RECLAMATION

*Managing Water in the West*

**Interim Report No. 1**

# Colorado River Basin Water Supply and Demand Study

## Technical Report C – Water Demand Assessment


**U.S. Department of the Interior**
**Bureau of Reclamation**



**June 2011**

# Mission Statements

**Protecting America's Great Outdoors and Powering Our Future**
The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

**Interim Report No. 1**

## Colorado River Basin Water Supply and Demand Study

# Technical Report C—Water Demand Assessment

*Prepared by:*

**Colorado River Basin Water Supply and Demand Study Study Team**

**U. S. Department of the Interior**
**Bureau of Reclamation**

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# Technical Report C—Water Demand Assessment

## 1.0 Introduction

The *Plan of Study*, provided in Appendix 1 of the *Status Report*, states that the purpose of the Colorado River Basin Water Supply and Demand Study (Study) is to define current and future imbalances in water supply and demand in the Colorado River Basin (Basin) and the adjacent areas of the seven Colorado River Basin States[1] (Basin States) that receive Colorado River water over the next 50 years, and to develop and analyze adaptation and mitigation strategies to resolve those imbalances. The Study contains four major phases to accomplish this goal: Water Supply Assessment, Water Demand Assessment, System Reliability Analysis, and Development and Evaluation of Opportunities for balancing supply and demand.

The Water Demand Assessment will assess the quantity and location of current and future water demands in the Study Area (i.e., the hydrologic boundaries of the Colorado River Basin plus the adjacent areas of the Basin States that receive Colorado River water) to meet the needs of Basin resources, including municipal and irrigation use, hydropower generation, recreation, and fish and wildlife habitat. In addition, losses in the Basin due to evaporation and other factors will be assessed. Because future water supply and demand throughout the Basin are uncertain, scenarios (i.e., alternative views of how the future might unfold but not predictions or forecasts of the future) are being developed that are sufficiently broad to span that uncertainty, including the potential effects of future climate change. The water demand scenarios, coupled with water supply scenarios also under development (see *Technical Report B – Water Supply Assessment*) will be used to analyze the future reliability of the Colorado River system, with and without future adaptation and mitigation strategies.

This report presents the progress as of January 31, 2011, in the development of the water demand scenarios to be used in the Study. It first defines key terms and then describes the approach taken for the development of the water demand scenarios, presents the narratives of the water demand scenarios under consideration, and details the approach that is being taken to quantify the scenarios. Quantification of the scenarios is in progress and will be presented in the next Interim Report. Lastly, this report presents historical uses and losses of Colorado River water from 1971 through 2008.

## 2.0 Key Terms Used in this Report

For the Study, the following definitions are used:

- "Demand" is water needed to meet identified uses.
- "Diversion" is water withdrawn from the river system.
- "Return flow" is water diverted from and returned to the river system.

[1] Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming

- "Consumptive use" is water used, diminishing the available supply.
- "Non-consumptive use" is water used, without diminishing the available supply.
- "Shortage" is unmet demand.
- "Loss" is water unavailable for identified uses due to reservoir/channel evaporation, phreatophyte use, and operational inefficiencies.

# 3.0 Approach to Water Demand Scenario Development

A scenario planning process was implemented to examine the uncertainty in future water supply and demand and is detailed in *Technical Report A - Scenario Development*. As noted in that report, a collaborative process that engages stakeholders is essential to the successful development of future scenarios. For this Water Demand Assessment, representatives of several organizations have participated, including water management entities, federal resource management agencies, Native American tribes and communities, environmental organizations, and others interested in the Basin. This collaboration has been accomplished through a variety of means, including participation in a Water Demand Sub-Team and direct contact with representatives of specific organizations. The Water Demand Sub-Team members and the points of contact are provided in Appendix C1 of this report.

The scenario planning process involved the identification of the key driving forces (i.e., the factors that likely will have the greatest influence on the future state of the system and thereby the performance of the system over time); ranking of the driving forces as to their relative importance and relative uncertainty; and associating the highly uncertain and highly important driving forces, identified as critical uncertainties, with either water supply or water demand. The process is shown graphically in Figure C-1, which is also presented in *Technical Report A - Scenario Development*. Table C-1 (also presented in *Technical Report A - Scenario Development*) lists the critical uncertainties that were identified and associated with water demand, grouped by broader categories of driving forces. This table is the result of the step "Associate Critical Uncertainties with Water Supply and Demand" for water demand shown in Figure C-1. See *Technical Report B – Water Supply Assessment* for a discussion of the critical uncertainties associated with water supply.

**TABLE C-1**
Critical Uncertainties Associated with Water Demand

| Critical Uncertainties Identified in Basin Study | General Driving Force Category |
|---|---|
| • Changes in population and distribution<br>• Changes in agricultural land use (e.g., irrigated agricultural areas, crop mixes, etc.) | Demographics and Land Use |
| • Changes in agricultural water use efficiency<br>• Changes in municipal and industrial water use efficiency<br>• Changes in water needs for energy generation (e.g., solar, oil shale, thermal, nuclear, etc.) | Technology and Economics |
| • Changes in institutional and regulatory conditions (e.g., laws, regulations, etc.)<br>• Changes in flow-dependent ecosystem needs for ESA-listed species<br>• Changes in other flow-dependent ecosystem needs<br>• Changes in social values affecting water use<br>• Changes in water availability due to tribal water use and settlement of tribal water rights claims | Social and Governance |

**NOTE**:
Endangered Species Act is abbreviated as "ESA"

The subsequent process (shown on the right-hand side of Figure C-1 and labeled "Demand") is being used by the Water Demand Sub-Team to move from the critical uncertainties to demand scenarios. Each step of this process is described in the following sub-sections.

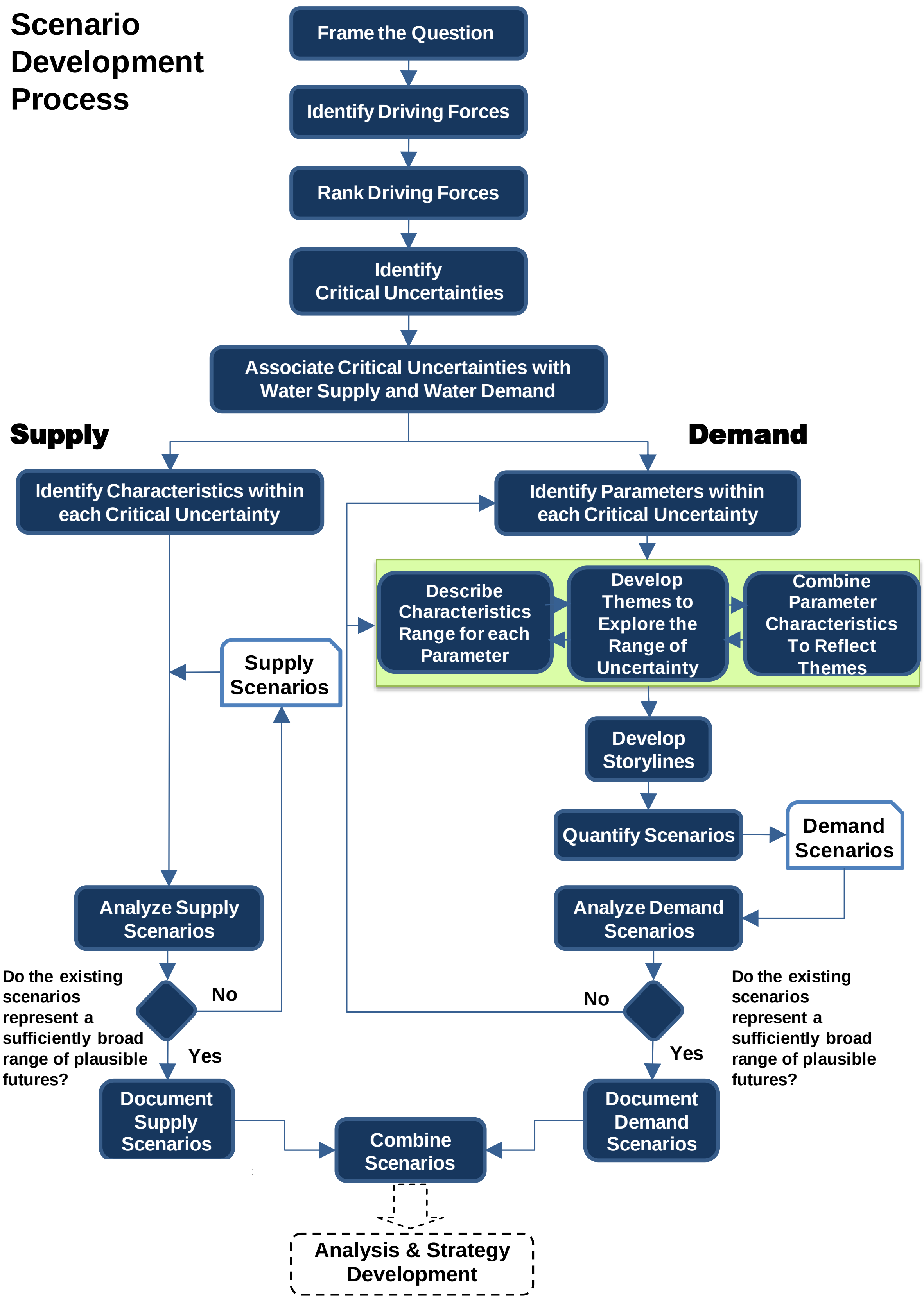
## 3.1 Identify Parameters Influencing Each Critical Uncertainty

Parameters are the variables that describe the behavior of a critical uncertainty. For example, the critical uncertainty "change in population and distribution" has the parameters "population" and "population distribution." Parameters associated with each of the critical uncertainties were identified and are presented in Table C-2.

**TABLE C-2**
Parameters Identified with each Critical Uncertainty

| Critical Uncertainties Identified in Basin Study | Parameters |
|---|---|
| Changes in population and distribution | Population, population distribution |
| Changes in agricultural land use (e.g., irrigated agricultural areas, crop mixes, etc.) | Irrigated acreage |
| Changes in agricultural water use efficiency | Irrigation efficiency |
| Changes in municipal and industrial (M&I) water use efficiency | M&I water use efficiency, consumptive use factor |
| Changes in water needs for energy generation (e.g., solar, oil shale, thermal, nuclear, etc.) | Water needs for energy generation |
| Changes in institutional and regulatory conditions (e.g., laws, regulations, etc.) | Institutional and regulatory conditions |
| Changes in flow-dependent ecosystem needs for ESA-listed species | ESA-listed species needs |
| Changes in other flow-dependent ecosystem needs | Ecosystem needs |
| Changes in social values affecting water use | Social values affecting water use |
| Changes in water availability due to tribal water use and settlement of tribal water rights claims | Tribal use and settlements |

**FIGURE C-1**
Scenario Development Process



## 3.2 Describe Characteristics for Each Parameter

Each parameter can be defined by a set of characteristics. Characteristics are defined by a description and a set of values that show the trajectory of a parameter over time. For example, for population, a characteristic may be described as “high growth” where high growth is represented by a set of population values over time. A well-defined set of characteristics for a single parameter represents the plausible range of values for that parameter over time.

Before defining the set of quantitative characteristics for each parameter, the Water Demand Sub-Team postulated a future based on “current trends”. Current trends are not direct, mathematical projections of historical data, but rather are the sum of historical and current knowledge, as well as expert thinking about future water demand, that shape the trajectory of each parameter describing future water demand.

After describing the qualitative characteristic for each parameter for current trends, the sub-team found it easier to conceptualize the plausible ranges around these current trend characteristics. For example, “slow growth” and “rapid expansive growth” describe a plausible range relative to current trends in population growth. In this way, “current trends” becomes a baseline from which other scenarios may emerge.

Appendix C2 presents the current trend characteristic for each parameter and the set of characteristics that represent the plausible range for each parameter, as identified by the Demand Sub-Team.

## 3.3 Develop Themes to Explore the Range of Uncertainty

In order to frame the plausible uncertainty, the Water Demand Sub-Team explored logical themes by considering the range of characteristics for each parameter. A theme built on the qualitative current trends characteristics was first considered and titled the “Current Trends” theme, with additional themes explored in relation to current trends. The Current Trends theme was developed from the current trends parameter characteristics defined in Appendix C2.

A one-day workshop was held with the Water Demand Sub-Team and other contributing members (listed in Appendix C1) and resulted in the following themes to be considered for scenario development:

- **Current Trends:** growth, development patterns, and institutions continue along recent trends
- **Economic Slowdown**: low growth with emphasis on economic efficiency
- **Expansive Growth**: economic resurgence (population and energy) and current preferences toward human and environmental values
- **Enhanced Environment and Healthy Economy**: expanded environmental awareness and stewardship with growing economy

These themes are broad descriptions of alternative futures, defining a range of future conditions with potentially different parameter characteristics.

## 3.4 Combine Parameter Characteristics to Reflect Themes

For each theme noted above, a characteristic was selected from the range of characteristics for each parameter and combined to define each theme. For example, the slow growth characteristic of the "population" parameter and the current trends characteristic for the "agricultural land use" parameter (plus selected characteristics for the other parameters) were combined to reflect the Economic Slowdown theme.

Describing the characteristics for each parameter, developing themes to explore the range of uncertainty, and combining parameter characteristics to reflect themes is an interrelated process, as shown in Figure C-1. Both parameter characteristics and theme definitions were refined to reflect coherent representations of plausible future scenarios.

Two examples of refinements that occurred are:

- Individual parameter characteristics assigned to each theme must reflect a coherent representation of a plausible future scenario. For example, high growth in water use for energy production likely corresponds to an Expansive Economic Growth theme more than with an Economic Slowdown theme.
- Likewise, the likely trajectory of an individual parameter in a particular theme can result in refining the characteristics for that parameter. For example, the Water Demand Sub-Team initially assigned the parameter "M&I water use efficiency" a low range characteristic of "no change in efficiency." While assigning the "M&I water use efficiency" characteristics to the Economic Slowdown theme, the Demand Sub-Team recognized that water use efficiency would likely increase relative to current trends because economic conditions would likely result in behavioral changes that offset any decrease in efficiency due to lower capital investment. Therefore, the low range of the characteristic for the "water use efficiency" parameter was refined to "M&I consumer efficiency continues according to current trends."

Appendix C3 presents the characteristics for each parameter that were assigned to each theme.

## 3.5 Develop Storylines

Using the logical combinations of parameter characteristics, the Water Demand Sub-Team developed storylines of each scenario. Storylines are narrative descriptions of how the future may unfold and provide the plot for describing the scenario. These storylines are presented in below.

In some cases, a storyline can have multiple logical branches, resulting in more than one scenario. For example, in the "Expansive Growth" storyline, significant new water use for energy requirements could result. Logical branches currently considered for this storyline include:

- Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. Current requirements for renewables are met according to schedules. Fossil fuel development and, in particular, oil-shale development, occurs at a faster rate due to economic drivers spurring growth in energy production.

- Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. However, investment in technology results in adoption of water saving techniques (e.g., dry cooling). Renewable energy requirements continue with an emphasis on dry cooling due to an increase in social considerations related to carbon production. World economic conditions do not favor new fossil fuel development in the Southwest.

Logical branches that may provide unique information about future conditions under a single storyline are carried forward for quantification. Branches may be added (or removed) in the quantification process if quantification suggests that new insight will (or will not) come from analyzing a particular branch.

## 3.6 Quantify Storylines

The next step in the process is to quantify each storyline, and that work is ongoing. Current Trends is the first scenario that is being quantified. Data and information are being provided by the Basin States, Native American tribes and communities, environmental organizations, and other stakeholders to develop the trajectories defining the characteristics for each parameter. These data and information will allow for quantification of the Current Trends scenario and will be used as a starting point for quantification of the remaining scenarios. The approach being taken for scenario quantification is presented below.

## 3.7 Analyze and Document Scenarios

Once quantified, each scenario will be analyzed to ensure that the components are logically consistent and that the scenario provides additional insight into the plausible range of future demands. The intent for these scenarios is to span the plausible range of uncertainty, where the Current Trends scenario represents the central tendency of future trajectories. In particular, where a given storyline has multiple branches resulting in more than one scenario, consideration is given as to whether analyzing each of these scenarios provides additional insight into the plausible range of uncertainty of future water demand.

The quantified characteristics for each parameter behind each scenario will be documented so that the logic used to develop each scenario is transparent. For example, in the case of population, where the critical uncertainty results in a set of characteristics ranging from slow growth to high growth, the assumptions behind these population projections will be documented. This work is ongoing and will be presented in future interim reports.

# 4.0 Storylines Currently Under Consideration

The scenario narratives, currently under consideration as of January 31, 2011, are described in this section and are organized by the general driving force categories (“demographics and land use,” “technology and economics,” and “social and governance”) and by specific parameter. The characteristics of each parameter are then briefly described. During quantification, these descriptions will likely be refined to maintain consistency and provide coherent descriptions of each scenario.

## 4.1 Storyline for the Current Trends Scenario

### *4.1.1 Demographics and Land Use*

**Population –** Populations in the Colorado River Basin, the adjacent water-dependent basins, and the Southwestern United States grow at rates commensurate with the "best estimate" demographic projections. Population growth generally occurs centered in existing urban areas.

**Agricultural Land Use –** There are nominal increases in irrigated agricultural lands primarily due to the build out of currently planned agricultural water supply projects. Agricultural land use growth varies by location with some agriculture to urban land conversion occurring and lower economic-value crops being phased out in some areas.

### *4.1.2 Technological and Economics*

**Agricultural Water Use Efficiency –** Current trends in agricultural water use efficiency continue making modest improvements to on-farm and system efficiency through projects such as those supported under the Salinity Control Program. These improvements result in little change to Colorado River Basin consumptive use. No radical changes in technology are anticipated. Agricultural uses are generally consistent with today's practices (e.g., no major changes in techniques, crops, or practices).

**M&I Water Use Efficiency –** Water use efficiency increases according to current Colorado River Basin water provider policies (e.g. Southern Nevada Water Authority's [SNWA's] current gallons per capita per day [gpcd] planning goals) and technology. External factors, beyond the control of Colorado River Basin water providers, that limit the water use of fixtures and appliances (e.g., federal statutes) continue resulting in "natural" increases in in-home efficiency. Water use efficiency changes vary by location according to local goals and mix of water use categories. No radical changes in technology are anticipated.

**Water Needs for Energy –** Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. Current requirements for renewables are met according to current schedules. Fossil fuel development and, in particular, oil-shale development occurs according to current plans. No dramatic changes to global economies or energy demand that would spur additional consideration occur (e.g., increased fossil fuel prices.)

### *4.1.3 Social and Governance*

**Institutional and Regulatory –** Federal and state laws and regulations affecting the Basin continue in a similar manner as today. Despite the potential for sunsetting of future regulations and agreements, the operations of the Colorado River are relatively unchanged.

**Flow-dependent ESA Needs –** There is no expansion of the federal endangered species program, change to the needs of currently listed ESA species, or updates of existing Biological Opinions. Operations for ESA needs continues according to recent practices, agreements, and regulations.

**Flow-dependent non-ESA Needs –** No change is anticipated in currently realized ecosystem needs or operational practices to meet needs. Operations to meet ecosystem needs continue according to recent practices.

**Social Values –** Social values that affect water use in all categories remain consistent with the recent past. These values include continued support for ongoing planned M&I and agricultural conservation efforts as well as support for the ESA and its implementation.

**Tribal Use –** Tribal use develops according to current settlements and use patterns.

## 4.2 Storyline for the Economic Slowdown Scenario

### *4.2.1 Demographics and Land Use*

**Population –** Populations continue to grow primarily in urban centers but at slower rates than "current trends." Population growth is consistent with moderate to low economic growth or a slow economic recovery period followed by economic and subsequent population growth that is less robust than occurred in the recent past.

**Agricultural Land Use –** There are nominal increases in irrigated agricultural lands primarily due to the build out of currently planned agricultural water supply projects. Agricultural land use growth varies by location with some agriculture to urban land transfer occurring and lower economic-value crops being phased out in some areas.

### *4.2.2 Technological and Economics*

**Agricultural Water Use Efficiency –** Lack of economic growth results in decreased revenues and reduced capital investment for routine and long-term maintenance. Reduced maintenance results in an overall decline in on-farm and delivery efficiency. These efficiency reductions require greater diversions to meet consumptive use requirements. However, Colorado River Basin consumption changes little as additional losses are returned to the Colorado River system.

**M&I Water Use Efficiency –** Water use efficiency increases according to current policies (e.g., SNWA's current gpcd planning goals) and technology. External factors that limit the water use of fixtures and appliances (e.g., federal statutes) continue resulting in "natural" increases in in-home efficiency. Water use efficiency changes vary by location according to local goals and mix of water use categories. No radical changes in technology are anticipated. Aging infrastructure and lack of capital investment due to economic slowdown result in some acute water loss events. However, these events are generally absorbed by the long-term natural trends toward greater efficiency.

**Water Needs for Energy –** Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. Current requirements for renewables are met according to current schedules. Despite the regional economic slowdown, global energy demand and in particular fossil fuel development (including oil-shale development) occurs according to current plans. No dramatic changes to global economies or energy demand that would spur additional consideration occur (e.g., increased fossil fuel prices.)

### *4.2.3 Social and Governance*

**Institutional and Regulatory –** Economic slowdown and focus on economic efficiency lead to no significant change in institutional and regulatory requirements. Existing federal and state laws and regulations affecting the Basin continue.

**Flow-dependent ESA Needs –** No change is anticipated in currently realized ecosystem needs or operational practices to meet needs. Operations to meet ecosystem needs continue according to recent practices.

**Flow-dependent non-ESA Needs –** No change is anticipated in currently realized ecosystem needs or operational practices to meet needs. Operations for ecosystem needs continue according to recent practices.

**Social Values –** Economic efficiency is overwhelming driver affecting social values. Social values that affect water use in all categories trend toward preferences for human water use and systems over other concerns. This focus is driven largely by a lack of funds for capital outlay and a lack of societal willingness to take on new programs.

**Tribal Use –** Tribal use continues to develop but at slower than planned rates due to economic conditions and pressure to reduce tribal expenditures or federal settlement expenditures.

## 4.3 Storyline for the Expansive Growth Scenario

This storyline includes 2 branches: (C1) slower technology adoption, and (C2) rapid technology adoption and slight increase in social values. Once quantified these branches could produce 2 scenarios.

### *4.3.1 Demographics and Land Use*

**Population –** Rapid population growth focused around urban centers with sprawl to outlying areas is driven by rapid economic recovery followed by a period of prolonged growth. This population growth is similar to typical “High” demographic projections for the southwest Basin States.

**Agricultural Land Use –** Agricultural land use increases at a slightly faster rate than current trends due primarily to economic growth resulting in faster development of currently planned projects. Agricultural land use growth varies by location with some agriculture to urban land transfer occurring and lower economic-value crops being phased out in some areas.

### *4.3.2 Technological and Economics*

**Agricultural Water Use Efficiency –** (C1) Lack of economic growth results in decreased revenues and reduced capital investment for routine and long-term maintenance. Reduced maintenance results in an overall decline in on-farm and delivery efficiency. These efficiency reductions require greater diversions to meet consumptive use requirements. However, Colorado River Basin consumption changes little as additional losses are returned to the Colorado River system.

(C2) Economic conditions result in investment and rapid adoption of new technologies resulting in significant increases in agricultural water use efficiency. These technologies result in denser cropping patterns and higher yields with subsequent greater overall consumptive use demand. Irrigation techniques and delivery system water control are significantly improved over current trends. Gains in distribution efficiency partially offset the increased consumptive use.

**M&I Water Use Efficiency –** (C1) Water use efficiency increases according to current policies (e.g., SNWA’s current gpcd planning goals) and technology. External factors that limit the water use of fixtures and appliances (e.g., federal statutes) continue, resulting in "natural" increases in in-home efficiency. Water use efficiency changes vary by location according to local goals and mix of water use categories. No radical changes in technology are anticipated.

(C2) Increased federal investment in water-saving technology and conservation programs results in a substantive increase in water-saving technology (e.g., WaterSmart, EnergyStar, landscape technology). These technologies are applied Basin-wide, resulting in reduced demand and consumptive use.

**Water Needs for Energy –** (C1) Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. Current requirements for renewables are met according to schedules. Fossil fuel development and, in particular, oil-shale development, occurs at a faster rate due to economic drivers spurring growth in energy production.

(C2) Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. However, investment in technology results in adoption of water-saving techniques (e.g., dry cooling). Renewable energy requirements continue, with an emphasis on dry cooling due to an increase in social considerations related to carbon production. World economic conditions do not favor new fossil fuel development in the southwest.

### *4.3.3 Social and Governance*

**Institutional and Regulatory –** (C1) Federal and state laws and regulations affecting the Basin continue in a similar manner as today. Despite the potential for sunsetting of future regulations and agreements, the operations of the Colorado River are relatively unchanged.

(C2) Changing social values lead to increased governmental regulation, including the enactment of climate change and greenhouse gas mitigation measures. These measures primarily manifest themselves in more-integrated management of water and energy (water use efficiency).

**Flow-dependent ESA Needs –** No change is anticipated in currently realized ecosystem needs or operational practices to meet needs. Operations to meet ecosystem needs continue according to recent practices.

**Flow-dependent non-ESA Needs –** No change is anticipated in currently realized ecosystem needs or operational practices to meet needs. Operations for ecosystem needs continue according to recent practices.

**Social Values –** (C1) Social values that affect water use in all categories remain consistent with the recent past. These values include continued support for ongoing planned M&I and agricultural conservation efforts as well as support for the ESA and its implementation.

(C2) Slight increase in social values and subsequent pressure focused on conservation efforts results in management of the Basin with increased flexibility for multiple water uses (e.g., recreational). Trends continue toward M&I conservation adoption.

**Tribal Use –** Due to economic forces, tribal use and development occurs at a rate faster than currently planned. In addition, new tribal claims and settlements are realized.

## 4.4 Storyline for the Enhanced Environment and Healthy Economy Scenario

This storyline includes two branches: (D1) current growth trend, and (D2) higher growth and technology. Once quantified, these branches could produce two scenarios.

### *4.4.1 Demographics and Land Use*

**Population –** (D1) Populations in the Basin, the adjacent water-dependent basins, and the Southwestern United States grow at rates commensurate with the “best estimate” demographic projections. Population growth generally occurs centered in existing urban areas.

(D2) Rapid population growth focused around urban centers driven by rapid economic recovery, followed by a period of prolonged growth. This population growth is similar to typical “High” demographic projections for the southwest Basin States.

**Agricultural Land Use –** There are nominal increases in irrigated agricultural lands primarily due to the build-out of currently planned agricultural water supply projects. Agricultural land use growth varies by location, with some agriculture to urban land conversion occurring and lower economic-value crops being phased out in some areas.

### *4.4.2 Technological and Economics*

**Agricultural Water Use Efficiency –** (D1) Current trends in agricultural water use efficiency continue making modest improvements to on-farm and system efficiency through projects such as those supported under the Salinity Control Program. These improvements result in little change to Colorado River Basin consumptive use. No radical changes in technology are anticipated. Agricultural uses are generally consistent with today’s practices (e.g., no major changes in techniques, crops, or practices).

(D2) Economic conditions result in investment and rapid adoption of new technologies, resulting in significant increases in agricultural water use efficiency. These technologies result in denser cropping patterns and higher yields with subsequent greater overall consumptive use demand. Irrigation techniques and delivery system water control are significantly improved over current trends. Gains in distribution efficiency partially offset the increased consumptive use.

**M&I Water Use Efficiency –** Increased federal investment in water-saving technology and conservation programs results in a substantive increase in water-saving technology (e.g., WaterSmart, EnergyStar, landscape technology). These technologies are applied Basin-wide, resulting in reduced demand and consumptive use.

**Water Needs for Energy –** Water needs for energy expand relative to population growth and current regulations, policies, and planning for the energy industry. However, investment in technology results in adoption of water-saving techniques (e.g., dry cooling). Renewable energy requirements continue, with an emphasis on dry cooling due to an increase in social considerations related to carbon production. World economic conditions do not favor new fossil fuel development in the southwest.

### *4.4.3 Social and Governance*

Institutional and Regulatory – Changing social values lead to increased governmental regulation, including the enactment of climate change and greenhouse gas mitigation measures. These measures primarily manifest themselves in more-integrated management of water and energy (water use efficiency).

**Flow-dependent ESA Needs –** ESA flow targets for existing listed species are met and recovery of the species is maintained.

**Flow-dependent non-ESA Needs –** Increased social values lead to institutional agreements for ecological flows sufficient to ensure a resilient ecosystem (in timing, amount, and location).

**Social Values –** Increase in social values and subsequent pressure focused on conservation efforts results in management of the Basin with increased flexibility for multiple water uses (e.g., recreational). Trends continue toward M&I conservation adoption and public demand for in-stream flows (tourism, Wild and Scenic Rivers).

**Tribal Use –** (D1) Tribal use develops according to current settlements and use patterns.

(D2) Due to economic forces, tribal use and development occurs at a rate faster than currently planned. In addition, new tribal claims and settlements are realized.

# 5.0 Approach to Quantifying Demand Scenarios

The previous sections discussed the scenario development approach and the resulting storylines that are currently under consideration in the Study. This section describes how those storylines will be quantified into detailed numeric estimates for use in subsequent phases of the Study (e.g., analysis of the future system reliability).

Water demands for each scenario are quantified using the associated parameter characteristics for each category of demand. Categories of demand used historically in the Upper Basin (and proposed for use in the Study) are agriculture, M&I, energy, minerals, and fish, wildlife, and recreation. The sum of the demand for all categories over a given geographic area defines the total demand for that area.

For the Study, water demand within the Study Area (i.e., the hydrologic boundaries of the Colorado River Basin plus the adjacent areas of the Basin States that receive Colorado River water) is of interest. Many of the geographic areas within the Study area have significant water supplies from sources in addition to the Colorado River (e.g., non-tributary groundwater, imports from other basins, other surface water supplies, etc.). Information about the contribution from these other sources is necessary to quantify the portion of the total demand in a geographic area that is to be met with Colorado River water. In addition, this information may allow for the assessment of potential additional demands for Colorado River water due to risks associated with these other supplies.

There may be practical limitations, however, that will preclude representation of the total demand for some geographic areas included in the Study and in those cases, only the demand for Colorado River water will be considered.

In addition to water demand categories, water loss categories have also been defined for the Study; these are reservoir evaporation (water lost due to evaporation from reservoirs), phreatophyte use[2] (water lost due to evapotranspiration by riparian vegetation along the Colorado River in the Lower Basin), and operational inefficiency[3] (water unavailable for delivery due to operational inefficiencies in the Lower Basin).

The following sections describe the overview of the approach to quantifying the demand scenarios, including a discussion of the quantification of parameter characteristics, a further discussion of the demand and loss categories, and a further discussion of Study Area demand and the determination of Colorado River demand.

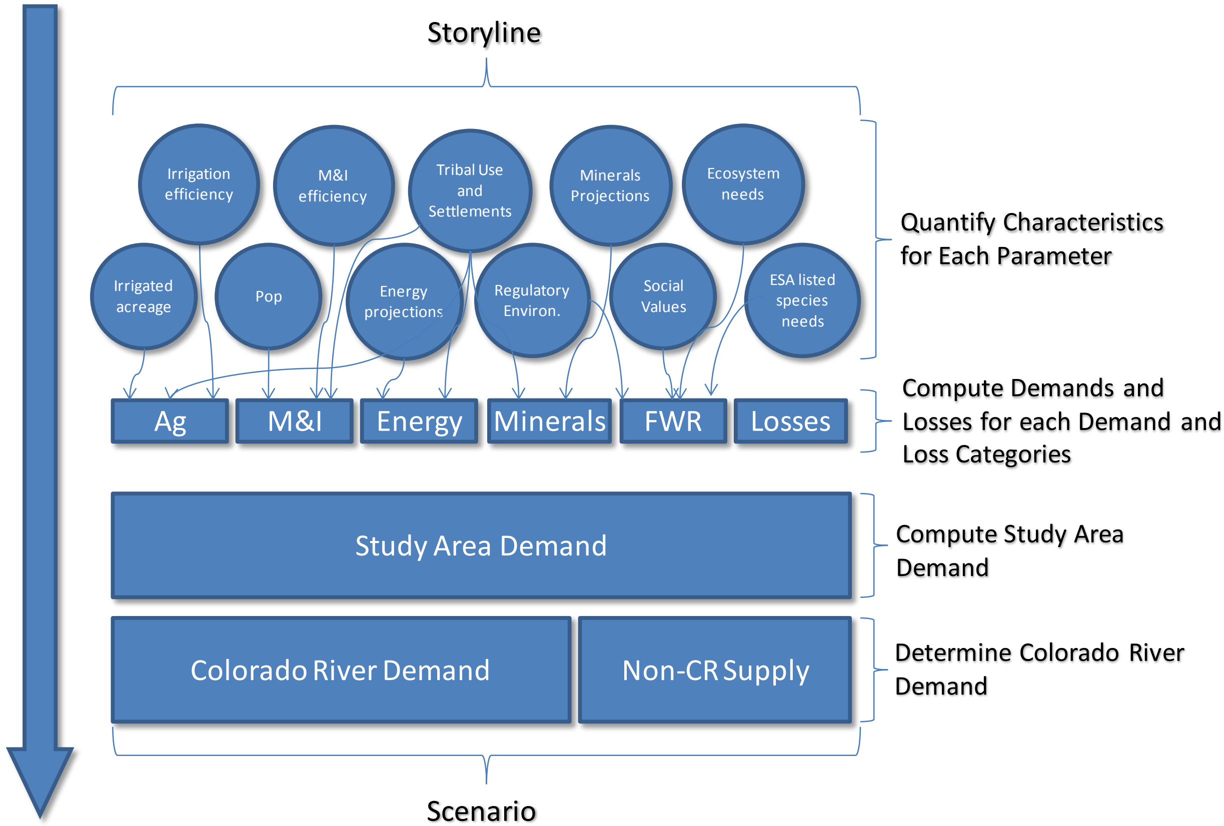
## 5.1 Overview of Approach

Figure C-2 presents the approach to quantifying a demand scenario. This approach details the activities occurring under the single box “Quantify Scenarios” in Figure C-1. The storyline, shown at the top of Figure C-2, is required to begin the approach. First, the parameter characteristics are quantified for that particular storyline and used to quantify demand by category. Summing all the categories establishes the Study Area demand. Last, the Colorado River demand can be determined as the Study Area demand minus demand met by non-Colorado River supplies. The following sections further describe each of these steps.

[2] Phreatophyte losses are estimated for portions of the Lower Basin along the Colorado River mainstream and explicitly included in the water budget using those estimates. Phreatophyte losses in the Upper Basin are implicitly included in the water budget through the natural flow computations and therefore are not shown separately as losses.

[3] Operational inefficiency losses include return flows from the Wellton-Mohawk Irrigation and Drainage District that are not allowed to return to the river due to salinity concerns and non-storable flows that are delivered to Mexico in excess of treaty requirements.

**FIGURE C-2**
Approach to Quantifying a Demand Scenario




### *5.1.1 Quantify Characteristics for Each Parameter*

For a given storyline, the qualitative characteristics for each parameter are quantified. For example, for the Economic Slowdown storyline, the qualitative characteristic for the population parameter is "slow growth". This parameter characteristic is quantified using low-growth population projections throughout the areas served by the Colorado River.

### *5.1.2 Compute Demands and Losses for each Demand and Loss Category*

One or more quantified parameter characteristics are combined to compute the demand for each category. For example, the quantified characteristic for population and the quantified characteristic for M&I efficiency are combined to compute the M&I demand. The common categories of demand facilitate understanding and comparison of scenarios, and comparison of scenarios to available historical data.

In the Study, losses are assumed to not be directly affected by the critical uncertainties and therefore are not computed from quantified parameter characteristics. However, recognizing that losses may vary by scenario (e.g., reservoir evaporation, which is a function of the reservoir water surface area, will vary at a given location and time depending upon the particular scenario), losses will be computed for each scenario to ensure consistent projections of supply and demand imbalances.

The demand and loss categories, their definitions, and associated parameters are presented in Table C-3.

