RECLAMATION

Managing Water in the West

Colorado River Basin Water Supply and Demand Study

Technical Memorandum C – Quantification of Water Demand Scenarios

U.S. Department of the Interior
Bureau of Reclamation

May 2012

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.

Colorado River Basin Water Supply and Demand Study

Technical Memorandum C—Quantification of Water Demand Scenarios

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Colorado River Basin Water Supply and Demand Study Study Team

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Acronyms/Abbreviations

ADWR	Arizona Department of Water Resources
afy	acre-feet per year
ASCE	American Society of Civil Engineers
Basin	Colorado River Basin
Basin States	Colorado River Basin States
BC	Blaney-Criddle
CAP	Central Arizona Project
CIMIS	California Irrigation Management Information System
Commission	Wyoming Water Development Commission
CRB	Colorado River Board
CRIT	Colorado River Indian Tribes
CRSS	Colorado River Simulation System
CVWD	Coachella Valley Water District
CVWMP	Coachella Valley Water Management Plan
CWCB	Colorado Water Conservation Board
DBSA	Daniel B. Stephens & Associates
DWR	Department of Water Resources
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESA	Endangered Species Act
gpcd	gallons per capita per day
Harg	Hargreaves
ICS	Intentionally Created Surplus
IID	Imperial Irrigation District
ITA	Indian Trust Asset
ITCA	Inter Tribal Council of Arizona
kaf	thousand acre-feet
M&I	municipal and industrial
maf	million acre-feet
MWD	Metropolitan Water District of Southern California

NIA	Non-Indian Agriculture
NIAR	Non-Indian Agriculture Relinquished
NMISC	Mexico Office of the State Engineer and the New Mexico Interstate Stream Commission
NWR	National Wildlife Refuge
PET	Potential evapotranspiration
PM	Penman-Monteith
Prs-Tylr	Priestley-Taylor
PVID	Palo Verde Irrigation District
Reclamation	Bureau of Reclamation
Secretary	Secretary of the Interior
SNWA	Southern Nevada Water Authority
SRP	Salt River Project
SSI	self-served industrial
Study	Colorado River Basin Water Supply and Demand Study
SWSI	Statewide Water Supply Initiative
Tribes	Federally recognized tribes
TSC	Technical Services Center
UMUR	Ute Mountain Ute Reservation
UMUT	Ute Mountain Ute Tribe
USGS	U.S. Geological Survey
VIC	Variable Infiltration Capacity

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1.0 Introduction

The Colorado River Basin Water Supply and Demand Study (Study) initiated in January 2010, is being conducted by the Bureau of Reclamation's (Reclamation) Upper Colorado and Lower Colorado regions, and agencies representing the seven Colorado River Basin States[1] (Basin States). The purpose of the 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 Basin States that receive Colorado River water over the next 50 years (through 2060), and to develop and analyze options and strategies to resolve those imbalances.

Interim Report No. 1, published in June 2011, included four Technical Reports A through D. *Technical Report C – Water Demand Assessment* (Reclamation, 2011b) presented six water demand scenarios in narrative or "storyline" format and historical consumptive use information. This memorandum updates the information related to the six demand scenarios and provides the quantification for those scenarios.

Specifically, this memorandum presents water demand for a range of future demand scenarios within the Study Area for each of the Basin States. The Study Area encompasses the Colorado River hydrologic basin and areas adjacent to the hydrologic basin that receive Colorado River water (figure C-1). The water demand is presented by use category, including a compilation of demand information by federally recognized tribes. Additionally, this memorandum presents an update to the method used to assess the impact of climate change on demand and the associated results.

Key Terms Used in this Memorandum

- Hydrologic Basin – the geographic region naturally draining to the Colorado River.
- Adjacent Area – geographic regions outside the Colorado River hydrologic basin that receive Colorado River water.
- Study Area – the hydrologic boundaries of the Colorado River Basin, plus the adjacent areas of the Basin States that receive Colorado River water.
- Demand – water needed to meet identified uses.
- Diversion – water withdrawn from the river system.
- Return Flow – water diverted from and returned to the river system.
- Consumptive Use – water used, diminishing the available supply.
- Non-consumptive Use – water used without diminishing the available supply.
- Loss – water unavailable for identified uses due to reservoir/channel evaporation, phreatophyte use, and operational inefficiencies.
- Other Supplies – water supplies other than Colorado River Simulation System (CRSS) simulated Colorado River water supplies that may meet demand.
- Parameter – a variable which impacts a demand category (for example, population).
- Colorado River Demand – Potential Colorado River demand as computed by Study Area demand minus other supplies.

