals from Pueblo Reservoir to the state line. The second area is the Purgatoire River Water Conservancy District (PRWCD) in Water District 19. Colorado Division of Water Resources – Division 2 recently prepared an irrigated lands assessment of the 2008 parcels mapping for these two areas. This dataset contains polygons representing parcels with attributes indicating the 2008 cultivated crop, the type of irrigation and the structure ID of the source of water for each parcel. The third area is all other irrigated land in the basin, from the mountain valleys of District 11 to the corn fields of the Southern High Plains Designated Basin. This memo presents sources and methods used to develop Water District-wide irrigated acreage, IWR, consumptive use, and shortage.

Lower Arkansas Basin

This study area includes irrigated acreage along the Arkansas River downstream of Pueblo Reservoir (i.e. in Water Districts 14, 17, 67), as shown in Figure 1.

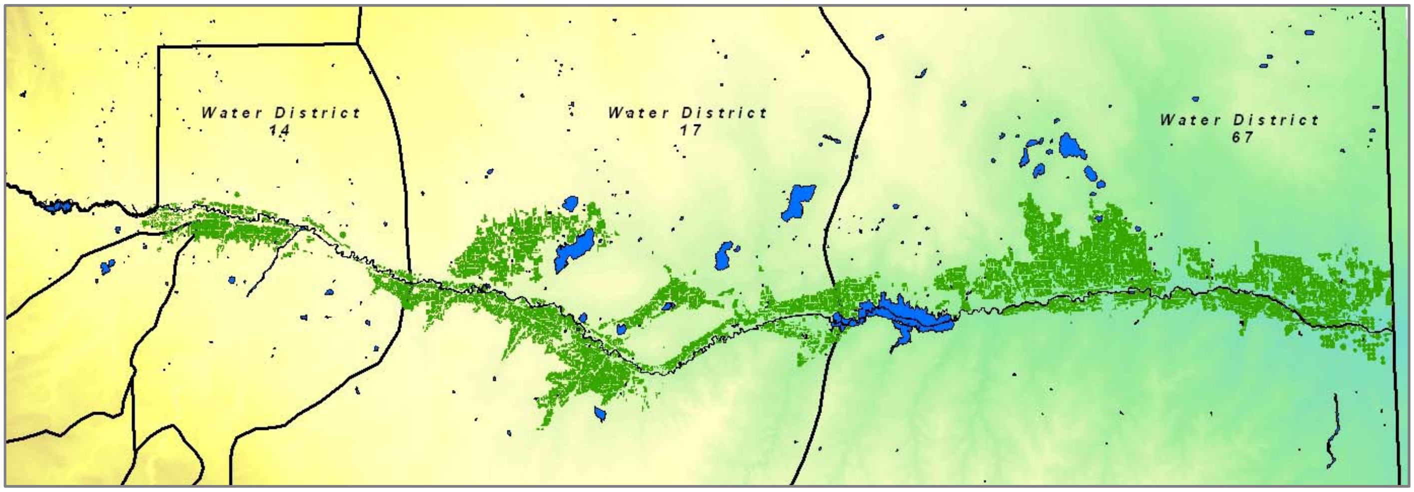

Figure 1 - Lower Arkansas Basin Study Area, Pueblo Reservoir to Stateline

Water budget analyses, including estimates of irrigation water requirement, were originally developed using the Hydrological Institutional (HI) Model in support of the Kansas v. Colorado litigation. These values were provided by the Division 2 office.

Refinement of the analyses to a farm level and incorporation of historical diversions for the purpose of estimating supply-limited consumptive use, was performed using the Irrigation Systems Analysis Model (ISAM). This program was developed by Colorado Division of Water Resources Division 2 in support of the Arkansas Basin Agricultural Efficiency Rules proposed in November 2009. The ISAM calculations rely on the same canal loss, lateral loss, maximum farm efficiency, deep percolation, and secondary evapotranspiration (SEV) assumptions used in the HI Model. Furthermore, ISAM uses the same soil moisture banking computations as the HI Model, and methods for developing crop consumptive use and irrigation source/supply are consistent with the HI Model. Surface water irrigation deliveries to the farm each month are applied to the net irrigation requirement of the crops on the farm. If the crop demand exceeds the irrigation supply, the remaining crop demand can be completely or partially met by available soil moisture from the soil moisture profile. Excess irrigation supply can re-fill the soil moisture profile, and amounts in excess of soil profile capacity result in deep percolation to the ground water table. The ISAM analyses reflect surface water diversions only; supplemental ground water pumping and presumed consumptive use has been quantified in support of the HI Model, and was supplied on a Water District basis by Division 2.

ISAM calculations report ‘Usable Supply’ in acre-feet per year for each ditch analysis performed. The Usable Supply includes consumptive use met by surface water diversions as well as non-beneficial

SEV. SEV is non-beneficial (or incidental) loss of return flows as simulated by both the ISAM and HI Model. The Lower Arkansas basin 'SEV' summarized by Water District is a component of the total Arkansas River basin incidental loss information, which is reported in a separate subtask that estimates non-irrigation agricultural demand.

Sixteen ditches are explicitly represented in ISAM, totaling 293,890 acres or 96 percent of the total Lower Arkansas basin irrigated acreage. Five additional ditches, not included in ISAM, represent 10,864 acres, based on the CDSS irrigated acreage GIS coverage (2003). The irrigation water requirement, consumptive use by surface water, and shortages are estimated for these ditches based on average results from ISAM by Water District, and supplemental groundwater use data for these additional ditches, which the Division 2 office provided.

The most recent 10-year period for which Lower Arkansas information was available was 1997 – 2006. This period represents current irrigated acreage and irrigation practices, such as efficiencies and use of surface water and ground water; in addition, this period includes variation in climate conditions and water supply.

Purgatoire River Water Conservancy District

Data for the ten diversion structures in this district were readily available from the 2008 irrigated lands assessment provided by Division 2. Irrigated acreage by structure was taken from the Division 2 GIS parcel data, after filtering out parcels that were designated "Not Irrigated". Thus the analysis reflects lands actively irrigated in 2008. A StateCU "structure scenario" was developed and executed to estimate crop irrigation water requirement and historical consumptive use, given historical diversions. Key assumptions or approaches for the simulation included the following:

- Simulation period was 1999-2008. That is, the historical decade's climate and diversion time series were used, applied to the 2008 irrigated acres, crop types, and irrigation practices.
- Not all parcels were assigned crop types. If the structure had parcels with crop assignments, areas for each crop were scaled upward so that total acreage for the structure was correct. Structures with no crop type assignments on any parcels were assume to irrigate pasture grass.
- Based on discussion with Jeris Danielson, general manager of PRWCD, maximum system efficiency for the Model Ditch was set at .65, in accordance with two change cases out of that ditch. Other ditches were assigned an efficiency of .50.
- All structures were assigned climate stations 8429 Trinidad and 8434 Trinidad Las Animas Airport, weighted equally. The time series are available in the Arkansas basin station scenario available at the CDSS website. Orographic adjustment was used, since the irrigated lands all lie below both climate stations.
- Modified Blaney-Criddle method was used, with elevation adjustment, as all irrigated lands are below 6500 feet. This is in accordance with CDSS guidelines developed in other basins.

Other Lands

Irrigated Area

AECOM explored several sources for determining irrigated acreage in “Other” parts of the Arkansas basin, including the Total Irrigated Acreage and Water Commissioner Comment fields in diversion structure records in Hydrobase; Colorado and National Agricultural Statistics in Hydrobase; and water commissioner general knowledge of their respective jurisdictions. None of these sources yielded information with a satisfactory level of confidence. In the absence of these traditional sources of information, AECOM pursued remote sensing techniques to produce an estimate of irrigated acreage on a basin-wide scale.

An approach based on Landsat remote sensing for determining irrigated land has been used to estimate irrigated land throughout eastern Colorado (Qi, *et al*. 2002). Qi, et al. utilizes satellite images (scenes) taken by Landsat Thematic Mapper (TM) scanner, which provides spatial resolution of 30 meters (each pixel in the image is 30 m by 30 m). The Landsat scenes are mosaicked to provide the coverage of the study area. Following this approach, scenes from the Landsat 5 TM archive were obtained through the Earth Resources Observation and Science (EROS) Center, using the USGS Global Visualization Viewer (GloVis), processed at Standard Terrain Correction (Level 1T). Satellite images are stored and distributed in data areas, overlapping rectangles of coverage. At least three scenes between May and September 2009 were obtained for each of the seven data areas covering the Arkansas basin. The selected scenes have less than 10% of cloud cover.

Vegetation Index

Landsat 5 TM band 4 and band 3, which measure reflectance in the visible red, provide data on the influence of light-absorbing chlorophyll. The ratio between the band 4 (near infrared) and band 3 (visible red) is an approximation of the vegetation index (VI) (Thelin and Heimes 1987).

$$VI = \frac{NIR}{R}$$

Vegetation Index raster maps were processed for all the scenes downloaded for the study area. The resulting maps were single-band gray scale images, with brighter white cells indicating vigorous vegetation (presumably irrigated fields) and all other vegetation a range of gray. Defining a VI threshold is required to classify irrigated (larger than the threshold) and non-irrigated areas (smaller that the threshold).

All VI raster maps were mosaicked using the maximum VI value per pixel to (1) capture irrigated fields that grow crops with several cutting cycles during the irrigation season that could register low VI in single scenes, (2) correct areas covered by clouds in a particular scene and (3) account for damaged crops registered in the late season scenes.

Agricultural Mask using the National Land Cover Data

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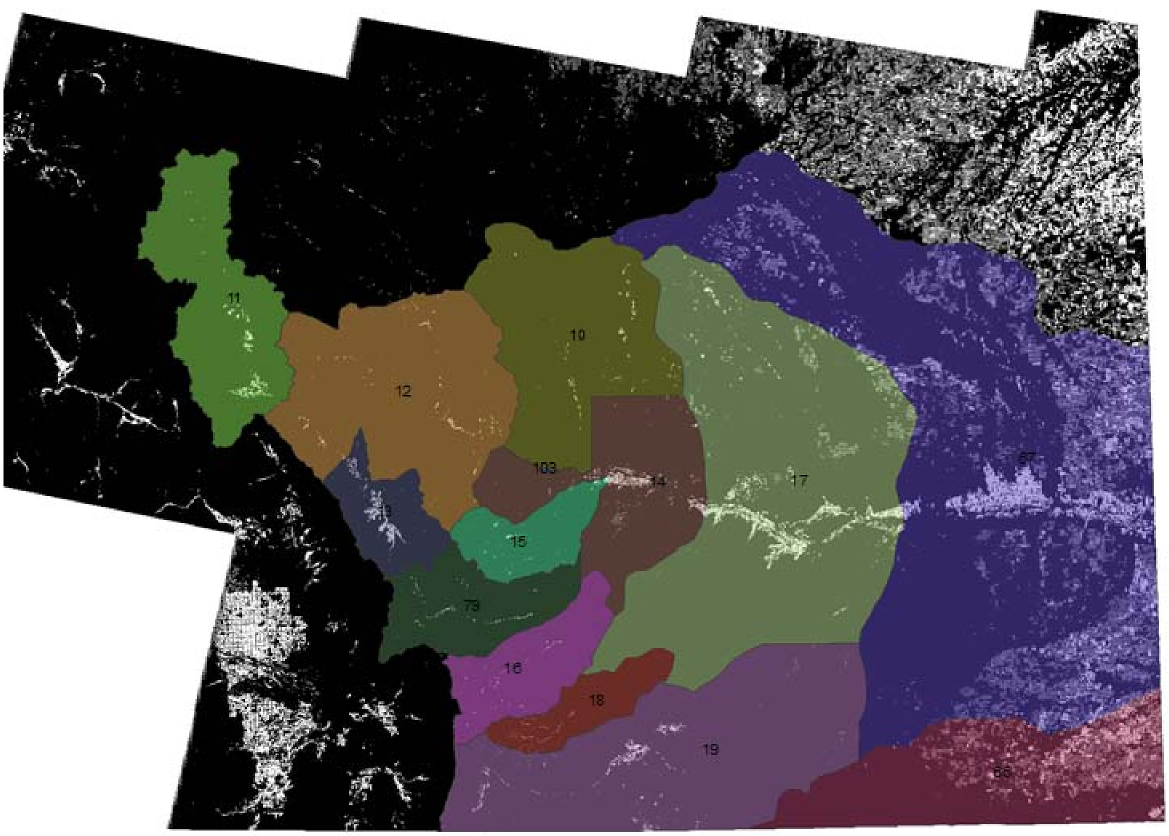