**TABLE C-3**
Definition of Demand and Loss Categories and Their Associated Parameters

| | Definition | Parameters |
|---|---|---|
| **Demand Categories** | | |
| Agriculture | Water used to meet irrigation requirements of agricultural crops, maintain stockponds, and sustain livestock | Irrigated acreage, Irrigation efficiency |
| Municipal and Industrial | Water used to meet urban and rural population needs | Population, Population distribution, M&I water use efficiency, consumptive use factor |
| Energy | Water used for energy services and development | Water needs for energy generation |
| Minerals | Water used for mineral extraction not related to energy services | Water needs for mineral extraction |
| Fish, Wildlife, Recreation | Water used to meet National Wildlife Refuge, National Recreation Area, state park, and off-stream wetland habitat needs | Institutional and regulatory conditions, social values affecting water use, ESA-listed species needs, and ecosystem needs |
| Tribal Use | Water used to meet tribal needs and settlement of tribal water rights claims | Tribal use and settlements |
| **Loss Categories** | | |
| Reservoir Evaporation | Water lost due to evaporation from reservoirs. | Reservoir surface area, evaporation rates |
| Phreatophyte Use | Water lost due to evapotranspiration by riparian vegetation along the Colorado River in the Lower Basin.[1] | Historical loss |
| Operational Inefficiency | Water unavailable for delivery due to operational inefficiencies (i.e., in the Lower Basin, return flow from the Wellton-Mohawk Irrigation and Drainage District is not allowed to return to the river due to salinity concerns and non-storable flows that are delivered to Mexico in excess of Treaty requirements). | Historical loss |

**NOTE:**
[1]Phreatophyte losses are estimated for portions of the Lower Basin along the Colorado River mainstream and are explicitly included in the water budget using those estimates. Phreatophyte losses in the Upper Basin are implicitly included in the water budget through the natural flow (i.e., the flow that would have occurred at a location had depletions and reservoir regulation not been present upstream of that location) computations and therefore are not shown separately as losses.

### *5.1.3 Compute Study Area Demand*

Aggregating demand and loss across all categories for all geographic areas within the Study Area results in the Study Area demand. As previously noted, the Study Area is defined by the hydrologic boundaries of the Colorado River Basin plus the adjacent areas of the Basin States that receive Colorado River water and is depicted in Figure C-3.

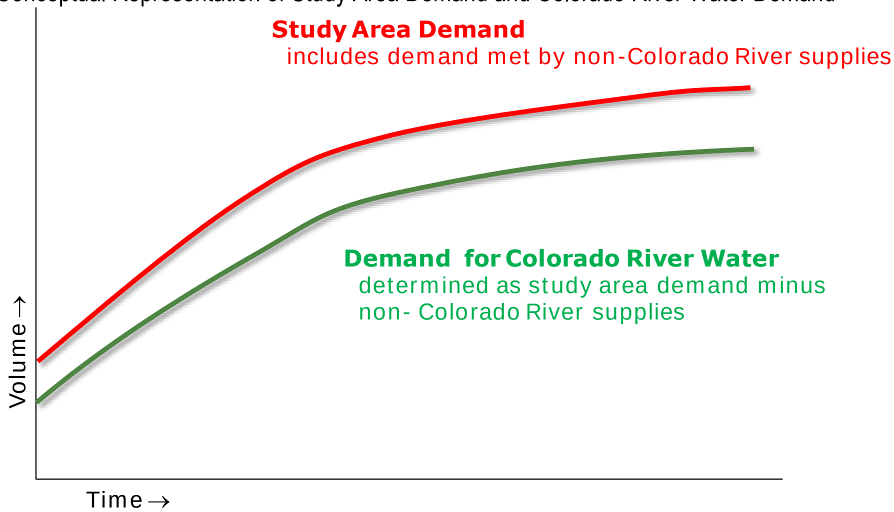
**FIGURE C-3**
The Study Area


The concept of Study Area demand facilitates straightforward documentation of the characteristics for each parameter. However, because parameter characteristics represent basic demand information tied to a specific geographic area that may be served by significant water supplies from sources in addition to the Colorado River system (e.g., non-tributary groundwater, imports from other basins, other surface water supplies, etc.), information about the contribution of these other sources is necessary to quantify the portion of the total demand in a geographic area that is to be met with Colorado River water.

### *5.1.4 Determine Colorado River Demand*

To determine demand for Colorado River water, non-Colorado River water supplies are subtracted from the Study Area demand. Figure C-4 depicts this approach with Study Area demand (upper line) determined from aggregated demand and loss categories, and Colorado River demand (lower line) determined as the Study Area demand minus non-Colorado River supplies.

**FIGURE C-4**
Conceptual Representation of Study Area Demand and Colorado River Water Demand




## 6.0 Approach to Incorporating Climate Change Effects on Demands

*Technical Report A - Scenario Development* identified “changes in stream flow variability” and “trends and changes in climate variability” (e.g. temperature, precipitation, etc.) as the most important and most uncertain of the critical uncertainties. Because of its importance, “climate change” is considered separately from other driving forces and will be considered across all future demand scenarios when matched with water supply scenarios that incorporate climate change. Future demands may be affected by climate change primarily due to changes in ambient temperature and the amount and distribution of precipitation. The Study will address possible effects of changing temperature and precipitation on evapotranspiration, which impacts agriculture and outdoor M&I demand, and on phreatophyte and reservoir evaporation losses.

As noted, projection of future climate conditions is highly uncertain, and these uncertainties are further described in *Technical Report B – Water Supply Assessment*. There are varying methods for projecting future climate conditions, with new science and methods being continually developed. The methods chosen for the Study represent one suite of available techniques.

Possible changes in demand related to climate change that are not evaluated in the Study include changes in water demand for energy production, changes to environmental flow requirements associated with increasing ambient temperature, and changes in crop type. Regarding water demand for energy production, the additional variability in water demands for energy due to climate change would likely be small compared with the overall uncertainty in future energy demands. For environmental flows, insufficient data currently exist to quantify new habitat and species flow needs due to climate change. Changes in crop type are highly uncertain, and there are insufficient data to understand how crop type will change in response to changes in temperature and precipitation.

## 6.1 Climate Change Effects on Evapotranspiration

The Bureau of Reclamation (Reclamation) and others have historically calculated crop evapotranspiration to arrive at agricultural demand using the modified Blaney-Criddle method (Stephens and Stewart, circa 1960). Blaney-Criddle is a general empirical formula that allows for calculation of gross demand based on crop type, crop acreage, and temperature. Net crop demand is determined after considering available precipitation, typically by using the Soil Conservation Service effective precipitation method.

In 2010, Reclamation's Technical Services Center (TSC) applied the modified Blaney-Criddle method, coupled with the Soil Conservation Service effective precipitation method, to examine potential change in agricultural demand due to changes in temperature and precipitation (Reclamation, 2010a – see Appendix C4 ). The TSC considered incremental increases in temperature and precipitation to gauge the sensitivity of each state’s agricultural areas to possible climate change. The TSC found that agricultural demands increased by approximately 5 percent for each degree Celsius increase in temperature, and by approximately 1 percent for each 5 percent reduction in precipitation.

The Blaney-Criddle method uses empirical methods to relate complex evaporation and transpiration processes into an equation based solely on temperature. The limitations with this approach are recognized, and a sensitivity analysis will be completed to provide a limited comparison of the modified Blaney-Criddle method and the Penman-Monteith method. The Penman-Monteith method determines potential evapotranspiration based on a more explicit physical process method. The Variable Infiltration Capacity model used in the quantification of the water supply scenarios (see *Technical Report B – Water Supply Assessment*) computes potential and actual evapotranspiration based on the Penman-Monteith method.

Evapotranspiration from both methods will be compared to better understand potential differences. The results of this sensitivity analysis will be evaluated, and final climate change indexing methods will be chosen based on the outcome of the analysis and applied to those scenarios that incorporate climate change. Indices will be created to incrementally change agricultural demands based on projected changes in temperature and effective precipitation due to climate change. Using a similar methodology for changes in outdoor M&I demand and phreatophyte losses will also be considered.

## 6.2 Climate Change Effects on Reservoir Evaporation

Reservoir evaporation will be affected by changes in temperature and rainfall. Evaporation from mainstream reservoirs is calculated by estimating reservoir surface area and applying monthly unit net evaporation rates. Open water surface evaporation rates will be used from the Variable Infiltration Capacity model (see *Technical Report B – Water Supply Assessment*) to adjust historical evaporation rates to reflect higher temperatures.

# 7.0 Historical Consumptive Uses and Losses

Historical consumptive use and loss information may be used in conjunction with future planning data (e.g., land use, policy, population growth, economic conditions, etc.) to inform the development of projected demand. As noted previously, although current trends are not direct, mathematical projections of historical data, the Current Trends scenario in particular relies on knowledge of historical consumptive uses and losses as well as planning data and expertise to estimate future trends in water demands.

The historical consumptive use and loss information presented in this section represents use and loss of Colorado River water within the Study Area and as such, does not represent the total use of water within the Study Area (i.e., it does not include the use of other sources of water).

Furthermore, historical use does not necessarily reflect historical water demand, particularly for periods of drought. A decrease in reported consumptive use during a drought period may reflect the lack of available supply at the point of use rather than a decrease in the demand for water. For example, significant consumptive use reductions due to a lack of available supply (shortage) are readily apparent in the Upper Basin during the recent drought (shown later herein). Due to the large geographic area of the Basin and the location and volume of available water in storage, drought may impact consumptive use differently in different parts of the Basin. Unfortunately, the historical demand for water at a given point and time is not typically available in many areas of the Basin.

The consumptive use and loss data presented herein was obtained primarily from the following sources, with additional information provided by individual Basin States:

- Colorado River System Consumptive Uses and Losses Reports (CU&L Reports), 1971–2000 (Reclamation, 2004, 2005); data for Upper Basin states only
- Provisional CU&L Reports, 2001–2008 (Reclamation, 2007, 2010b); data for Upper Basin states only
- Water Accounting Reports *(Colorado River Accounting and Water Use Reports; Arizona, California, and Nevada*, [Reclamation, 1972-2009]); data for Lower Basin States mainstream use only

In the Upper Basin, some states estimate their consumptive uses and losses of Colorado River water using methods different from those used by Reclamation, resulting in estimates that differ. Reclamation and the states are continuing to work collaboratively to resolve these differences. For consistency purposes, however, the CU&L Reports (and subsequently the data presented in this report) use Reclamation's methodologies to estimate consumptive uses and losses for all Upper Basin states, with the exception of New Mexico. The New Mexico Interstate Stream Commission provides historical consumptive use and loss estimates to Reclamation for subsequent review and publication in the CU&L Reports.

In the Lower Basin, Reclamation accounts for use on the mainstream using a "diversion minus return flow" methodology for all water users within the Lower Basin states and publishes that information each year in the Water Accounting Reports. The CU&L Reports include information taken from the Water Accounting Reports for mainstream Lower Basin use and also estimate consumptive use and losses in the Lower Basin tributaries (primarily the Little Colorado, Virgin, Bill Williams, and Gila rivers). The process of estimating Lower Basin tributary consumptive uses and losses has not received a great deal of attention in the past, and the quality of the resulting information has suffered (see Appendix C5). Due to the issues and problems associated with the Lower Basin tributary consumptive uses and losses data, the historical consumptive use and loss data presented in the following sections do not include data from the Lower Basin tributaries.

Furthermore, Reclamation does not use consumptive uses and losses and other data to compute natural flows[4] for the Lower Basin tributaries for use in the Colorado River Simulation System (CRSS), the primary modeling tool used for the Study. Specifically, CRSS uses historical inflows based on U.S. Geological Survey gaged records for the Little Colorado, Virgin and Bill Williams rivers. In addition, the Gila River is not included in CRSS. In Appendix C5, three commitments are made to engage in efforts independent of the Study: 1) to resolve and correct, in collaboration with the Basin States, the methodological and data inconsistencies in Reclamation's CU&L Reports pertaining to all of the Lower Basin tributaries; 2) to develop natural flows for the Little Colorado, Virgin and Bill Williams rivers and to modify CRSS to use natural flows for those tributaries; and 3) to explore the feasibility and usefulness of computing natural flows for the Gila River Basin and the feasibility and usefulness of adding that basin to CRSS.

Although some limitations will be imposed on the Study by this treatment of the Lower Basin tributaries, through other approaches the Study will be able to examine several important issues, including potential climate change impacts on the tributaries represented in CRSS, future demand scenarios for those tributaries, and future demand scenarios for the Colorado River from the Gila River Basin, factoring in other water supplies within that basin (see Appendix C5).

## 7.1 Historical Basin-wide Consumptive Use and Loss

Figure C-5 shows historical (1971–2008) Colorado River water use by each state[5], delivery to Mexico (pursuant to the 1944 treaty[6]), reservoir evaporation, and other losses. Over the historical period 1971-2008, basin-wide consumptive uses and losses (including delivery to Mexico) have grown from approximately 13 million acre-feet (maf) in 1971 to 16 maf in 1999, an increase of about 23 percent.

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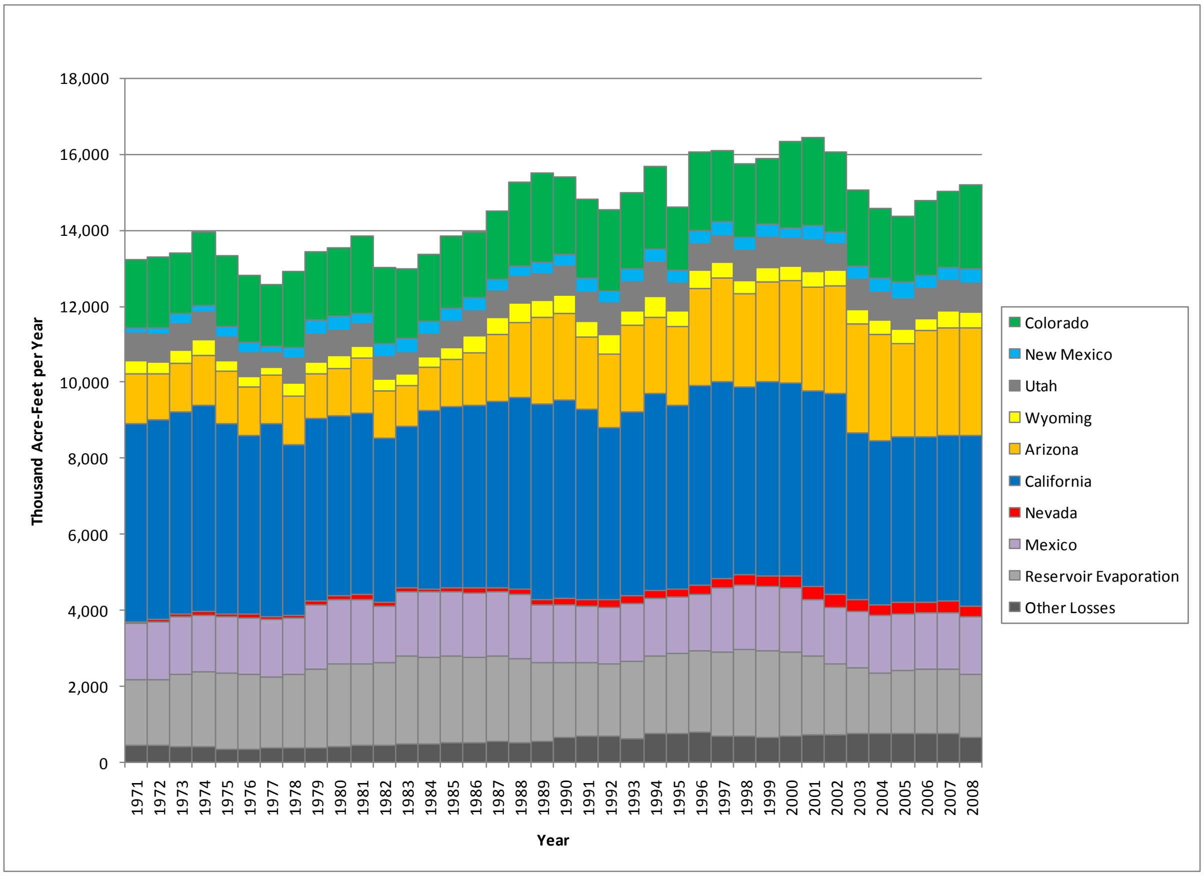
[4]Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location.

[5]Excluding consumptive use in Lower Basin tributaries.

[6]Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty between the United States and Mexico, 1944.

**FIGURE C-5**

Historical Colorado River Water Consumptive Use[1] by State, Delivery to Mexico, Reservoir Evaporation, and Other Losses,[2] 1971-2008




**NOTES:**

[1]Excluding consumptive use in Lower Basin tributaries.

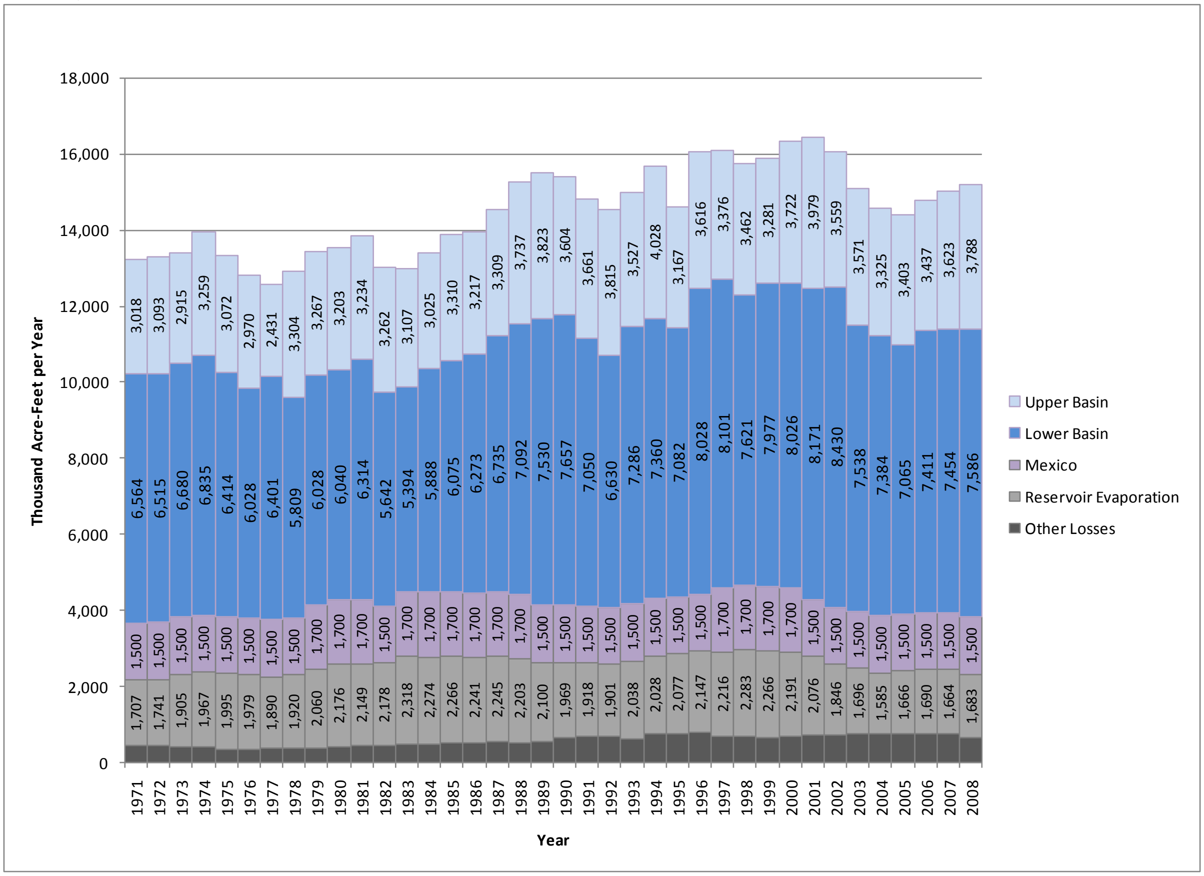
[2]Phreatophyte and operational inefficiency losses.

Figure C-6 shows the same information as Figure C-5, with the water use by each state[7] aggregated by Upper and Lower Basin. Over the historical period 1971-2008, Upper Basin uses have grown from approximately 3.0 maf in 1971 to 3.3 maf in 1999, an increase of about 10 percent. Lower Basin uses have grown from approximately 6.6 maf in 1971 to 8.0 maf [8] in 1999, an increase of about 21 percent.

7 Excluding consumptive use in Lower Basin tributaries.

8 Lower Basin use greater than 7.5 maf is due to surplus water supply conditions for the Lower Division States.

**FIGURE C-6**
Historical Colorado River Water Consumptive Use[1] by Basin[2], Delivery to Mexico, Reservoir Evaporation, and Other Losses[3], 1971-2008




**NOTES:**
[1]Excluding consumptive use in Lower Basin tributaries.

[2]Lower Basin use greater than 7.5 maf is due to surplus water supply conditions for the Lower Division States.

[3]Phreatophyte and operational inefficiency losses.

Figure C-7 shows historical (1971-2008) Colorado River water use[9] and loss by demand category. Over the historical period 1971-2008, agricultural uses have grown from approximately 7.7 maf in 1971 to 8 maf in 1999, an increase of about 4 percent. M&I uses have grown from approximately 1.4 maf in 1971 to 2.2 maf in 1999, an increase of about 57 percent.

Although Colorado River water delivered to areas adjacent to the hydrologic basin are accounted for, that accounting has not included a breakdown into demand categories. Rather the CU&L Reports consider such water uses to be "exports" and treats them as a separate category. The Basin States provided additional information (with the exception of Colorado) regarding the use categories for exports, allowing for a composite of basin-wide use by

[9]Excluding consumptive use in Lower Basin tributaries.

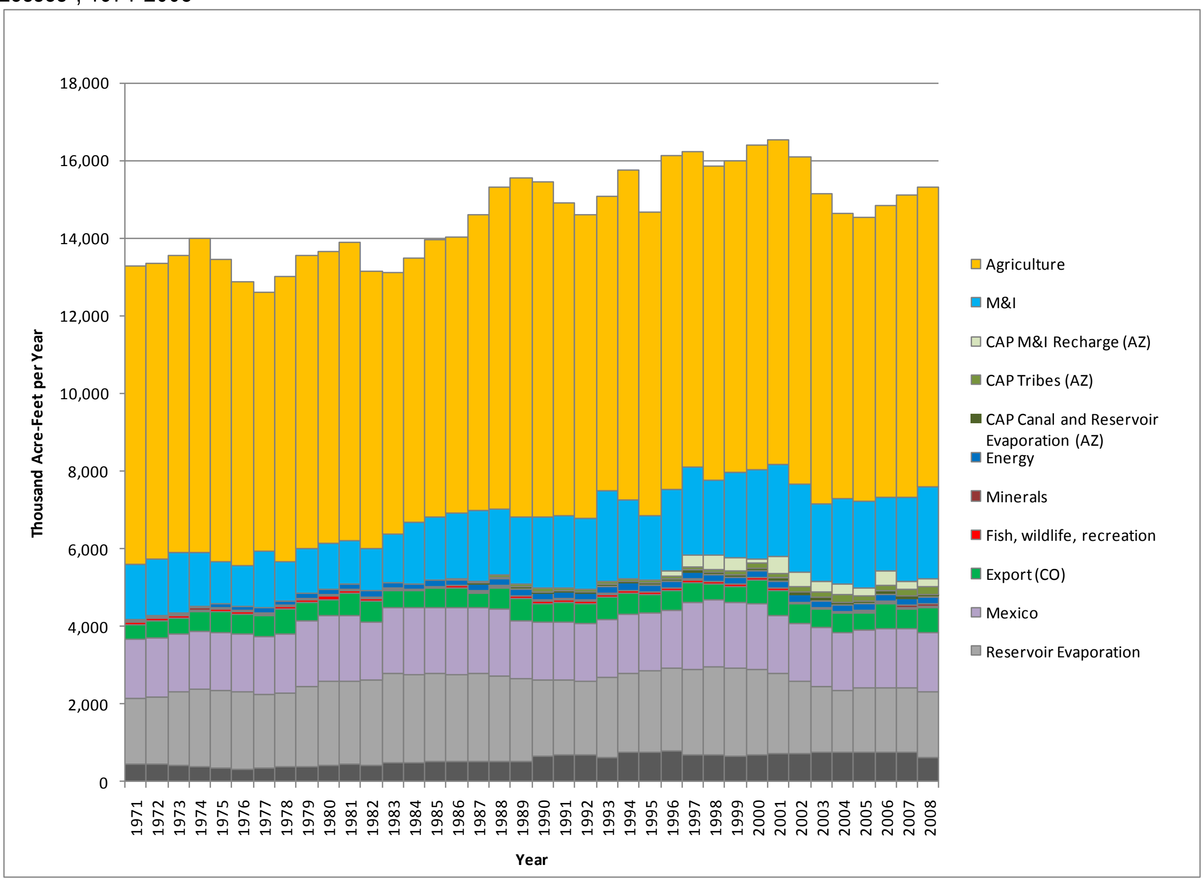
category. These data, however, should be considered preliminary and may be modified in future interim reports.

Arizona also provided a breakdown by use category of Central Arizona Project (CAP) deliveries from the mainstream to the Gila River Basin, with three additional use categories. These are CAP M&I Recharge, representing the activities of the Central Arizona Groundwater Replenishment District, Arizona Water Banking Authority, and interstate banking; CAP Tribes, representing the CAP water delivered to meet tribal use; and CAP Canal and Reservoir Evaporation, representing losses within the CAP delivery system. Tribal use in other states, including Arizona except for CAP deliveries, is included as a component of the agriculture and/or M&I demand categories. The CAP data by use category, however, should be considered preliminary and may be updated in future interim reports.

Additionally, use categories for delivery to Mexico are not reported.

**FIGURE C-7**

Historical Colorado River Water Consumptive Use[1] by Use Category[2], Delivery to Mexico, Reservoir Evaporation, and Other Losses[3], 1971-2008




**NOTES:**

[1]Excluding consumptive use in Lower Basin tributaries

[2]Data for "M&I Recharge" and "Tribes" categories were provided by AZ for CAP deliveries and are preliminary. Colorado did not provide additional information regarding the use categories for exports for this report.

[3]Phreatophyte and operational inefficiency losses.

## 7.2 Details of Historical Consumptive Use by State

A series of three figures showing historical consumptive use are presented for each state to facilitate understanding of the total consumptive uses by category, the relative consumptive use by category, and the consumptive use by category over the period 1971 – 2008. To indicate the change in consumptive use by category over time, the average use and loss for each category over the period 1971-1980 was used to represent the historic pattern and is then compared to the maximum value for each category in the recent period, 1999-2008. The maximum from 1999-2008 was taken to offset the potential impact on use due to the recent drought. Based on feedback by stakeholders and other interested parties, other analyses and presentations may be included in future interim reports.

### *7.2.1 Colorado*

Figure C-8 shows historical (1971-2008) state of Colorado use by category. Colorado consumptive use has grown from approximately 2.1 maf in 1971 to a high of 2.7 maf in 1989, an increase of about 29 percent. Agriculture is the largest consumptive use category in Colorado, followed by exports. Exports consist of trans-basin diversions from within the hydrologic boundaries of the Basin to Front Range areas east of the Continental Divide in Colorado. The detailed information necessary to disaggregate the trans-basin diversions into use categories was not available at the time of publication of this report.

Colorado has identified some concerns with the data and methodologies used in the CU&L Reports from which these data are based, including: high-altitude crop coefficients are not used in appropriate locations (i.e., grass pasture at elevations above 6,500 feet); the Crop Irrigation Water Requirement shortage estimates underestimate shortages; non-CRSP reservoir evaporation is underestimated; and agricultural incidental losses are overestimated. Reclamation and Colorado are continuing to work collaboratively to resolve these concerns.

Figure C-9 displays the percent of Colorado consumptive use by category in the past (1971-1980 average) and recently (1999-2008 maximum). Although Colorado River consumptive use has increased over time, the distribution across consumptive use categories appears to have remained relatively unchanged.

Figure C-10 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture, followed by exports. Agriculture is the most variable category year to year. The agriculture category is strongly influenced by supply, which can result in reduced requests for diversion in years with abundant precipitation and result in shortages during years of drought. The remaining categories comprise a small percentage of Colorado's consumptive use.

**FIGURE C-8**
Historical Colorado Consumptive Use by Category, 1971-2008

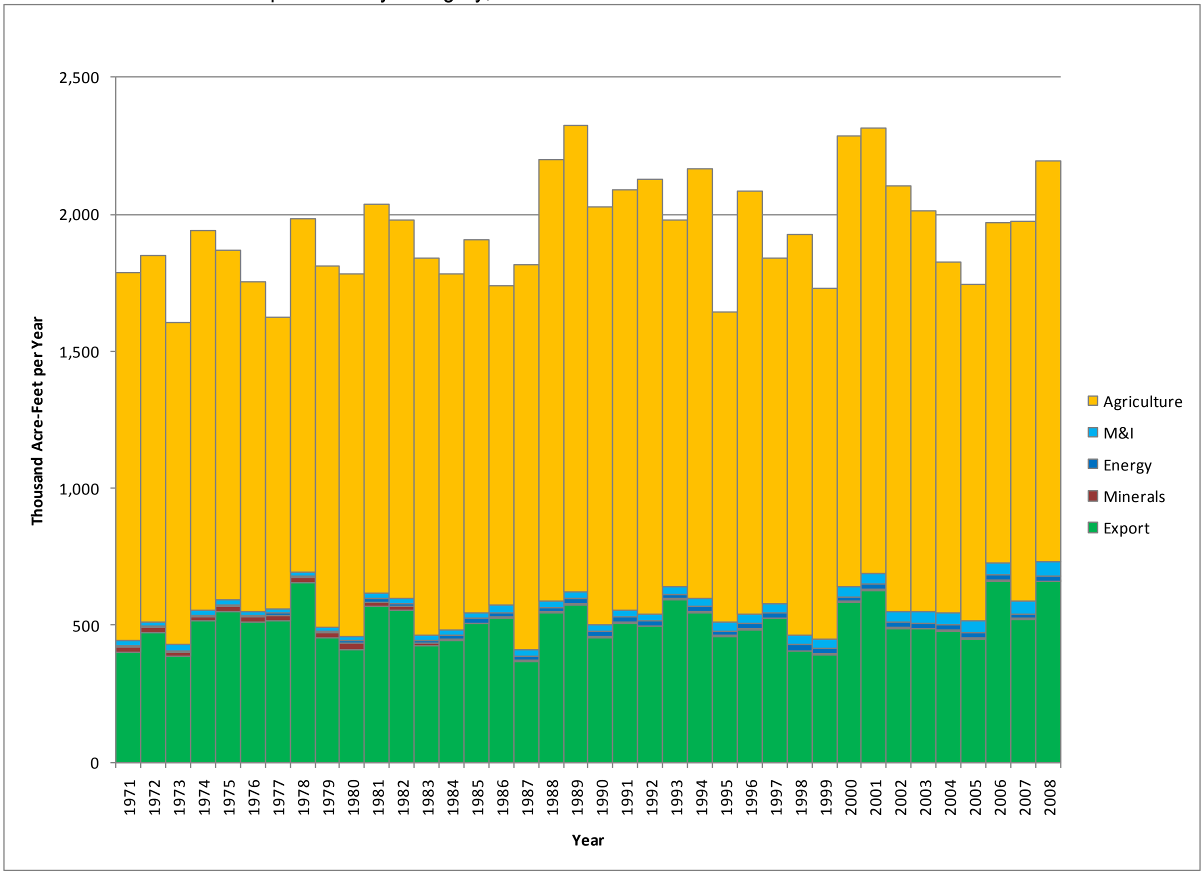



**FIGURE C-9**
Historical Colorado Consumptive Use by Category, 1971-2008

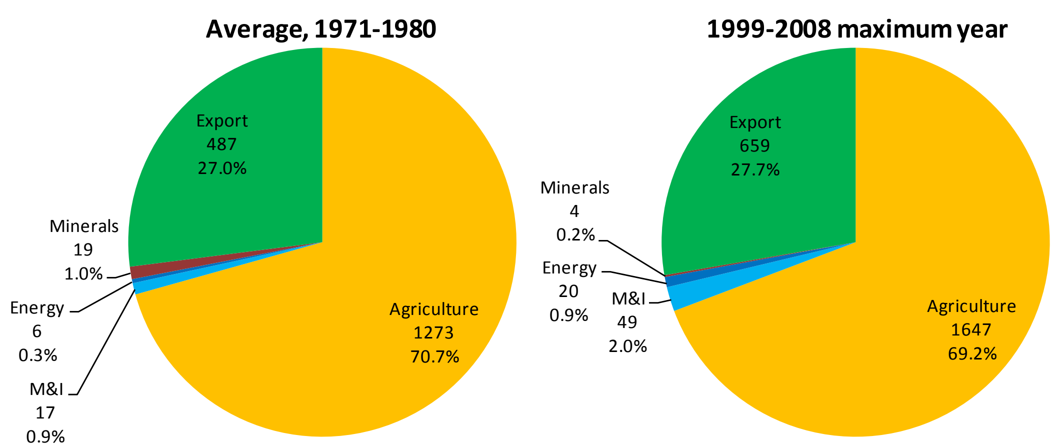
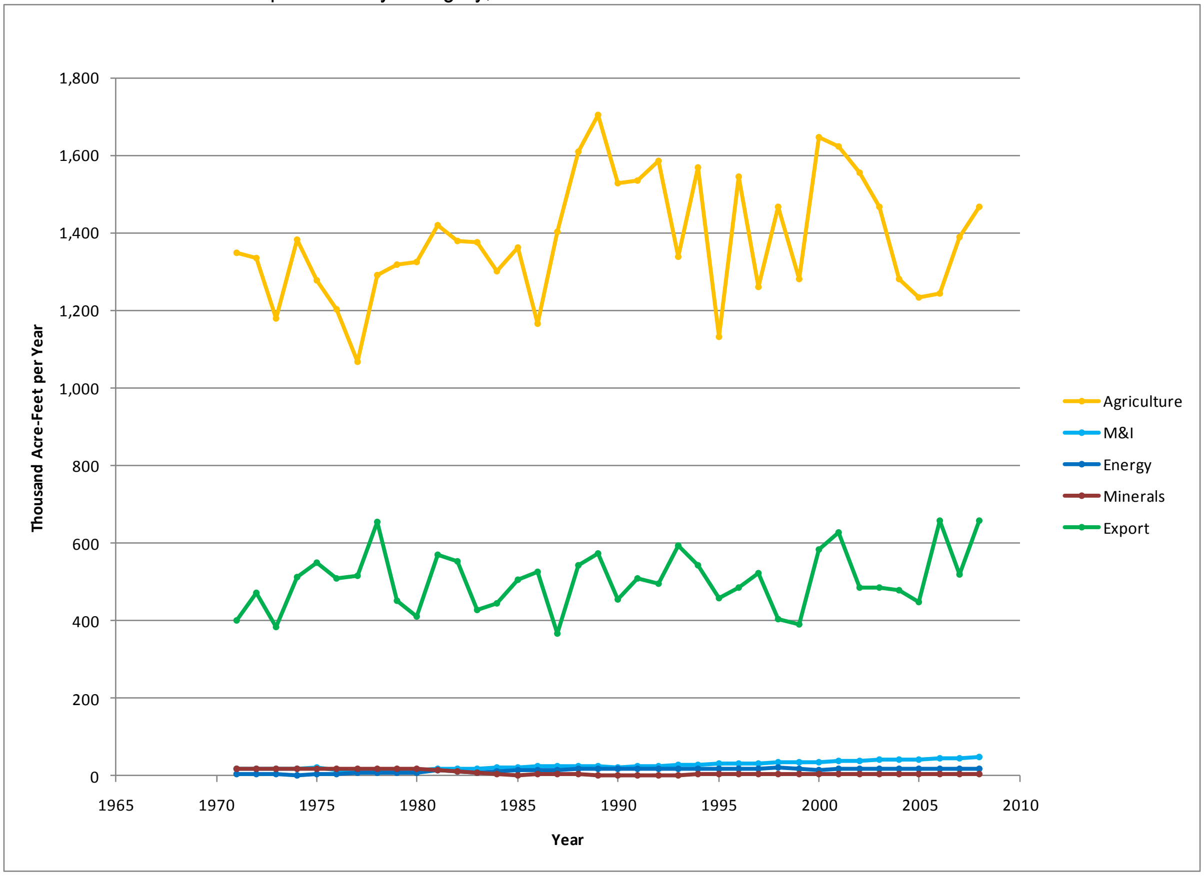


**FIGURE C-10**
Historical Colorado Consumptive Use by Category, 1971-2008




### 7.2.2 New Mexico

Figure C-11 shows historical (1971-2008) state of New Mexico use[10] by category. New Mexico consumptive use has grown from approximately 302 thousand acre-feet (kaf) in 1971 to a high of 671 kaf in 2005, an increase of about 122 percent. Agriculture is the largest consumptive use category in New Mexico.

Figure C-12 displays the percent of New Mexico consumptive use by category in the past (1971-1980 average) and recently (1999-2008 maximum). New Mexico consumptive use distribution across categories appears to have shifted slightly in the recent period, with M&I and agricultural use increasing and energy use decreasing.

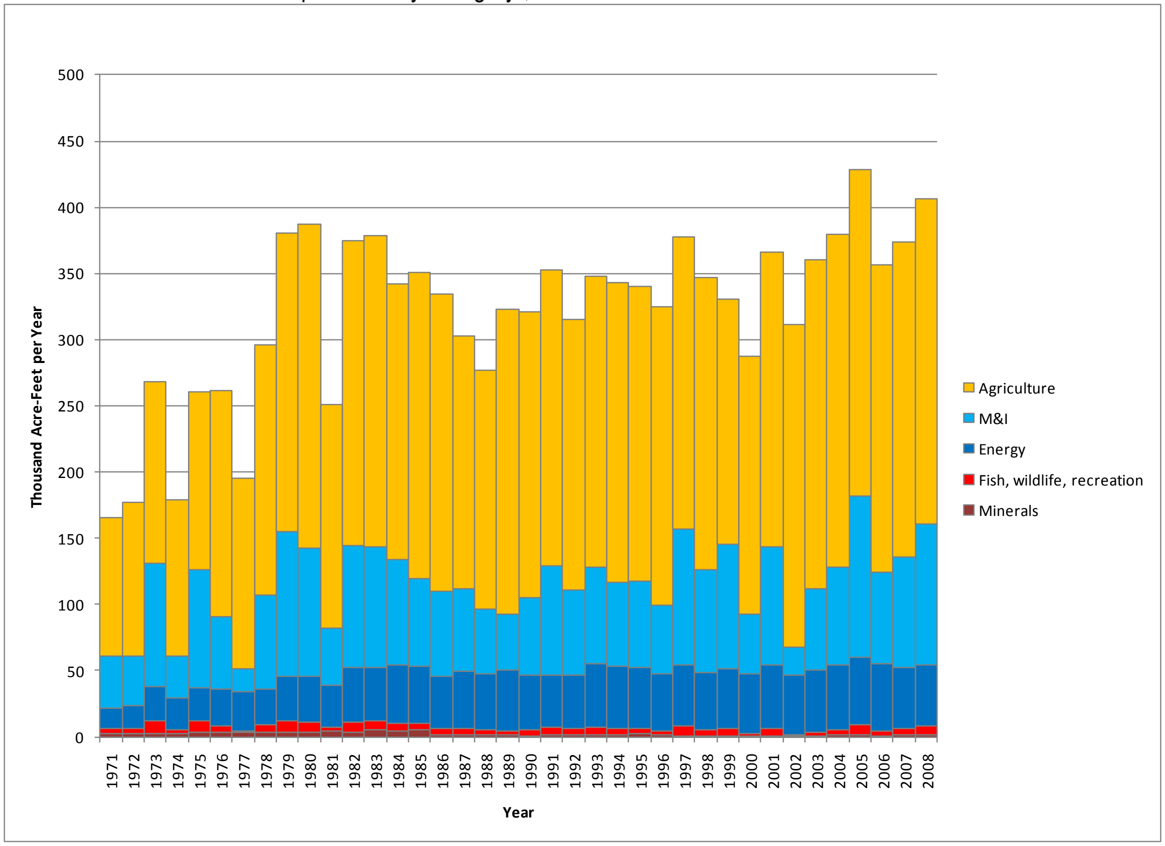
Figure C-13 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture, followed by M&I. Both agriculture and M&I (via the San Juan-Chama project) are the most variable categories year to year. The agriculture category is strongly influenced by supply, which can result in reduced requests for diversion in years with abundant precipitation and result in shortages during years of drought. Diversions for the San Juan-Chama project that serve both agricultural and M&I categories are determined annually based on bypass flow requirements and maximum in year and decadal diversions. Variations from year to year are due to diversion limitations and not

[10] Excluding consumptive use in Lower Basin tributaries.

changes in demand. The next largest category is energy, with the remaining categories comprising a small percentage of New Mexico's consumptive use.

**FIGURE C-11**

Historical New Mexico Consumptive Use by Category[1], 1971-2008




**NOTES:**

[1]San Juan-Chama project diversions are determined annually based on bypass flow requirements and maximum in year and decadal diversions. Variations from year to year are due to flow limitations and not changes in demand.

**FIGURE C-12**
Historical New Mexico Consumptive Use Percent by Category

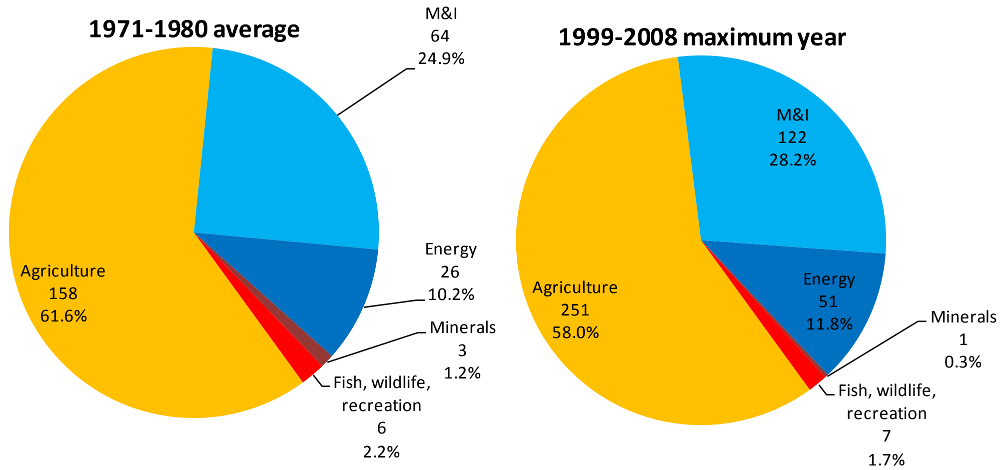
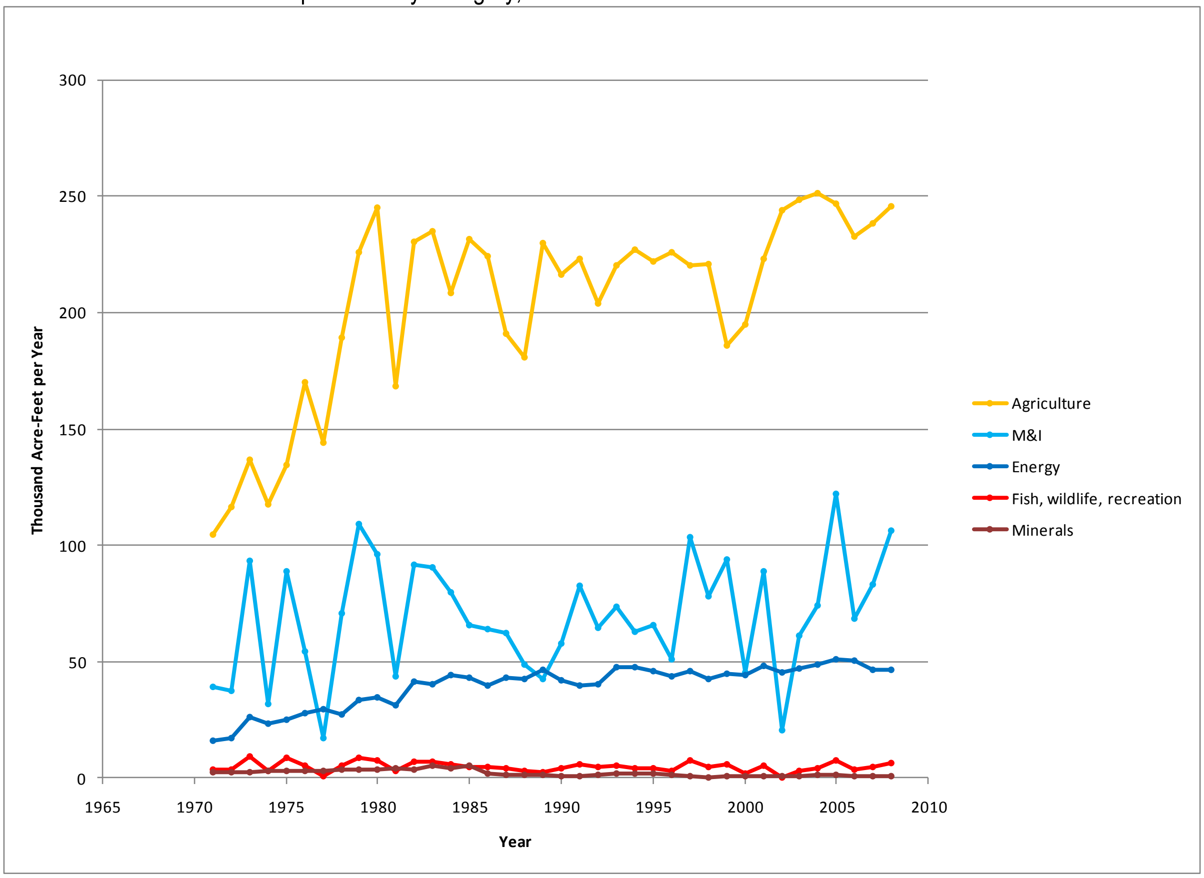



**FIGURE C-13**
Historical New Mexico Consumptive Use by Category, 1971-2008




**NOTE:**
[1]San Juan-Chama project diversions are determined annually based on bypass flow requirements and maximum in year and decadal diversions. Variations from year to year are due to flow limitations and not changes in demand.

### *7.2.3 Utah*

Figure C-14 shows historical (1971–2008) state of Utah use[11] by category. Utah consumptive use has grown from approximately 870 kaf in 1971to a high of 1,123 kaf in 1994, an increase of about 29 percent. Agriculture is the largest consumptive use category in Utah.

Figure C-15 displays the percent of Utah consumptive use by category in the past (1971-1980 average) and recently (1999–2008 maximum). Utah consumptive use distribution across categories appears to have shifted in the recent period, with an increase in M&I and energy, and a decrease in agricultural use.

Figure C-16 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture, followed by M&I. Both agriculture and M&I are the most variable categories year to year. The agriculture category is strongly influenced by supply, which can result in reduced requests for diversion in years with abundant precipitation and result in shortages during years of drought. Agricultural use in 1977 was significantly impacted by reduced natural flows in the Basin, which were 36 percent below the annual long-term average at the Colorado River at Lees Ferry, AZ. The next-largest category is M&I, followed by energy, with the remaining categories comprising a small percentage of Utah's consumptive use.

[11] Excluding consumptive use in Lower Basin tributaries.

**FIGURE C-14**
Historical Utah Consumptive Use by Category, 1971-2008

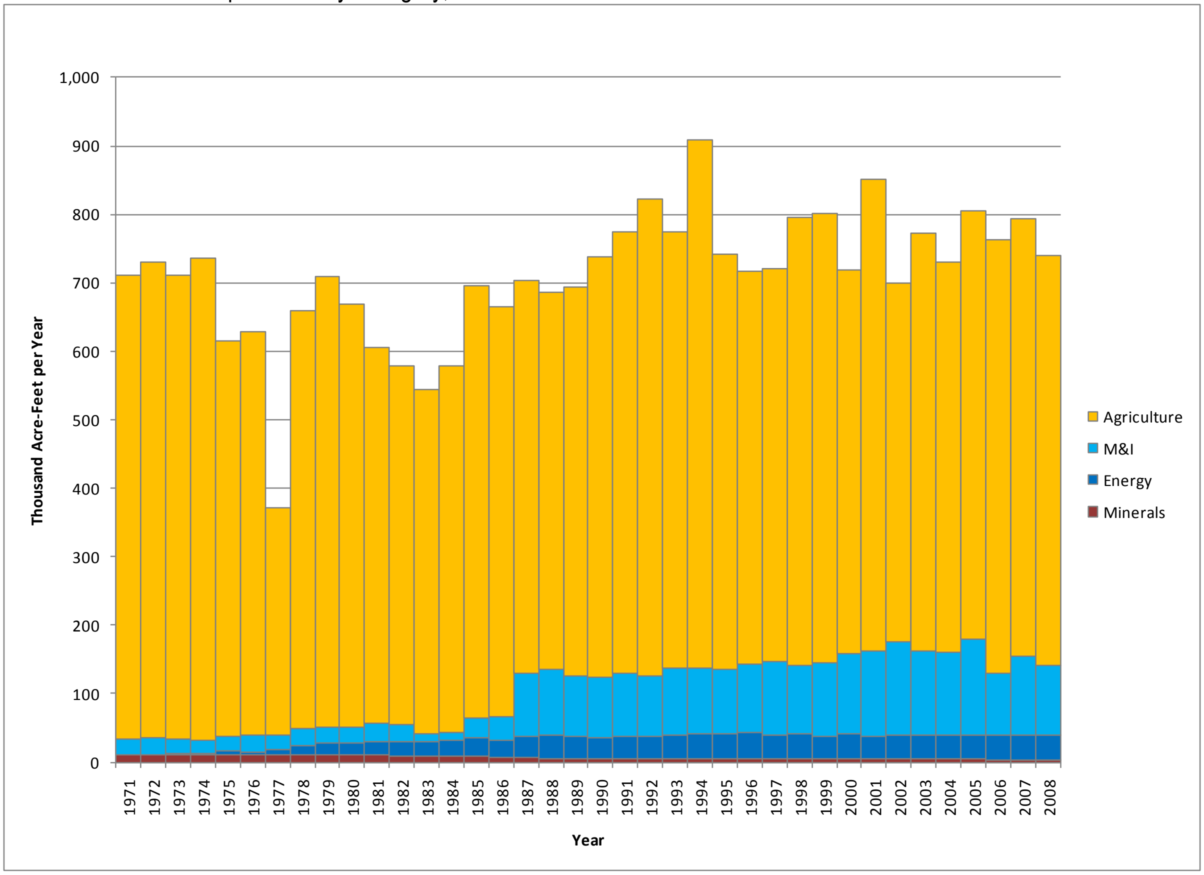



**FIGURE C-15**
Historical Utah Consumptive Use Percent by Category

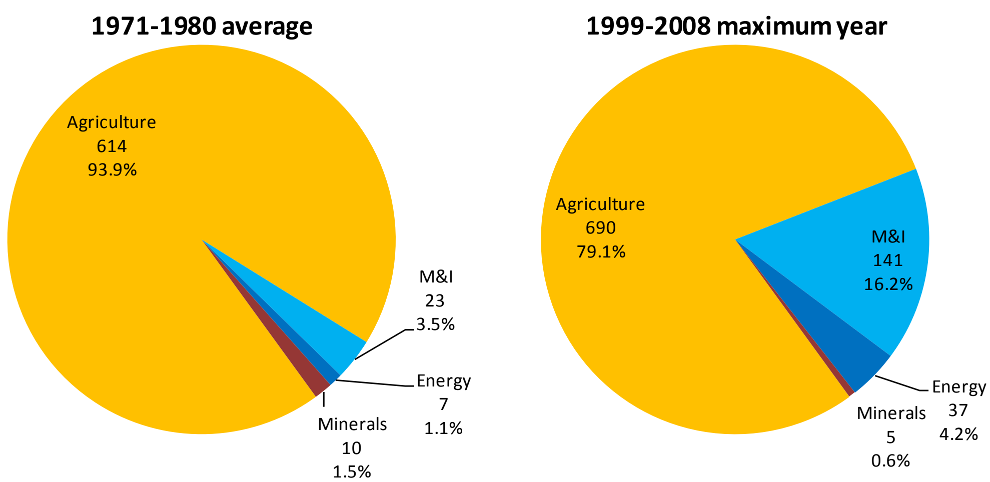
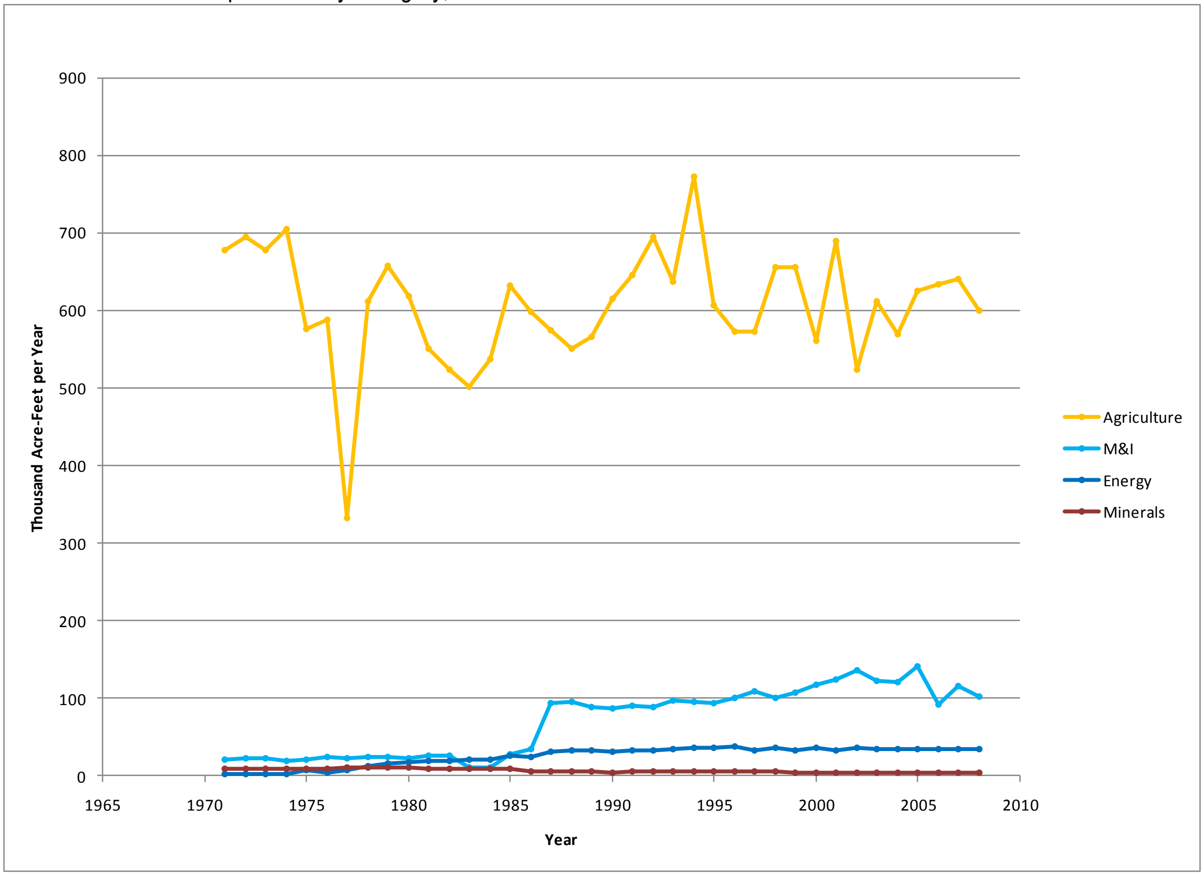


**FIGURE C-16**
Historical Utah Consumptive Use by Category, 1971-2008




### *7.2.4 Wyoming*

Figure C-17 shows historical (1971-2008) state of Wyoming use by category. Wyoming consumptive use has grown from approximately 430 kaf in 1971 to a high of 683 kaf in 1994, an increase of about 59 percent. Agriculture is the largest consumptive use category in Wyoming.

Figure C-18 displays the percent of Wyoming consumptive use by category in the past (1971-1980 average) and recently (1999-2008 maximum). Wyoming consumptive use distribution across categories appears to have shifted slightly in the recent period, with an increase in energy, M&I, and agriculture uses, as well as a decrease in minerals use and reservoir evaporation.

Figure C-19 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture. The agriculture category is strongly influenced by supply, which can result in reduced requests for diversion in years with abundant precipitation and result in shortages during years of drought. Agricultural use in 1977 was significantly impacted by reduced natural flows in the Basin, which were 36 percent below the annual long-term average at the Colorado River at Lees Ferry, AZ. The next largest category is energy, followed by M&I, with the remaining categories comprising a small percentage of Wyoming's consumptive use.

**FIGURE C-17**
Historical Wyoming Consumptive Use by Category, 1971-2008

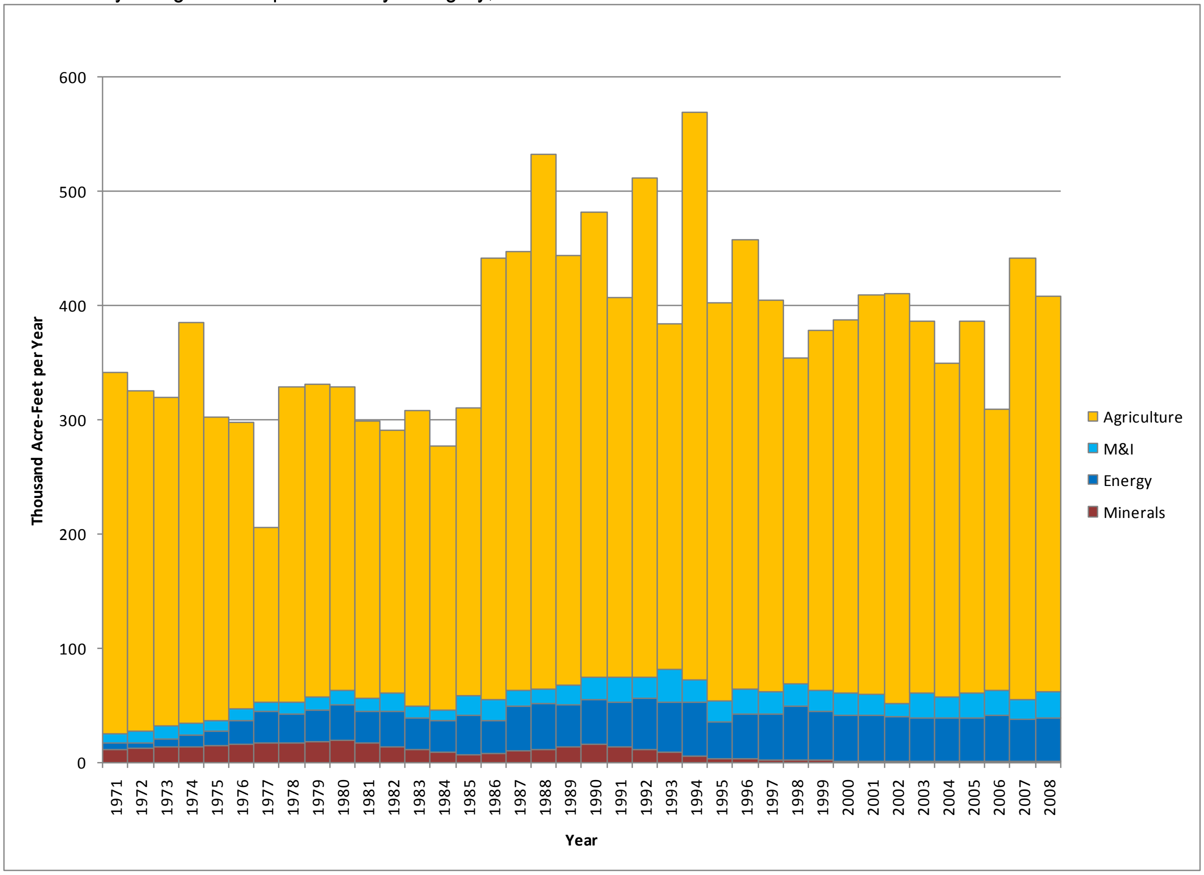



**FIGURE C-18**
Historical Wyoming Consumptive Use Percent by Category

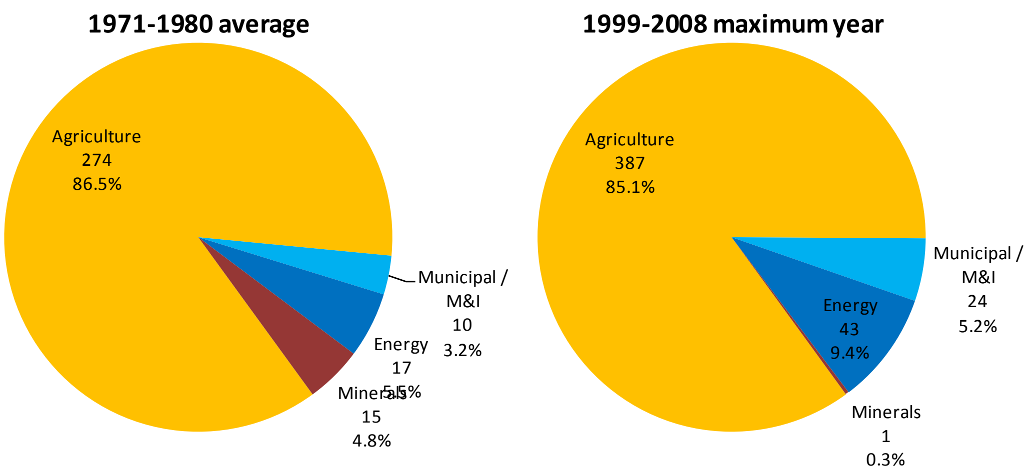
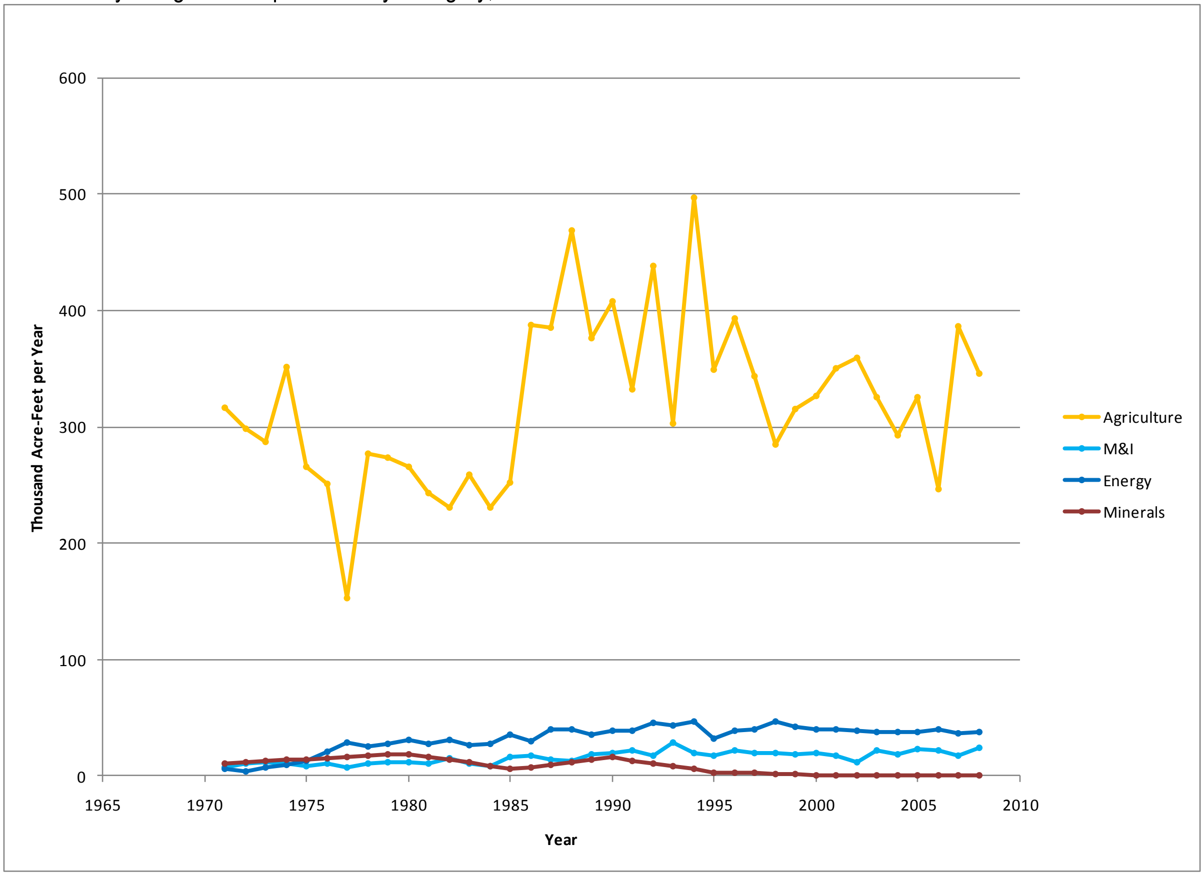


**FIGURE C-19**
Historical Wyoming Consumptive Use by Category, 1971-2008




### *7.2.5 Arizona*

**Upper Basin.** Figure C-20 shows historical (1971-2008) state of Arizona Upper Basin consumptive use by category. Arizona Upper Basin consumptive use has grown from approximately 11 kaf in 1971 to a high of 46 kaf in 1985, an increase of about 318 percent. Energy is the largest consumptive use category for Arizona's Upper Basin use and accounts for most of the increase.

Figure C-21 displays the percent of Arizona consumptive use by category in the past (1971–1980 average) and recently (1999-2008 maximum). Arizona Upper Basin consumptive use distribution across categories appears to have shifted in the recent period, with an increase in energy use and a decrease in agricultural use.

Figure C-22 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is energy. Water used within the energy category serves the Navajo Generating Station, which began operation in 1974. The remaining categories comprise a small percentage of Arizona's Upper Basin consumptive use.

**FIGURE C-20**
Historical Arizona Upper Basin Consumptive Use by Category, 1971-2008

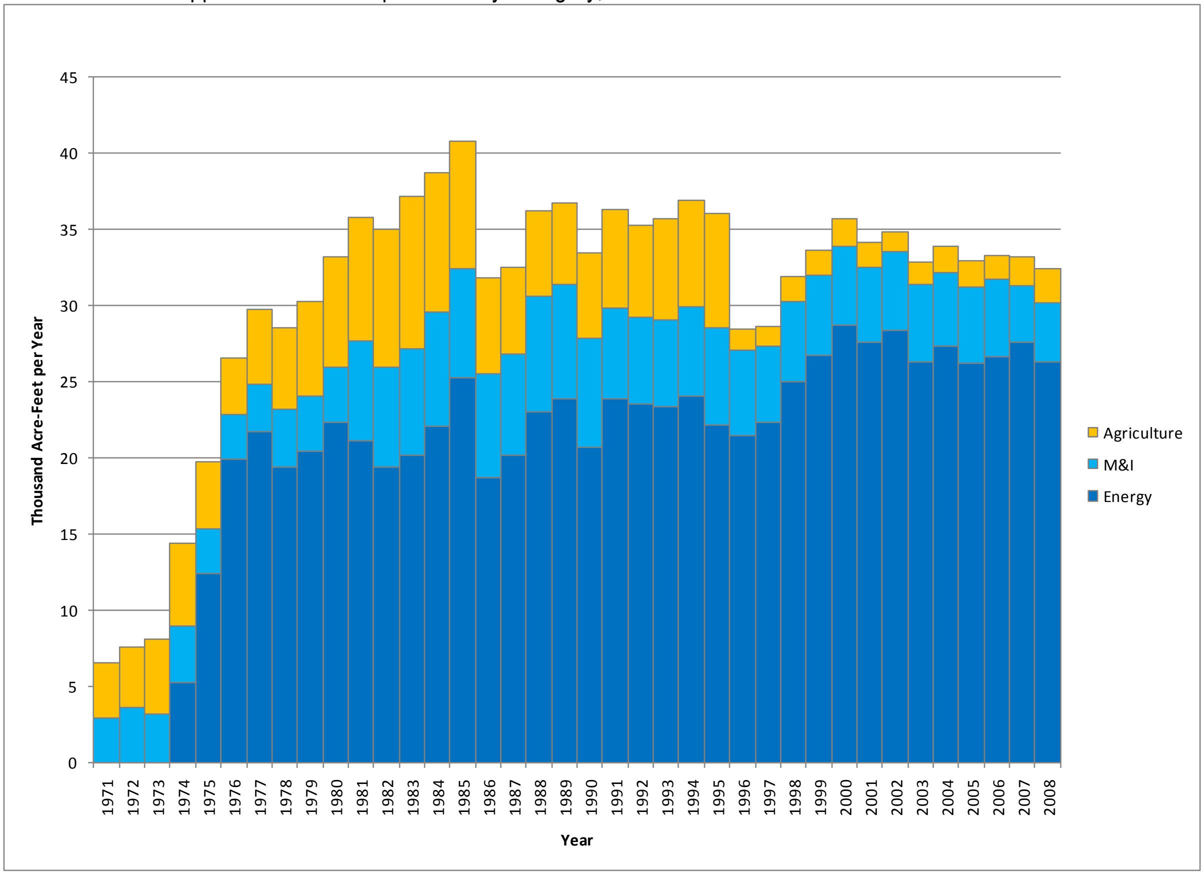


**FIGURE C-21**
Historical Arizona Upper Basin Consumptive Use Percent by Category

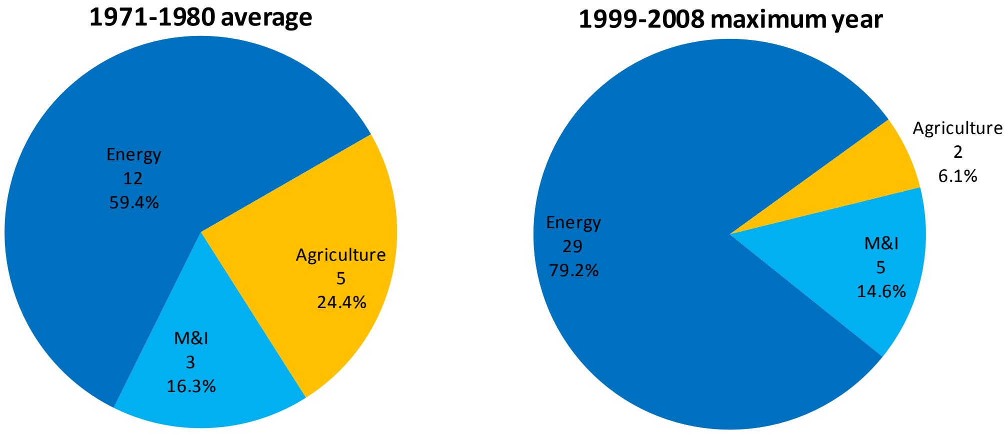
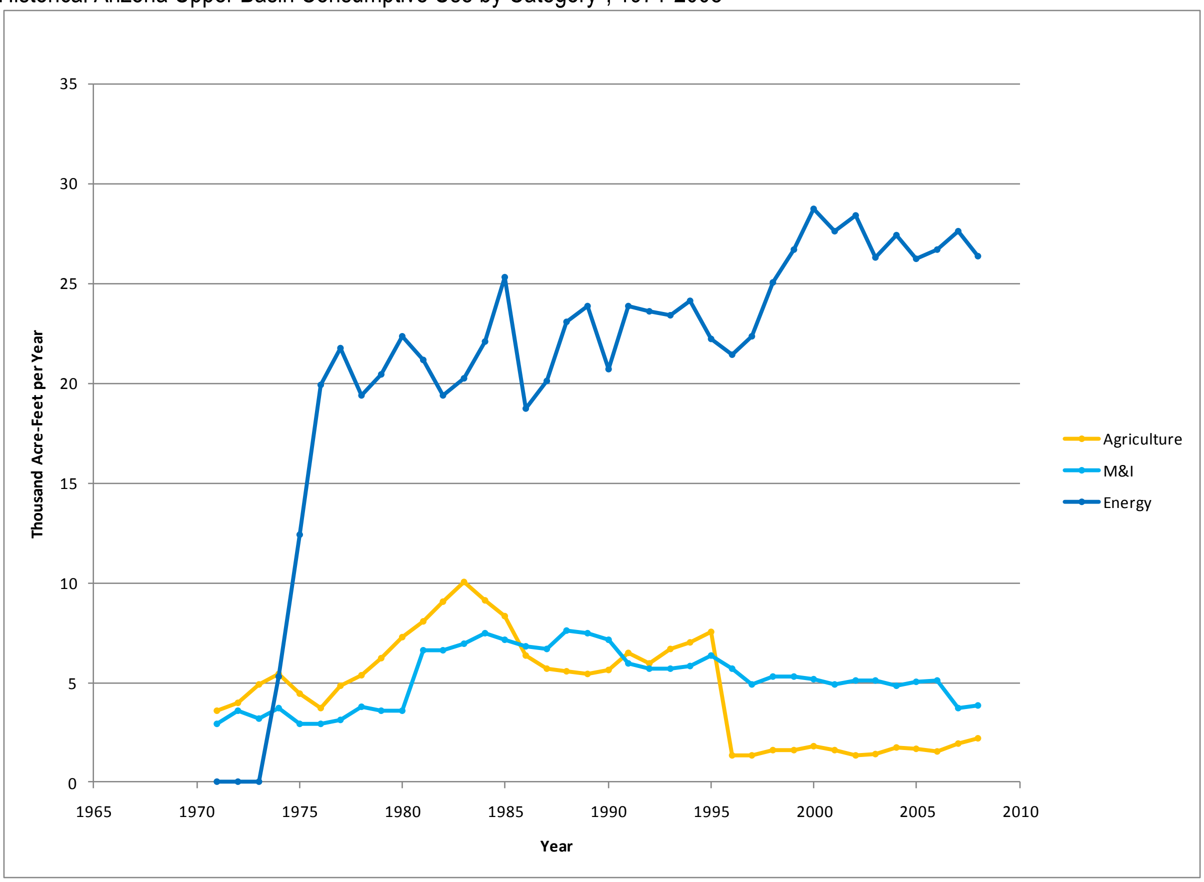



**FIGURE C-22**
Historical Arizona Upper Basin Consumptive Use by Category[1], 1971-2008




**NOTES:**
[1]Water used within the energy category serves the Navajo Generating Station, which began operation in 1974.

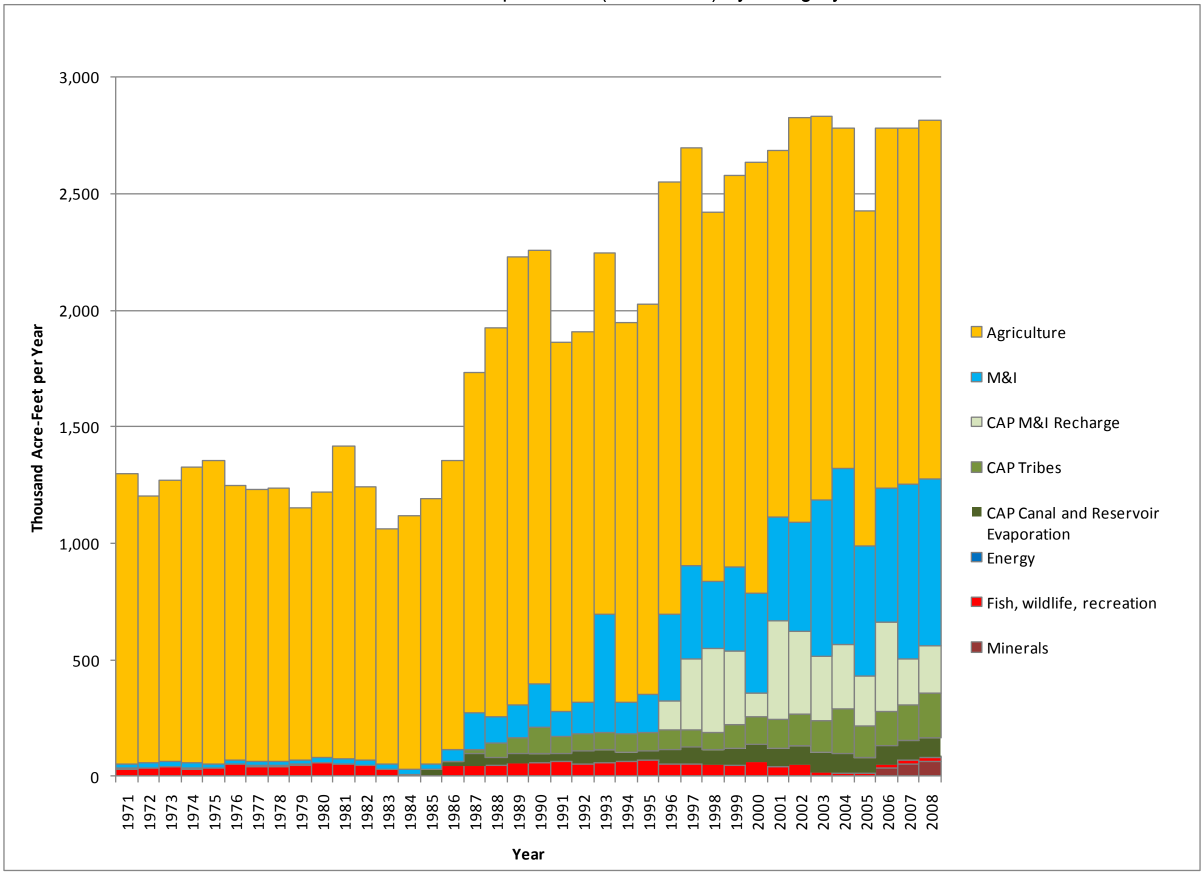
**Lower Basin.** Figure C-23 shows historical (1971-2008) state of Arizona Lower Basin mainstream consumptive use by category. Arizona's Lower Basin mainstream use has grown from approximately 1.3 maf in 1971 to a high of 2.8 maf in 2003, an increase of about 115 percent. Agriculture is the largest use category. The agriculture and M&I consumptive use categories show an increase beginning in the late 1980s, largely due to the construction of the CAP.