Figure 2 - Vegetation Index for the Arkansas Basin with the NLCD mask

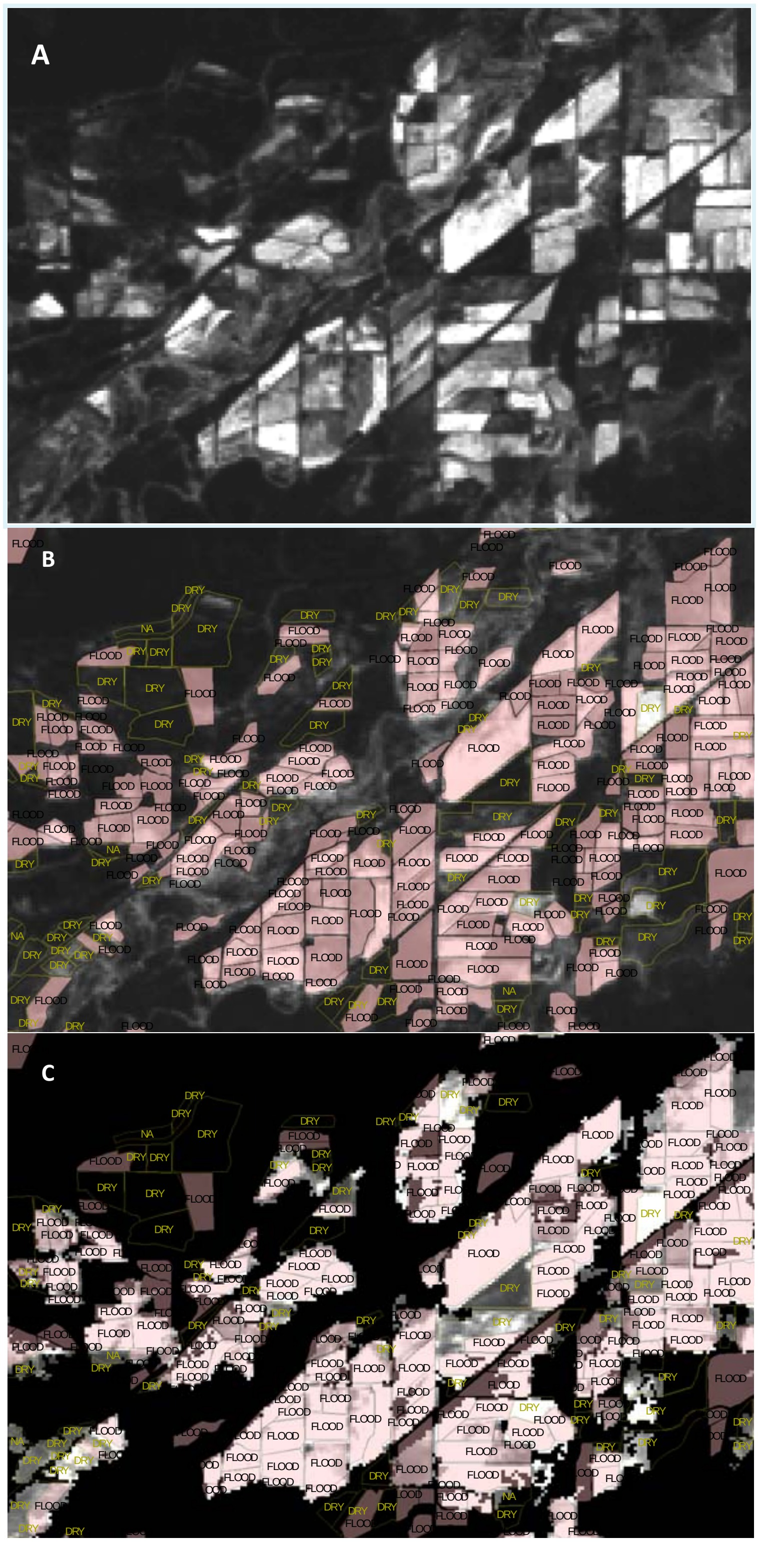
A
B
C

Figure 3 - Effect of the Land Cover Data Mask

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Errors in the method were explored by comparing results with the Division 2 2008 irrigated lands mapping. Errors in NLCD land classification (Stehman, et al. 2003) are inherited in this analysis by using this mask, i.e., misclassified agricultural land in the NLCD will be excluded of the irrigated land estimation regardless its vegetation index. Examples of this error are shown in Figure 3, where parcels that lie under the mask are excluded from the analysis. The opposite error occurs when riparian or non-agricultural zones, with potentially high vegetation indexes, are left inside the mask, thereby overpredicting the irrigated area. From the mapped (test area) for 2008 irrigated parcels, we estimate this error to be ± 14 %.

Another type of error can occur in identifying irrigated land within the mask (agricultural land) using the vegetation index threshold. In general, the higher the threshold, the less land will be categorized as irrigated, but there is more certainty that the land is actually irrigated. Conversely, the lower the threshold, the greater the area that will be identified as irrigated, and the less certainty that the land is actually being irrigated. The selection of the threshold attempts to reduce uncertainty by balancing over and under predictions.

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Vegetation Index Threshold Selection

Selection of the threshold for classifying irrigated vs. non irrigated land was based on minimization of the prediction error when compared with ground-truth data (Qi, et al. 2002). In this study, the accuracy of the predicted irrigated area, within the NLCD agricultural land, was based on the comparison of predicted irrigated area with the 2008 mapped irrigated parcels in the lower Arkansas Valley and PRWCD. Parcels were divided in irrigated and non-irrigated groups based on the information available for 2008. A range of VI thresholds was tested, and their performance evaluated observing the relationship between under prediction in irrigated parcels and over prediction in the non-irrigated parcels. The best prediction was achieved with a threshold of 2.25, balancing the under and over predictions with a calculated error of approximately ±12 % of the mapped irrigated area inside the mask.

The actual error in the prediction is potentially smaller than that calculated in the test area since it was computed using 2008 mapped parcels and 2009 satellite imagery, but it provides an upper bound to interpret the results of this study. Visual inspection shows effects of rotation of cultivated plots, fallow and other changes in agricultural practices between 2008 and 2009. For example in Figure 4, parcels labeled as irrigated in the 2008 mapping register low vegetation index (dark red color) in all the scenes for 2009, with neighboring parcels classified as dry in 2008 with high VI values (bright white) in 2009.

Figure 4 – Example of Changes in Agricultural Activities between 2008 and 2009

Adjustments for Dryland Farming on Eastern Plains

The calibrated VI threshold described above was applied throughout the Arkansas basin "Other Lands", with good results in the mountainous upper basin and the tributary headwater Water Districts. In the eastern plains where dryland farming is practiced, however, the method identified too much land as being irrigated. Most irrigation in this area is by wells and center pivot sprinklers, but the mapping produced numerous small and randomly-shaped irrigated areas not consistent with center pivots. In some counties, the remote sensing-derived irrigated acreage differed from county ag statistics by an order of magnitude.

Sampling of VI values showed that obviously irrigated circles in Water Districts 17, 66, and 67 (exclusive of the HI Model area) had VI values well above 2.25 and presumably dry, rectangular fields exhibited lower VI's. Accordingly, a VI threshold of 3.6 was selected for these districts. Qi, *et. al.*, similarly found that VI thresholds were regionally sensitive, and used different threshold values in different parts of their study area. Furthermore, fields that were less than 80 acres were filtered out, based on the assumption that irrigation would not be practiced on less than an eighth-section on the plains. Finally, with input from the Division of Water Resources, certain sub-areas were visually reviewed, and non-circular polygons were designated as non-irrigated.

Figure 5 shows the spatial distribution of the predicted and mapped irrigated areas in the Arkansas River Basin.