Arizona also provided a breakdown by use category of CAP deliveries from the mainstream to the Gila River Basin, with three additional use categories. These are CAP M&I Recharge, representing the activities of the Central Arizona Groundwater Replenishment District, Arizona Water Banking Authority, and interstate banking; CAP Tribes, representing the CAP water delivered to meet tribal use; and CAP Canal and Reservoir Evaporation, representing losses within the CAP delivery system. Tribal use in Arizona except for CAP deliveries is included as a component of the agriculture and/or M&I demand categories. The CAP data by use category, however, should be considered preliminary and may be updated in future interim reports.

Figure C-24 displays the percent of Arizona Lower Basin mainstream use by category in the past (1971-1980 average) and recently (1999-2008 maximum). Arizona's use distribution across categories appears to have shifted in the recent period, with a significant increase in M&I portion of total use and a significant decrease in the agriculture portion of total use.

Figure C-25 displays the consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture, while M&I sharply increases after deliveries from the CAP begin in 1985. Agriculture, M&I, and M&I Recharge are the most variable categories year to year. The remaining categories comprise a small percentage of Arizona's consumptive use. Again, the Tribe category contains only deliveries to tribes through the CAP.

**FIGURE C-23**
Historical Arizona Lower Basin Mainstream Consumptive Use (1971-2008) by Category[1]




**NOTES:**
[1]CAP began deliveries in 1985.

**FIGURE C-24**
Historical Arizona Lower Basin Mainstream Consumptive Use Percent by Category

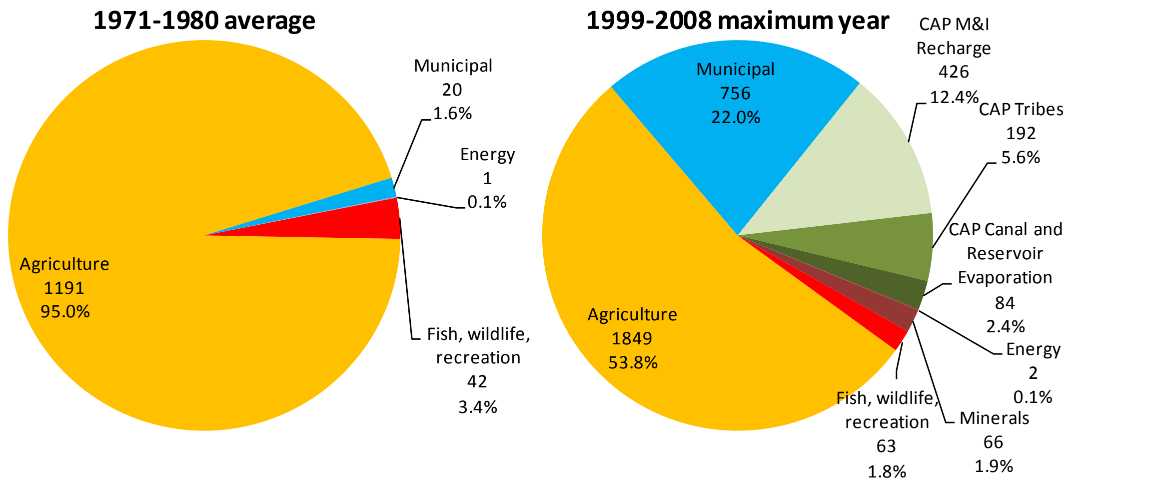
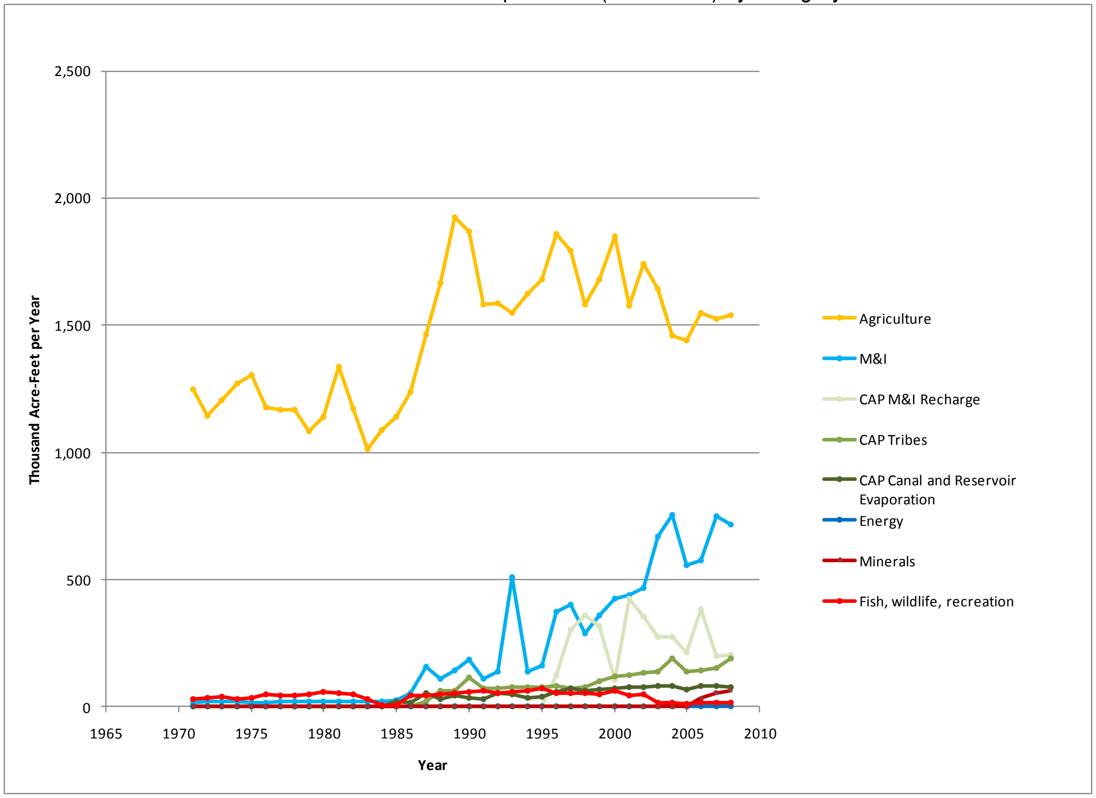


**FIGURE C-25**
Historical Arizona Lower Basin Mainstream Consumptive Use (1971-2008) by Category




### *7.2.6 California*

Figure C-26 shows historical (1971-2008) state of California mainstream consumptive use by category. California consumptive use increased from approximately 5.2 maf in 1971 to a high of 5.4 maf in 1974 then reduced to approximately 4.4 maf over the period 2003-2008, a decrease of about 19 percent. California's use above its apportionment of 4.4 maf per year was due to available unused apportionment in the Lower Basin and surplus water supply conditions for the Lower Division States.

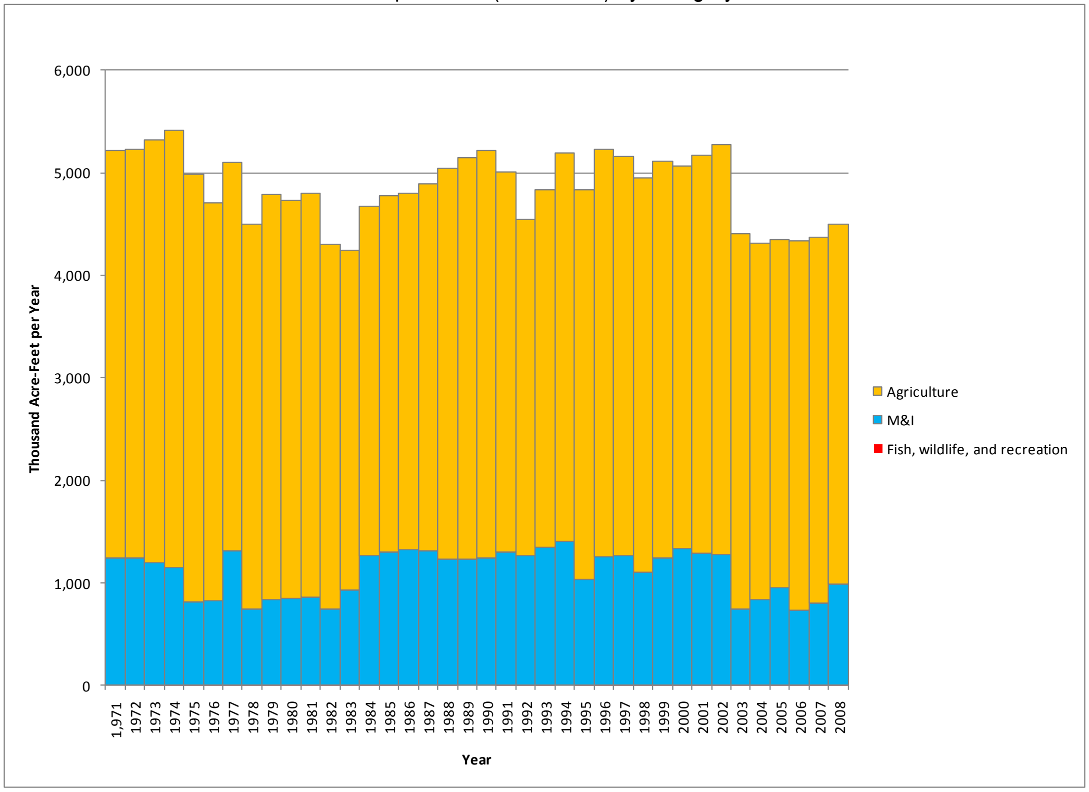
Figure C-27 displays the percent of California mainstream consumptive use by category in the past (1971-1980 average) and recently (2003-2008 maximum). A period from 2003-2008 was used instead of 1999-2008 to represent recent use since the Colorado River Water Delivery Agreement (Federal Quantification Settlement Agreement), an integral part of implementing California's "4.4 Plan," was signed in 2003. Although California consumptive use has reduced over time, the distribution across categories remains relatively unchanged.

Figure C-28 displays the mainstream consumptive use for each category. It can again be seen that the largest category of consumptive use is agriculture followed by M&I[12]. The M&I and agriculture categories show significant variability from year to year. Delivery losses incurred by the irrigation districts have been included in the agriculture category. The remaining categories comprise a small percentage of California's consumptive use.

---

[12] M&I includes entities served by The Metropolitan Water District of Southern California, Imperial Irrigation District, and Coachella Valley Water District.

**FIGURE C-26**
Historical California Mainstream Consumptive Use (1971-2008) by Category[1]




**NOTES:**
[1]California's use above its normal apportionment of 4.4 mafy was due to available unused apportionment in the Lower Basin and surplus water supply conditions for the Lower Division States.

**FIGURE C-27**
Historical California Mainstream Consumptive Use Percent by Category

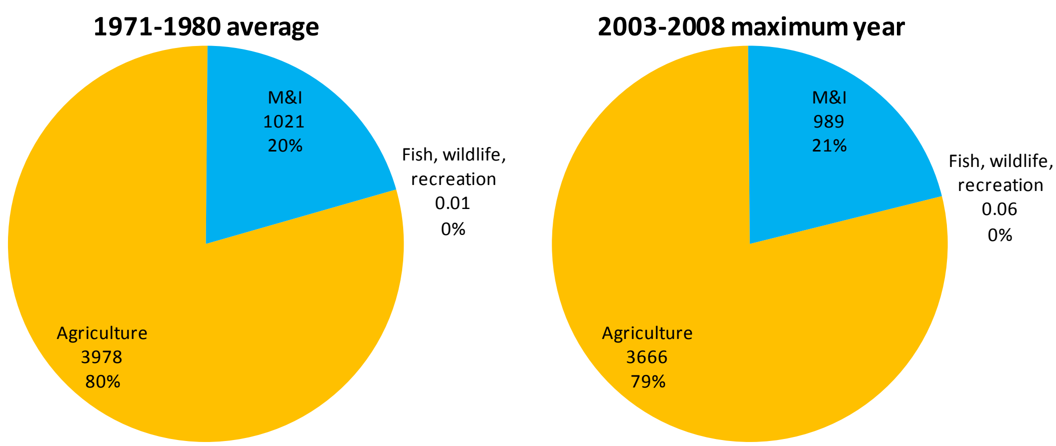


**FIGURE C-28**
Historical California Mainstream Consumptive Use[1] (1971-2008) by Category


**NOTES:**
[1]California's use above its normal apportionment of 4.4 mafy was due to available unused apportionment in the Lower Basin and surplus water supply conditions for the Lower Division States.

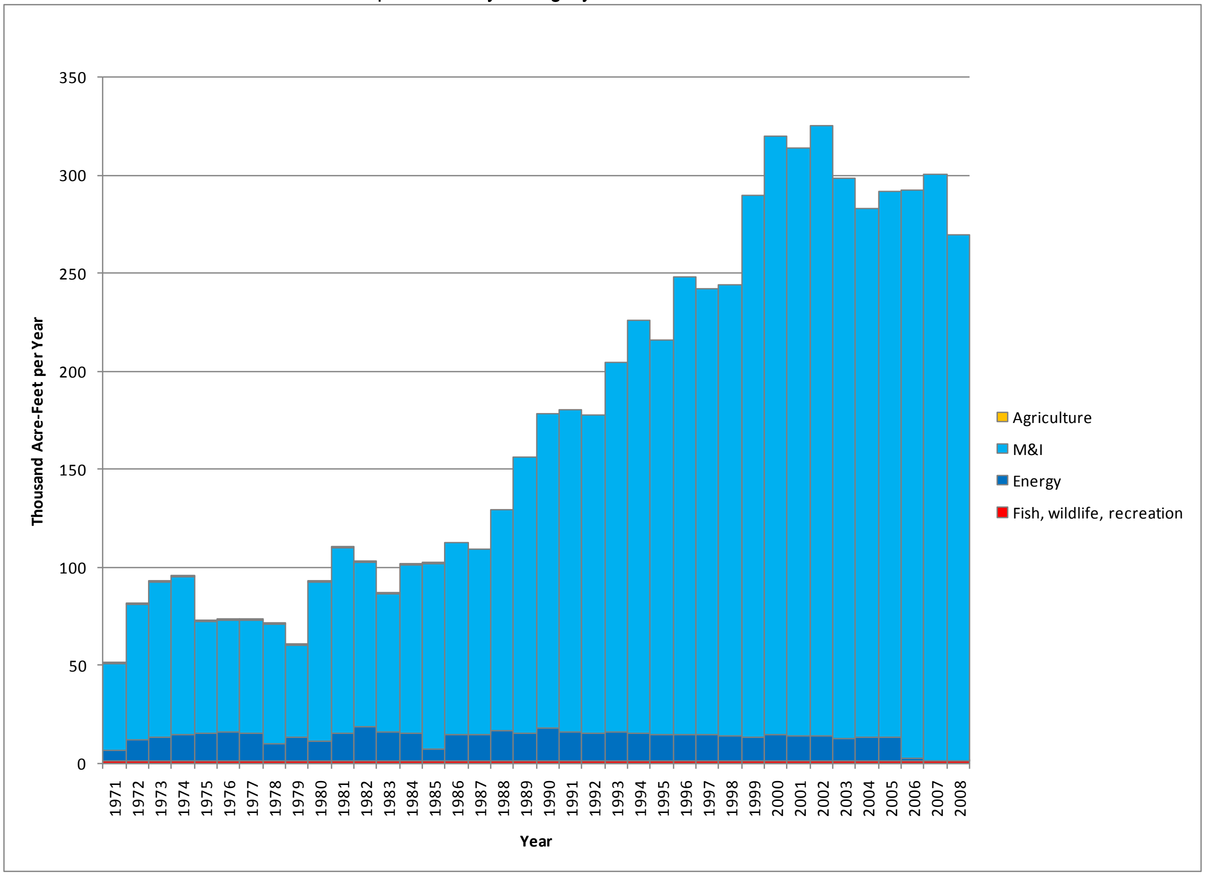
### *7.2.7 Nevada*

Figure C-29 shows historical (1971-2008) state of Nevada mainstream consumptive use by category. Nevada consumptive use has grown from approximately 51 kaf in 1971 to high of 325 kaf in 2002, an increase of about 537 percent. Nevada's use above its apportionment of 300 thousand acre-feet per year (kafy) is due to surplus water supply conditions for the Lower Division States. M&I is essentially the only mainstream consumptive use category in Nevada. Although there is a small amount of agricultural use by the Fort Mohave Indian Reservation, all of that use has been categorized as M&I.

Figure C-30 displays the percent of Nevada mainstream consumptive use by category in the past (1971-1980 average) and recently (1999-2008 maximum). Beginning in 2006, water use by Southern California Edison Company declined to approximately 500 acre-feet per year (afy), accounting for the decrease in the energy category. Figure C-31 displays the consumptive use for each category.

**FIGURE C-29**

Historical Nevada Mainstream Consumptive Use by Category[1,2] 1971-2008




**NOTES:**

[1]Nevada's use above its 300 kafy apportionment was due to surplus water supply conditions for the lower Division states.

[2]Beginning in 2006, water use by Southern California Edison Company (energy category) declined to approximately 500 afy.

**FIGURE C-30**

Historical Nevada Mainstream Consumptive Use Percent by Category

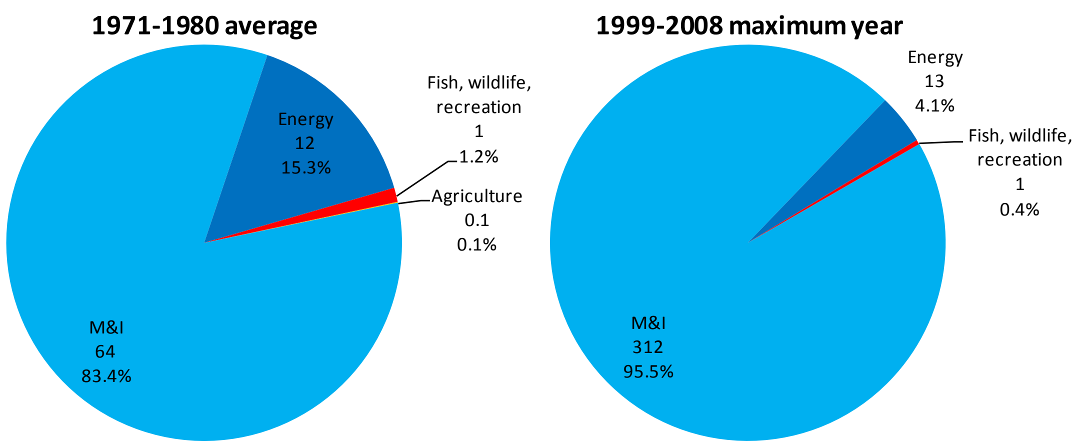
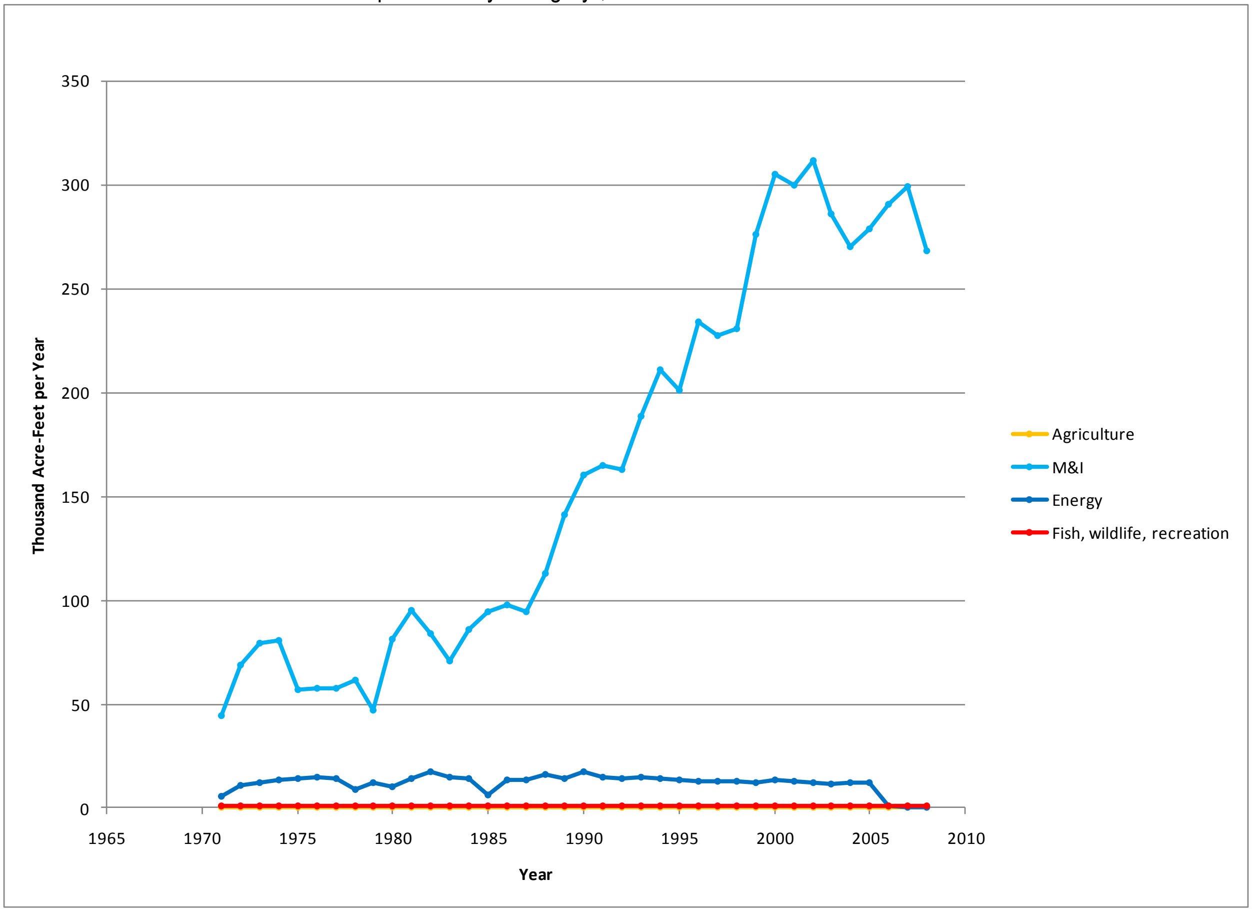


**FIGURE C-31**
Historical Nevada Mainstream Consumptive Use by Category[1], 1971-2008




**NOTES:**
[1]Nevada's use above its 300 kafy apportionment was due to surplus water supply conditions for the Lower Division States.

[2]Beginning in 2006, water use by Southern California Edison Company (energy category) declined to approximately 500 afy.

# 8.0 Limitations and Next Steps

## 8.1 Limitations

Data contain inherent uncertainties through their measurement, scale, and reporting. In many cases, consumptive uses and losses are not directly measured, adding additional uncertainty due to the methodologies used to estimate the consumptive uses and losses data from other measurements. As previously mentioned, the methods, underlying data, and assumptions used by Reclamation are not entirely consistent with the methods used by individual states to estimate consumptive uses and losses. Reclamation and the states are continuing to work collaboratively to resolve these differences. In addition, the data presented in this report were not developed for the express purposes of the Study and therefore may not be ideal to represent the full intent of the Study approach (e.g., the lack of category data for all historical export data).

Although Colorado River water delivered to areas adjacent to the hydrologic basin are accounted for, that accounting has not included a breakdown into demand categories. Rather the CU&L Reports consider such water "exports" and treats them as a separate category. The Basin States provided additional information (with the exception of Colorado) regarding the use categories for exports, allowing for a composite of Basin-wide use by category. These data, however, should be considered preliminary and may be modified in future interim reports.

Finally, as discussed previously, the process of estimating Lower Basin tributary consumptive uses and losses has not received a great deal of attention in the past and the quality of the resulting information has suffered (see Appendix C5). Due to the issues and problems associated with the Lower Basin tributary consumptive uses and losses data, the historical consumptive use and loss data presented in this report do not include data from the Lower Basin tributaries. Furthermore, Reclamation does not use consumptive uses and losses and other data to compute natural flows on the Lower Basin tributaries for use in CRSS, the primary modeling tool used for the Study. Specifically, CRSS uses historical inflows based on U.S. Geological Survey gaged records for the Little Colorado, Virgin and Bill Williams rivers. In addition, the Gila River is not included in CRSS.

Although some limitations will be imposed on the Study by this treatment of the Lower Basin tributaries, through other approaches the Study will be able to examine several important issues, including potential climate change impacts on the tributaries represented in CRSS, future demand scenarios for those tributaries, and future demand scenarios for Colorado River from the Gila River Basin, factoring in other water supplies within that basin (see Appendix C5).

## 8.2 Next Steps

In the coming months, additional review of the consumptive uses and losses data will occur, particularly with regard to the disaggregation of data into use categories. Any modifications in the data and information will be included in future interim reports.

Quantifying the scenarios according to the steps presented earlier will be the focus of the coming months. A significant quantity of data has been collected to quantify the Current Trends scenario, and that work will be completed. Following completion of the quantification of the Current Tends scenario, the remaining scenarios that derive from it (Economic Slowdown, Expansive Growth, and Enhanced Environment and Healthy Economy) will be quantified. The scenarios will then be analyzed as indicated in Figure C-1, and presented in future interim reports, including a complete accounting of the assumptions used to quantify those scenarios.

The demand scenarios will then be coupled with the water supply scenarios developed in *Technical Report B -Water Supply Assessment* and will be used to analyze the future reliability of the Colorado River system, with and without future adaptation and mitigation strategies.

# 9.0 References

Reclamation. 2010a. *Climate Change Effects on Colorado River Basin Irrigation Demands – A Quick Estimate*.

Reclamation. 2007, 2010b. 5 year reports. Provisional Upper *Colorado River Basin Consumptive Uses and Losses Report 2001-2008*. (http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html)

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Stephens, J, and Stewart, E, circa 1960. *A Comparison of Procedures for Computing Evaporation and Evapotranspiration.* International Association of Hydrologic Sciences, available at: http://iahs.info/redbooks/a062/iahs_062_0123.pdf

Tansey, Michael – USBR, Francisco Flores & Chuck Young – SEI, Armin Munevar – CH2M Hill, David Yates – NCAR. 2010. *Modeling Effects of Climate Change on Central Valley Water Demands. Bay Delta Science Conference*. September.

# Disclaimer

The Colorado River Basin Water Supply and Demand Study (Study) is funded jointly by the Bureau of Reclamation (Reclamation) and the seven Colorado River Basin States (Basin States). The purpose of the Study is to analyze water supply and demand imbalances throughout the Colorado River Basin and those adjacent areas of the Basin States that receive Colorado River water through 2060; and develop, assess and evaluate options and strategies to address the current and projected imbalances.

Reclamation and the Basin States intend that this Study will promote and facilitate cooperation and communication throughout the Basin regarding the reliability of the system to continue to meet Basin needs and the strategies that may be considered to ensure that reliability. Reclamation and the Basin States recognize the Study will have to be constrained by funding, timing and technological and other limitations, which may present specific policy questions and issues, particularly related to modeling and interpretation of the provisions of the Law of the River during the course of the Study. In such cases, Reclamation and the Basin States will develop and incorporate assumptions to further complete the Study. Where possible, a range of assumptions will typically be used to identify the sensitivity of the results to those assumptions.

Nothing in the Study, however, is intended for use against any Basin State, the Federal government or the Upper Colorado River Commission in administrative, judicial or other proceedings to evidence legal interpretations of the law of the river. As such, assumptions contained in the Study or any reports generated during the Study do not, and shall not, represent a legal position or interpretation by the Basin States, Federal government or Upper Colorado River Commission as it relates to the law of the river. Furthermore, nothing in this Study is intended to, nor shall this Study be construed so as to, interpret, diminish or modify the rights of any Basin State, the Federal government, or the Upper Colorado River Commission under federal or state law or administrative rule, regulation or guideline, including without limitation the Colorado River Compact, (45 Stat. 1057), the Upper Colorado River Basin Compact (63 Stat. 31), the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico (Treaty Series 994, 59 Stat. 1219), the United States/Mexico agreement in Minute No. 242 of August 30, 1973, (Treaty Series 7708; 24 UST 1968) or Minute No. 314 of November 26, 2008, or Minute No. 318 of December 17, 2010, the Consolidated Decree entered by the Supreme Court of the United States in Arizona v. California (547 U.S 150 (2006)), the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), the Colorado River Storage Project Act of 1956 (70 Stat. 105; 43 U.S.C. 620), the Colorado River Basin Project Act of 1968 (82 Stat. 885; 43 U.S.C. 1501), the Colorado River Basin Salinity Control Act (88 Stat. 266; 43 U.S.C. 1951), the Hoover Power Plant Act of 1984 (98 Stat. 1333), the Colorado River Floodway Protection Act (100 Stat. 1129; 43 U.S.C. 1600), or the Grand Canyon Protection Act of 1992 (Title XVIII of Public Law 102-575, 106 Stat. 4669). Reclamation and the Basin States continue to recognize the entitlement and right of each State under existing law to use and develop the water of the Colorado River system.[13]

[13] Reclamation and the Basin States have exchanged letters and are in the process of amending the Contributors' funding agreement to, among other things, document and clarify the intent of the Parties consistent with the above disclaimer.

# Appendix C1
# Water Demand Sub-Team Members

# Appendix C1—Water Demand Sub-Team Members

The information presented in this *Technical Report C - Water Demand Assessment* is the outcome of a collaborative process involving representatives of numerous organizations.

A list of Water Demand Sub-Team members (as of January 31, 2011) and their affiliations is presented below.

Demand Sub-Team members included:

- Greg Gates, CH2M HILL (co-lead)
- Jim Prairie, Reclamation (co-lead)
- John Whipple, New Mexico Interstate Stream Commission
- Tom Maher, Southern Nevada Water Authority
- Ted Kowalski, Colorado Water Conservation Board
- Perri Benemelis, Arizona Department of Water Resources
- Bill Hasencamp, The Metropolitan Water District of Southern California
- Don Ostler, Upper Colorado River Commission
- Jennifer Pitt, Environmental Defense Fund
- Andrew Hautzinger, U.S. Fish and Wildlife Service
- Jason John, Navajo Nation

Alternate and/or contributing members who participated include:

- Drew Beckwith, Western Resource Advocates
- Brian Westfall, Keller-Bliesner Engineering (consultant for the Navajo Nation)
- Michael Foley, Navajo Nation
- Don Gross, Arizona Department of Water Resources
- Larry Tamashiro, Southern Nevada Water Authority

Members added in November-December 2010 include:

- Marc Waage, Denver Water
- Charles Vaughn, Hualapai Tribal Nation
- Carole Klopatek, Fort McDowell Yavapai Nation
- Darryl Vigil, Jicarilla Apache Nation

# Appendix C2
# Plausible Range of Parameter Characteristics

# Appendix C2—Plausible Range of Parameter Characteristics

Table AC2-1 describes the parameter characteristic range for each parameter of the Current Trends scenario. The storyline for the Current Trends scenario is: growth, development patterns, and institutions continue along recent trends.