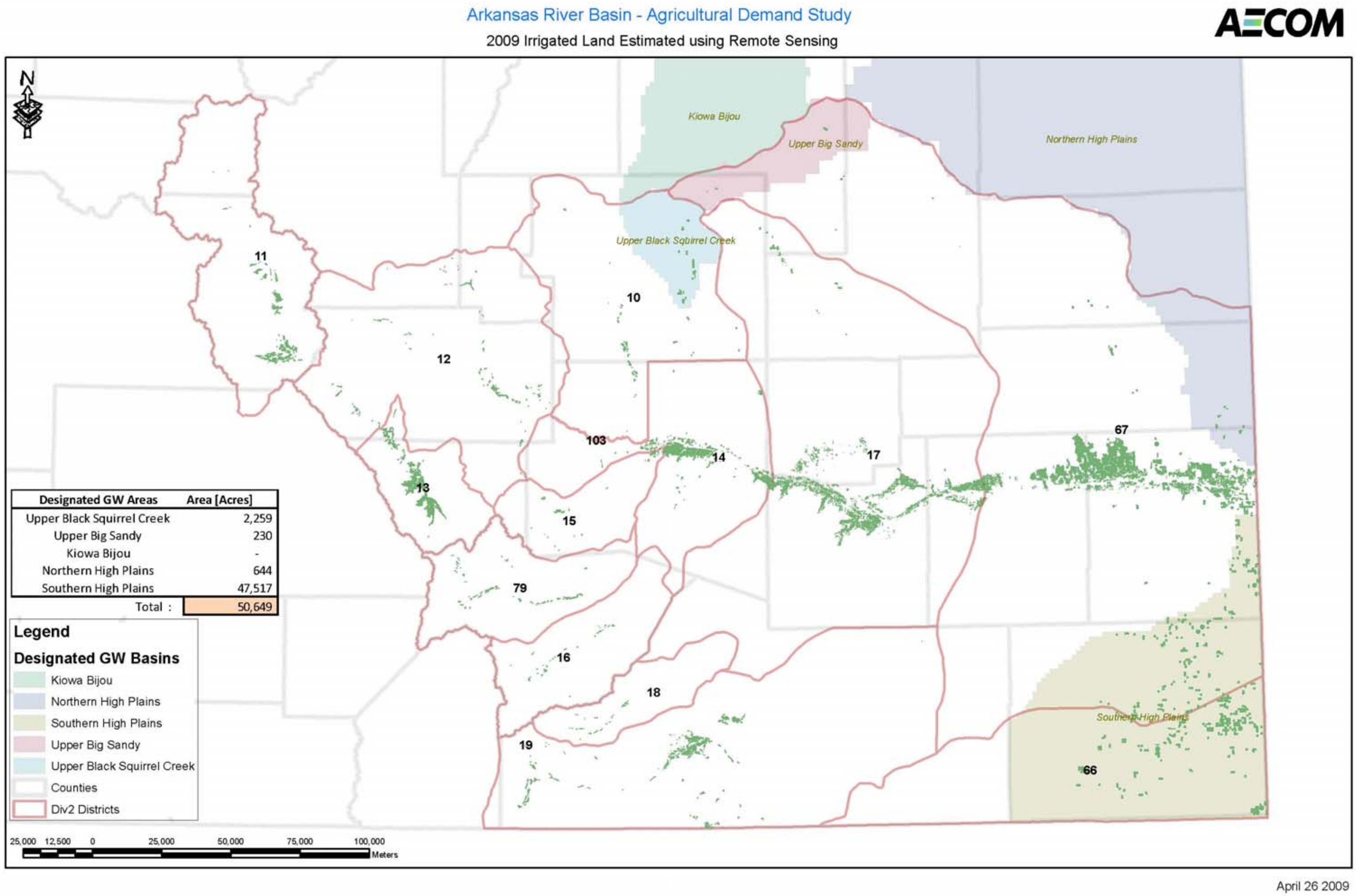

Figure 5 - Irrigated Land in the Arknasas River Basin

Irrigation Water Requirement

A StateCU station scenario was developed and executed, where each Water District was a station, and was assigned a total irrigated acreage as determined through the procedure described above. The composite crop blend from PRWCD mapping was used for crop type in Water Districts 15, 16, 18, 19, and 79. The Colorado and National Agricultural Statistics from 2006 (the most recent year for which data appears to be reliably complete) were used to estimate a blend of typical crops for other districts. Since the statistics are available by county, and not Water District, a representative county (or counties) was selected, from which to compute a crop blend. Similarly, a climate station or stations was selected to represent conditions in each Water District. These selections, shown in Table 1, were based on proximity and general understanding of terrain. A more rigorous approach for assigning climate stations to specific diversion structures has been used in CDSS basins. Given the spatial resolution of the analysis (Water District rather than diversion structure) and estimation required for other components of the calculations, this non-rigorous approach was deemed adequate.

The Modified Blaney-Criddle approach, with elevation adjustment, was used in general. The Original Blaney-Criddle approach, with high altitude coefficients, was used for pasture grass in Districts 11, 13, and 15, where elevation of the associated climate station is over 6500 feet. The simulation period was 1999 through 2008.

Table 1 – Source of Estimated Crop Type and Climate Stations for Water Districts

District	Selected Source of Crop Type	Selected Climate Station*
10	Cheyenne-Lincoln-El Paso	Colorado Springs, Pueblo
11	Lake-Chaffee	Buena Vista
12	Fremont	Canon City
13	Custer	Westcliffe
14	El Paso-Lincoln-Cheyenne	Pueblo
15	PRWCD	Rye
16	PRWCD	Walsenberg
17	El Paso-Lincoln-Cheyenne	Rush
18	PRWCD	Walsenberg, Trinidad
19	PRWCD	Trinidad
66	Baca	Springfield
67	El Paso-Lincoln-Cheyenne	Eads, Springfield
79	PRWCD	Walsenberg, Rye

*where two stations are listed, the average of the two was used

Water Supply Limited CU

For Arkansas basin "Other Lands," water supply limited CU could not be easily modeled or calculated because there is no association of irrigated acres to individual diversion structures. In the absence of the level of information available in CDSS basins, AECOM estimated water supply limited CU by transferring information from areas where we have knowledge or quantitative indication of shortages, to other areas. The extrapolation is reasonable, given constraints of data availability and general understanding of the basin; but it is subject to error because conditions in the "known" areas are not identical to those in the "unknown" areas.

Decrees for recent change cases in Water Districts 11, 12, and 13 were researched to find an average or typical annual shortage in historical consumptive use, relative to full IWR, for these mountainous areas. Only one decree, 98CW137A contained enough information to develop such a value. The change was a joint application of the City of Aurora and Lake County, involving eight ditches on two ranches. The decree cited the effective irrigated acreage on the ranches, and historical consumptive use. Using the IWR calculated for District 11 for this study, the composite historical shortage for these ditches was estimated at approximately 46.3%, as shown in Table 2 below. This factor was applied to IWR in Water Districts 11, 12, and 13, to estimate supply limited consumptive use.

Table 2 Estimation of Shortage Factor from Case 98CW137A

	Decree ¶	Hayden Ranch	Decree ¶	Spurlin-Shaw Ranch	Combined
Acreage	11.1.1	889	11.1.2	314	
Eff Irr %	11.3.1	0.65	11.3.2	0.84	
Eff Acres		577.85		263.76	841.61
Dist 11 CIR (acft/ac)[1]		2.38		2.38	2.38
Est. IWR		1375.283		627.7488	2003.0318
HCU	11.4.1	828	11.4.2	247	1075
Estimated Shortage					928.0318
% Shortage					**46.33%**

[1] Ag Demand study value, derived by Districtwide StateCU "station" scenario

The south side tributary districts, that is Water Districts 15, 79, 16, 18, and 19 were grouped together for the purpose of consumptive use computations. No decrees were discovered that adequately described shortages or IWR in these districts. It was assumed, then, that the average shortage derived from StateCU analysis of the PRWCD (33.1%) was applicable. It is probable that PRWCD is less water short than other areas in these water districts because Trinidad Reservoir supplements direct flow supply within PRWCD. Thus the assumption provides an upper limit estimate of consumptive use in these Water Districts.

Shortage estimates from the HI and ISAM analysis for Water Districts 14, 17, and 67 (52.2%, 49.4%, and 37.5%, respectively) were applied to irrigation in these districts outside the HI model domain. In addition, the Water District 14 shortage factor of 52.2% was applied to Water District 10, and the

Water District 67 shortage factor of 37.5% was applied to Water District 66. According to the State Engineer's Office, there have been no recent transfer cases in the Southern High Plains Designated Basin (parts of Water District 67 and more or less all the irrigated area in Water District 66). Conversations with the groundwater commissioner from this area and personnel at the Eastern Cheyenne Groundwater Management District indicated that water supply is generally short along Colorado's southeastern border, and probably greater than 25%. This information confirmed use of 37.5% to estimate shortages and consumptive use throughout Water Districts 66 and 67.

Agricultural Demand Summary Tables

Table 1. Arkansas Basin 10-year Average Agricultural Demand

Water District	Irrigated Acres	Irrigated Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD10	4,723	9,620	4,598	5,022
WD11	10,179	24,271	13,026	11,245
WD12	5,596	14,214	7,628	6,586
WD13	17,983	38,430	20,625	17,805
WD14	90,526	222,958	106,563	116,395
WD15	1,104	2,001	1,339	662
WD16	1,399	3,151	2,108	1,043
WD17	143,543	346,231	175,157	171,075
WD18	1,277	2,861	1,914	947
WD19	16,495	38,365	25,668	12,696
WD66	27,181	53,667	33,545	20,122
WD67	104,991	233,082	145,689	87,393
WD79	3,040	5,685	3,803	1,881

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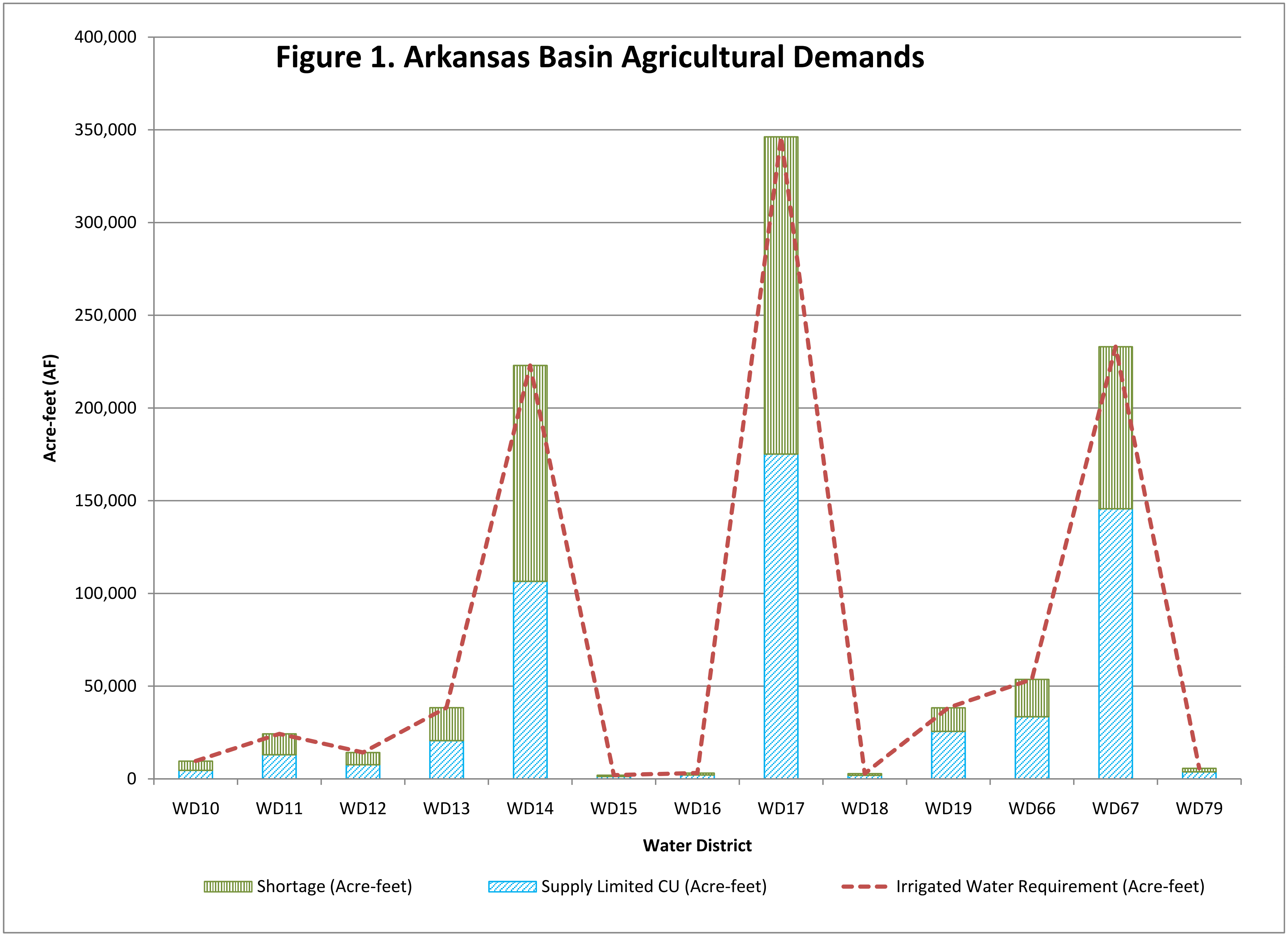
Figure 1. Arkansas Basin Agricultural Demands
Acre-feet (AF)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
WD10
WD11
WD12
WD13
WD14
WD15
WD16
WD17
WD18
WD19
WD66
WD67
WD79
Water District
Shortage (Acre-feet)
Supply Limited CU (Acre-feet)
Irrigated Water Requirement (Acre-feet)

Appendix E
Arkansas Basin Agricultural Demands Methodology

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Memorandum

To	Nicole Rowan, CDM	Page	1
CC	Todd Doherty, CWCB		
Subject	Current Ag Demand, Arkansas Basin		
From	Enrique Triana and Meg Frantz, AECOM Kara Sobieski and Adam Kremers, LRE		
Date	5/13/2010		

Purpose

This memorandum documents the methods AECOM and Leonard Rice Engineers used to produce the spreadsheet workbook ArkansasSummary.xlsx, which tabulates Irrigated Acreage, Irrigation Water Requirement (IWR, the irrigation agricultural demand), estimated supply limited Consumptive Use, and Shortage. This task proceeded without the benefit of an existing CDSS component for the basin; therefore, many data types that are available in other basins have not been collected, processed or analyzed for the entire basin.