**TABLE AC2-1**
Plausible Range of Parameter Characteristics for Each Critical Uncertainty Associated with Water Demand

| General Driving Force Categories | Critical Uncertainties[1] | Description of Parameter Characteristic if Current Trends Continue | Plausible Low End of Range | Plausible High End of Range |
|---|---|---|---|---|
| Demographic and land use | Changes in population and distribution [4] | Best estimate of population growth | Slow growth:<br>• Increases principally in existing urban areas | Rapid, expansive growth:<br>• Focused in urban centers and "sprawl" to traditionally non-urban areas (likely driven by economic growth) |
| | Changes in agricultural land use (e.g., irrigated agricultural areas, crop mixes, etc.) [5] | Nominal increase in irrigated agricultural lands due to the build out of currently planned agricultural supply projects:<br>• Varies from state to state with some natural decreases also occurring | Significant decrease in agricultural lands in many basin states<br>• Due to permanent agricultural. retirement | Slightly faster increase in irrigated agricultural lands (varies from state to state) due to the buildout of currently planned agricultural supply projects |
| Technology and economics | Changes in agricultural water use efficiency [8] | Continued current trends in agricultural water use efficiency:<br>• Salinity control projects continue to be pursued | Decreased agricultural efficiency resulting from aging infrastructure and minimal capital investment in repair/replacement | Externally driven increases in water saving technology<br>Rapid adoption of new water saving technologies |
| | Changes in municipal and industrial water use efficiency [9] | Water use efficiency is increasing according to current policy and technology:<br>• External factors limiting water use of appliances/fixtures (e.g., federal statutes dictating water use efficiency of fixtures)<br>• Policies in place affecting future—vary by municipality and state | M&I consumer efficiency continues according to current trends:<br>• Aging infrastructure could have effects on water efficiency | Diversification of supply portfolios and increased costs, leading to increased water use efficiency:<br>• Increased implementation of WaterSense, EnergyStar, efficient landscaping technology, etc. |
| | Changes in water needs for energy generation (e.g., solar, oil shale, thermal, nuclear, etc.) [12] | Water needs for energy expand:<br>• Some expansion of oil shale/fossil fuel development<br>• Some expansion of thermal solar development<br>• Existing requirements for renewable energy are applied | Decreases in water for energy based on reduced freshwater for cooling (e.g., dry cooling) or technology improvements:<br>• High technology adaptation<br>• Increased requirements for renewable as a percentage of energy portfolio, with emphasis on dry technologies | Increased water use for energy, including solar, oil shale, and nuclear:<br>• Low technology adaptation<br>• Economic drivers encouraging growth in energy production |
| Social and governance | Changes in institutional and regulatory conditions (e.g. laws, regulations, etc.) [10] | No anticipated changes in institutional and regulatory conditions | Same as current trends | Increased institutional and regulatory conditions<br>National climate change regulations implemented (related to greenhouse gas management) |
| | Changes in flow-dependent ecosystem needs for ESA-listed species [13] | No change in currently realized ESA-listed species needs | Same as current trends | ESA flow targets for existing listed species are met and recovery is maintained |
| | Changes in other flow-dependent ecosystem needs [14] | No change in current planning and/or projections associated with ecosystem needs or practices | Same as current trends | Institutional agreements for ecological flows sufficient to ensure a resilient ecosystem (in timing, amount and location) |
| | Changes in social values affecting water use [15] | Social values affecting water use are similar to recent past:<br>• Continue along current trend of increased conservation, increased support in parts of the Basin for meeting environmental flows | Societal focus on economic efficiency | Societal values result in greater flexibility of water use for multiple purposes:<br>• Acceptance of water recycling<br>• Social values affecting water use accelerate current trend of increased conservation |
| | Changes in water availability due to tribal water use and settlement of tribal water rights claims [17] | Tribal water use continues as projected in settlements | Slower implementation of development within the settlements | Faster implementation of development within the settlements<br>• Additional tribal claims and settlements realized |

**NOTE:**
[1]Bracketed number reflects the number assigned to the 18 driving forces listed in *Technical Report A - Scenario Development,* Table A-1.

# Appendix C3
# Parameter Characteristics Assigned to Each Theme

# Appendix C3—Parameter Characteristics Assigned to Each Theme

**TABLE AC3-1**
Parameter Characteristics Assigned to Each Theme

| General Driving Force Categories | Critical Uncertainties[1] | A | B | C1 | C2 | D1 | D2 |
|---|---|---|---|---|---|---|---|
| | | **Theme** | | | | | |
| | | **Current Trends – Growth, development patterns, and institutions continue along recent trends** | **Economic Slowdown – Low growth with emphasis on economic efficiency** | **Expansive Growth – Economic resurgence (population and energy) and current preferences toward human and environmental values** | | **Enhanced Environment and Healthy Economy – Expanded environmental awareness and stewardship with growing economy** | |
| | | **A** | **B** | **C1 Slower technology adoption** | **C2 Rapid technology adoption and slight increase in social values** | **D1 Current growth trend** | **D2 Higher growth and technology** |
| Demographic and land use | Changes in population and distribution [4] | Best estimate of population growth | Slow growth:<br>• Increase principally in existing urban areas | Rapid, expansive growth:<br>• Focused in urban centers and "sprawl" to traditionally non-urban areas (likely driven by economic growth) | | Same as current trends | Rapid, expansive growth:<br>• Focused in urban centers and "sprawl" to traditionally non-urban areas (likely driven by economic growth) |
| | Changes in agricultural land use (e.g., irrigated agricultural areas, crop mixes, etc.) [5] | Nominal increase in irrigated agricultural lands due to the buildout of currently planned agricultural supply projects:<br>• Varies from state to state, with some natural decreases also occurring | Same as current trends | Slightly faster increase in irrigated agricultural lands (varies from state to state) due to the buildout of currently planned agricultural supply projects | | Same as current trends | |
| Technology and economics | Changes in agricultural water use efficiency [8] | Continued current trends in agricultural water use efficiency:<br>• Salinity control projects continue to be pursued | Decreased agricultural efficiency resulting from aging infrastructure and minimal capital investment in repair/replacement | Decreased agricultural efficiency resulting from aging infrastructure and minimal capital investment in repair/replacement | Externally driven increases in water saving technology<br>Rapid adoption of new water saving technologies | Same as current trends | Externally driven increases in water-saving technology<br>Rapid adoption of new water-saving technologies |
| | Changes in municipal and industrial water use efficiency [9] | Water use efficiency is increasing according to current policy and technology:<br>• External factors limiting water use of appliances/fixtures (e.g., federal statutes dictating water use efficiency of fixtures)<br>• Policies in place affecting future—vary by municipality and state | M&I consumer efficiency continues according to current trends:<br>• Aging infrastructure could have effects on water efficiency | M&I consumer efficiency continues according to current trends:<br>• Aging infrastructure could have effects on water efficiency | Diversification of supply portfolios and increased costs leading to increased water use efficiency:<br>• Increased implementation of WaterSense, EnergyStar, efficient landscaping technology, etc. | Diversification of supply portfolios and increased costs, leading to increased water use efficiency:<br>• Increased implementation of WaterSense, EnergyStar, efficient landscaping technology, etc. | |
| | Changes in water needs for energy generation (e.g., solar, oil shale, thermal, nuclear, etc.) [12] | Water needs for energy expand:<br>• Some expansion of oil shale/fossil fuel development<br>• Some expansion of Thermal Solar development<br>• Existing requirements for renewable energy are applied | Same as current trends | Increased water use for energy, including solar, oil shale, and nuclear:<br>• Low technology adaptation<br>• Economic drivers encouraging growth in energy production | Decreases in water for energy based on reduced freshwater for cooling (e.g., dry cooling) or technology improvements:<br>• High technology adaptation<br>• Increased requirements for renewable as a | Decreases in water for energy based on reduced freshwater for cooling (e.g., dry cooling) or technology improvements:<br>• High technology adaptation<br>• Increased requirements for renewable as a percent of energy portfolio, with emphasis on dry technologies | |

# Appendix C3—Parameter Characteristics Assigned to Each Theme

**TABLE AC3-1**
Parameter Characteristics Assigned to Each Theme

| General Driving Force Categories | Critical Uncertainties[1] | Theme: Current Trends – Growth, development patterns, and institutions continue along recent trends<br>A | Economic Slowdown – Low growth with emphasis on economic efficiency<br>B | Expansive Growth – Economic resurgence (population and energy) and current preferences toward human and environmental values<br>C1<br>Slower technology adoption | <br>C2<br>Rapid technology adoption and slight increase in social values | Enhanced Environment and Healthy Economy – Expanded environmental awareness and stewardship with growing economy<br>D1<br>Current growth trend | <br>D2<br>Higher growth and technology |
|---|---|---|---|---|---|---|---|
| | | | | | percentage of energy portfolio, with emphasis on dry technologies | | |
| Social and governance | Changes in institutional and regulatory conditions (e.g. laws, regulations, etc.) [10] | No anticipated change in regulations (interim guidelines extended through 2060) | Same as current trends | Same as current trends | • Increased institutional and regulatory conditions<br>• National climate change regulations implemented, (related to greenhouse gas management) | • Increased institutional and regulatory conditions<br>• National climate change regulations implemented (related to greenhouse gas management) | |
| | Changes in flow-dependent ecosystem needs for ESA-listed species [13] | No change in currently realized ESA-listed species needs | Same as current trends | Same as current trends | | ESA flow targets for existing listed species are met and recovery is maintained | |
| | Changes in other flow-dependent ecosystem needs [14] | No change in current planning and/or projections associated with ecosystem needs or practices | Same as current trends | Same as current trends | | Institutional agreements for ecological flows sufficient to ensure a resilient ecosystem (in timing, amount and location) | |
| | Changes in social values affecting water use [15] | Social values affecting water use are similar to recent past:<br>• Continue along current trend of increased conservation, increased support in parts of the Basin for meeting environmental flows | Societal focus on economic efficiency | Same as current trends | Societal values result in greater flexibility of water use for multiple purposes:<br>• Acceptance of water recycling<br>• Social values affecting water use accelerate current trend of increased conservation | Societal values result in greater flexibility of water use for multiple purposes:<br>• Acceptance of water recycling<br>• Social values affecting water use accelerate current trend of increased conservation<br>• Increased support for meeting environmental flows<br>• Tourism economy booms creating more demand for in-stream flows | |
| | Changes in water availability due to tribal water use and settlement of tribal water rights claims [17] | Tribal water use continues as projected in settlements | Slower implementation of development within the settlements | • Faster implementation of development within the settlements<br>• Additional tribal claims and settlements realized | | Same as current trends | • Faster implementation of development within the settlements<br>• Additional tribal claims and settlements realized |

**NOTE:**
[1]Bracketed column reflects the number assigned to the 18 driving forces listed in *Technical Report A - Scenario Development,* Table A-1.

# Appendix C4
# Climate Change Effects on Colorado River Basin Irrigation Demands

**Technical Memorandum No. 86-68210-2010-03**
**Reclamation, July 2010**

RECLAMATION
*Managing Water in the West*

**Technical Memorandum No. 86-68210 – 2010-03**

# Climate Change Effects on Colorado River Basin Irrigation Demands

**July 2010**

# Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

**Technical Memorandum No. 86-68210 - 2010-03**

# Climate Change Effects on Colorado River Basin Irrigation Demands

**Upper Colorado Regional Office, Salt Lake City, Utah**
**Technical Service Center**
**Water Resources Planning and Operations Support Group (86-68210)**
**Water and Environmental Resources Division (86-68200)**

*Prepared by:*

Alan Harrison, Environmental Engineer

*Peer reviewed by:*

Subhrendu Gangopadhyay, P.E., Civil Engineer (Hydrologic)

# Contents



## Tables

# Climate Change Effects on Colorado River Basin Irrigation Demands

## 1.1 Introduction

The Bureau of Reclamation (Reclamation) operates the Colorado River basin to meet many competing needs, including: irrigation, municipal, recreation, hydroelectric, fish & wildlife. Reclamation is required to work within the allocation and deliveries apportionment limits under the Law of the River, including the seven basin states and Mexico. The Colorado River Basin Water Supply & Demand Study has been established to define current and future imbalances in water supply and demand in the Colorado River Basin and the adjacent areas of the Basin States that receive Colorado River water for approximately the next 50 years, and will develop and analyze adaptation and mitigation strategies to resolve identified imbalances. One of the potential imbalances that will be explored is impacts to water supply and demand related to changes in climate and meteorological inputs to the basin. This paper reports a study commissioned to check the response of basin-wide irrigated agriculture to temperature and precipitation changes that may be realized as the basin climate changes. This study does not use any of the various Global Circulation Models (GCMs) available to estimate specific climate response, nor is it intended to explore the potential response of growers to various climate changes, only to estimate what the demand of current agricultural development levels might be if temperatures and/or precipitation rates were to change.

## 1.2 Study Approach

Reclamation is required to provide estimates of Colorado River consumptive uses. Under Public law 90-537, Section 601 (b)(1), dated September, 30, 1968, which directs the secretary of the Interior to:

> *"...make reports as to the annual consumptive uses and losses of water from the Colorado River System. . . starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a state-by-state basis."*

The major consumptive use in the Colorado River basin is irrigated agriculture. As part of the requirements under the law, Reclamation has, for many years, gathered data related to the acreage of lands under irrigation as well as the crops cultivated. Using this data, meteorological information and growth rate/water use curves, estimates of agricultural demands are made. Crop type and acreage data is developed from annual USDA Agricultural Statistics Service reports and 5-year Census of Agriculture information. GIS coverages are also utilized when available. These data are reported on a county basis, but techniques have been developed to subdivide these data into individual Hydrologic Units (HUC) within each county. It is at this county/HUC scale that the agricultural demands are estimated. These individual estimation units are gathered into major tributary areas for the Consumptive Uses and Losses reports. Table AC4-1 identifies the major tributary areas for each of the Colorado River Basin states considered.

**TABLE AC4-1**
Major Tributary Areas for Colorado River Basin States

| | State | Tributary Area |
|---|---|---|
| Upper Basin | Wyoming | Green River |
| | Colorado | Green River |
| | | Main Stem |
| | | San Juan |
| | Utah | Green River |
| | | Main Stem |
| | | San Juan |
| | Arizona | San Juan |
| Lower Basin | Utah | Tributary Area Above Lake Mead |
| | | Virgin River |
| | Nevada | Muddy River |
| | | Virgin River |
| | | Tributary Area Above Lake Mead |
| | Arizona | Little Colorado River |
| | | Virgin River |
| | | Tributary Area Above Lake Mead |
| | | Tributary Area Below Lake Mead |
| | | Bill Williams River |
| | | Gila River |

Agricultural and meteorological data, previously compiled for use in the Consumptive Uses and Losses studies, from 1996 through 2005 for both upper and lower Colorado River Basins was used to conduct this study. Acreages and crop types were considered to be constant regardless of the temperature and precipitation adjustments made. The study considered the agricultural demand response to an increase of average monthly temperatures by 1°, 2°, 3°, 4°, and 5°F. Separately, demand response was estimated when total monthly precipitation was adjusted by -10%, -5%, +5%, and +10%. Finally, demand estimates were developed to simulate irrigation demands based on a combination of temperature and precipitation adjustments. Each of the temperature increases (1°, 2°, 3°, 4°, 5°) were evaluated in conjunction with the extreme precipitation adjustments (i.e., -10%, +10%). Each of the meteorological permutations was compared to a base run to determine the potential impact of the temperature and/or precipitation adjustment. Temperature and precipitation adjustments were chosen to give a general idea of what the demand might be. None of the many Global Circulation Models (GCM) were used to estimate climate adjustments. As such, no potential seasonal or spatial variations are included in the estimate.

Agricultural demand was estimated using the modified Blaney-Criddle method as implemented in Reclamation's XCONS software program. This method was used throughout the Colorado River Basin except in the extreme southern portions of Arizona where an unmodified Blaney-Criddle method was utilized, referenced as the Erie Method. The model calculates evapotranspiration estimates for irrigated agriculture on a monthly basis. Required model inputs include: acreage, crop type, average monthly temperature, total monthly precipitation. Note that irrigation demands in only six of the seven Colorado River Basin states were estimated. New Mexico conducts its own irrigation demand calculations and provides those results to Reclamation for use in the Consumptive Uses and Losses report, but the detailed information necessary to estimate irrigation demand consistent with the rest of the basin for the purposes of this study was not available at the time of publication of this report.

The Blaney-Criddle model utilizes a start and stop temperature concept to determine when the crops break dormancy and begin to grow or stops respiring. Total potential water demand for a given crop at a given point in its growth cycle is first calculated based on temperature, net water requirements is then calculated by subtracting the effective precipitation available to meet that water demand. Net water demand, defined as the water required to be supplied through irrigation, is reported in this report.

## 1.3 Results

A percent difference statistics is used report the effect of temperature and/or precipitation changes to irrigation requirements. This is calculated by subtracting the base run results from the climate modified run results, then dividing that by the base run. A percent difference was developed for each county/HUC combination for the upper and lower basins. A positive percent difference indicates more water required by irrigated agriculture for the climate modified run (climate modified run requirement is greater than the base for the same county/HUC). As expected, increasing the temperature resulted in the increase of water demanded. In the upper basin, each degree of temperature increase resulted in an overall basin average rise of about 5.5% in water demand. The same is true for the lower basin where the percent difference was approximately 4.2%. In both upper and lower basins, the average percent difference tended to increase slightly as the temperature was raised. For instance, in the upper basin, the average percent difference resulting from a 1°F temperature rise was 5.4% for the first 1°F temperature increment, and 6.0% for the 4°F to 5°F increment. Similar results were seen for the lower basin with the first temperature increment resulting in a 4.1% average difference and the last increment resulting in a 4.6% average difference. Tables AC4-2 and 3 show the state wide average percent difference for the upper and lower basins, respectively.

**TABLE AC4-2**
Percent difference in irrigated demand for the Upper Colorado River Basin resulting from temperature changes only

| Upper Basin | | Percent Difference | | | |
|---|---|---|---|---|---|
| | | Wyoming | Utah | Colorado | Arizona |
| Temperature | +1°F | 6.4% | 5.2% | 6.1% | 3.7% |
| | +2°F | 13.0% | 10.6% | 12.4% | 7.5% |
| | +3°F | 19.9% | 16.1% | 18.8% | 11.2% |
| | +4°F | 27.0% | 21.7% | 25.5% | 15.1% |
| | +5°F | 34.3% | 27.8% | 32.4% | 19.1% |

**TABLE AC4-3**
Percent difference in irrigated demand for the Lower Colorado River Basin resulting from temperature changes only

| Lower Basin | | Percent Difference | | |
|---|---|---|---|---|
| | | Arizona | Utah | Nevada |
| Temperature | +1°F | 3.5% | 4.2% | 4.8% |
| | +2°F | 7.0% | 8.4% | 9.6% |
| | +3°F | 10.6% | 12.8% | 14.5% |
| | +4°F | 14.3% | 17.2% | 19.7% |
| | +5°F | 18.0% | 21.7% | 24.8% |

In addition to temperature increments, precipitation was also incremented independently of temperature. Similar to the temperature modifications reported above, as expected, reduction of precipitation resulted in more water demand, and precipitation increases resulted in less water demand. For the upper basin, an average of 0.9% difference in demand was seen for each 5% increment of precipitation change (either an increase or decrease in precipitation). It should be noted that this average is a bit misleading in that the Northern Arizona (extreme north eastern Arizona) percent difference is very low compared to the other three states that comprise the Upper Colorado River Basin. It appears that this result is because of the very low overall rainfall seen in this area. Adjusting a very low rainfall number by 5% or 10% doesn't make much difference in accommodating the needs of irrigated agriculture. If Arizona is removed from the upper basin average, then a 1.2% difference is realized for each 5% precipitation increment. The lower basin followed a similar pattern resulting in an average 0.8% demand difference for each 5% precipitation increment. Tables AC4-4 and 5 show the state average percent differences resulting from precipitation changes. Note that positive precipitation increments (increases in precipitation rates) resulted in negative percent differences in water demand indicating that adding water to the system in the form of increased rainfall resulted in decreased irrigation demand.

**TABLE AC4-4**
Percent difference in irrigated demand for the Upper Colorado River Basin resulting from precipitation changes only

| Upper Basin | | Percent Difference | | | |
|---|---|---|---|---|---|
| | | Wyoming | Utah | Colorado | Arizona |
| Precipitation | -5% | 1.1% | 0.8% | 1.6% | 0.006% |
| | -10% | 2.2% | 1.7% | 3.3% | 0.012% |
| | 5% | -1.1% | -0.8% | -1.6% | -0.006% |
| | 10% | -2.1% | -1.7% | -3.1% | -0.012% |

**TABLE AC4-5**
Percent difference in irrigated demand for the Lower Colorado River Basin resulting from precipitation changes only

| **Lower Basin** | | **Percent Difference** | | |
|---|---|---|---|---|
| | | Arizona | Utah | Nevada |
| Precipitation | -5% | 0.8% | 0.8% | 0.7% |
| | -10% | 1.6% | 1.6% | 1.4% |
| | 5% | -0.8% | -0.8% | -0.7% |
| | 10% | -1.5% | -1.6% | -1.4% |

Results are also available for the combination of temperature and precipitation changes. Tables AC4-6 through 9 show the results in the upper basin. Tables AC4-10 though 12 present the results for the lower basin. Note also the relatively minor influence of precipitation on the overall demand in the upper basin Arizona results displayed in Table AC4-9.

**TABLE AC4-6**
Percent difference in irrigated demand for Wyoming in the upper basin resulting from both temperature and precipitation changes.

| **Upper Basin** | | Precipitation | |
|---|---|---|---|
| **Wyoming** | | -10% | +10% |
| Temperature | +1°F | 8.7% | 4.1% |
| | +2°F | 13.6% | 10.7% |
| | +3°F | 22.5% | 17.4% |
| | +4°F | 29.6% | 24.4% |
| | +5°F | 37.1% | 31.6% |

**TABLE AC4-7**
Percent difference in irrigated demand for Utah in the upper basin resulting from both temperature and precipitation changes.

| Upper Basin | | Precipitation | |
|---|---|---|---|
| Utah | | -10% | +10% |
| Temperature | +1°F | 7.0% | 3.5% |
| | +2°F | 10.9% | 8.8% |
| | +3°F | 18.0% | 14.2% |
| | +4°F | 23.7% | 19.8% |
| | +5°F | 29.8% | 25.8% |

**TABLE AC4-8**
Percent difference in irrigated demand for Colorado in the upper basin resulting from both temperature and precipitation changes

| Upper Basin | | Precipitation | |
|---|---|---|---|
| Colorado | | -10% | +10% |
| Temperature | +1°F | 9.5% | 2.8% |
| | +2°F | 15.2% | 9.0% |
| | +3°F | 22.5% | 15.3% |
| | +4°F | 29.4% | 21.8% |
| | +5°F | 36.4% | 28.6% |

**TABLE AC4-9**
Percent difference in irrigated demand for Arizona in the upper basin resulting from both temperature and precipitation changes

| Upper Basin | | Precipitation | |
|---|---|---|---|
| Arizona | | -10% | +10% |
| Temperature | +1°F | 3.727% | 3.703% |
| | +2°F | 7.477% | 7.452% |
| | +3°F | 11.219% | 11.195% |
| | +4°F | 15.094% | 15.069% |
| | +5°F | 19.080% | 19.056% |

**TABLE AC4-10**
Percent difference in irrigated demand for Arizona in the lower basin resulting from both temperature and precipitation changes.

| Lower Basin | | Precipitation | |
|---|---|---|---|
| Arizona | | -10% | +10% |
| Temperature | +1°F | 5.1% | 1.9% |
| | +2°F | 8.6% | 5.4% |
| | +3°F | 12.3% | 8.9% |
| | +4°F | 16.0% | 12.5% |
| | +5°F | 19.7% | 16.2% |

**TABLE AC4-11**
Percent difference in irrigated demand for Utah in the lower basin resulting from both temperature and precipitation changes

| Lower Basin | | Precipitation | |
|---|---|---|---|
| Utah | | -10% | +10% |
| Temperature | +1°F | 5.8% | 2.5% |
| | +2°F | 10.1% | 6.7% |
| | +3°F | 14.6% | 11.1% |
| | +4°F | 19.1% | 15.4% |
| | +5°F | 23.7% | 19.8% |

**TABLE AC4-12**
Percent difference in irrigated demand for Utah in the lower basin resulting from both temperature and precipitation changes

| Lower Basin | | Precipitation | |
|---|---|---|---|
| Nevada | | -10% | +10% |
| Temperature | +1°F | 6.3% | 3.3% |
| | +2°F | 11.1% | 8.1% |
| | +3°F | 16.1% | 13.0% |
| | +4°F | 21.3% | 18.1% |
| | +5°F | 26.5% | 23.1% |

The results shown in this section are state and basin averages. For additional detail please refer to the appendix where tables are shown displaying the results on a basin/state/drainage area basis for each of the 10 years of the study. Additionally, the Excel files that accompany this report can be referenced to see the results on a county/HUC level.

## 1.4 Conclusion

As expected, adjustments to the meteorological inputs of the evapotranspiration model used in the Consumptive Uses & Losses reporting resulted in changes to irrigation demands throughout the Colorado River Basin. Temperature increases and precipitation decreases resulted in increases in water demand while precipitation increases resulted in irrigation demand reductions. In general, a 1°F change in temperature resulted in greater demand requirements than a 5% adjustment in precipitation. In areas where precipitation currently plays a minimal role in the satisfaction of irrigation demand, temperature differences will play a majority role.

# Appendix A
# Tables Displaying Study Results for Each Drainage Area

## Temperature: +1°F, Precipitation: 0

### Upper Basin

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 5.9% | 6.7% | 7.1% | 6.7% | 6.4% | 6.2% | 5.7% | 6.4% | 6.4% | 6.4% | 6.4% |
| Utah | Green River Drainage | 5.5% | 5.7% | 5.7% | 6.3% | 5.4% | 5.5% | 5.0% | 5.4% | 5.8% | 6.0% | 5.6% |
| | Main Stem Drainage | 4.8% | 4.9% | 4.6% | 5.5% | 4.8% | 4.4% | 5.4% | 5.0% | 4.9% | 4.3% | 4.9% |
| | San Juan Drainage | 5.0% | 5.7% | 5.4% | 5.4% | 4.7% | 4.8% | 4.9% | 4.8% | 5.4% | 5.2% | 5.1% |
| Colorado | Green River Drainage | 5.6% | 6.5% | 6.0% | 6.4% | 5.9% | 5.5% | 5.2% | 6.0% | 6.3% | 6.5% | 6.0% |
| | Main Stem Drainage | 5.6% | 6.5% | 6.0% | 7.0% | 5.6% | 6.1% | 5.6% | 5.9% | 6.4% | 6.2% | 6.1% |
| | San Juan Drainage | 5.7% | 8.4% | 5.4% | 7.4% | 5.3% | 6.2% | 5.1% | 6.1% | 7.4% | 5.7% | 6.3% |
| Arizona | San Juan drainage | 3.6% | 3.9% | 3.6% | 3.9% | 3.5% | 3.4% | 3.9% | 3.6% | 3.9% | 3.8% | 3.7% |

### Lower Basin

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 5.5% | 5.8% | 5.5% | 6.7% | 4.6% | 5.0% | 5.2% | 5.1% | 5.4% | 5.2% | 5.4% |
| | Virgin River Drainage | 3.4% | 3.1% | 3.5% | 3.2% | 3.2% | 3.7% | 3.0% | 3.0% | 3.2% | 3.2% | 3.2% |
| | Tributaries Above Lake Mead | 3.8% | 4.8% | 4.7% | 4.6% | 3.6% | 5.7% | 6.6% | 6.2% | 6.3% | 6.9% | 5.3% |
| | Tributaries Below Lake Mead | 1.2% | 1.3% | 1.4% | 1.3% | 1.4% | 1.3% | 1.3% | 1.3% | 1.4% | 1.4% | 1.3% |
| | Bill Williams River Drainage | 2.9% | 2.9% | 3.4% | 3.6% | 2.8% | 2.8% | 3.3% | 2.7% | 2.8% | 3.0% | 3.0% |
| | Gila River Drainage | 2.7% | 2.8% | 2.6% | 2.9% | 2.6% | 2.3% | 2.4% | 2.4% | 2.4% | 2.4% | 2.5% |
| Utah | Tributaries Above Lake Mead | 4.2% | 5.8% | 4.9% | 5.1% | 4.2% | 4.0% | 4.3% | 4.4% | 4.4% | 4.3% | 4.6% |
| | Virgin River Drainage | 3.4% | 4.2% | 3.9% | 3.9% | 3.8% | 3.6% | 3.6% | 3.5% | 3.6% | 3.7% | 3.7% |
| Nevada | Muddy River Drainage | 5.0% | 5.1% | 5.8% | 5.2% | 5.1% | 4.4% | 5.1% | 4.0% | 5.2% | 5.0% | 5.0% |
| | Virgin River Drainage | 5.0% | 5.7% | 5.8% | 5.2% | 6.5% | 4.4% | 5.1% | 4.0% | 5.2% | 5.0% | 5.2% |
| | Tributaries Above Lake Mead | 4.0% | 4.4% | 4.5% | 4.2% | 4.7% | 3.6% | 4.0% | 3.6% | 4.2% | 4.0% | 4.1% |

**Temperature: +2°F, Precipitation: 0**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 12.0% | 13.6% | 14.4% | 13.6% | 13.2% | 12.5% | 11.6% | 13.0% | 13.4% | 13.0% | 13.0% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 11.1% | 12.1% | 11.5% | 12.8% | 11.1% | 11.1% | 10.1% | 11.3% | 11.7% | 12.0% | 11.5% |
| | Main Stem Drainage | 9.7% | 9.8% | 9.3% | 11.3% | 9.7% | 8.9% | 10.4% | 10.1% | 9.8% | 8.8% | 9.8% |
| | San Juan Drainage | 10.2% | 12.0% | 10.9% | 11.5% | 9.5% | 9.6% | 9.8% | 9.7% | 10.8% | 10.6% | 10.5% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 11.4% | 13.5% | 12.3% | 13.6% | 12.0% | 11.1% | 10.4% | 12.1% | 13.3% | 13.2% | 12.3% |
| | Main Stem Drainage | 11.5% | 13.2% | 11.9% | 14.2% | 11.4% | 12.4% | 11.3% | 12.0% | 12.9% | 12.6% | 12.3% |
| | San Juan Drainage | 11.7% | 17.1% | 10.9% | 14.4% | 10.6% | 12.4% | 10.5% | 12.2% | 14.2% | 11.7% | 12.6% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 7.2% | 7.7% | 7.3% | 8.0% | 6.9% | 7.0% | 7.7% | 7.3% | 7.8% | 7.7% | 7.5% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 10.8% | 11.4% | 11.2% | 14.9% | 9.1% | 10.5% | 10.5% | 10.1% | 11.0% | 10.3% | 11.0% |
| | Virgin River Drainage | 6.8% | 6.3% | 7.0% | 6.4% | 6.5% | 6.7% | 6.0% | 6.1% | 6.5% | 6.5% | 6.5% |
| | Tributaries Above Lake Mead | 8.3% | 9.4% | 9.2% | 9.4% | 7.6% | 12.5% | 13.2% | 12.2% | 12.5% | 13.3% | 10.8% |
| | Tributaries Below Lake Mead | 2.5% | 2.6% | 2.8% | 2.6% | 2.7% | 2.6% | 2.6% | 2.6% | 2.7% | 2.7% | 2.6% |
| | Bill Williams River Drainage | 5.8% | 6.0% | 6.9% | 6.9% | 5.7% | 5.6% | 6.1% | 5.5% | 5.7% | 5.9% | 6.0% |
| | Gila River Drainage | 5.4% | 5.6% | 5.4% | 5.8% | 5.0% | 4.7% | 4.9% | 4.8% | 4.8% | 4.8% | 5.1% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 8.6% | 11.8% | 9.9% | 10.2% | 8.4% | 8.4% | 8.6% | 9.1% | 8.9% | 8.6% | 9.2% |
| | Virgin River Drainage | 7.1% | 8.2% | 7.8% | 7.7% | 7.4% | 7.3% | 7.5% | 7.1% | 7.2% | 7.7% | 7.5% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 10.0% | 10.8% | 11.6% | 10.3% | 10.1% | 8.9% | 10.0% | 8.3% | 11.1% | 9.9% | 10.1% |
| | Virgin River Drainage | 10.1% | 11.6% | 11.8% | 10.3% | 11.6% | 8.8% | 9.9% | 8.3% | 11.0% | 10.1% | 10.3% |
| | Tributaries Above Lake Mead | 8.1% | 8.9% | 9.1% | 8.3% | 8.8% | 7.3% | 8.0% | 7.2% | 8.7% | 8.1% | 8.2% |

**Temperature: +3°F, Precipitation: 0**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 18.4% | 20.6% | 22.4% | 20.8% | 20.3% | 18.9% | 17.7% | 19.6% | 20.4% | 19.9% | 19.9% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 17.0% | 18.7% | 17.4% | 19.6% | 17.0% | 17.0% | 15.2% | 17.0% | 17.8% | 18.3% | 17.5% |
| | Main Stem Drainage | 14.6% | 14.7% | 14.1% | 17.1% | 14.8% | 13.5% | 15.7% | 15.3% | 14.8% | 13.2% | 14.8% |
| | San Juan Drainage | 15.5% | 18.6% | 16.8% | 17.5% | 14.2% | 14.6% | 14.7% | 14.8% | 16.2% | 16.1% | 15.9% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 17.5% | 20.5% | 18.6% | 20.6% | 18.1% | 16.9% | 15.7% | 18.2% | 20.4% | 20.0% | 18.6% |
| | Main Stem Drainage | 17.5% | 20.2% | 17.9% | 22.2% | 17.3% | 19.0% | 17.1% | 18.2% | 19.4% | 19.1% | 18.8% |
| | San Juan Drainage | 17.7% | 25.9% | 16.5% | 22.2% | 16.0% | 18.9% | 15.8% | 18.3% | 21.4% | 17.9% | 19.1% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 11.0% | 11.5% | 10.8% | 11.9% | 10.6% | 10.5% | 11.5% | 11.0% | 11.7% | 11.6% | 11.2% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 16.5% | 17.5% | 16.9% | 21.8% | 13.8% | 15.9% | 15.9% | 15.3% | 16.7% | 15.6% | 16.6% |
| | Virgin River Drainage | 10.3% | 9.6% | 10.6% | 9.6% | 9.8% | 10.1% | 9.1% | 9.2% | 9.9% | 9.8% | 9.8% |
| | Tributaries Above Lake Mead | 11.8% | 13.8% | 14.1% | 14.4% | 12.1% | 19.0% | 19.7% | 18.5% | 19.6% | 20.2% | 16.3% |
| | Tributaries Below Lake Mead | 3.7% | 3.9% | 4.1% | 4.0% | 4.1% | 3.9% | 3.9% | 3.9% | 4.1% | 4.1% | 4.0% |
| | Bill Williams River Drainage | 8.7% | 8.9% | 10.6% | 11.7% | 8.5% | 8.5% | 9.0% | 8.3% | 8.5% | 9.0% | 9.2% |
| | Gila River Drainage | 8.2% | 8.5% | 8.3% | 9.0% | 7.6% | 7.0% | 7.4% | 7.1% | 7.3% | 7.3% | 7.8% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 13.0% | 17.9% | 15.0% | 16.6% | 12.8% | 12.7% | 13.4% | 13.6% | 13.5% | 13.4% | 14.2% |
| | Virgin River Drainage | 10.6% | 12.3% | 11.9% | 11.9% | 11.0% | 11.0% | 11.6% | 10.7% | 11.0% | 11.6% | 11.4% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 14.9% | 16.7% | 17.6% | 15.5% | 15.1% | 13.7% | 14.8% | 12.7% | 17.6% | 15.0% | 15.4% |
| | Virgin River Drainage | 15.0% | 17.7% | 17.8% | 15.7% | 16.6% | 13.9% | 14.8% | 12.7% | 17.5% | 15.3% | 15.7% |
| | Tributaries Above Lake Mead | 12.1% | 13.5% | 13.7% | 12.6% | 12.9% | 11.4% | 11.9% | 11.1% | 13.5% | 12.2% | 12.5% |

**Temperature: +4°F, Precipitation: 0**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Wyoming | Green River Drainage | 25.0% | 27.8% | 30.7% | 28.2% | 27.6% | 25.6% | 23.9% | 26.3% | 27.8% | 26.8% | 27.0% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 23.3% | 25.7% | 23.7% | 26.6% | 23.1% | 23.0% | 20.5% | 23.3% | 23.9% | 24.7% | 23.8% |
| | Main Stem Drainage | 19.7% | 19.7% | 19.0% | 23.2% | 19.9% | 18.2% | 21.0% | 20.5% | 20.1% | 17.8% | 19.9% |
| | San Juan Drainage | 21.0% | 25.1% | 22.8% | 24.2% | 19.3% | 19.7% | 19.8% | 19.9% | 22.0% | 21.7% | 21.5% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 23.7% | 27.8% | 25.1% | 27.8% | 24.5% | 22.8% | 21.2% | 24.4% | 27.7% | 26.9% | 25.2% |
| | Main Stem Drainage | 23.6% | 27.6% | 24.0% | 29.9% | 23.3% | 25.7% | 23.0% | 24.5% | 26.2% | 25.8% | 25.3% |
| | San Juan Drainage | 24.2% | 35.4% | 22.4% | 30.5% | 21.6% | 25.3% | 21.5% | 24.7% | 30.2% | 24.5% | 26.0% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 14.7% | 15.6% | 14.6% | 15.7% | 14.2% | 14.2% | 15.2% | 14.8% | 16.1% | 15.5% | 15.1% |
| | | | | | | | | | | | | |
| **Lower Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 22.2% | 23.6% | 23.1% | 28.6% | 18.4% | 21.4% | 21.4% | 20.7% | 22.8% | 21.3% | 22.4% |
| | Virgin River Drainage | 13.8% | 12.9% | 14.2% | 12.9% | 13.2% | 13.2% | 12.3% | 12.3% | 13.3% | 13.1% | 13.1% |
| | Tributaries Above Lake Mead | 16.6% | 18.5% | 19.0% | 19.2% | 16.2% | 25.2% | 26.3% | 24.8% | 26.1% | 26.8% | 21.9% |
| | Tributaries Below Lake Mead | 5.0% | 5.2% | 5.5% | 5.3% | 5.4% | 5.2% | 5.2% | 5.2% | 5.5% | 5.5% | 5.3% |
| | Bill Williams River Drainage | 11.6% | 11.8% | 16.6% | 15.1% | 11.6% | 11.4% | 12.0% | 11.2% | 11.4% | 12.1% | 12.5% |
| | Gila River Drainage | 11.1% | 11.4% | 11.3% | 12.0% | 10.1% | 9.4% | 9.8% | 9.5% | 9.7% | 9.8% | 10.4% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 17.7% | 23.8% | 20.2% | 22.2% | 17.3% | 17.1% | 18.0% | 18.5% | 18.2% | 18.3% | 19.1% |
| | Virgin River Drainage | 14.2% | 16.3% | 16.0% | 16.0% | 14.7% | 15.0% | 15.3% | 14.4% | 14.8% | 15.5% | 15.2% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 20.0% | 22.6% | 23.8% | 20.7% | 20.5% | 18.6% | 19.8% | 18.0% | 24.6% | 20.2% | 20.9% |
| | Virgin River Drainage | 20.3% | 23.9% | 24.1% | 20.9% | 22.1% | 18.9% | 19.8% | 18.0% | 24.4% | 20.5% | 21.3% |
| | Tributaries Above Lake Mead | 16.3% | 18.2% | 18.5% | 16.9% | 17.1% | 15.4% | 15.9% | 15.3% | 18.6% | 16.4% | 16.9% |