Introduction

The Arkansas basin can be divided into three areas, in terms of the data available and approach taken for this analysis. The first is the Lower Arkansas basin, the area covered by the Hydrologic Institutional (HI) model that Colorado must use for compact accounting, pursuant to settlement of the *Kansas v. Colorado* litigation. This area consists of irrigated lands under Arkansas River canals from Pueblo Reservoir to the state line. The second area is the Purgatoire River Water Conservancy District (PRWCD) in Water District 19. Colorado Division of Water Resources – Division 2 recently prepared an irrigated lands assessment of the 2008 parcels mapping for these two areas. This dataset contains polygons representing parcels with attributes indicating the 2008 cultivated crop, the type of irrigation and the structure ID of the source of water for each parcel. The third area is all other irrigated land in the basin, from the mountain valleys of District 11 to the corn fields of the Southern High Plains Designated Basin. This memo presents sources and methods used to develop Water District-wide irrigated acreage, IWR, consumptive use, and shortage.

Lower Arkansas Basin

This study area includes irrigated acreage along the Arkansas River downstream of Pueblo Reservoir (i.e. in Water Districts 14, 17, 67), as shown in Figure 1.

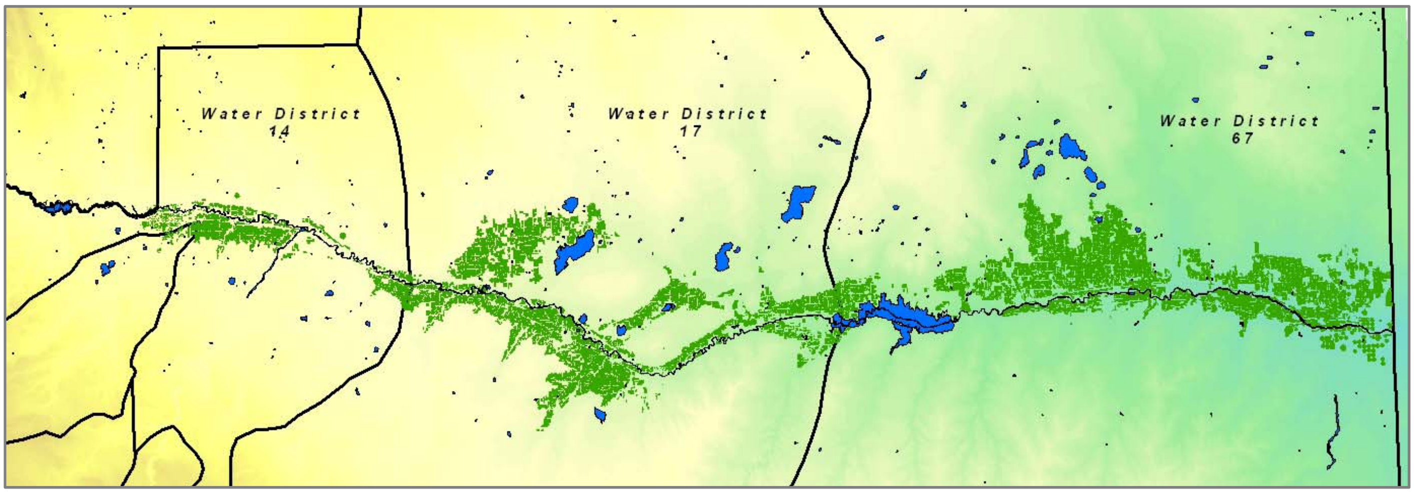

Figure 1 - Lower Arkansas Basin Study Area, Pueblo Reservoir to Stateline

Water budget analyses, including estimates of irrigation water requirement, were originally developed using the Hydrological Institutional (HI) Model in support of the Kansas v. Colorado litigation. These values were provided by the Division 2 office.

Refinement of the analyses to a farm level and incorporation of historical diversions for the purpose of estimating supply-limited consumptive use, was performed using the Irrigation Systems Analysis Model (ISAM). This program was developed by Colorado Division of Water Resources Division 2 in support of the Arkansas Basin Agricultural Efficiency Rules proposed in November 2009. The ISAM calculations rely on the same canal loss, lateral loss, maximum farm efficiency, deep percolation, and secondary evapotranspiration (SEV) assumptions used in the HI Model. Furthermore, ISAM uses the same soil moisture banking computations as the HI Model, and methods for developing crop consumptive use and irrigation source/supply are consistent with the HI Model. Surface water irrigation deliveries to the farm each month are applied to the net irrigation requirement of the crops on the farm. If the crop demand exceeds the irrigation supply, the remaining crop demand can be completely or partially met by available soil moisture from the soil moisture profile. Excess irrigation supply can re-fill the soil moisture profile, and amounts in excess of soil profile capacity result in deep percolation to the ground water table. The ISAM analyses reflect surface water diversions only; supplemental ground water pumping and presumed consumptive use has been quantified in support of the HI Model, and was supplied on a Water District basis by Division 2.

ISAM calculations report ‘Usable Supply’ in acre-feet per year for each ditch analysis performed. The Usable Supply includes consumptive use met by surface water diversions as well as non-beneficial

SEV. SEV is non-beneficial (or incidental) loss of return flows as simulated by both the ISAM and HI Model. The Lower Arkansas basin 'SEV' summarized by Water District is a component of the total Arkansas River basin incidental loss information, which is reported in a separate subtask that estimates non-irrigation agricultural demand.

Sixteen ditches are explicitly represented in ISAM, totaling 293,890 acres or 96 percent of the total Lower Arkansas basin irrigated acreage. Five additional ditches, not included in ISAM, represent 10,864 acres, based on the CDSS irrigated acreage GIS coverage (2003). The irrigation water requirement, consumptive use by surface water, and shortages are estimated for these ditches based on average results from ISAM by Water District, and supplemental groundwater use data for these additional ditches, which the Division 2 office provided.

The most recent 10-year period for which Lower Arkansas information was available was 1997 – 2006. This period represents current irrigated acreage and irrigation practices, such as efficiencies and use of surface water and ground water; in addition, this period includes variation in climate conditions and water supply.

Purgatoire River Water Conservancy District

Data for the ten diversion structures in this district were readily available from the 2008 irrigated lands assessment provided by Division 2. Irrigated acreage by structure was taken from the Division 2 GIS parcel data, after filtering out parcels that were designated "Not Irrigated". Thus the analysis reflects lands actively irrigated in 2008. A StateCU "structure scenario" was developed and executed to estimate crop irrigation water requirement and historical consumptive use, given historical diversions. Key assumptions or approaches for the simulation included the following:

- Simulation period was 1999-2008. That is, the historical decade's climate and diversion time series were used, applied to the 2008 irrigated acres, crop types, and irrigation practices.
- Not all parcels were assigned crop types. If the structure had parcels with crop assignments, areas for each crop were scaled upward so that total acreage for the structure was correct. Structures with no crop type assignments on any parcels were assume to irrigate pasture grass.
- Based on discussion with Jeris Danielson, general manager of PRWCD, maximum system efficiency for the Model Ditch was set at .65, in accordance with two change cases out of that ditch. Other ditches were assigned an efficiency of .50.
- All structures were assigned climate stations 8429 Trinidad and 8434 Trinidad Las Animas Airport, weighted equally. The time series are available in the Arkansas basin station scenario available at the CDSS website. Orographic adjustment was used, since the irrigated lands all lie below both climate stations.
- Modified Blaney-Criddle method was used, with elevation adjustment, as all irrigated lands are below 6500 feet. This is in accordance with CDSS guidelines developed in other basins.

Other Lands

Irrigated Area

AECOM explored several sources for determining irrigated acreage in “Other” parts of the Arkansas basin, including the Total Irrigated Acreage and Water Commissioner Comment fields in diversion structure records in Hydrobase; Colorado and National Agricultural Statistics in Hydrobase; and water commissioner general knowledge of their respective jurisdictions. None of these sources yielded information with a satisfactory level of confidence. In the absence of these traditional sources of information, AECOM pursued remote sensing techniques to produce an estimate of irrigated acreage on a basin-wide scale.

An approach based on Landsat remote sensing for determining irrigated land has been used to estimate irrigated land throughout eastern Colorado (Qi, *et al*. 2002). Qi, et al. utilizes satellite images (scenes) taken by Landsat Thematic Mapper (TM) scanner, which provides spatial resolution of 30 meters (each pixel in the image is 30 m by 30 m). The Landsat scenes are mosaicked to provide the coverage of the study area. Following this approach, scenes from the Landsat 5 TM archive were obtained through the Earth Resources Observation and Science (EROS) Center, using the USGS Global Visualization Viewer (GloVis), processed at Standard Terrain Correction (Level 1T). Satellite images are stored and distributed in data areas, overlapping rectangles of coverage. At least three scenes between May and September 2009 were obtained for each of the seven data areas covering the Arkansas basin. The selected scenes have less than 10% of cloud cover.

Vegetation Index

Landsat 5 TM band 4 and band 3, which measure reflectance in the visible red, provide data on the influence of light-absorbing chlorophyll. The ratio between the band 4 (near infrared) and band 3 (visible red) is an approximation of the vegetation index (VI) (Thelin and Heimes 1987).

$$VI = \frac{NIR}{R}$$

Vegetation Index raster maps were processed for all the scenes downloaded for the study area. The resulting maps were single-band gray scale images, with brighter white cells indicating vigorous vegetation (presumably irrigated fields) and all other vegetation a range of gray. Defining a VI threshold is required to classify irrigated (larger than the threshold) and non-irrigated areas (smaller that the threshold).

All VI raster maps were mosaicked using the maximum VI value per pixel to (1) capture irrigated fields that grow crops with several cutting cycles during the irrigation season that could register low VI in single scenes, (2) correct areas covered by clouds in a particular scene and (3) account for damaged crops registered in the late season scenes.

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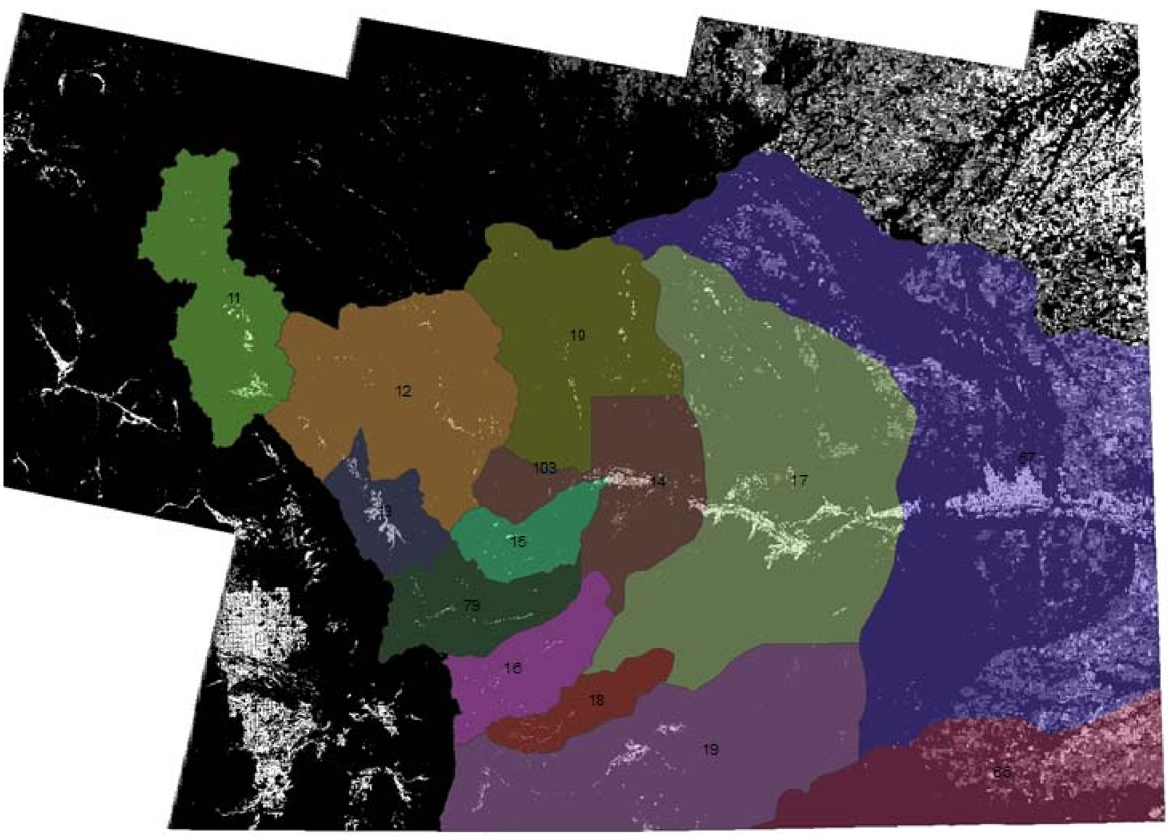
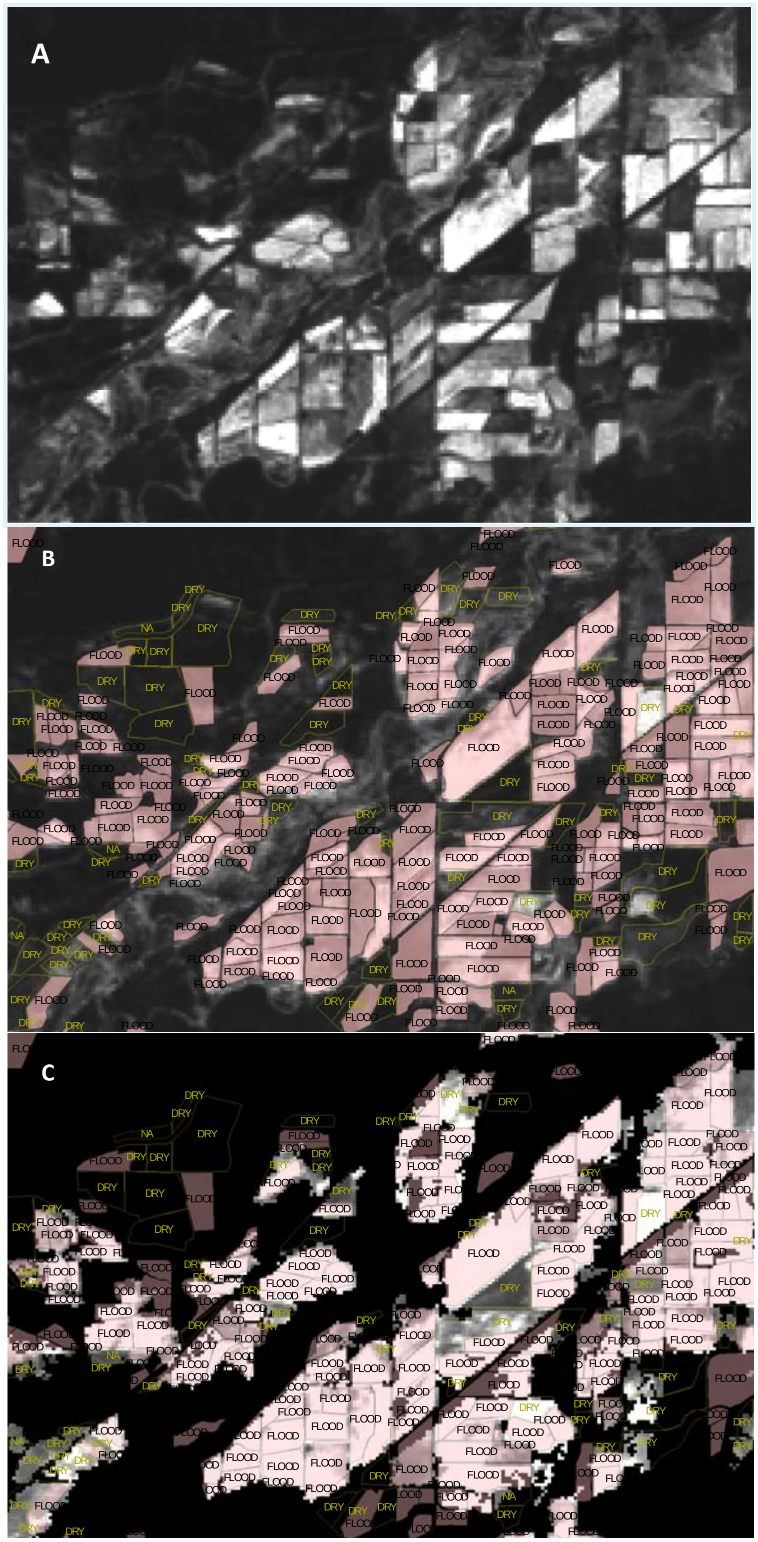


Figure 2 - Vegetation Index for the Arkansas Basin with the NLCD mask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B
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Figure 4 – Example of Changes in Agricultural Activities between 2008 and 2009

Adjustments for Dryland Farming on Eastern Plains

The calibrated VI threshold described above was applied throughout the Arkansas basin “Other Lands”, with good results in the mountainous upper basin and the tributary headwater Water Districts. In the eastern plains where dryland farming is practiced, however, the method identified too much land as being irrigated. Most irrigation in this area is by wells and center pivot sprinklers, but the mapping produced numerous small and randomly-shaped irrigated areas not consistent with center pivots. In some counties, the remote sensing-derived irrigated acreage differed from county ag statistics by an order of magnitude.

Sampling of VI values showed that obviously irrigated circles in Water Districts 17, 66, and 67 (exclusive of the HI Model area) had VI values well above 2.25 and presumably dry, rectangular fields exhibited lower VI’s. Accordingly, a VI threshold of 3.6 was selected for these districts. Qi, *et. al.*, similarly found that VI thresholds were regionally sensitive, and used different threshold values in different parts of their study area. Furthermore, fields that were less than 80 acres were filtered out, based on the assumption that irrigation would not be practiced on less than an eighth-section on the plains. Finally, with input from the Division of Water Resources, certain sub-areas were visually reviewed, and non-circular polygons were designated as non-irrigated.

Figure 5 shows the spatial distribution of the predicted and mapped irrigated areas in the Arkansas River Basin.