**Temperature: +5°F, Precipitation: 0**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 32.0% | 35.2% | 39.4% | 35.8% | 35.2% | 32.4% | 30.4% | 33.3% | 35.4% | 34.0% | 34.3% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 29.5% | 33.7% | 30.3% | 34.2% | 29.5% | 29.3% | 26.8% | 30.6% | 30.2% | 31.8% | 30.6% |
| | Main Stem Drainage | 24.9% | 25.5% | 24.1% | 28.9% | 25.2% | 22.9% | 26.4% | 25.8% | 26.7% | 22.4% | 25.3% |
| | San Juan Drainage | 26.7% | 31.8% | 29.1% | 31.3% | 24.4% | 25.0% | 25.0% | 25.2% | 28.1% | 27.5% | 27.4% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 30.0% | 35.2% | 32.0% | 35.6% | 30.8% | 28.8% | 26.7% | 30.8% | 35.2% | 34.1% | 31.9% |
| | Main Stem Drainage | 29.9% | 35.1% | 30.3% | 38.3% | 29.3% | 32.4% | 28.9% | 30.9% | 33.0% | 32.7% | 32.1% |
| | San Juan Drainage | 30.8% | 45.2% | 28.3% | 39.0% | 26.8% | 32.0% | 27.2% | 31.1% | 39.1% | 31.3% | 33.1% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 18.6% | 19.4% | 18.4% | 21.4% | 17.3% | 18.0% | 19.1% | 18.8% | 20.0% | 19.5% | 19.1% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 28.6% | 29.8% | 29.5% | 35.8% | 23.4% | 27.1% | 27.1% | 26.5% | 28.9% | 26.8% | 28.3% |
| | Virgin River Drainage | 17.4% | 16.2% | 17.9% | 16.3% | 16.6% | 16.8% | 15.5% | 15.5% | 16.7% | 16.6% | 16.5% |
| | Tributaries Above Lake Mead | 20.3% | 23.3% | 24.0% | 24.0% | 20.2% | 32.2% | 33.0% | 31.6% | 33.1% | 33.9% | 27.6% |
| | Tributaries Below Lake Mead | 6.2% | 6.5% | 6.9% | 6.6% | 6.8% | 6.5% | 6.5% | 6.5% | 6.8% | 6.8% | 6.6% |
| | Bill Williams River Drainage | 14.9% | 14.8% | 20.3% | 18.4% | 14.7% | 14.3% | 14.9% | 14.2% | 14.4% | 15.3% | 15.6% |
| | Gila River Drainage | 14.1% | 14.5% | 14.3% | 15.3% | 12.8% | 11.9% | 12.2% | 11.9% | 12.2% | 12.2% | 13.1% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 22.4% | 29.7% | 25.4% | 27.9% | 21.7% | 21.6% | 23.0% | 23.4% | 23.3% | 23.2% | 24.2% |
| | Virgin River Drainage | 17.9% | 20.3% | 20.1% | 20.2% | 18.4% | 18.8% | 19.1% | 18.3% | 18.6% | 19.5% | 19.1% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 25.5% | 28.5% | 30.1% | 26.2% | 25.6% | 23.6% | 25.0% | 22.6% | 30.6% | 25.5% | 26.3% |
| | Virgin River Drainage | 25.9% | 29.9% | 30.5% | 26.5% | 27.3% | 23.9% | 25.0% | 22.7% | 30.4% | 25.9% | 26.8% |
| | Tributaries Above Lake Mead | 20.7% | 22.8% | 23.4% | 21.4% | 21.4% | 19.5% | 20.1% | 19.3% | 23.2% | 20.7% | 21.2% |

**Temperature: +0°F, Precipitation: -5%**

| Upper Basin | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Wyoming | Green River Drainage | 1.0% | 1.7% | 1.9% | 1.0% | 0.9% | 0.8% | 0.6% | 0.9% | 1.1% | 1.0% | 1.1% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 0.8% | 1.5% | 1.0% | 1.1% | 0.8% | 0.6% | 0.5% | 0.6% | 0.8% | 0.8% | 0.9% |
| | Main Stem Drainage | 0.7% | 1.2% | 0.7% | 1.5% | 0.7% | 0.9% | 0.6% | 0.6% | 0.8% | 0.6% | 0.8% |
| | San Juan Drainage | 0.7% | 1.4% | 1.0% | 1.1% | 0.7% | 0.7% | 0.5% | 0.6% | 0.8% | 1.0% | 0.8% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 1.3% | 2.7% | 1.6% | 1.6% | 1.3% | 1.2% | 0.9% | 1.0% | 1.6% | 2.0% | 1.5% |
| | Main Stem Drainage | 1.3% | 2.4% | 1.4% | 2.2% | 1.3% | 1.6% | 1.0% | 1.4% | 1.5% | 1.9% | 1.6% |
| | San Juan Drainage | 1.5% | 4.5% | 1.1% | 2.2% | 1.0% | 1.7% | 0.9% | 1.4% | 1.3% | 1.7% | 1.7% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| | | | | | | | | | | | | |
| Lower Basin | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 1.1% | 1.3% | 1.6% | 1.9% | 0.8% | 1.3% | 1.2% | 1.1% | 1.6% | 0.9% | 1.3% |
| | Virgin River Drainage | 0.6% | 0.3% | 0.7% | 0.3% | 0.4% | 0.3% | 0.1% | 0.3% | 0.6% | 0.4% | 0.4% |
| | Tributaries Above Lake Mead | 0.2% | 0.8% | 0.8% | 0.9% | 0.5% | 1.8% | 1.7% | 1.9% | 1.8% | 1.7% | 1.2% |
| | Tributaries Below Lake Mead | 0.1% | 0.4% | 0.5% | 0.2% | 0.2% | 0.2% | 0.1% | 0.2% | 0.5% | 0.3% | 0.3% |
| | Bill Williams River Drainage | 0.5% | 0.8% | 1.3% | 1.0% | 0.8% | 0.6% | 0.4% | 0.6% | 0.8% | 0.8% | 0.7% |
| | Gila River Drainage | 0.9% | 1.0% | 1.0% | 0.9% | 0.9% | 0.8% | 0.6% | 0.6% | 0.9% | 0.7% | 0.8% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 0.8% | 1.6% | 1.8% | 1.4% | 0.9% | 0.7% | 0.6% | 0.9% | 0.8% | 0.8% | 1.0% |
| | Virgin River Drainage | 0.5% | 0.7% | 1.0% | 0.7% | 0.5% | 0.4% | 0.3% | 0.4% | 0.5% | 0.6% | 0.6% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 0.4% | 1.0% | 1.2% | 0.7% | 1.0% | 0.6% | 0.4% | 0.5% | 1.3% | 0.7% | 0.8% |
| | Virgin River Drainage | 0.3% | 1.1% | 1.3% | 0.7% | 1.0% | 0.7% | 0.4% | 0.5% | 1.3% | 0.8% | 0.8% |
| | Tributaries Above Lake Mead | 0.3% | 0.7% | 0.8% | 0.5% | 0.6% | 0.4% | 0.3% | 0.4% | 0.8% | 0.5% | 0.5% |

**Temperature: +0°F, Precipitation: -10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 2.1% | 3.3% | 3.9% | 2.1% | 1.8% | 1.6% | 1.1% | 1.9% | 2.2% | 2.0% | 2.2% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 1.6% | 3.0% | 2.1% | 2.3% | 1.6% | 1.2% | 1.1% | 1.2% | 1.5% | 1.7% | 1.7% |
| | Main Stem Drainage | 1.5% | 2.3% | 1.5% | 3.1% | 1.3% | 1.8% | 1.1% | 1.2% | 1.6% | 1.2% | 1.7% |
| | San Juan Drainage | 1.3% | 2.9% | 2.1% | 2.2% | 1.3% | 1.3% | 0.9% | 1.3% | 1.6% | 2.0% | 1.7% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 2.6% | 5.5% | 3.2% | 3.2% | 2.7% | 2.4% | 1.8% | 2.0% | 3.3% | 4.1% | 3.1% |
| | Main Stem Drainage | 2.6% | 4.9% | 2.8% | 4.5% | 2.6% | 3.2% | 2.0% | 2.8% | 3.1% | 3.8% | 3.2% |
| | San Juan Drainage | 3.0% | 9.1% | 2.3% | 4.5% | 2.1% | 3.4% | 1.8% | 2.9% | 2.8% | 3.5% | 3.5% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 2.2% | 2.6% | 3.3% | 3.8% | 1.6% | 2.7% | 2.4% | 2.2% | 3.1% | 1.9% | 2.6% |
| | Virgin River Drainage | 1.2% | 0.6% | 1.5% | 0.5% | 0.8% | 0.6% | 0.3% | 0.6% | 1.2% | 0.8% | 0.8% |
| | Tributaries Above Lake Mead | 0.4% | 1.6% | 1.7% | 1.8% | 1.0% | 3.5% | 3.5% | 3.9% | 3.7% | 3.5% | 2.4% |
| | Tributaries Below Lake Mead | 0.3% | 0.7% | 1.0% | 0.4% | 0.4% | 0.5% | 0.2% | 0.4% | 1.0% | 0.6% | 0.6% |
| | Bill Williams River Drainage | 0.9% | 1.5% | 2.6% | 2.1% | 1.6% | 1.2% | 0.7% | 1.2% | 1.6% | 1.5% | 1.5% |
| | Gila River Drainage | 1.8% | 2.0% | 2.0% | 1.8% | 1.8% | 1.5% | 1.2% | 1.2% | 1.7% | 1.3% | 1.6% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 1.7% | 3.4% | 3.6% | 2.8% | 1.8% | 1.4% | 1.1% | 1.9% | 1.7% | 1.7% | 2.1% |
| | Virgin River Drainage | 0.9% | 1.5% | 2.1% | 1.3% | 1.0% | 0.8% | 0.6% | 0.8% | 1.1% | 1.2% | 1.1% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 0.8% | 2.0% | 2.5% | 1.4% | 1.9% | 1.3% | 0.9% | 1.0% | 2.5% | 1.5% | 1.6% |
| | Virgin River Drainage | 0.8% | 2.1% | 2.6% | 1.4% | 2.0% | 1.3% | 0.9% | 1.0% | 2.6% | 1.5% | 1.6% |
| | Tributaries Above Lake Mead | 0.6% | 1.3% | 1.6% | 1.0% | 1.1% | 0.7% | 0.5% | 0.9% | 1.7% | 1.0% | 1.0% |

## Temperature: +0°F, Precipitation: +5%

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | -1.0% | -1.6% | -1.9% | -1.0% | -0.9% | -0.8% | -0.6% | -0.9% | -1.1% | -0.9% | -1.1% |
| Utah | Green River Drainage | -0.8% | -1.5% | -1.0% | -1.1% | -0.8% | -0.6% | -0.5% | -0.6% | -0.7% | -0.8% | -0.9% |
| | Main Stem Drainage | -0.7% | -1.2% | -0.7% | -1.5% | -0.6% | -0.9% | -0.6% | -0.6% | -0.8% | -0.6% | -0.8% |
| | San Juan Drainage | -0.6% | -1.4% | -1.0% | -1.1% | -0.6% | -0.7% | -0.4% | -0.6% | -0.8% | -1.0% | -0.8% |
| Colorado | Green River Drainage | -1.3% | -2.6% | -1.5% | -1.6% | -1.3% | -1.2% | -0.9% | -1.0% | -1.6% | -2.0% | -1.5% |
| | Main Stem Drainage | -1.3% | -2.4% | -1.3% | -2.2% | -1.3% | -1.6% | -1.0% | -1.3% | -1.5% | -1.9% | -1.6% |
| | San Juan Drainage | -1.4% | -4.4% | -1.1% | -2.2% | -1.0% | -1.7% | -0.8% | -1.4% | -1.3% | -1.6% | -1.7% |
| Arizona | San Juan drainage | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | -1.1% | -1.3% | -1.5% | -1.9% | -0.8% | -1.3% | -1.2% | -1.1% | -1.5% | -0.9% | -1.3% |
| | Virgin River Drainage | -0.6% | -0.3% | -0.7% | -0.3% | -0.4% | -0.3% | -0.1% | -0.3% | -0.6% | -0.4% | -0.4% |
| | Tributaries Above Lake Mead | -0.2% | -0.8% | -0.8% | -0.9% | -0.5% | -1.7% | -1.7% | -1.9% | -1.8% | -1.7% | -1.2% |
| | Tributaries Below Lake Mead | -0.1% | -0.4% | -0.5% | -0.2% | -0.2% | -0.2% | -0.1% | -0.2% | -0.5% | -0.3% | -0.3% |
| | Bill Williams River Drainage | -0.5% | -0.8% | -1.3% | -1.0% | -0.8% | -0.6% | -0.3% | -0.6% | -0.8% | -0.8% | -0.7% |
| | Gila River Drainage | -0.9% | -1.0% | -1.0% | -0.9% | -0.9% | -0.8% | -0.6% | -0.6% | -0.9% | -0.6% | -0.8% |
| Utah | Tributaries Above Lake Mead | -0.8% | -1.5% | -1.8% | -1.4% | -0.9% | -0.7% | -0.6% | -0.9% | -0.8% | -0.8% | -1.0% |
| | Virgin River Drainage | -0.5% | -0.7% | -1.0% | -0.7% | -0.5% | -0.4% | -0.3% | -0.4% | -0.5% | -0.6% | -0.6% |
| Nevada | Muddy River Drainage | -0.4% | -1.0% | -1.2% | -0.7% | -1.0% | -0.7% | -0.4% | -0.5% | -1.3% | -0.7% | -0.8% |
| | Virgin River Drainage | -0.3% | -1.0% | -1.3% | -0.7% | -1.0% | -0.7% | -0.4% | -0.5% | -1.3% | -0.7% | -0.8% |
| | Tributaries Above Lake Mead | -0.3% | -0.6% | -0.8% | -0.5% | -0.6% | -0.4% | -0.3% | -0.4% | -0.8% | -0.5% | -0.5% |

**Temperature: +0°F, Precipitation: +10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | -2.0% | -3.3% | -3.7% | -2.0% | -1.8% | -1.5% | -1.1% | -1.9% | -2.2% | -1.9% | -2.1% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | -1.6% | -2.9% | -2.0% | -2.2% | -1.6% | -1.2% | -1.0% | -1.2% | -1.5% | -1.7% | -1.7% |
| | Main Stem Drainage | -1.5% | -2.3% | -1.4% | -3.0% | -1.3% | -1.8% | -1.1% | -1.2% | -1.6% | -1.1% | -1.6% |
| | San Juan Drainage | -1.3% | -2.8% | -2.0% | -2.1% | -1.3% | -1.3% | -0.9% | -1.2% | -1.6% | -2.0% | -1.6% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | -2.5% | -5.2% | -3.1% | -3.1% | -2.6% | -2.4% | -1.7% | -1.9% | -3.1% | -4.0% | -3.0% |
| | Main Stem Drainage | -2.5% | -4.7% | -2.7% | -4.4% | -2.6% | -3.2% | -2.0% | -2.6% | -2.9% | -3.7% | -3.1% |
| | San Juan Drainage | -2.9% | -8.4% | -2.2% | -4.3% | -2.0% | -3.4% | -1.7% | -2.8% | -2.6% | -3.1% | -3.3% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | -2.1% | -2.5% | -3.1% | -3.8% | -1.5% | -2.6% | -2.3% | -2.2% | -3.0% | -1.9% | -2.5% |
| | Virgin River Drainage | -1.1% | -0.6% | -1.5% | -0.5% | -0.7% | -0.5% | -0.3% | -0.6% | -1.1% | -0.8% | -0.8% |
| | Tributaries Above Lake Mead | -0.4% | -1.6% | -1.6% | -1.8% | -0.9% | -3.5% | -3.3% | -3.8% | -3.6% | -3.4% | -2.4% |
| | Tributaries Below Lake Mead | -0.3% | -0.7% | -1.0% | -0.4% | -0.4% | -0.5% | -0.2% | -0.4% | -1.0% | -0.6% | -0.5% |
| | Bill Williams River Drainage | -0.9% | -1.5% | -2.5% | -2.0% | -1.5% | -1.2% | -0.7% | -1.2% | -1.5% | -1.5% | -1.5% |
| | Gila River Drainage | -1.8% | -2.0% | -1.9% | -1.7% | -1.7% | -1.5% | -1.2% | -1.2% | -1.7% | -1.3% | -1.6% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | -1.7% | -2.9% | -3.5% | -2.7% | -1.7% | -1.4% | -1.1% | -1.9% | -1.6% | -1.7% | -2.0% |
| | Virgin River Drainage | -0.9% | -1.4% | -2.1% | -1.3% | -0.9% | -0.8% | -0.6% | -0.8% | -1.1% | -1.1% | -1.1% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | -0.8% | -2.0% | -2.4% | -1.4% | -1.9% | -1.3% | -0.9% | -0.9% | -2.4% | -1.4% | -1.5% |
| | Virgin River Drainage | -0.7% | -2.0% | -2.6% | -1.4% | -1.9% | -1.3% | -0.9% | -1.0% | -2.4% | -1.5% | -1.6% |
| | Tributaries Above Lake Mead | -0.5% | -1.2% | -1.6% | -1.0% | -1.1% | -0.7% | -0.5% | -0.8% | -1.6% | -0.9% | -1.0% |

**Temperature: +1°F, Precipitation: -10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 8.1% | 10.1% | 11.2% | 8.8% | 8.3% | 7.8% | 6.9% | 8.4% | 8.8% | 8.5% | 8.7% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 7.2% | 9.0% | 7.9% | 8.7% | 7.0% | 6.7% | 6.1% | 6.7% | 7.5% | 7.7% | 7.5% |
| | Main Stem Drainage | 6.3% | 7.3% | 6.1% | 8.7% | 6.2% | 6.3% | 6.5% | 6.3% | 6.6% | 5.5% | 6.6% |
| | San Juan Drainage | 6.4% | 8.7% | 7.6% | 7.6% | 6.1% | 6.2% | 5.8% | 6.1% | 7.1% | 7.3% | 6.9% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 8.3% | 12.2% | 9.3% | 9.6% | 8.7% | 8.0% | 7.0% | 8.1% | 9.8% | 10.7% | 9.2% |
| | Main Stem Drainage | 8.3% | 11.6% | 8.9% | 11.7% | 8.3% | 9.5% | 7.7% | 8.8% | 9.6% | 10.1% | 9.4% |
| | San Juan Drainage | 8.8% | 17.8% | 7.8% | 12.1% | 7.4% | 9.7% | 7.0% | 9.0% | 10.4% | 9.4% | 9.9% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 3.6% | 3.9% | 3.6% | 4.0% | 3.5% | 3.5% | 3.9% | 3.6% | 3.9% | 3.8% | 3.7% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 7.7% | 8.4% | 8.9% | 10.6% | 6.3% | 7.8% | 7.6% | 7.3% | 8.6% | 7.1% | 8.0% |
| | Virgin River Drainage | 4.5% | 3.8% | 5.0% | 3.7% | 4.0% | 4.3% | 3.3% | 3.6% | 4.5% | 4.0% | 4.1% |
| | Tributaries Above Lake Mead | 4.2% | 6.5% | 6.4% | 6.5% | 4.6% | 9.3% | 10.3% | 10.1% | 10.0% | 10.5% | 7.8% |
| | Tributaries Below Lake Mead | 1.5% | 2.0% | 2.4% | 1.8% | 1.7% | 1.8% | 1.5% | 1.8% | 2.4% | 1.9% | 1.9% |
| | Bill Williams River Drainage | 3.9% | 4.5% | 6.1% | 5.7% | 4.4% | 4.0% | 4.1% | 4.0% | 4.5% | 4.6% | 4.6% |
| | Gila River Drainage | 4.4% | 4.7% | 4.5% | 4.7% | 4.2% | 3.8% | 3.5% | 3.5% | 4.0% | 3.6% | 4.1% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 6.0% | 9.6% | 8.6% | 8.0% | 6.1% | 5.5% | 5.5% | 6.4% | 6.3% | 6.1% | 6.8% |
| | Virgin River Drainage | 4.4% | 5.8% | 6.0% | 5.2% | 4.8% | 4.5% | 4.3% | 4.3% | 4.7% | 4.9% | 4.9% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 5.9% | 7.2% | 8.3% | 6.6% | 7.1% | 5.7% | 6.1% | 5.1% | 7.8% | 6.6% | 6.6% |
| | Virgin River Drainage | 5.9% | 8.0% | 8.6% | 6.6% | 8.5% | 5.8% | 6.0% | 5.1% | 7.8% | 6.6% | 6.9% |
| | Tributaries Above Lake Mead | 4.6% | 5.7% | 6.2% | 5.2% | 5.9% | 4.4% | 4.6% | 4.5% | 5.9% | 5.0% | 5.2% |

**Temperature: +1°F, Precipitation: +10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 3.8% | 3.4% | 3.1% | 4.5% | 4.5% | 4.6% | 4.5% | 4.5% | 4.1% | 4.4% | 4.1% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 3.8% | 2.8% | 3.5% | 4.0% | 3.7% | 4.2% | 3.9% | 4.2% | 4.3% | 4.2% | 3.9% |
| | Main Stem Drainage | 3.2% | 2.5% | 3.1% | 2.5% | 3.4% | 2.6% | 4.2% | 3.7% | 3.3% | 3.1% | 3.2% |
| | San Juan Drainage | 3.7% | 2.7% | 3.3% | 3.2% | 3.4% | 3.4% | 4.0% | 3.5% | 3.7% | 3.2% | 3.4% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 2.9% | 1.1% | 2.8% | 3.1% | 3.2% | 3.0% | 3.4% | 4.0% | 3.0% | 2.4% | 2.9% |
| | Main Stem Drainage | 3.0% | 1.6% | 3.2% | 2.4% | 3.0% | 2.9% | 3.5% | 3.2% | 3.3% | 2.3% | 2.8% |
| | San Juan Drainage | 2.8% | -0.7% | 3.1% | 2.9% | 3.2% | 2.7% | 3.4% | 3.2% | 4.7% | 2.4% | 2.8% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 3.6% | 3.9% | 3.6% | 3.9% | 3.5% | 3.4% | 3.9% | 3.6% | 3.9% | 3.7% | 3.7% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 3.3% | 3.2% | 2.3% | 2.9% | 3.1% | 2.4% | 2.8% | 2.9% | 2.3% | 3.3% | 2.8% |
| | Virgin River Drainage | 2.2% | 2.5% | 2.0% | 2.6% | 2.5% | 3.1% | 2.7% | 2.4% | 2.0% | 2.4% | 2.4% |
| | Tributaries Above Lake Mead | 3.4% | 3.2% | 3.0% | 2.8% | 2.6% | 2.2% | 3.1% | 2.3% | 2.6% | 3.4% | 2.8% |
| | Tributaries Below Lake Mead | 1.0% | 0.6% | 0.4% | 0.9% | 1.0% | 0.8% | 1.1% | 0.9% | 0.4% | 0.8% | 0.8% |
| | Bill Williams River Drainage | 2.0% | 1.4% | 0.8% | 1.5% | 1.2% | 1.6% | 2.5% | 1.5% | 1.3% | 1.4% | 1.5% |
| | Gila River Drainage | 0.8% | 0.6% | 0.5% | 1.0% | 0.7% | 0.7% | 1.1% | 1.0% | 0.6% | 0.9% | 0.8% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 2.5% | 2.8% | 1.3% | 2.4% | 2.4% | 2.6% | 3.2% | 2.5% | 2.7% | 2.6% | 2.5% |
| | Virgin River Drainage | 2.5% | 2.7% | 1.8% | 2.6% | 2.8% | 2.8% | 3.0% | 2.7% | 2.5% | 2.6% | 2.6% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 4.2% | 3.1% | 3.2% | 3.7% | 3.1% | 3.0% | 4.2% | 3.0% | 2.7% | 3.4% | 3.4% |
| | Virgin River Drainage | 4.2% | 3.6% | 3.1% | 3.7% | 4.5% | 2.9% | 4.2% | 3.0% | 2.6% | 3.4% | 3.5% |
| | Tributaries Above Lake Mead | 3.5% | 3.1% | 2.8% | 3.1% | 3.6% | 2.8% | 3.5% | 2.7% | 2.5% | 3.0% | 3.1% |

**Temperature: +2°F, Precipitation: -10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 14.3% | 17.1% | 18.9% | 15.9% | 15.2% | 10.3% | 8.7% | 11.4% | 12.5% | 11.7% | 13.6% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 12.9% | 15.5% | 13.7% | 15.3% | 12.8% | 8.6% | 7.8% | 8.6% | 10.1% | 10.4% | 11.6% |
| | Main Stem Drainage | 11.3% | 12.2% | 10.9% | 14.5% | 11.1% | 9.1% | 8.3% | 8.3% | 9.2% | 7.3% | 10.2% |
| | San Juan Drainage | 11.6% | 15.1% | 13.2% | 13.8% | 10.9% | 8.3% | 7.3% | 8.1% | 9.8% | 10.5% | 10.9% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 14.3% | 19.4% | 15.7% | 17.0% | 14.9% | 11.8% | 9.8% | 11.2% | 15.1% | 17.2% | 14.6% |
| | Main Stem Drainage | 14.3% | 18.5% | 14.9% | 19.0% | 14.1% | 14.6% | 11.0% | 13.2% | 14.6% | 16.3% | 15.0% |
| | San Juan Drainage | 14.8% | 26.7% | 13.3% | 19.5% | 12.8% | 15.3% | 11.1% | 13.4% | 16.9% | 15.1% | 15.9% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 7.3% | 7.8% | 7.3% | 8.0% | 7.0% | 7.0% | 7.7% | 7.3% | 7.8% | 7.7% | 7.5% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 13.1% | 14.1% | 14.8% | 18.9% | 10.8% | 13.3% | 13.1% | 12.4% | 14.3% | 12.3% | 13.7% |
| | Virgin River Drainage | 7.9% | 7.0% | 8.5% | 6.9% | 7.2% | 7.3% | 6.3% | 6.7% | 7.8% | 7.3% | 7.3% |
| | Tributaries Above Lake Mead | 8.7% | 11.0% | 10.9% | 11.2% | 8.7% | 16.2% | 16.9% | 16.2% | 16.3% | 17.1% | 13.3% |
| | Tributaries Below Lake Mead | 2.8% | 3.3% | 3.8% | 3.1% | 3.1% | 3.1% | 2.8% | 3.1% | 3.8% | 3.3% | 3.2% |
| | Bill Williams River Drainage | 6.7% | 7.5% | 9.7% | 9.0% | 7.3% | 6.8% | 6.9% | 6.8% | 7.3% | 7.5% | 7.6% |
| | Gila River Drainage | 7.2% | 7.6% | 7.3% | 7.7% | 6.7% | 6.1% | 6.0% | 6.0% | 6.5% | 6.1% | 6.7% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 10.4% | 15.8% | 13.7% | 13.1% | 10.3% | 9.9% | 9.9% | 11.2% | 10.9% | 10.4% | 11.6% |
| | Virgin River Drainage | 8.0% | 9.9% | 10.0% | 9.1% | 8.5% | 8.2% | 8.1% | 7.9% | 8.4% | 8.9% | 8.7% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 10.9% | 12.9% | 14.3% | 11.8% | 12.2% | 10.3% | 10.9% | 9.4% | 13.8% | 11.6% | 11.8% |
| | Virgin River Drainage | 11.0% | 13.9% | 14.6% | 11.8% | 13.7% | 10.3% | 10.9% | 9.5% | 13.8% | 11.7% | 12.1% |
| | Tributaries Above Lake Mead | 8.7% | 10.3% | 10.8% | 9.4% | 10.0% | 8.2% | 8.5% | 8.2% | 10.5% | 9.1% | 9.4% |

**Temperature: +2°F, Precipitation: +10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 9.8% | 10.1% | 10.2% | 11.4% | 11.2% | 10.9% | 10.3% | 11.0% | 10.9% | 10.8% | 10.7% |
| Utah | Green River Drainage | 9.3% | 8.8% | 9.2% | 10.4% | 9.4% | 9.9% | 8.9% | 10.0% | 10.1% | 10.2% | 9.6% |
| | Main Stem Drainage | 8.1% | 7.3% | 7.8% | 8.1% | 8.2% | 7.0% | 9.2% | 8.8% | 8.1% | 7.5% | 8.0% |
| | San Juan Drainage | 8.8% | 9.0% | 8.8% | 9.2% | 8.1% | 8.2% | 8.8% | 8.4% | 9.1% | 8.4% | 8.7% |
| Colorado | Green River Drainage | 8.6% | 7.8% | 8.9% | 10.2% | 9.2% | 8.6% | 8.5% | 10.0% | 9.8% | 8.9% | 9.0% |
| | Main Stem Drainage | 8.7% | 8.1% | 9.1% | 9.5% | 8.7% | 9.1% | 9.2% | 9.2% | 9.6% | 8.6% | 9.0% |
| | San Juan Drainage | 8.6% | 7.6% | 8.5% | 9.8% | 8.5% | 8.8% | 8.8% | 9.2% | 11.3% | 8.1% | 8.9% |
| Arizona | San Juan drainage | 7.2% | 7.7% | 7.3% | 8.0% | 6.9% | 7.0% | 7.7% | 7.3% | 7.7% | 7.7% | 7.5% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 8.5% | 8.8% | 8.0% | 11.0% | 7.5% | 7.8% | 8.1% | 7.9% | 7.8% | 8.3% | 8.4% |
| | Virgin River Drainage | 5.6% | 5.7% | 5.5% | 5.8% | 5.7% | 6.1% | 5.8% | 5.4% | 5.3% | 5.6% | 5.7% |
| | Tributaries Above Lake Mead | 8.0% | 7.7% | 7.4% | 7.6% | 6.6% | 8.8% | 9.5% | 8.3% | 8.7% | 9.7% | 8.2% |
| | Tributaries Below Lake Mead | 2.2% | 1.9% | 1.7% | 2.2% | 2.3% | 2.1% | 2.4% | 2.2% | 1.7% | 2.1% | 2.1% |
| | Bill Williams River Drainage | 4.9% | 4.4% | 4.2% | 4.8% | 4.1% | 4.4% | 5.3% | 4.2% | 4.1% | 4.3% | 4.5% |
| | Gila River Drainage | 3.5% | 3.4% | 3.3% | 3.9% | 3.2% | 3.0% | 3.6% | 3.4% | 3.0% | 3.4% | 3.4% |
| Utah | Tributaries Above Lake Mead | 6.8% | 8.6% | 6.2% | 7.3% | 6.6% | 6.8% | 7.5% | 7.1% | 7.1% | 6.8% | 7.1% |
| | Virgin River Drainage | 6.1% | 6.7% | 5.7% | 6.4% | 6.4% | 6.4% | 6.8% | 6.2% | 6.1% | 6.5% | 6.3% |
| Nevada | Muddy River Drainage | 9.2% | 8.7% | 9.0% | 8.8% | 8.1% | 7.4% | 9.0% | 7.2% | 8.4% | 8.3% | 8.4% |
| | Virgin River Drainage | 9.1% | 9.3% | 9.0% | 8.8% | 9.5% | 7.3% | 9.0% | 7.2% | 8.3% | 8.4% | 8.6% |
| | Tributaries Above Lake Mead | 7.4% | 7.5% | 7.4% | 7.3% | 7.6% | 6.5% | 7.4% | 6.3% | 6.9% | 7.0% | 7.1% |

**Temperature: +3°F, Precipitation: -10%**

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 20.8% | 24.2% | 27.2% | 23.2% | 22.6% | 20.6% | 19.1% | 21.7% | 23.1% | 22.2% | 22.5% |
| Utah | Green River Drainage | 18.9% | 22.3% | 19.8% | 22.2% | 19.0% | 18.3% | 16.5% | 18.4% | 19.6% | 20.2% | 19.5% |
| | Main Stem Drainage | 16.3% | 17.3% | 15.7% | 20.4% | 16.4% | 15.4% | 16.9% | 16.7% | 16.6% | 14.5% | 16.6% |
| | San Juan Drainage | 17.0% | 21.7% | 19.1% | 19.9% | 15.7% | 16.1% | 15.7% | 16.2% | 18.0% | 18.3% | 17.8% |
| Colorado | Green River Drainage | 20.4% | 26.6% | 22.1% | 24.2% | 21.1% | 19.6% | 17.6% | 20.4% | 24.1% | 24.5% | 22.1% |
| | Main Stem Drainage | 20.3% | 25.6% | 21.0% | 27.2% | 20.1% | 22.6% | 19.4% | 21.3% | 22.9% | 23.4% | 22.4% |
| | San Juan Drainage | 21.0% | 35.8% | 19.0% | 27.5% | 18.2% | 22.7% | 17.9% | 21.3% | 25.7% | 21.9% | 23.1% |
| Arizona | San Juan drainage | 11.1% | 11.5% | 10.8% | 12.0% | 10.6% | 10.5% | 11.5% | 11.0% | 11.7% | 11.6% | 11.2% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 18.9% | 20.3% | 20.6% | 25.8% | 15.7% | 18.8% | 18.5% | 17.7% | 20.1% | 17.6% | 19.4% |
| | Virgin River Drainage | 11.4% | 10.2% | 12.1% | 10.2% | 10.6% | 10.7% | 9.4% | 9.8% | 11.2% | 10.7% | 10.6% |
| | Tributaries Above Lake Mead | 12.2% | 15.5% | 15.9% | 16.2% | 13.2% | 22.8% | 23.6% | 22.6% | 24.0% | 24.0% | 19.0% |
| | Tributaries Below Lake Mead | 4.0% | 4.6% | 5.2% | 4.4% | 4.5% | 4.4% | 4.1% | 4.4% | 5.1% | 4.7% | 4.5% |
| | Bill Williams River Drainage | 9.6% | 10.5% | 13.5% | 13.9% | 10.2% | 9.7% | 9.8% | 9.6% | 10.2% | 10.6% | 10.8% |
| | Gila River Drainage | 10.0% | 10.5% | 10.2% | 11.0% | 9.3% | 8.5% | 8.5% | 8.3% | 8.9% | 8.6% | 9.4% |
| Utah | Tributaries Above Lake Mead | 14.9% | 22.2% | 18.9% | 19.6% | 14.8% | 14.4% | 14.9% | 15.8% | 15.5% | 15.3% | 16.6% |
| | Virgin River Drainage | 11.6% | 14.0% | 14.1% | 13.3% | 12.1% | 11.9% | 12.3% | 11.6% | 12.2% | 12.8% | 12.6% |
| Nevada | Muddy River Drainage | 15.8% | 18.9% | 20.3% | 17.1% | 17.2% | 15.2% | 15.7% | 13.9% | 20.4% | 16.7% | 17.1% |
| | Virgin River Drainage | 16.0% | 20.1% | 20.7% | 17.2% | 18.7% | 15.5% | 15.7% | 13.9% | 20.3% | 17.0% | 17.5% |
| | Tributaries Above Lake Mead | 12.8% | 14.9% | 15.5% | 13.7% | 14.1% | 12.2% | 12.5% | 12.0% | 15.3% | 13.3% | 13.6% |