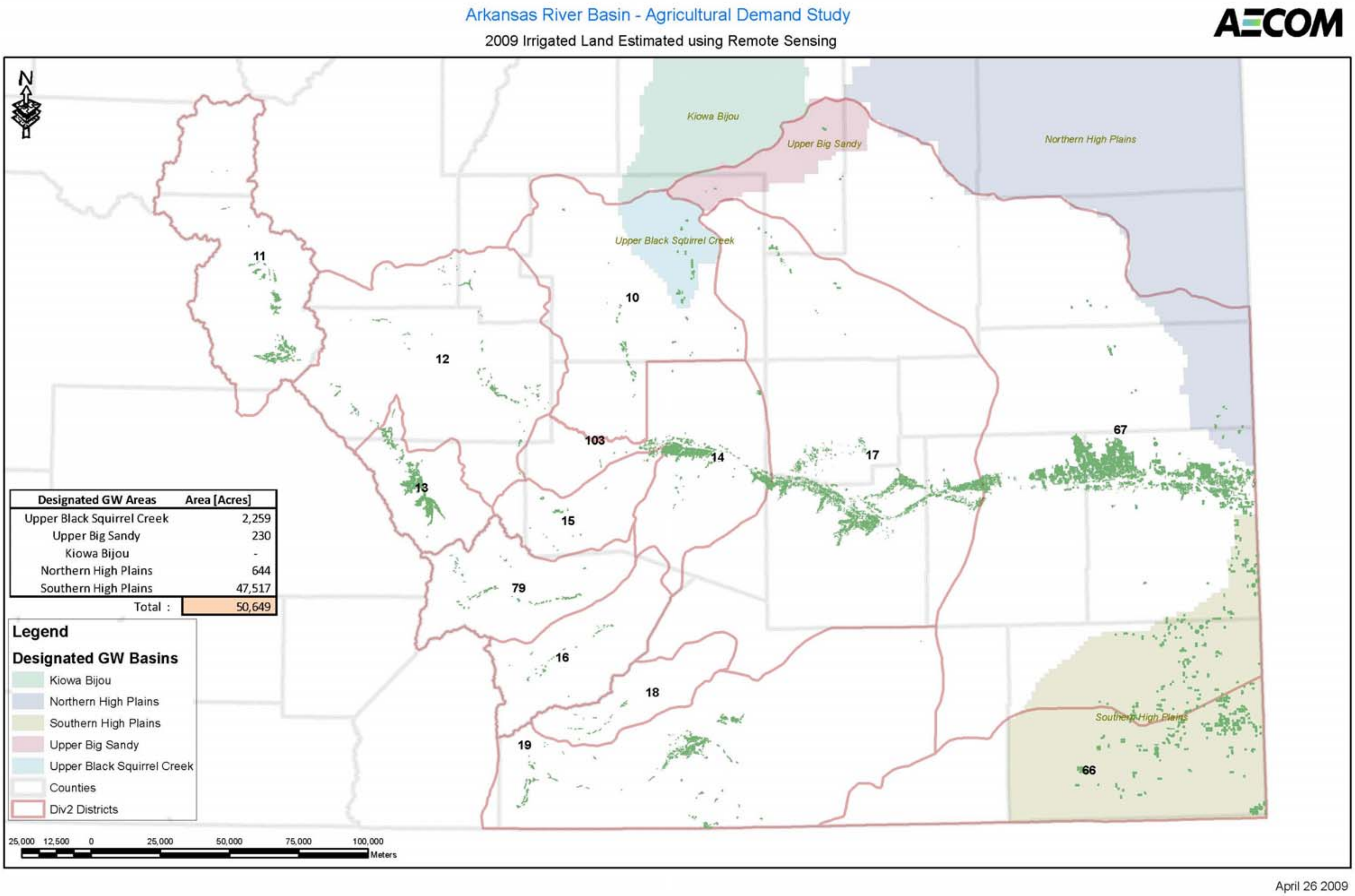

Figure 5 - Irrigated Land in the Arknasas River Basin

Irrigation Water Requirement

A StateCU station scenario was developed and executed, where each Water District was a station, and was assigned a total irrigated acreage as determined through the procedure described above. The composite crop blend from PRWCD mapping was used for crop type in Water Districts 15, 16, 18, 19, and 79. The Colorado and National Agricultural Statistics from 2006 (the most recent year for which data appears to be reliably complete) were used to estimate a blend of typical crops for other districts. Since the statistics are available by county, and not Water District, a representative county (or counties) was selected, from which to compute a crop blend. Similarly, a climate station or stations was selected to represent conditions in each Water District. These selections, shown in Table 1, were based on proximity and general understanding of terrain. A more rigorous approach for assigning climate stations to specific diversion structures has been used in CDSS basins. Given the spatial resolution of the analysis (Water District rather than diversion structure) and estimation required for other components of the calculations, this non-rigorous approach was deemed adequate.

The Modified Blaney-Criddle approach, with elevation adjustment, was used in general. The Original Blaney-Criddle approach, with high altitude coefficients, was used for pasture grass in Districts 11, 13, and 15, where elevation of the associated climate station is over 6500 feet. The simulation period was 1999 through 2008.

Table 1 – Source of Estimated Crop Type and Climate Stations for Water Districts

District	Selected Source of Crop Type	Selected Climate Station*
10	Cheyenne-Lincoln-El Paso	Colorado Springs, Pueblo
11	Lake-Chaffee	Buena Vista
12	Fremont	Canon City
13	Custer	Westcliffe
14	El Paso-Lincoln-Cheyenne	Pueblo
15	PRWCD	Rye
16	PRWCD	Walsenberg
17	El Paso-Lincoln-Cheyenne	Rush
18	PRWCD	Walsenberg, Trinidad
19	PRWCD	Trinidad
66	Baca	Springfield
67	El Paso-Lincoln-Cheyenne	Eads, Springfield
79	PRWCD	Walsenberg, Rye

*where two stations are listed, the average of the two was used

Water Supply Limited CU

For Arkansas basin "Other Lands," water supply limited CU could not be easily modeled or calculated because there is no association of irrigated acres to individual diversion structures. In the absence of the level of information available in CDSS basins, AECOM estimated water supply limited CU by transferring information from areas where we have knowledge or quantitative indication of shortages, to other areas. The extrapolation is reasonable, given constraints of data availability and general understanding of the basin; but it is subject to error because conditions in the "known" areas are not identical to those in the "unknown" areas.

Decrees for recent change cases in Water Districts 11, 12, and 13 were researched to find an average or typical annual shortage in historical consumptive use, relative to full IWR, for these mountainous areas. Only one decree, 98CW137A contained enough information to develop such a value. The change was a joint application of the City of Aurora and Lake County, involving eight ditches on two ranches. The decree cited the effective irrigated acreage on the ranches, and historical consumptive use. Using the IWR calculated for District 11 for this study, the composite historical shortage for these ditches was estimated at approximately 46.3%, as shown in Table 2 below. This factor was applied to IWR in Water Districts 11, 12, and 13, to estimate supply limited consumptive use.

Table 2 Estimation of Shortage Factor from Case 98CW137A

	Decree ¶	Hayden Ranch		Decree ¶	Spurlin-Shaw Ranch		Combined
Acreage	11.1.1	889		11.1.2	314		
Eff Irr %	11.3.1	0.65		11.3.2	0.84		
Eff Acres		577.85			263.76		841.61
Dist 11 CIR (acft/ac)[1]		2.38			2.38		2.38
Est. IWR		1375.283			627.7488		2003.0318
HCU	11.4.1	828		11.4.2	247		1075
Estimated Shortage							928.0318
% Shortage							**46.33%**

[1] Ag Demand study value, derived by Districtwide StateCU "station" scenario

The south side tributary districts, that is Water Districts 15, 79, 16, 18, and 19 were grouped together for the purpose of consumptive use computations. No decrees were discovered that adequately described shortages or IWR in these districts. It was assumed, then, that the average shortage derived from StateCU analysis of the PRWCD (33.1%) was applicable. It is probable that PRWCD is less water short than other areas in these water districts because Trinidad Reservoir supplements direct flow supply within PRWCD. Thus the assumption provides an upper limit estimate of consumptive use in these Water Districts.

Shortage estimates from the HI and ISAM analysis for Water Districts 14, 17, and 67 (52.2%, 49.4%, and 37.5%, respectively) were applied to irrigation in these districts outside the HI model domain. In addition, the Water District 14 shortage factor of 52.2% was applied to Water District 10, and the

Water District 67 shortage factor of 37.5% was applied to Water District 66. According to the State Engineer's Office, there have been no recent transfer cases in the Southern High Plains Designated Basin (parts of Water District 67 and more or less all the irrigated area in Water District 66). Conversations with the groundwater commissioner from this area and personnel at the Eastern Cheyenne Groundwater Management District indicated that water supply is generally short along Colorado's southeastern border, and probably greater than 25%. This information confirmed use of 37.5% to estimate shortages and consumptive use throughout Water Districts 66 and 67.

Agricultural Demand Summary Tables

Table 1. Arkansas Basin 10-year Average Agricultural Demand

Water District	Irrigated Acres	Irrigated Water Requirement (Acre-feet)	Supply Limited CU (Acre-feet)	Shortage (Acre-feet)
WD10	4,723	9,620	4,598	5,022
WD11	10,179	24,271	13,026	11,245
WD12	5,596	14,214	7,628	6,586
WD13	17,983	38,430	20,625	17,805
WD14	90,526	222,958	106,563	116,395
WD15	1,104	2,001	1,339	662
WD16	1,399	3,151	2,108	1,043
WD17	143,543	346,231	175,157	171,075
WD18	1,277	2,861	1,914	947
WD19	16,495	38,365	25,668	12,696
WD66	27,181	53,667	33,545	20,122
WD67	104,991	233,082	145,689	87,393
WD79	3,040	5,685	3,803	1,881

AECOM

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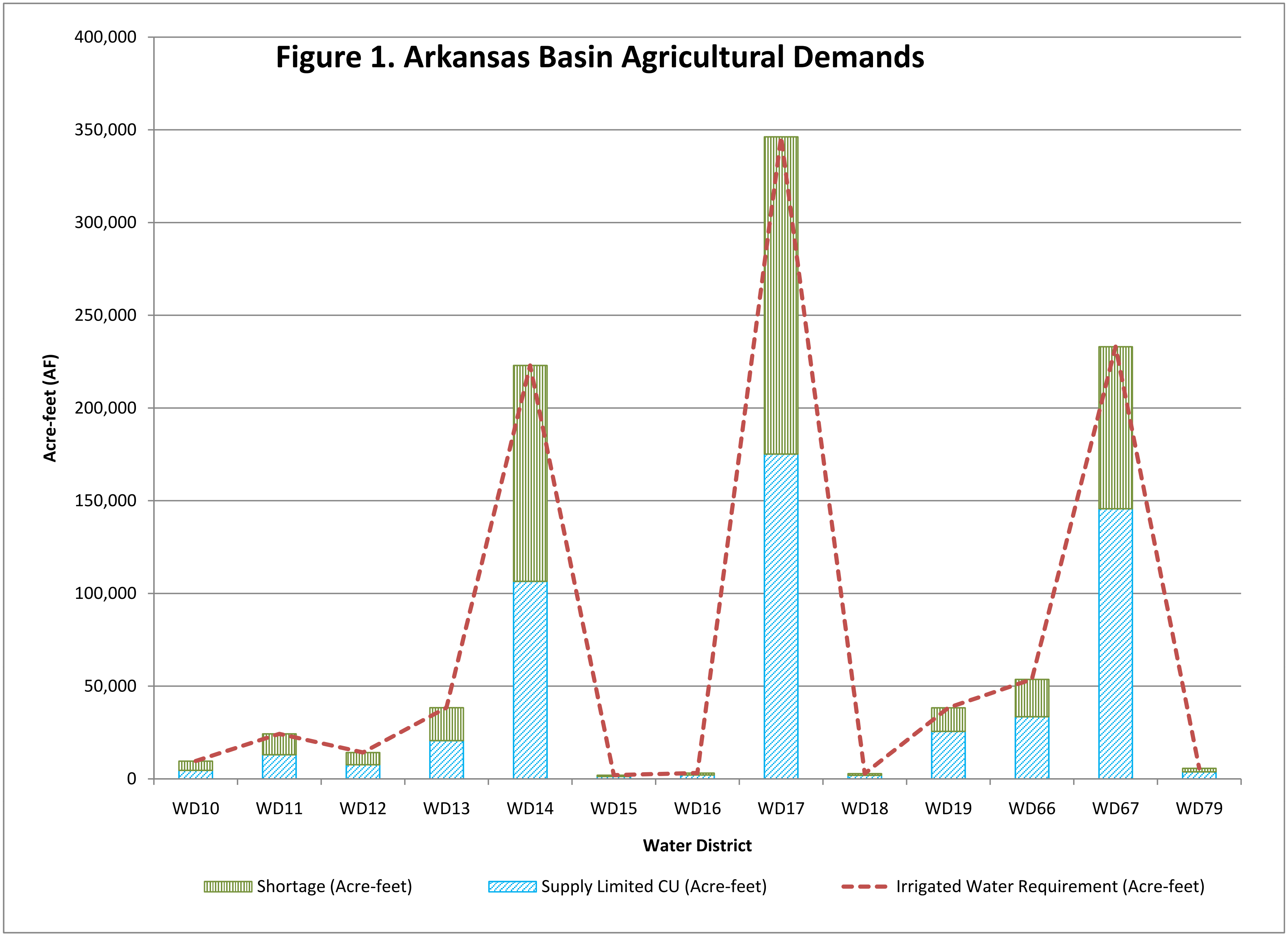
Figure 1. Arkansas Basin Agricultural Demands
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Acre-feet (AF)
WD10
WD11
WD12
WD13
WD14
WD15
WD16
WD17
WD18
WD19
WD66
WD67
WD79
Water District
Shortage (Acre-feet)
Supply Limited CU (Acre-feet)
Irrigated Water Requirement (Acre-feet)

Appendix F
Non-Irrigated Agricultural Demands Methodology

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Memorandum

To	Nicole Rowan, CDM	Page	1
CC	Todd Doherty, CWCB		
Subject	Non-irrigation Demands		
From	Kara Sobieski and Adam Kremers, LRE Meg Frantz, AECOM		
Date	May 27, 2010		

Introduction

This memo supports Subtask 4 of Task 1.3.1; developing estimates for livestock consumptive use, incidental losses, and stock pond evaporation for the South Platte, North Platte, Arkansas, Republican, Rio Grande, Yampa, White, Colorado, Gunnison and San Juan basins.