## Temperature: +3°F, Precipitation: +10%

**Upper Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wyoming | Green River Drainage | 16.1% | 17.1% | 18.0% | 18.4% | 18.3% | 17.2% | 16.4% | 17.5% | 17.8% | 17.6% | 17.4% |
| Utah | Green River Drainage | 15.2% | 15.3% | 15.1% | 17.0% | 15.3% | 15.6% | 14.1% | 15.7% | 16.1% | 16.5% | 15.6% |
| | Main Stem Drainage | 13.0% | 12.3% | 12.5% | 13.9% | 13.3% | 11.5% | 14.5% | 13.9% | 13.1% | 11.9% | 13.0% |
| | San Juan Drainage | 14.0% | 15.5% | 14.6% | 15.2% | 12.8% | 13.1% | 13.8% | 13.4% | 14.4% | 13.9% | 14.1% |
| Colorado | Green River Drainage | 14.5% | 14.5% | 15.2% | 17.1% | 15.2% | 14.3% | 13.8% | 16.1% | 16.7% | 15.5% | 15.3% |
| | Main Stem Drainage | 14.6% | 14.9% | 14.9% | 17.3% | 14.5% | 15.5% | 14.9% | 15.3% | 16.1% | 15.0% | 15.3% |
| | San Juan Drainage | 14.6% | 16.1% | 14.0% | 17.4% | 13.8% | 15.2% | 14.0% | 15.3% | 18.4% | 14.1% | 15.3% |
| Arizona | San Juan drainage | 11.0% | 11.5% | 10.8% | 11.9% | 10.6% | 10.5% | 11.5% | 11.0% | 11.6% | 11.6% | 11.2% |

**Lower Basin**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arizona | Little Colorado River Drainage | 14.2% | 14.9% | 13.6% | 17.8% | 12.1% | 13.1% | 13.4% | 13.0% | 13.3% | 13.5% | 13.9% |
| | Virgin River Drainage | 9.1% | 9.0% | 9.1% | 9.1% | 9.1% | 9.5% | 8.8% | 8.5% | 8.6% | 8.9% | 9.0% |
| | Tributaries Above Lake Mead | 11.4% | 12.1% | 12.3% | 12.5% | 10.9% | 15.2% | 15.9% | 14.5% | 15.4% | 16.4% | 13.7% |
| | Tributaries Below Lake Mead | 3.5% | 3.2% | 3.1% | 3.5% | 3.7% | 3.4% | 3.7% | 3.5% | 3.1% | 3.5% | 3.4% |
| | Bill Williams River Drainage | 7.7% | 7.3% | 7.9% | 9.6% | 6.9% | 7.3% | 8.2% | 7.0% | 6.9% | 7.4% | 7.6% |
| | Gila River Drainage | 6.3% | 6.3% | 6.2% | 7.0% | 5.7% | 5.3% | 6.1% | 5.7% | 5.4% | 5.8% | 6.0% |
| Utah | Tributaries Above Lake Mead | 11.2% | 14.4% | 11.3% | 13.6% | 11.0% | 11.1% | 12.2% | 11.5% | 11.5% | 11.5% | 11.9% |
| | Virgin River Drainage | 9.6% | 10.7% | 9.7% | 10.6% | 10.0% | 10.1% | 10.9% | 9.8% | 9.9% | 10.4% | 10.2% |
| Nevada | Muddy River Drainage | 14.0% | 14.6% | 14.8% | 14.0% | 13.1% | 12.2% | 13.8% | 11.6% | 14.8% | 13.4% | 13.6% |
| | Virgin River Drainage | 14.1% | 15.4% | 14.9% | 14.1% | 14.5% | 12.3% | 13.8% | 11.6% | 14.7% | 13.5% | 13.9% |
| | Tributaries Above Lake Mead | 11.4% | 12.1% | 11.9% | 11.6% | 11.6% | 10.5% | 11.3% | 10.1% | 11.7% | 11.1% | 11.3% |

## Temperature: +4°F, Precipitation: -10%

| Upper Basin | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Wyoming | Green River Drainage | 27.5% | 31.5% | 35.7% | 30.7% | 30.1% | 27.4% | 25.4% | 28.4% | 30.6% | 29.2% | 29.6% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 25.2% | 29.5% | 26.1% | 29.3% | 25.2% | 24.4% | 21.9% | 24.7% | 25.8% | 26.7% | 25.9% |
| | Main Stem Drainage | 21.5% | 22.3% | 20.7% | 26.6% | 21.5% | 20.2% | 22.3% | 21.9% | 22.0% | 19.2% | 21.8% |
| | San Juan Drainage | 22.5% | 28.3% | 25.2% | 26.6% | 20.8% | 21.2% | 20.8% | 21.3% | 23.9% | 24.0% | 23.5% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 26.8% | 34.2% | 28.8% | 31.5% | 27.5% | 25.5% | 23.2% | 26.7% | 31.6% | 31.6% | 28.7% |
| | Main Stem Drainage | 26.6% | 33.2% | 27.1% | 35.0% | 26.2% | 29.3% | 25.3% | 27.6% | 29.7% | 30.2% | 29.0% |
| | San Juan Drainage | 27.6% | 45.7% | 25.2% | 35.9% | 23.9% | 29.3% | 24.1% | 27.8% | 34.8% | 28.6% | 30.3% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 14.8% | 15.6% | 14.6% | 15.8% | 14.2% | 14.2% | 15.2% | 14.8% | 16.1% | 15.6% | 15.1% |

| Lower Basin | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 24.6% | 26.3% | 26.9% | 32.6% | 20.4% | 24.4% | 24.0% | 23.1% | 26.4% | 23.4% | 25.2% |
| | Virgin River Drainage | 15.0% | 13.5% | 15.7% | 13.5% | 13.9% | 13.8% | 12.6% | 13.0% | 14.7% | 14.0% | 14.0% |
| | Tributaries Above Lake Mead | 17.1% | 20.2% | 20.9% | 21.1% | 17.3% | 29.2% | 30.2% | 29.1% | 30.8% | 30.8% | 24.7% |
| | Tributaries Below Lake Mead | 5.2% | 5.9% | 6.6% | 5.7% | 5.8% | 5.7% | 5.4% | 5.7% | 6.5% | 6.1% | 5.9% |
| | Bill Williams River Drainage | 12.6% | 13.5% | 19.5% | 17.2% | 13.3% | 12.6% | 12.8% | 12.5% | 13.2% | 13.8% | 14.1% |
| | Gila River Drainage | 12.9% | 13.5% | 13.3% | 14.1% | 11.9% | 11.0% | 10.9% | 10.7% | 11.5% | 11.0% | 12.1% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 19.7% | 28.5% | 24.4% | 25.3% | 19.2% | 18.9% | 19.6% | 20.8% | 20.5% | 20.2% | 21.7% |
| | Virgin River Drainage | 15.2% | 18.1% | 18.2% | 17.5% | 15.8% | 15.9% | 16.0% | 15.4% | 16.0% | 16.8% | 16.5% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 21.0% | 24.9% | 26.7% | 22.3% | 22.7% | 20.2% | 20.7% | 19.2% | 27.5% | 22.0% | 22.7% |
| | Virgin River Drainage | 21.4% | 26.3% | 27.2% | 22.5% | 24.2% | 20.5% | 20.8% | 19.3% | 27.2% | 22.3% | 23.2% |
| | Tributaries Above Lake Mead | 17.0% | 19.6% | 20.4% | 18.0% | 18.4% | 16.3% | 16.5% | 16.3% | 20.4% | 17.6% | 18.1% |

**Temperature: +4°F, Precipitation: +10%**

| State | Drainage | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Basin** | | | | | | | | | | | | |
| Wyoming | Green River Drainage | 22.6% | 24.2% | 26.0% | 25.7% | 25.4% | 23.8% | 22.5% | 24.2% | 25.0% | 24.4% | 24.4% |
| Utah | Green River Drainage | 21.3% | 22.1% | 21.3% | 24.0% | 21.2% | 21.6% | 19.3% | 21.9% | 22.1% | 22.7% | 21.8% |
| | Main Stem Drainage | 18.0% | 17.2% | 17.4% | 19.9% | 18.4% | 16.2% | 19.8% | 19.1% | 18.3% | 16.5% | 18.1% |
| | San Juan Drainage | 19.5% | 21.9% | 20.5% | 21.8% | 17.8% | 18.1% | 18.8% | 18.5% | 20.1% | 19.5% | 19.7% |
| Colorado | Green River Drainage | 20.6% | 21.7% | 21.6% | 24.2% | 21.5% | 20.0% | 19.2% | 22.2% | 23.9% | 22.3% | 21.7% |
| | Main Stem Drainage | 20.7% | 22.1% | 20.9% | 24.8% | 20.4% | 22.1% | 20.7% | 21.5% | 22.7% | 21.6% | 21.7% |
| | San Juan Drainage | 21.0% | 25.4% | 19.8% | 25.3% | 19.4% | 21.5% | 19.7% | 21.7% | 26.7% | 20.5% | 22.1% |
| Arizona | San Juan drainage | 14.7% | 15.5% | 14.6% | 15.7% | 14.2% | 14.2% | 15.2% | 14.8% | 16.1% | 15.5% | 15.1% |
| **Lower Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 19.9% | 20.8% | 19.6% | 24.6% | 16.7% | 18.6% | 18.9% | 18.3% | 19.3% | 19.2% | 19.6% |
| | Virgin River Drainage | 12.6% | 12.2% | 12.7% | 12.4% | 12.4% | 12.6% | 12.0% | 11.7% | 12.0% | 12.3% | 12.3% |
| | Tributaries Above Lake Mead | 16.2% | 16.8% | 17.2% | 17.3% | 15.0% | 21.4% | 22.4% | 20.8% | 21.9% | 22.9% | 19.2% |
| | Tributaries Below Lake Mead | 4.7% | 4.5% | 4.5% | 4.8% | 5.0% | 4.7% | 5.0% | 4.8% | 4.5% | 4.9% | 4.7% |
| | Bill Williams River Drainage | 10.7% | 10.2% | 13.7% | 12.9% | 9.9% | 10.1% | 11.2% | 9.8% | 9.7% | 10.5% | 10.9% |
| | Gila River Drainage | 9.1% | 9.2% | 9.1% | 9.9% | 8.1% | 7.7% | 8.5% | 8.1% | 7.8% | 8.2% | 8.6% |
| Utah | Tributaries Above Lake Mead | 15.8% | 20.0% | 16.4% | 19.2% | 15.4% | 15.5% | 16.7% | 16.3% | 16.2% | 16.4% | 16.8% |
| | Virgin River Drainage | 13.2% | 14.6% | 13.8% | 14.6% | 13.7% | 14.1% | 14.6% | 13.5% | 13.6% | 14.3% | 14.0% |
| Nevada | Muddy River Drainage | 19.1% | 20.5% | 20.9% | 19.1% | 18.4% | 17.1% | 18.8% | 16.8% | 21.8% | 18.5% | 19.1% |
| | Virgin River Drainage | 19.3% | 21.5% | 21.0% | 19.4% | 19.9% | 17.2% | 18.8% | 16.8% | 21.6% | 18.7% | 19.4% |
| | Tributaries Above Lake Mead | 15.6% | 16.8% | 16.6% | 15.8% | 15.9% | 14.5% | 15.4% | 14.3% | 16.7% | 15.3% | 15.7% |

**Temperature: +5°F, Precipitation: -10%**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Upper Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Wyoming | Green River Drainage | 34.6% | 38.9% | 44.4% | 38.4% | 37.7% | 34.3% | 32.0% | 35.5% | 38.4% | 36.5% | 37.1% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 31.6% | 37.6% | 32.8% | 36.9% | 31.6% | 30.7% | 28.2% | 32.0% | 32.2% | 33.8% | 32.8% |
| | Main Stem Drainage | 26.7% | 28.2% | 25.9% | 32.4% | 26.9% | 25.0% | 27.7% | 27.3% | 28.7% | 23.8% | 27.3% |
| | San Juan Drainage | 28.3% | 35.1% | 31.6% | 33.8% | 26.0% | 26.6% | 26.1% | 26.6% | 30.1% | 29.8% | 29.4% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 33.3% | 42.0% | 35.8% | 39.4% | 34.0% | 31.7% | 28.8% | 33.2% | 39.2% | 39.0% | 35.6% |
| | Main Stem Drainage | 33.0% | 40.9% | 33.6% | 43.7% | 32.3% | 36.2% | 31.4% | 34.1% | 36.7% | 37.3% | 35.9% |
| | San Juan Drainage | 34.5% | 55.7% | 31.4% | 44.6% | 29.2% | 36.1% | 30.3% | 34.3% | 43.8% | 35.5% | 37.5% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 18.6% | 19.4% | 18.4% | 21.5% | 17.3% | 18.0% | 19.1% | 18.9% | 20.1% | 19.5% | 19.1% |
| | | | | | | | | | | | | |
| **Lower Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 31.1% | 32.6% | 33.4% | 39.9% | 25.5% | 30.1% | 29.8% | 29.0% | 32.7% | 29.0% | 31.3% |
| | Virgin River Drainage | 18.6% | 16.9% | 19.4% | 16.9% | 17.4% | 17.4% | 15.8% | 16.2% | 18.2% | 17.5% | 17.4% |
| | Tributaries Above Lake Mead | 20.7% | 25.0% | 25.9% | 26.0% | 21.4% | 36.3% | 37.0% | 36.1% | 38.3% | 38.1% | 30.5% |
| | Tributaries Below Lake Mead | 6.5% | 7.2% | 7.9% | 7.0% | 7.2% | 7.0% | 6.7% | 7.0% | 7.9% | 7.4% | 7.2% |
| | Bill Williams River Drainage | 15.9% | 16.5% | 23.3% | 20.6% | 16.5% | 15.6% | 15.7% | 15.5% | 16.2% | 17.0% | 17.3% |
| | Gila River Drainage | 15.9% | 16.6% | 16.4% | 17.6% | 14.6% | 13.4% | 13.4% | 13.2% | 14.0% | 13.5% | 14.8% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 24.5% | 34.8% | 29.7% | 31.0% | 23.8% | 23.5% | 24.6% | 25.8% | 25.9% | 25.2% | 26.9% |
| | Virgin River Drainage | 18.9% | 22.2% | 22.4% | 21.6% | 19.5% | 19.8% | 19.9% | 19.3% | 19.9% | 20.8% | 20.4% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 26.4% | 30.7% | 33.1% | 27.8% | 27.8% | 25.2% | 26.0% | 23.9% | 33.5% | 27.3% | 28.2% |
| | Virgin River Drainage | 27.0% | 32.3% | 33.7% | 28.2% | 29.6% | 25.6% | 26.0% | 24.1% | 33.3% | 27.8% | 28.8% |
| | Tributaries Above Lake Mead | 21.4% | 24.3% | 25.3% | 22.5% | 22.6% | 20.4% | 20.7% | 20.3% | 25.1% | 21.9% | 22.5% |

**Temperature: +5°F, Precipitation: +10%**

| Upper Basin | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Wyoming | Green River Drainage | 29.4% | 31.5% | 34.4% | 33.3% | 32.8% | 30.6% | 28.9% | 31.1% | 32.5% | 31.5% | 31.6% |
| | | | | | | | | | | | | |
| Utah | Green River Drainage | 27.5% | 29.8% | 27.9% | 31.5% | 27.5% | 27.9% | 25.5% | 29.1% | 28.3% | 29.7% | 28.5% |
| | Main Stem Drainage | 23.1% | 22.8% | 22.4% | 25.6% | 23.6% | 20.9% | 25.2% | 24.4% | 24.8% | 21.0% | 23.4% |
| | San Juan Drainage | 25.1% | 28.5% | 26.7% | 28.8% | 22.8% | 23.4% | 24.0% | 23.7% | 26.2% | 25.2% | 25.4% |
| | | | | | | | | | | | | |
| Colorado | Green River Drainage | 26.8% | 28.9% | 28.3% | 31.8% | 27.8% | 26.0% | 24.7% | 28.6% | 31.3% | 29.3% | 28.4% |
| | Main Stem Drainage | 26.9% | 29.5% | 27.1% | 33.1% | 26.3% | 28.7% | 26.6% | 27.8% | 29.4% | 28.3% | 28.4% |
| | San Juan Drainage | 27.5% | 34.9% | 25.7% | 33.5% | 24.5% | 28.0% | 25.2% | 28.0% | 34.9% | 27.1% | 28.9% |
| | | | | | | | | | | | | |
| Arizona | San Juan drainage | 18.6% | 19.4% | 18.4% | 21.4% | 17.3% | 17.9% | 19.1% | 18.8% | 20.0% | 19.5% | 19.1% |
| | | | | | | | | | | | | |
| **Lower Basin** | | | | | | | | | | | | |
| **State** | **Drainage** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **Average** |
| Arizona | Little Colorado River Drainage | 26.2% | 27.0% | 25.9% | 31.7% | 21.5% | 24.2% | 24.5% | 24.0% | 25.3% | 24.7% | 25.5% |
| | Virgin River Drainage | 16.2% | 15.6% | 16.4% | 15.7% | 15.8% | 16.2% | 15.2% | 14.9% | 15.4% | 15.7% | 15.7% |
| | Tributaries Above Lake Mead | 19.9% | 21.6% | 22.1% | 22.2% | 19.1% | 28.2% | 29.0% | 27.5% | 28.5% | 29.9% | 24.8% |
| | Tributaries Below Lake Mead | 6.0% | 5.8% | 5.8% | 6.1% | 6.4% | 6.0% | 6.3% | 6.1% | 5.8% | 6.2% | 6.1% |
| | Bill Williams River Drainage | 13.9% | 13.2% | 17.4% | 16.3% | 13.0% | 13.1% | 14.0% | 12.8% | 12.6% | 13.7% | 14.0% |
| | Gila River Drainage | 12.1% | 12.2% | 12.1% | 13.2% | 10.8% | 10.2% | 10.9% | 10.5% | 10.3% | 10.7% | 11.3% |
| | | | | | | | | | | | | |
| Utah | Tributaries Above Lake Mead | 20.5% | 25.7% | 21.5% | 24.8% | 19.8% | 19.9% | 21.5% | 21.2% | 21.2% | 21.2% | 21.7% |
| | Virgin River Drainage | 16.9% | 18.7% | 17.9% | 18.8% | 17.4% | 17.9% | 18.4% | 17.4% | 17.4% | 18.2% | 17.9% |
| | | | | | | | | | | | | |
| Nevada | Muddy River Drainage | 24.5% | 26.2% | 27.1% | 24.6% | 23.5% | 22.0% | 24.0% | 21.4% | 27.8% | 23.8% | 24.5% |
| | Virgin River Drainage | 24.9% | 27.5% | 27.3% | 24.9% | 25.2% | 22.2% | 24.0% | 21.4% | 27.5% | 24.1% | 24.9% |
| | Tributaries Above Lake Mead | 20.0% | 21.4% | 21.5% | 20.3% | 20.1% | 18.6% | 19.5% | 18.3% | 21.4% | 19.6% | 20.0% |

# Appendix C5
# Modeling of Lower Basin Tributaries in the Colorado River Simulation System

# Contents



## Figures

# Appendix C5—Modeling of Lower Basin Tributaries in the Colorado River Simulation System

## 1.0 Overview

The Colorado River Simulation System (CRSS) is the primary modeling tool used in Reclamation's long-term planning studies for the Colorado River Basin (Basin) and is the primary modeling tool for this Study. CRSS simulates the operation of the major Colorado River system reservoirs on a monthly time step and provides information regarding the projected future state of the system in terms of output variables, which include the amount of water in storage, reservoir elevations, releases from the dams, diversions to and return flows from the water users, and the amount of water flowing at various points throughout the system. Major inputs to the model include projected natural flows[1] at 29 locations throughout the Basin (20 in the Upper Basin upstream of and including the Lees Ferry gaging station in Arizona, and nine below Lees Ferry, including the Paria River and inflow points in the Lower Basin[2]). For four of the inflow points below Lees Ferry (the Paria, Little Colorado, Virgin, and Bill Williams Rivers), CRSS uses historical inflows (not natural flows) based on U.S. Geological Survey (USGS) streamflow records. In addition, the Gila River is not included in CRSS.

Many Colorado River planning studies have been completed over the past two decades where this treatment of the major Lower Basin tributaries was used; however, questions regarding the adequacy of the treatment of the Lower Basin tributaries in CRSS for this Study arose during the phases focused on assessing future water supply and demand. Although some limitations will be imposed on the Study by this treatment, through other approaches the Study will be able to examine several important issues including potential climate change impacts on the tributaries represented in CRSS, future demand scenarios on those tributaries, and future demand scenarios for the Colorado River from the Gila River Basin factoring in other water supplies within that basin (see subsequent discussions in Sections 3.1 and 4.1).

This appendix provides technical information regarding the treatment of the Lower Basin tributaries in CRSS, including the availability of the data and information necessary to compute natural flows. Additionally, three commitments are made to engage in efforts independent of this Study: 1) to resolve and correct, in collaboration with the Basin States, the methodological and data inconsistencies in Reclamation's Consumptive Uses and Losses Reports pertaining to all of the Lower Basin tributaries; 2) to develop natural flows for the Little Colorado, Virgin, and Bill Williams Rivers and to modify CRSS to use natural flows for those tributaries; and 3) to explore the feasibility and usefulness of computing natural flows for the Gila River Basin and the feasibility and usefulness of adding that basin to CRSS.

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[1]Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location.

[2]The Lower Basin includes those parts of the States of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River System below Lee Ferry.

### 1.1 Introduction

This appendix first provides background regarding the methodologies that have been used to estimate and report historical consumptive use and loss data throughout the Basin. A summary of the efforts over the past decade to resolve inconsistencies in the Upper Basin data is provided, as well as a summary of the efforts in the Lower Basin which to date have primarily been directed toward measuring and reporting consumptive uses and losses from the mainstream of the Colorado River. Next, for each Lower Basin tributary, the current representation in CRSS is discussed along with the consumptive use and loss data from Reclamation's Consumptive Uses and Losses Reports. Discussion is also provided on additional sources of data and information relevant to the estimation of consumptive uses and losses on these tributaries. Finally, commitments are made for work independent of this Study to resolve the technical issues identified.

## 2.0 Background

CRSS, which evolved from programming efforts in the late 1970s and early 1980s, is used to simulate the future conditions of the Colorado River system for planning studies. The basis of the simulation is a mass balance calculation that accounts for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, evaporation, etc.) and water moving through the system (i.e., either water stored in reservoirs or flowing in river reaches).

Input data and information for the model includes physical parameters, initial reservoir conditions, reservoir operating rules, and the diversion and return flow schedules for entities in the Basin States and Mexico. Input data for the model also includes natural flow at 29 locations (20 in the Upper Basin upstream of and including the Lees Ferry gaging station in Arizona, and nine below Lees Ferry including the Paria River and inflow points in the Lower Basin) throughout the system, where natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location. Using these inputs, the model simulates the future state of the system in terms of output variables, which include the amount of water in storage, reservoir elevations, releases from the dams, diversions to and return flows from the water users, and the amount of water flowing at various points throughout the system.

The computation of natural flows for use in CRSS began in the early 1980s. At that time, different approaches (in terms of the methodologies and data) were taken for the computations of Upper Basin and Lower Basin natural flows. Over time, although the data and in some cases, the methodologies have been improved, these differences have remained. The following sections provide a summary of these data, methodologies, and differences.

### 2.1 Computation of Natural Flows above Lees Ferry, AZ

The first computation of natural flows above Lees Ferry was done in the 1980s and is described in the "Colorado River Simulation System Hydrology Data Base" June 1983 draft report (Reclamation, 1983). This report describes the methods employed to determine natural flows (and the salinity of those flows) at the 20 locations in the Upper Basin mainstream and tributaries for the time period 1906 through 1970. The accompanying data provides the monthly consumptive uses and losses and reservoir regulation data that were used in those computations.

In 1968, the Colorado River Basin Project Act (CRBPA) directed the Secretary of the Interior (Secretary) to "make reports as to the annual consumptive uses and losses of water from the Colorado River system after each successive five-year period starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a State-by-State basis. Specific figures on quantities consumptively used from the major tributary streams flowing into the Colorado River shall also be included on a State-by-State basis. Such reports shall be prepared in consultation with the States of the lower basin individually and with the Upper Colorado River Commission, and shall be transmitted to the President, the Congress, and to the Governors of each State signatory to the Colorado River Compact…" These reports (the Colorado River System Consumptive Uses and Losses Reports, or CU&L Reports[3]), have been prepared by Reclamation, in collaboration with the Basin States, for every five-year period from 1971-2005. To date, the report covering 2001 – 2005 is in final review and a provisional report covering the period 2006-2008 has been prepared.

The CU&L Reports estimate consumptive uses and losses across eight categories: reservoir evaporation, irrigated agriculture, livestock, stockponds, thermal electric power, minerals, municipal and industrial, and exports and imports. Specific methodologies are employed for each category and a large amount of data from a variety of sources is required. For example, to estimate consumptive use for irrigated agriculture, information regarding the actual acreage for specific crop types is coupled with weather data (precipitation, temperature, and frost dates) to estimate net evapotranspiration. Other specific information utilized includes data drawn from other published reports such as the USGS Water Use reports[4] as well as data supplied by specific entities.

Over a multi-year period in the early 2000s, the natural flow and salinity data for the Upper Basin was reviewed and re-developed for the period 1971 to 1995. A major component of this effort was resolving data and methodological inconsistencies found throughout the CU&L Reports up to that time. Based on these efforts, consistent data collection and computational methodologies were developed and are continually reviewed and updated to provide the best available information.

The review and re-development effort of the CU&L data included:

1. Review and collection of weather data (precipitation, temperature and frost dates) utilized within the modified Blaney-Criddle method required to estimate net evapotranspiration from irrigated croplands
2. Review and computation of irrigated acres estimates to ensure an objective methodology to determine these records from multiple datasets (GIS coverage, Census of Agriculture reports, and County Agriculture Statistics report) was employed when possible
3. Review and computation of irrigated agriculture consumptive use to ensure a consistent representation of the modified Blaney-Criddle method within a single software package

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[3]Available at: http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html

[4]Available at: http://water.usgs.gov/watuse/

4. Review and correction of reservoir evaporation estimates to ensure that the same set of reservoirs were used from one reporting period to the next, including the incorporation of new reservoirs constructed after 1971
5. Review and correction of USGS water use records used to assist in estimates of mineral and municipal and industrial uses
6. Review and collection of export and import uses to ensure consistent reporting of trans-basin exports and imports from one report period to the next, including the proper accounting of trans-basin exports and imports constructed or decommissioned since 1971
7. Correction of data entry errors and design of data entry and storage methods to assist in the implementation of quality control measures

The consumptive use and loss estimates from the CU&L Reports are used to compute natural flow[5] in the Upper Basin for the period after 1970. As the CU&L information is updated, the Upper Basin natural flows are also re-computed to ensure consistency. To this end, the Upper Basin States have raised issues regarding limitations, inconsistencies, and problems with the current CU&L information, and Reclamation will continue to improve the CU&L data through coordination and discussion with the Basin states.

## 2.2 Computation of Natural Flows below Lees Ferry, AZ

Methodologies and data used to develop the flows (and the salinity of those flows) for the nine inflow points below Lees Ferry from 1906 through 1982 for the tributaries and from 1935 through 1982 for the mainstream are described in a report titled “Colorado River Simulation System, Hydrology Data Base Lower Colorado Region (Lees Ferry to Imperial Dam)” (Reclamation, 1985). These nine inflow points represent tributary inflows as well as “gains and losses” within mainstream reaches. The inflow points representing tributary inflows are the Paria River, the Little Colorado River, the Virgin River, and the Bill Williams River. The inflow points representing mainstream gains and losses are Lees Ferry to Grand Canyon, Grand Canyon to Hoover Dam, Hoover Dam to Davis Dam, Davis Dam to Parker Dam, and Parker Dam to Imperial Dam.

Flows on the tributaries are computed not as natural flows, but instead by using historical, gaged streamflows. The report details the methodologies used to fill in missing records and extend the available records for these tributaries back to 1906.

Flows representing historical gains and losses along the mainstream reaches are estimates of natural flows calculated by adjusting historical gaged streamflows for reservoir regulation and consumptive uses and losses that occurred in the reach. The report details the methodologies used to fill in the missing consumptive use and historical gaged streamflow records to compute the reach gains back to 1935.

Regarding the Gila River, located in Reach 6 (defined in the May 1985 report as “Imperial Dam to International Boundary with Mexico”), the report states “Reach 6 is scheduled for completion during 1985. It is presently assumed that the reach gains, losses, and tributary inflows between Imperial Dam and the International Boundary sum to zero.” If any further work was done to

[5]Additional information is available at http://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html.

estimate natural flows on this reach, it was not documented. The configuration of CRSS reflects this statement in that the Gila River is not included.

In 1992, the methodologies of the May 1985 report were reviewed and updated in a report titled “Colorado River Simulation System, Hydrology Data Base Lower Colorado Region (Lees Ferry to Imperial Dam)” (Reclamation, 1992). Data discrepancies were corrected and the flows on the mainstream reaches were extended back to 1906, in most cases using monthly averages from a later period.

Both the mainstream reach flows and the tributary inflows have since been re-visited and re-developed using methodologies described in Lee and Salas, 2006. This was necessary as new information and techniques for record extension became available. The record extension technique is based on a multiple linear regression model that includes an error term so as to maintain a degree of variability in the extended records comparable to those of available historical reference gages.

As noted above, in 1968, the CRBPA directed the Secretary, in consultation with the Basin States, to make reports as to the annual consumptive uses and losses of water from the Colorado River system after each successive five-year period starting on October 1, 1970, and that “Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a State-by-State basis. Specific figures on quantities consumptively used from the major tributary streams flowing into the Colorado River shall also be included on a State-by-State basis.”

In addition to the direction provided by the CRBPA in 1968, the 1964 U.S. Supreme Court Decree in *Arizona v. California* (Consolidated Decree, 2006) directed the Secretary to make annual reports available that include the “diversions of water from the mainstream, return flow of such water to the stream as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation, and consumptive use of such water. These quantities shall be stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California and Nevada.”

Reclamation accounts for the use of Colorado River water from the mainstream in the Lower Basin using a “diversion minus return flow” methodology, whereby the diversions and return flows are measured or estimated for each water user. Reclamation publishes this information each year in the Colorado River Accounting and Water Use Reports: Arizona, California, and Nevada (Water Accounting Reports[6]). As the Lower Basin mainstream use has grown to its full apportionment, the Decree accounting process has evolved into a real-time accounting system that tracks Lower Basin mainstream use daily and provides updates of the estimated use-to-date and projected use to the end of the calendar year[7], in addition to providing the official Water Accounting Report after the completion of each calendar year.

The CU&L Reports include information taken from the Water Accounting Reports for mainstream Lower Basin use and also estimate consumptive uses and losses in the Lower Basin tributaries back to 1971. The methodologies used in the CU&L Reports to estimate Lower Basin tributary use is similar to those used for the Upper Basin. Due to the Lower Colorado Region’s focus on Decree accounting and the real-time monitoring system, the data, information, and

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[6]Available at: http://www.usbr.gov/lc/region/g4000/wtracct.html

[7]Available at: http://www.usbr.gov/lc/region/g4000/hourly/forecast11.pdf

methodologies for estimating Lower Basin tributary consumptive uses and losses have not received a great deal of attention over the past several years and the quality of the resulting information has suffered (see data presented in the following section). It is anticipated that similar issues that existed and were corrected with the Upper Basin tributary data will exist and will need to be corrected for the Lower Basin; however, to date, these investigations have not occurred.

Reclamation updates the natural flow[8] for the five locations on the mainstream annually using the data provided in the Water Accounting Reports. The approach for the four tributary locations has not been modified since the May 1985 report (i.e., Reclamation has not attempted to compute natural flows at these locations) and these flows are updated annually using the latest USGS streamflow records.

In the following sections, a preliminary examination of the Lower Basin tributary data is presented and specific commitments are made to engage in efforts independent of this Study to improve the information regarding Lower Basin consumptive uses and losses and enhance the capabilities of CRSS.

# 3.0 Current Information Pertaining to the Little Colorado, Virgin, and Bill Williams Rivers

## 3.1 Current Representation in CRSS

For the Little Colorado River, the Virgin River, and the Bill Williams River, flows at specific gage locations near the confluence of the tributary and the Colorado River mainstream have been used to generate future inflow sequences for input to CRSS. A similar approach has also been used for the Paria River. This approach is inconsistent, and, therefore, work will be completed as described below; however, due to timing and resource limitations, this work will not be completed within this Study.

By using gage data to represent the flow at these locations, the assumption is made that historical consumptive uses and losses above the gages on those tributaries may be ignored for modeling purposes. As discussed in *Technical Report C – Water Demand Assessment*, the Study will explore a range of plausible demand scenarios and the current representation of these tributaries does not preclude the exploration of additional future demands on those tributaries.

The approach is as follows: the USGS streamflow gage with the longest historical record nearest the confluence of the tributary and the Colorado River mainstream is used for the period that it is available and a record extension technique (see Lee and Salas, 2006 for more information) was used to reconstruct the flows back to 1906. The record extension technique is based on a multiple linear regression model that includes an error term so as to maintain a degree of variability in the extended records comparable to those of available historical reference gages.

Figures 1 through 3 present the historical inflow record utilized to generate future inflow sequences for input to CRSS for the Little Colorado, Virgin, and Bill Williams Rivers. The flow record includes the historical USGS streamflow (solid line) and the reconstructed flow using the record extension technique discussed above (dotted line).