Approach

The general approach to developing the livestock consumptive use, agricultural incidental losses and stock pond evaporation estimates included using the existing information developed through DSS efforts where available. Due to the lack of DSS in the Republican River basin, as well as the sensitivity of the recent litigation, information provided by the State Engineer's Office was used directly. In the Arkansas River basin, incidental losses associated with agricultural use were estimated by the HI-Model for areas included in the model study area. For areas where a DSS has not been created, or for parameters not previously developed, the established DSS procedures were used. The following summarizes the source of data, available DSS documentation, and the general procedure used for each of parameters.

Livestock Approach and Results

Livestock consumptive use is estimated by multiplying the number of cattle, sheep, and hogs located within the basin by their corresponding per capita consumptive use. The data necessary for determining livestock consumptive use for a basin includes:

- Cattle, sheep, and hog inventory estimates, and
- Representative per capita consumptive use for each type of livestock

Annual agricultural statistical inventory data for counties in Colorado are developed by the National Agricultural Statistical Service and are stored in HydroBase. Quantification of livestock inventory in each of the western slope DSS basins was performed in support of the Consumptive Use and Losses Report and documented in the *Colorado River Basin Consumptive Uses and Losses Report - Other (non-agricultural) Uses Procedures.* Quantification of the livestock inventory in the Platte basins was performed in support of the SPDSS Water Budget analysis and documented in SPDSS *Task 84 –*

South Platte River Basin Water Budget Procedures and Results Memo. A livestock inventory analysis was performed in the Rio Grande basin in support of the water budget analysis that basin, however only quantified data through 1997. Using the same methodology, basin-wide livestock inventories were developed for the Republican River, Arkansas River and Rio Grande basins.

Note that the purpose of this subtask is to determine consumptive use on a Water District level; therefore the basin-wide livestock information was redistributed to a Water District level based on the percent of Water District land area in each basin. This simplified approach to distributing basin-wide livestock use to water district is appropriated based on the minimal livestock consumptive use compared to other uses.

Various sources have estimated daily livestock water use rates. The EPA developed and published livestock water use rates in the *Manual of Individual and Non-Public Water Supply Systems, May 1991*. These consumptive use rates, summarized in **Table 1**, were used in previous CDSS efforts.

Table 1
Average Daily Consumptive Use by Livestock

Livestock Type	Daily Water Use (gal/head)
Cattle	10
Sheep	2
Hogs	3

The most recent 10-year period was chosen to represent current agricultural uses, including livestock consumptive use. **Table 2** summarizes the 10-year average annual value by Water District for livestock consumptive use.

Table 2
10-Year Average Annual
Livestock Consumptive Use (acre-feet)

Water District	Livestock Consumptive Use
Arkansas	
10	540
11	386
12	617
13	154
14	386
15	154
16	231
17	1,311
18	154
19	771
66	540
67	2,236
79	231
Total	7,711
San Juan	
29	98
30	135
31	74
32	148
33	49
34	86
60	197
61	37
63	74
69	37
71	148
73	37
77	25
78	86
Total	1,232

Water District	Livestock Consumptive Use
Gunnison	
28	184
40	382
41	92
42	105
59	224
62	237
68	92
Total	1,316
Colorado	
36	65
37	92
38	138
39	74
45	55
50	46
51	111
52	37
53	74
70	46
72	184
Total	922
Yampa	
44	306
54	102
55	186
56	121
57	65
58	149
Total	929
White	
43	399

Water District	Livestock Consumptive Use
South Platte	
1	4,923
2	684
3	1,231
4	547
5	414
6	276
7	414
8	966
9	138
23	1,104
48	414
64	2,070
76	138
80	414
Total	13,733
North Platte	
47	402
Republican	
49	2,390
65	3,900
Total	6,290
Rio Grande	
20	352
21	75
22	107
24	96
25	117
26	117
27	64
35	139
Total	1,067

Stock Pond Evaporation Approach and Results

Stock pond evaporation is based on net evaporation rates and stock pond surface area estimates. The methodologies for developing this information have been documented during the DSS efforts in the basin Water Resources Planning Model User's Manuals and technical memorandums and, as discussed below, will be used in non-DSS basins.

Evaporation Estimates

In the absence of site specific evaporation information, annual net reservoir evaporation is estimated by subtracting the average effective monthly precipitation from the estimated gross monthly free water surface evaporation. Annual estimates of gross free water surface evaporation were taken from the National Oceanic and Atmospheric Administration (NOAA) Technical Report NWS 33, based on the 1956 – 1970 time period. Gross annual estimates of evaporation were distributed to monthly values based on percentages used by the State Engineer's Office (presented by Wolfe and Stenzel at a 1995 ET and Irrigation Efficiency Seminar and summarized in a paper titled 'Evaporation'). As shown in **Table 3**, there are two average monthly distributions; above and below 6500' elevation.

Table 3
Average Monthly Gross Evaporation Distribution

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Below 6,500	3.0%	3.5%	5.5%	9.0%	12.0%	14.5%	15.0%	13.5%	10.0%	7.0%	4.0%	3.0%
Above 6,500	1.0%	3.0%	6.0%	9.0%	12.5%	15.5%	16.0%	13.0%	11.0%	7.5%	4.0%	1.5%

Average effective monthly precipitation data from key climate stations were area weighted and subtracted from the gross monthly evaporation to determine net evaporation rates for representative areas (e.g. water districts, reservoirs, upper/lower elevations). The net evaporation rates developed in DSS basins are in support of the StateMod surface water models, and read by the model from the *.eva file. The western slope DSS basins' net evaporation rates are documented in the basin's Water Resources Planning Model User's Manual. The Platte basins' net evaporation rates are documented in SPDSS *Task 53.3 – Assign Climate Information to Irrigated Acreage and Reservoirs* memorandum.

Net evaporation rates for the Rio Grande basin are documented in the RGDSS *Task 6.8 – Prepare Reservoir Files*. Note that historical site specific evaporation was used to determine gross evaporation, as opposed to using the NOAA TR NWS 33 report. Effective precipitation from key climate stations was subtracted from the gross evaporation to determine the monthly net evaporation rates shown below.

Evaporation rates for the Republican River basin, shown in **Table 4,** were based on gross evaporation information and recommended precipitation station as provided by the State of Colorado, as developed in accordance with the Republican River Compact Administration Accounting.

Table 4
Average Monthly Net Evaporation Rates (feet/month)
Republican River Basin

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
0.11	0.12	0.19	0.28	0.33	0.47	0.40	0.37	0.32	0.19	0.13	0.12	3.03

As there has not been a DSS developed in the Arkansas River basin, evaporation rates were developed under these efforts using the standard DSS procedure. Evaporation rates were estimated for each Water District based on an area-weighted spatial analysis of the NOAA TR NWS 33 map, distributed to monthly values based on Table 3, and representative precipitation data from a key climate station in each basin. A factor of 70 percent was applied to the precipitation data to quantify effective precipitation, as recommended by the State Engineer's Office. The difference between the gross monthly evaporation and the effective precipitation is the net monthly evaporation for the Arkansas River basin, as shown in **Table 5**.

Table 5
Average Monthly Net Evaporation Rates (feet/month)
Arkansas Basin

Water District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total
10	0.10	0.11	0.16	0.27	0.33	0.40	0.39	0.38	0.30	0.21	0.12	0.10	2.86
11	0.02	0.10	0.20	0.30	0.44	0.56	0.53	0.39	0.37	0.24	0.13	0.03	3.30
12	0.02	0.09	0.20	0.30	0.43	0.57	0.55	0.43	0.40	0.24	0.13	0.04	3.39
13	0.02	0.11	0.23	0.37	0.55	0.72	0.67	0.49	0.49	0.29	0.15	0.03	4.13
14	0.08	0.09	0.13	0.21	0.29	0.37	0.35	0.32	0.25	0.15	0.09	0.07	2.39
15	0.05	0.04	0.07	0.15	0.28	0.41	0.32	0.27	0.25	0.13	0.07	0.05	2.07
16	0.01	0.08	0.21	0.31	0.51	0.65	0.63	0.52	0.46	0.28	0.15	0.03	3.84
17	0.07	0.09	0.14	0.21	0.29	0.36	0.34	0.34	0.24	0.16	0.10	0.08	2.44
18	0.11	0.12	0.20	0.32	0.44	0.52	0.50	0.45	0.38	0.24	0.14	0.10	3.51
19	0.09	0.10	0.17	0.27	0.37	0.44	0.42	0.38	0.32	0.20	0.12	0.08	2.96
66	0.10	0.11	0.17	0.28	0.33	0.41	0.43	0.40	0.32	0.21	0.12	0.10	2.98
67	0.12	0.14	0.22	0.35	0.41	0.54	0.53	0.50	0.38	0.26	0.16	0.12	3.73
79	-0.03	0.02	0.08	0.14	0.29	0.43	0.35	0.25	0.27	0.14	0.07	0.00	2.02

The evaporation rates discussed above reflect periodic months where effective precipitation can exceed gross reservoir evaporation, resulting in negative net reservoir evaporation (a net addition to the reservoir). However, because these estimates are being used to represent physical conditions to quantify the total evaporation for stock ponds, negative net evaporation values are set to zero.

Surface Area Estimates

Storage contents and associated area/capacity information for stock ponds are not available; therefore estimates of aggregated stock pond surface area were developed for the DSS basins. The process for developing the capacities for the western slope basins is documented in five basin-specific CRDSS Non-Irrigation (Other Uses) Consumptive Use and Losses technical memoranda (Tasks 1.14-23, 2.09-10, 2.09-11, 2.09-12, 2.09-13). In general, stock pond capacities in these DSS basins were developed based on a list of the stock pond capacities provided from the State Engineer's Office, aggregation by location/Water District and then a 'fullness factor' was applied to account for partially full storage. The estimated capacity was then converted to a surface area based on an average 10 foot depth.

In the Rio Grande basin, smaller reservoirs that are not modeled explicitly and stock ponds were combined for the surface water modeling efforts. The aggregate reservoirs' capacities were estimated in RGDSS *Task 7.2 – Aggregate Reservoirs and Stock Ponds*, and converted to surface area based on an average 10 foot depth.

In the North and South Platte basins the process for estimating stock pond evaporation is documented in SPDSS Task 69 – Estimate Reservoir and Stock Pond Evaporation. In general, reservoir structures decreed for less than 30 acre-feet as well as non-jurisdictional dams were included as stock ponds for each basin. The decreed reservoir volumes and non-jurisdictional dam tank capacities were aggregated by Water District and converted to surface area based on an average 10 foot depth.

Stock pond capacities and surface areas for the Republican River basin, shown in **Table 6,** were provided by the State of Colorado, as estimated in accordance with the Republican River Compact Administration Accounting.

Table 6
Stock Pond Surface Area/Capacity Information
Republican River Basin

Stock Pond	Max Capacity (af)	Max Surface Area (ac)	Presumptive * Average Annual Surface Area (ac)
Chief Creek 4	291	27	6.75
Holy Joe	24	6	1.5
Rush Creek #2	39	2	0.5
Hanshaw	38	6	1.5
Rush Creek #1	57	14	3.5
Total	**449**	**55**	**13.75**

*Presumptive Average Annual Surface Area represents average estimated or measured surface area based on SEO provided data. This surface area value was used to estimate stock pond evaporation for the basin.

Stock pond surface areas for the Arkansas Basin were developed using the procedure summarized in SPDSS Task 69. Stock ponds were quantified by querying HydroBase for reservoir structures (with Use = STK) decreed for less than 30 acre-feet and for non-jurisdictional dams less than 20 acres of surface area and less than 10 feet high. Note that non-jurisdictional structures do not have decreed water rights so there is not the potential for double-accounting storage. The capacity information was aggregated by Water District and converted to surface area based on a 10 foot depth. The surface area results appear in **Table 7**.

Table 7
Stock Pond Surface Area/Capacity Information
Arkansas River Basin

WD	Capacity (af)	Surface Area (ac)
10	2,215	265
11	162	17
12	1,476	165
13	369	41
14	2,278	280
15	526	62
16	765	95
17	3,270	393
18	1,216	139
19	6,347	756
66	1,264	142
67	5,162	604
79	523	58
Total	**25,573**	**3,016**

Evaporation Results

As discussed above, stock pond evaporation is based on the net reservoir evaporation multiplied by the aggregated stock pond surface area. Current stock pond decreed volumes are used to represent the recent 10-year average in each basin. **Table 8** summarizes the monthly stock pond evaporation by Water District for all basins.

Table 8
Average Monthly Stock Pond Evaporation (acre-feet)

Water District	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
South Platte River basin													
1	387	482	610	1,024	1,168	1,552	1,559	1,490	1,142	857	492	384	11,149
2	7	9	11	19	22	36	40	37	25	17	8	7	239
3	11	15	17	28	32	56	64	60	40	27	13	11	374
4	5	7	7	12	15	28	34	28	18	13	6	5	177
5	3	4	4	7	9	17	21	17	11	8	4	3	109
6	6	7	6	13	19	37	41	37	24	16	5	5	215
7	2	2	2	5	6	11	12	11	7	5	2	2	68
8	106	121	131	301	387	603	585	525	425	276	123	97	3,681
9	3	3	3	7	9	15	17	15	10	7	3	3	94
23	2	16	32	50	68	88	66	34	57	39	21	3	475
48	0	0	0	0	0	0	0	0	0	0	0	0	0
64	45	55	73	123	122	174	187	189	147	98	57	45	1,315
76	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	1	1	2	3	2	1	2	1	0	0	13
Basin Total	577	721	897	1,590	1,859	2,620	2,628	2,444	1,908	1,364	734	565	17,909
North Platte River basin													
47	0	2	15	25	34	55	52	37	30	19	3	0	272
Arkansas River basin													
10	26	30	43	70	88	107	104	101	78	55	32	26	759
11	0	2	3	5	7	10	9	7	6	4	2	1	56
12	3	15	32	49	72	94	90	70	66	40	22	6	560
13	1	5	9	15	23	30	27	20	20	12	6	1	169
14	21	24	36	60	80	103	97	88	69	42	26	21	668
15	3	3	4	9	18	25	20	17	15	8	4	3	129
16	1	8	20	30	48	62	60	49	44	26	14	3	365
17	29	36	55	82	114	143	135	134	96	63	39	31	959
18	15	17	28	44	60	73	70	63	52	33	19	14	488
19	70	76	127	203	279	335	317	285	243	152	89	64	2,241
66	13	16	24	40	47	59	61	57	45	30	17	14	422
67	72	85	132	210	249	329	319	302	230	156	95	72	2,250
79	0	1	5	8	17	25	20	14	16	8	4	0	119
Basin Total	254	318	518	825	1,102	1,395	1,329	1,207	980	629	369	256	9,185

Table 8 cont.
Average Monthly Stock Pond Evaporation (acre-feet)

Rio Grande basin													
20	0	0	0	0	1135	1574	1265	774	897	596	0	0	6,242
21	0	0	0	0	140	194	156	95	111	73	0	0	769
22	0	0	0	0	85	118	94	58	67	45	0	0	468
24	0	0	0	0	8	11	9	5	6	4	0	0	43
25	0	0	0	0	89	124	99	61	70	47	0	0	490
26	0	0	0	0	42	58	46	28	33	22	0	0	229
27	0	0	0	0	3	4	3	2	2	1	0	0	15
35	0	0	0	0	188	261	210	128	149	99	0	0	1,033
Basin Total	0	0	0	0	1,690	2,344	1,882	1,151	1,335	887	0	0	9,289
Yampa River basin													
44	0	0	77	192	358	512	498	371	320	166	0	0	2,493
55	0	0	19	48	89	127	124	92	79	41	0	0	619
Basin Total	0	0	96	240	447	639	622	463	399	207	0	0	3,112
White River basin													
43	0	10	42	76	144	196	196	128	114	62	20	0	988
San Juan/Dolores River basin													
29	0	0	0	63	123	174	123	30	34	13	0	0	559
30	0	0	0	37	72	101	72	17	20	7	0	0	326
31	0	0	0	21	41	58	41	10	11	4	0	0	186
32	0	85	186	372	559	813	728	542	474	220	68	0	4,046
33	0	0	0	32	61	87	61	15	17	6	0	0	279
34	0	0	0	116	225	318	225	54	62	23	0	0	1,024
63	0	2	4	8	12	17	15	11	10	5	1	0	84
Basin Total	0	87	190	649	1,093	1,568	1,265	679	628	278	69	0	6,504
Gunnison River basin													
40	7	10	3	33	54	76	57	48	31	14	0	9	342
41	7	10	3	33	54	76	57	48	31	14	0	9	342
42	7	10	3	33	54	76	57	48	31	14	0	9	342
62	7	10	3	33	54	76	57	48	31	14	0	9	342
68	7	10	3	33	54	76	57	48	31	14	0	9	342
Basin Total	35	50	15	165	270	380	285	240	155	70	0	45	1,710
Colorado River basin													
72	0	0	16	38	72	93	95	66	54	29	5	0	468
Republican River basin													
65	2	2	3	4	5	6	5	5	4	3	2	2	42

Incidental Losses Approach and Results

Incidental loss factors are generally used to increase the crop consumptive use estimate to account for losses “incidental” to crop irrigation. These losses may include, but are not limited to, vegetative consumptive use that occurs along canals and in tailwater areas. As recommended by the USBR, the incidental loss factor is 10 percent of the crop consumptive use supplied by surface water diversions. Note that in general, ground water diversions tend to be more efficient which results in minimal incidental losses. A majority of the irrigated acreage in the Republican River basin is served by ground water; therefore the incidental losses in this basin are negligible and not included for this analysis.

In the Arkansas basin, the HI-Model has estimates of incidental loss determined as a model calibration factor. Incidental loss is termed ‘SEV’ or secondary evapotranspiration. For irrigated lands included in the HI-Model, SEV is used directly as an estimate of incidental loss. Based on information gathered in the exercise to estimate irrigated acreage outside the HI Model and Purgatory Water Conservancy District in the Arkansas basin, it was assumed that:

- all “Other Lands” in Water Districts 17, 66, and 67 were groundwater irrigated;
- all “Other Lands” in Water Districts 11, 12, 13, 14, 15, 16, 18, 19, and 79 were surface water irrigated; and
- based on spatial analysis of irrigated lands within and without the Upper Black Squirrel Designated Groundwater Basin, 52 percent of irrigated acreage is surface water irrigated, and 48 percent is groundwater irrigated.

There is a small amount of surface water irrigation in Water District 17, and there may be small amounts of groundwater irrigated land in the Districts listed in the second group above. These errors are not significant relative to the District-wide consumptive use, and are consistent with error introduced by the universal application of a single factor (10 percent) to estimate incidental loss.

The Rio Grande and South Platte CDSS StateCU analyses rigorously identify surface vs. groundwater-related consumptive use. The incidental loss factor was applied only to the surface water component of WSL CU. In all other basins, irrigation by groundwater is not significant, and the incidental loss factor was applied to the total WSL CU. The most recent 10-year period, separated by basin, was chosen to represent current incidental losses.

Results of the incidental loss computations are shown below in **Tables 9 through 17**.

Table 9
10-Year Average Annual Incidental Loss
South Platte River Basin

Water District	Incidental Loss (af)
1	19,108
2	16,207
3	20,626
4	7,013
5	5,182
6	4,385
7	927
8	247
9	283
23	457
48	474
64	8,420
80	103
Basin Total	**83,433**

Table 10
10-Year Average Annual Incidental Loss
North Platte River Basin

Water District	Incidental Loss (af)
47	**11,322**

Table 11
10-Year Average Annual Incidental Loss
Gunnison River Basin

Water District	Incidental Loss (af)
28	4,390
40	15,364
41	17,276
42	1,865
59	5,856
62	3,193
68	2,591
Basin Total	**50,535**

Table 12
10-Year Average Annual Incidental Loss
Arkansas River Basin

Water District	Incidental Loss (af)
10	239
11	1,303
12	763
13	2,062
14	9,015
15	134
16	211
17	14,310
18	191
19	2,567
66	0
67	7,771
79	380
Basin Total	**38,946**

Table 13
10-Year Average Annual Incidental Loss
Rio Grande River Basin

Water District	Incidental Loss (af)
20	15,030
21	2,752
22	6,795
24	3,228
25	1,954
26	1,482
27	657
35	2,388
Basin Total	**34,286**

Table 14
10-Year Average Annual Incidental Loss
Colorado River Basin

Water District	Incidental Loss (af)
36	1,789
37	2,702
38	6,694
39	3,208
45	4,378
50	2,971
51	4,144
52	528
53	1,927
70	793
72	19,348
Basin Total	**48,482**

Table 15
10-Year Average Annual Incidental Loss
San Juan/Dolores River Basin

Water District	Incidental Loss (af)
29	1,768
30	5,382
31	9,051
32	11,057
33	1,429
34	1,606
60	3,740
61	537
63	706
69	202
71	950
73	409
77	491
78	860
Basin Total	**38,188**

Table 16
10-Year Average Annual Incidental Loss
Yampa River Basin
(Colorado Structures Only)

Water District	Incidental Loss (af)
44	3,929
54	2,819
55	267
56	297
57	1,357
58	5,336
Basin Total	**14,005**

Table 17
10-Year Average Annual Incidental Loss
White River Basin

Water District	Incidental Loss (af)
43	4,117

Appendix G
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