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[8] Available at: http://www.usbr.gov/lc/region/g4000/NaturalFlow/Final-MethodsCmptgNatFlow.pdf

**FIGURE 1**
1906-2008 Historical Flow for the Little Colorado River near Cameron, AZ

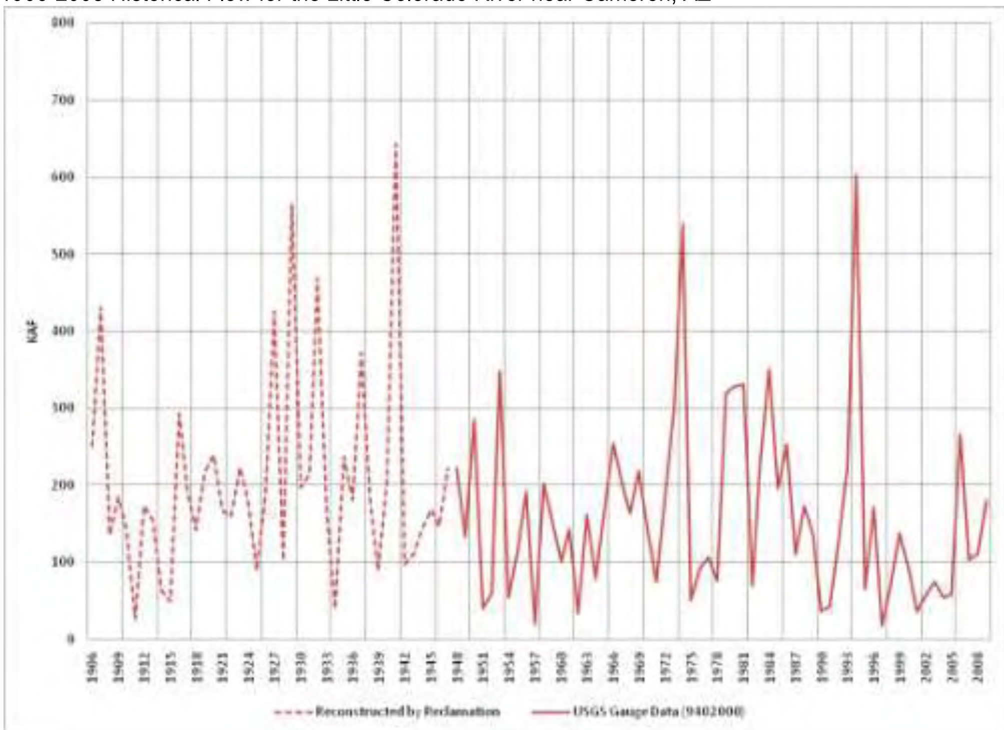


**FIGURE 2**
1906-2008 Historical Flow for the Virgin River at Littlefield, AZ

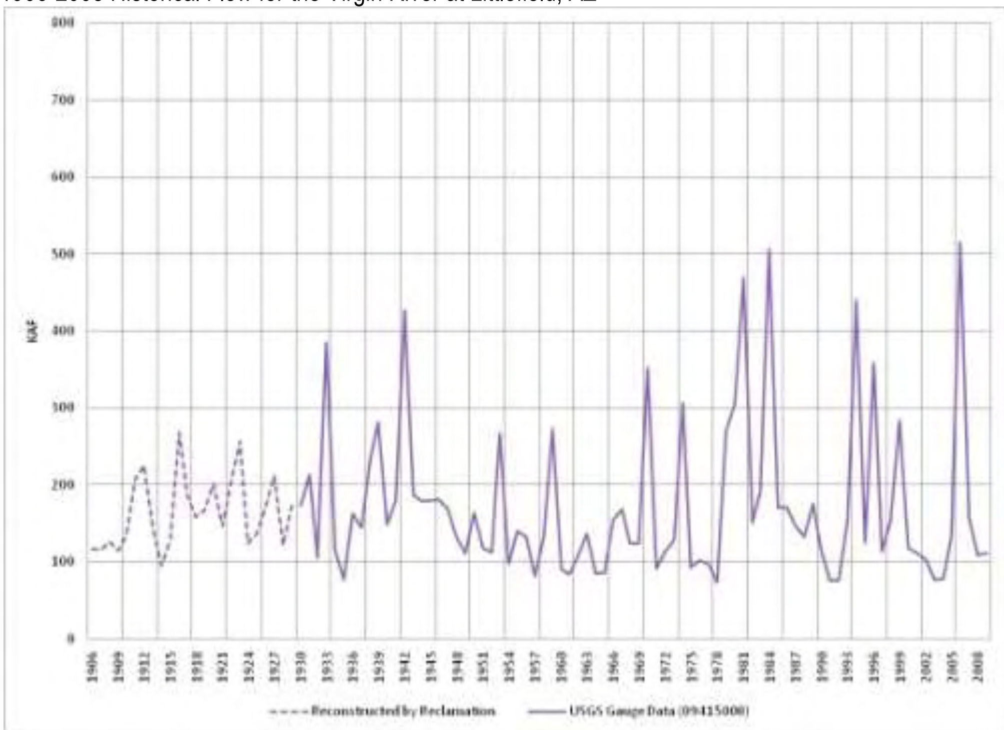
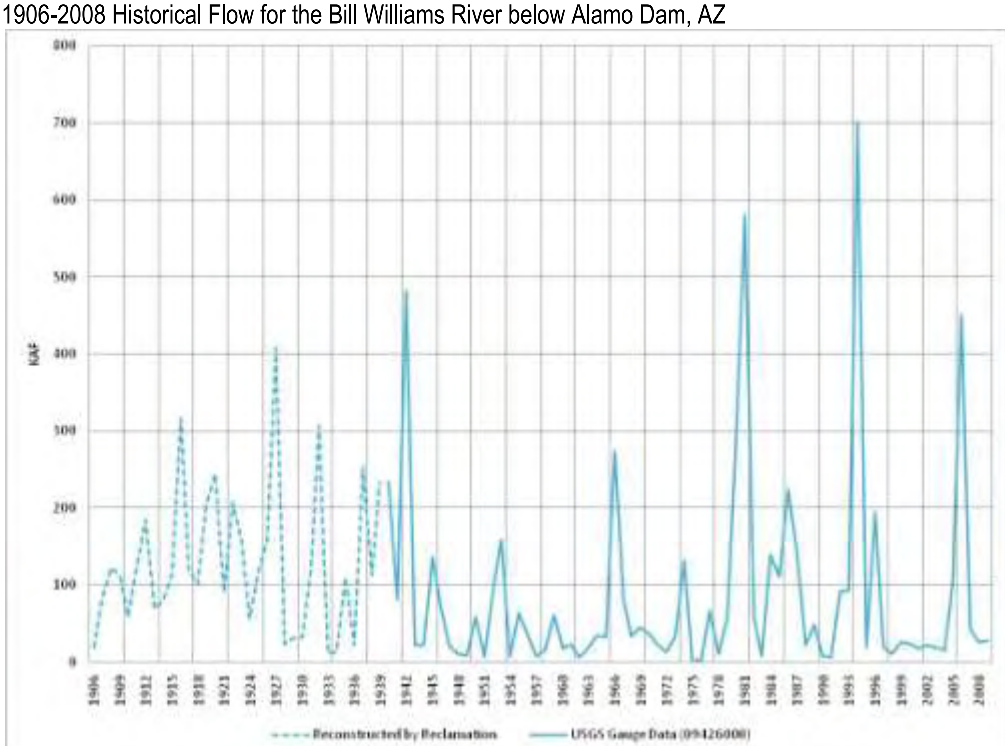



**FIGURE 3**
1906-2008 Historical Flow for the Bill Williams River below Alamo Dam, AZ



## 3.2 Consumptive Uses and Losses Data

### *3.2.1 Data from Reclamation's Consumptive Uses and Losses Reports from 1971-2005*

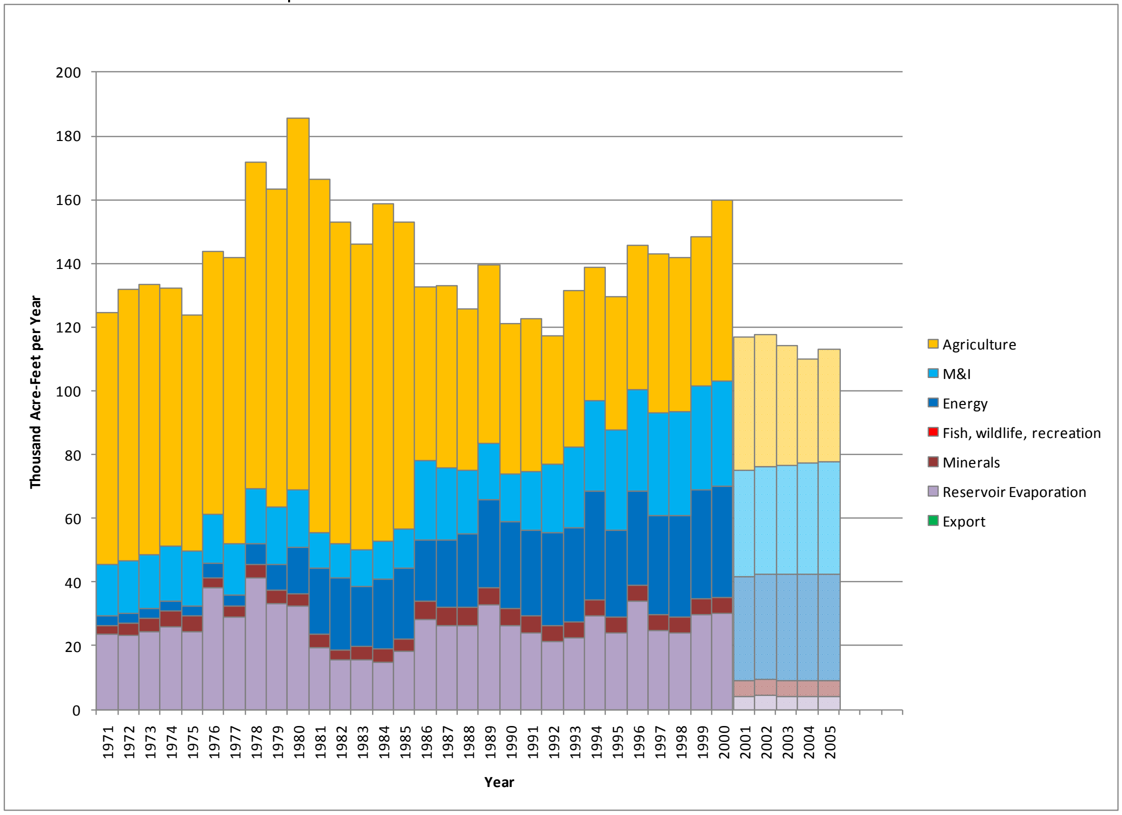
Consumptive use and loss data for the Lower Basin tributaries has been reported from 1971-2005 in the CU&L Reports; however, as discussed above, these data have not received the same level of scrutiny and analysis as the Upper Basin data.

Figure 4 shows Little Colorado River consumptive uses and losses from the CU&L Reports. Inconsistencies due to the five-year reporting periods are evident in the reservoir evaporation category, particularly in the sudden decline in the 1981-1985 and the 2001-2005 periods. A similar inconsistency can be seen in the municipal and industrial (M&I) category, which has the lowest use (averaging about 10 kaf/yr) during 1981-1985.

These inconsistencies from one reporting period to another may result from several factors including (1) different methods to determine M&I uses and losses employed each reporting period, (2) different personnel creating the report each reporting period, and (3) a lack of considering previous reports when computing the estimate for a current report. As discussed previously, similar problems existed in the Upper Basin CU&L Reports prior to Reclamation's review and re-computation of the data, and these reasons were identified for the inconsistencies in that data.

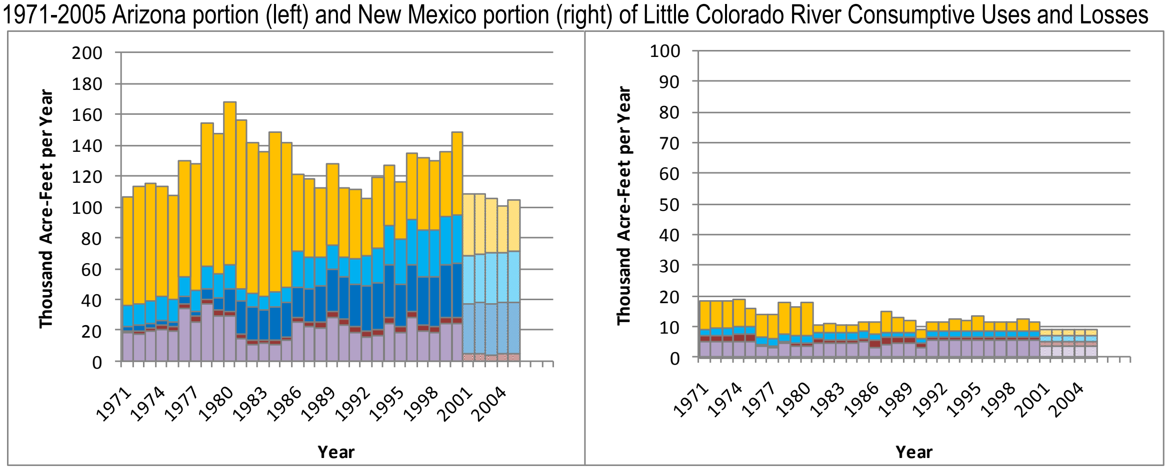
The Little Colorado River originates in New Mexico and flows through northeastern Arizona before discharging into the Colorado River in the Grand Canyon. Figure 5 (left) shows Arizona and (right) shows New Mexico consumptive uses and losses on the Little Colorado River from the CU&L Reports. The inconsistencies originating from the five-year reporting periods are again evident in the both the reservoir evaporation and M&I category for Arizona. Note the New Mexico y-axis is double the scale of Figure 4 to allow visualization of individual categories. The five-year reporting periods are again evident in the agriculture, reservoir evaporation and mineral categories.

**FIGURE 4**
1971-2005 Historical Consumptive Uses and Losses for the Little Colorado River




**NOTE:**
Data shown in cross hatch is currently being investigated and likely contains data and methodological inconsistencies.

**FIGURE 5**
1971-2005 Arizona portion (left) and New Mexico portion (right) of Little Colorado River Consumptive Uses and Losses



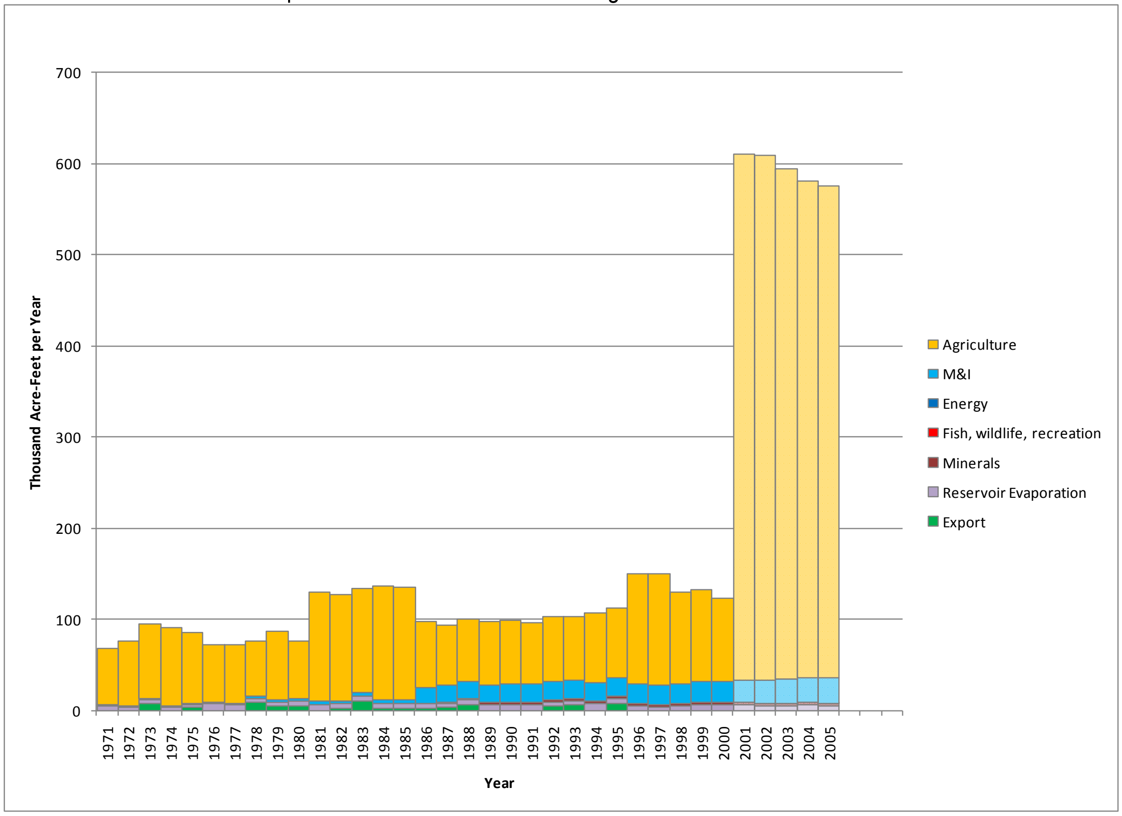

**NOTE:**
Data shown in cross hatch is currently being investigated and likely contains data and methodological inconsistencies.

The Virgin River originates in Utah and flows through the northwest corner of Arizona and a portion of eastern Nevada before discharging into Lake Mead. Figure 6 shows consumptive uses and losses on the Virgin River from the CU&L Reports. The five-year reporting periods are again evident, especially in the agriculture category. Obvious shifts in agriculture use occur between reporting periods. In particular, there is a large shift upward in agricultural consumptive use in 2001-2005 that is likely due to data and methodological inconsistencies and is currently being investigated.

Figure 7 shows the Arizona (top-left), Nevada (top-right), and Utah (bottom-left) consumptive uses and losses on the Virgin River. Again, shifts in categories consistently occur at the transition of reporting periods. Note the y-axis is increased by two for Arizona and by ten for Nevada from Figure 7 to allow visualization of individual categories.

**FIGURE 6**

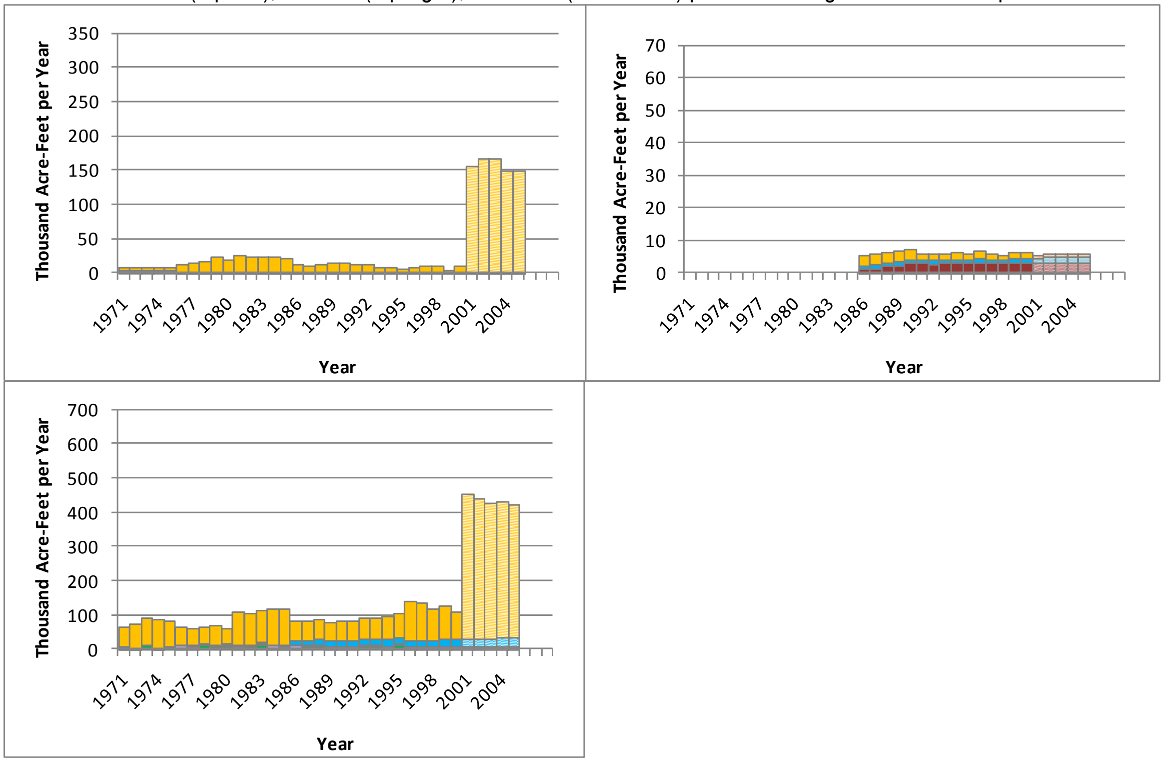
1971-2005 Historical Consumptive Uses and Losses for the Virgin River




**NOTE:**

Data shown in cross hatch is currently being investigated and likely contains data and methodological inconsistencies.

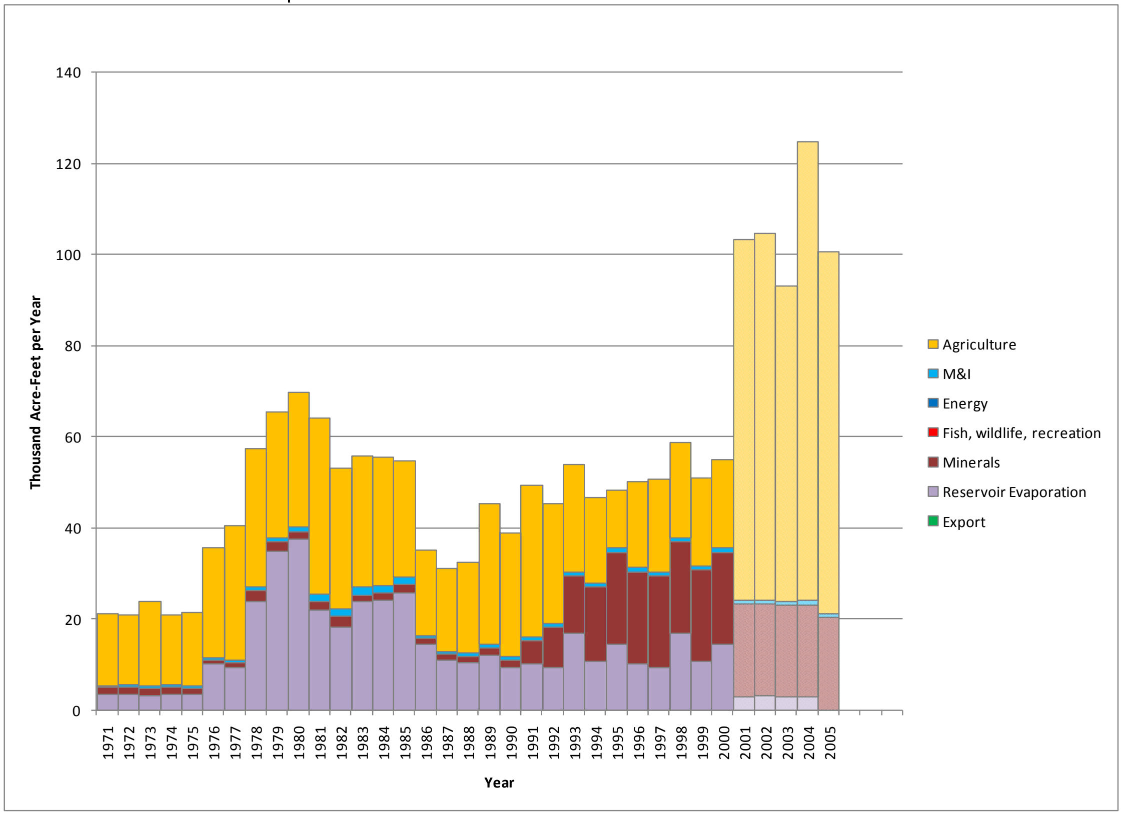
**FIGURE 7**
1971-2005 Arizona (top-left), Nevada (top-right), and Utah (bottom-left) portions of Virgin River Consumptive Uses and Losses




**NOTE:**
Data shown in cross hatch is currently being investigated and likely contains data and methodological inconsistencies.

The Bill Williams River originates in the west-central portion of Arizona and discharges into Lake Havasu near Parker Dam. Figure 8 shows consumptive uses and losses on the Bill Williams River from the CU&L Reports. The five-year reporting periods are again evident in the agriculture, mineral, and reservoir evaporation categories. Shifts in these categories consistently occur at the transition of reporting periods. In particular, there is a large shift upward in agricultural consumptive use in 2001-2005 that is likely due to data and methodological inconsistencies and is currently being investigated.

**FIGURE 8**
1971-2005 Historical Consumptive Uses and Losses for the Bill Williams River




**NOTE:**
Data shown in cross hatch is currently being investigated and likely contains data and methodological inconsistencies.

### *3.2.2 Other Data and Information Sources*

Several sources beyond Reclamation's CU&L Reports exist that provide information regarding consumptive uses and losses on the Little Colorado, Virgin, and Bill Williams Rivers. For the Little Colorado and Bill Williams Rivers, information sources include the Arizona Water Atlas published by the Arizona Department of Water Resources (ADWR), studies by the State of New Mexico, the USGS, the U.S. Army Corps of Engineers, and Reclamation.

For the Virgin River, information sources include reports prepared as part of the Utah State Water Plan, the Arizona Water Atlas, studies by the Natural Resources Conservation Service, and Dixie Project investigations by Reclamation.

In addition, the Lower Colorado Region, recognizing the need to improve information on historical flows for these tributaries, has been collaborating with the University of Arizona's Laboratory of Tree-Ring Research to develop tree-ring reconstructions of streamflow for these tributaries since 2005. Information gained from this effort can be used to further the development of natural flows on these tributaries.

### *3.2.3 Future Work*

The consumptive uses and losses reported in the CU&L Reports for the Little Colorado, Virgin, and Bill Williams Rivers show inconsistencies similar to those observed in the Upper Basin reports prior to Reclamation's multi-year effort to address and correct data and methodological inconsistencies undertaken in the early 2000s. Furthermore, the methodologies used in the CU&L Reports do not distinguish between consumptive uses and losses from tributary water and non-tributary water along these tributaries. In efforts independent of this Study, Reclamation, in collaboration with the states in the Lower Basin, will work to resolve these issues.

Additionally, in efforts independent of this Study, natural flows for the Little Colorado, Virgin and Bill Williams Rivers will be developed along with the necessary modifications to CRSS in order to use these natural flows. Major activities required to develop natural flows for these tributaries include:

- Collect data and develop methodologies to extend consumptive uses and losses estimates for these Lower Basin tributaries from 1971 (the earliest data reported in the CU&L Reports) back to 1906 (the start of the natural flow record).
- Collect data and apply methodologies to remove the effects of historical reservoir regulation on these tributaries, e.g., Alamo Dam on the Bill Williams River, and account for reservoir regulation in the future.
- Develop, in collaboration with the states of the Lower Basin, projected future demand schedules for uses along these tributaries for input to the model.

# 4.0 Current Information Pertaining to the Gila River

## 4.1 Current Representation in CRSS

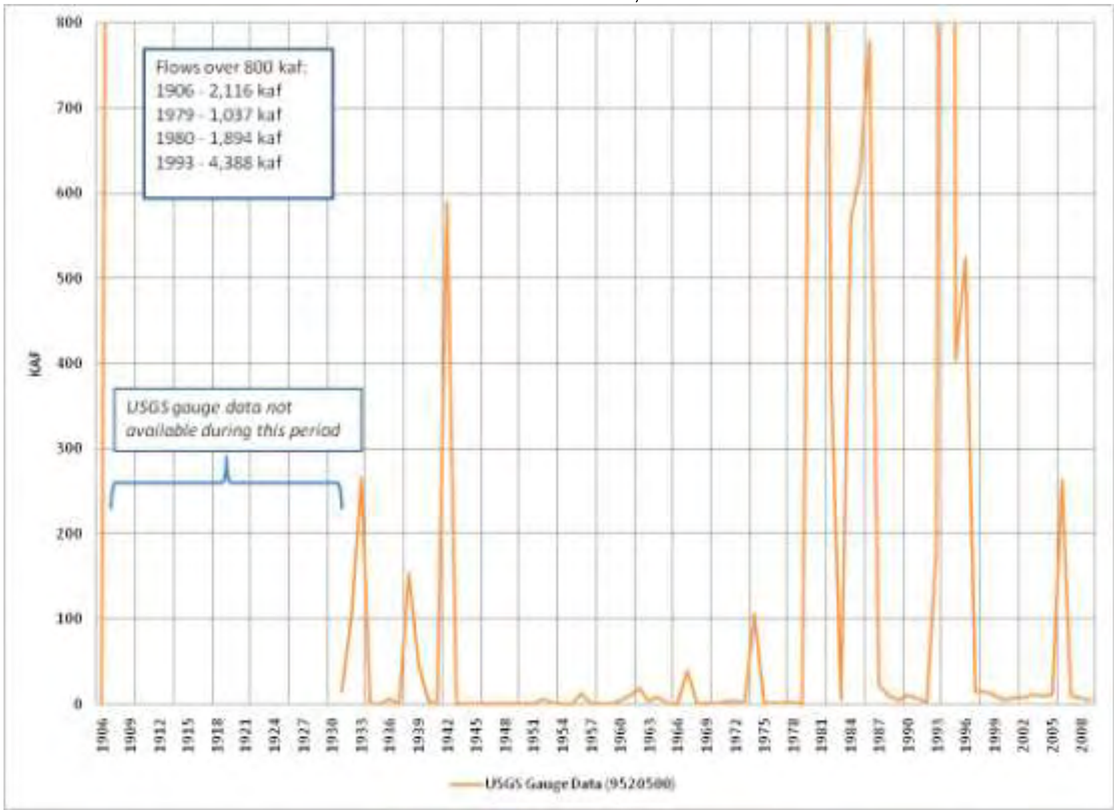
Although the Gila River drains a large portion of the Colorado River Basin, the Gila River has not been represented in CRSS since the model's inception. Flows from the Gila River seldom reach the mainstream of the Colorado River, and when they do, the flows are very sporadic and are typically of high magnitude, as illustrated in Figure 9. The confluence of the Gila River and the Colorado River mainstream is below all the major reservoir storage in the United States.

Although the Gila River is not explicitly represented in CRSS, exploration of future water demands and water supplies in the Gila River Basin will be implicitly accomplished for this Study by the representation of Arizona's Colorado River demand as expressed in the quantified demand scenarios. Information used to develop those scenarios may include data developed by Arizona's Water Resources Development Commission[9].

Figure 9 shows the USGS gage for the Gila River near Dome and illustrates the sporadic nature of the Gila River flow. The dataset is complete back to 1930 but incomplete from 1930 to 1906.

[9]The Arizona Water Resources Development Commission is compiling and considering the projected water needs of each Arizona county in the next 25, 50, and 100 years. See http://www.adwr.state.az.us/AzDWR/WaterManagement/WRDC_HB2661/

**FIGURE 9**
1906 and 1930-2008 Historical Flow for the Gila River near Dome, AZ




## 4.2 Consumptive Uses and Losses Data

### *4.2.1 Data from Reclamation's Consumptive Uses and Losses Reports from 1971-2005*

Figure 10 shows the consumptive uses and losses on the Gila River from the CU&L Reports. Data inconsistencies associated with the five-year reporting periods are suspected although are more difficult to discern as the magnitudes of those inconsistencies are likely smaller relative to the total use in the Gila River tributary. There are multiple sources of water that supply consumptive uses in the Gila River tributary, including tributary water, mainstream Colorado River water that is delivered via the Central Arizona Project (CAP), and non-tributary groundwater. The CU&L Reports report the annual CAP delivery, but do not provide information regarding the category of use of that water[10]. Furthermore, the contribution of the non-tributary groundwater use and supplies are not considered in the CU&L reports. Other tributaries have sources of water other than tributary water; however, the issue is more significant with respect to the Gila River because the other sources supply a relatively larger portion of the consumptive use.

10 Arizona provided a preliminary breakdown by use category of CAP deliveries from the mainstream to the Gila River Basin (see Technical Report C–Water Demand Assessment)

**FIGURE 10**
1971-2005 Historical Consumptive Uses and Losses for the Gila River

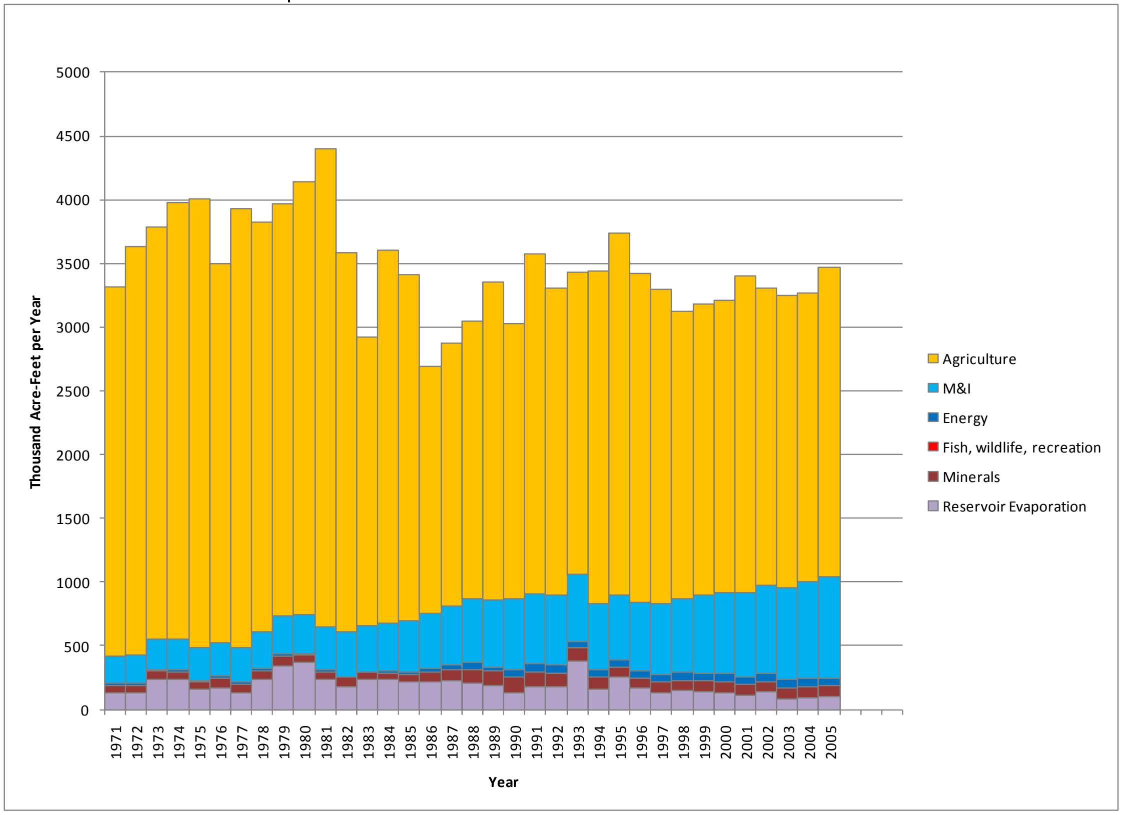
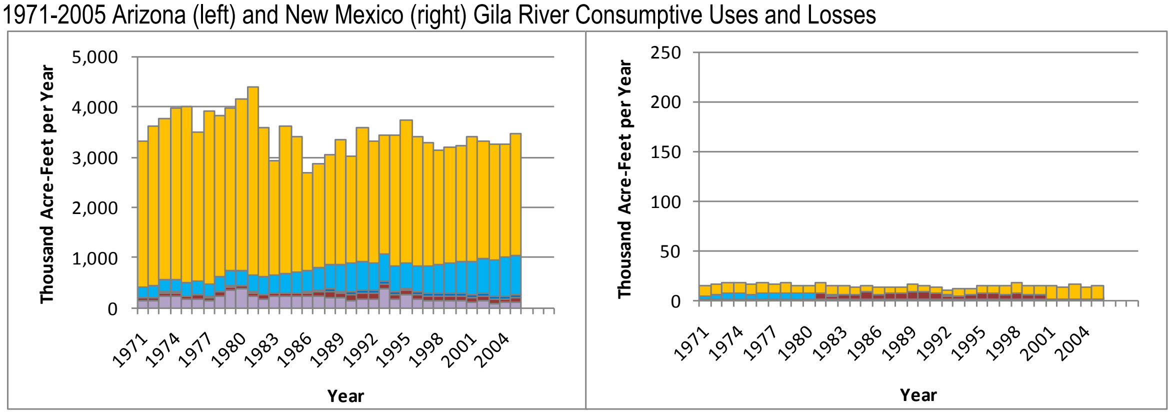



**FIGURE 11**
1971-2005 Arizona (left) and New Mexico (right) Gila River Consumptive Uses and Losses




## 4.2.2 Other Data and Information Sources

Several sources beyond Reclamation's CU&L Reports exist that provide information regarding consumptive uses and losses on the Gila River. These sources include the Arizona Water Atlas published by the ADWR, studies by the State of New Mexico, the USGS, and Reclamation. In addition, the Western Water Assessment at the University of Colorado is presently developing tree-ring reconstructions of streamflow on the Gila River.

### 4.2.3 Future Work

The consumptive uses and losses reported in the CU&L Reports for the Gila River show inconsistencies similar to those observed in the Upper Basin reports prior to Reclamation's multi-year effort to address and correct data and methodological inconsistencies undertaken in the early 2000s. Furthermore, the methodologies used in the CU&L Reports do not distinguish between consumptive uses and losses from tributary water and non-tributary water in the Gila River Basin. In efforts independent of this Study, Reclamation, in collaboration with the Basin States, will work to resolve these issues. In addition, a commitment is made to explore the feasibility and usefulness of computing natural flows for the Gila River Basin and the feasibility and usefulness of adding that basin to CRSS.

# 5.0 Summary

In the current configuration of CRSS, historical inflows based on USGS streamflow records have been used to generate future inflow sequences for the Little Colorado, Virgin, and Bill Williams Rivers, inconsistent with the approach taken for the other tributaries (with the exception of the Paria River). In addition, the Gila River is not included in CRSS. This approach was used for past Colorado River planning studies; however, questions regarding the adequacy of the treatment of the Lower Basin tributaries in CRSS for this Study arose during the phases focused on assessing future water supply and demand. Although some limitations will be imposed on the Study by this treatment, through other approaches the Study will be able to examine several important issues including potential climate change impacts on the tributaries represented in CRSS, future demand scenarios on those tributaries, and future demand scenarios for the Colorado River from the Gila River Basin factoring in other water supplies within that basin.

Consumptive use and loss estimates reported in Reclamation's CU&L Reports show methodological and data inconsistencies on these Lower Basin tributaries. Similar inconsistencies were present in the Upper Basin estimates prior to Reclamation's multi-year effort in the early 2000s to resolve them. Reclamation, in collaboration with the Basin States, is committed to resolving the issues on the Lower Basin tributaries in an effort independent of this Study. Additional data and information sources exist as well as ongoing research efforts concerning consumptive use and loss estimates on these tributaries. These sources will be utilized and coordination with on-going efforts will be accomplished as appropriate.

Also, in an effort independent of this Study, Reclamation is committed to developing natural flows on the Little Colorado, Virgin, and Bill Williams Rivers and modifying CRSS to use these flows. This effort will require the extension of consumptive use and loss estimates from 1971 to 1906, the development of methodologies to account for past and future reservoir regulation, and the development of future demand schedules for those tributaries. In addition, a commitment is made to explore the feasibility and usefulness of computing natural flows for the Gila River Basin and the feasibility and usefulness of adding that basin to CRSS.

# 6.0 References

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