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

FIGURE C-1
The Study Area

2.0 Background

2.1 State Water Planning

Each of the Basin States has a statewide water planning process in place for estimating future water supply and demand. These processes typically projects demand based on planning regions that are associated with the hydrologic basins of that state. In most states, demand is developed based on parameters in a similar manner employed in the Study. For example, Wyoming's Green River Basin Plan projects future municipal and industrial (M&I) demand by projecting population under "low," "medium," and "high" growth scenarios provided by the Wyoming Division of Economic Analysis (States West Water Resources Corporation, 2001). These population data are coupled with per capita water use estimates to arrive at future M&I demand. Similarly, agricultural demand is based on projections of future irrigated crop acreage, estimates of crop irrigation requirements, and losses.

Parameter and demand estimates for the Study were provided by the Basin States and were generally derived from the states' planning processes or, in some cases, the planning of individual water agencies such as the Southern Nevada Water Authority (SNWA) and Metropolitan Water District of Southern California (MWD). Appendices C2 through C8 of this memorandum present details about the assumptions and data sources used for each state in this demand assessment.

2.2 Other Studies

As part of the demand scenario quantification process, several studies were reviewed to provide information on the regional trends in water use or parameters affecting water use.

This information was provided to the Basin States to assist in demand scenario quantification where local information may not have been available, or where the range of parameter characteristics had not been previously assessed in state or water agency plans. For example, in the development of demand projections for the San Juan planning area in New Mexico, it was found that the San Juan Regional Water Plan did not include a range of estimates of population for this region. To examine high- and low-growth scenarios, a range of population projections for New Mexico was developed from U.S. Census data.

Regional and national studies consulted include:

- Population Projections: U.S. Census Bureau Projections (U.S. Census Bureau, 2010), *U.S. Population Projections 2005-2050* (Pew Research Center, 2010), and *World Population Prospects 2010 Revision* (United Nations Department of Economic and Social Affairs, 2010).
- Municipal Water Use: *North American Water Use Trends Since 1992* (Water Research Foundation, 2010), *Residential Water Use Trends in North America* (Rockaway et al., 2011), *20x2020 Water Conservation Plan* (California Department of Water Resources, 2010), *Growing Toward More Efficient Water Use* (U.S. Environmental Protection Agency [EPA], 2010) and *Municipal Deliveries of Colorado River Basin Water* (Pacific Institute, 2011).
- Irrigated Acreage and Agricultural Water Use: *Agricultural Resources and Environmental Indicators* (U.S. Department of Agriculture, 2010) and *Estimated Use of Water in the United States* reports (U.S. Geological Survey, 2009).

- Energy Water Use: *Energy-Water Nexus, A Better and Coordinated Understanding of Water Resources Could Help Mitigate the Impacts of Potential Oil Shale Development*, (General Accounting Office, 2010), *State Electricity Profiles* (U.S. Department of Energy, 2009).

2.3 Federally Recognized Tribes

Federally recognized tribes (tribes) hold quantified rights to a significant amount of water from the Colorado River and its tributaries (approximately 2.9 million acre-feet [maf] of annual diversion rights). In many cases, these rights are senior to other uses. Therefore, representing these rights and the associated demand is a critical component to assessing future water demand in the Basin. An additional component of future demand is an assessment of demands by tribes that have unquantified rights or claims. Where information on these unquantified rights or claims has been provided by tribes, it has been incorporated into the Study, as appropriate.

Based on quantified rights and with additional input from tribes, future demand for water by tribes in the Basin has been quantified by the Study. The term “quantified rights”, as used in the context of the Study, is defined as the amount of rights reserved by or granted to tribes by federal court decrees, state court decrees, treaties, agreements, and Executive Orders.

Throughout the Study, Reclamation has met with tribes in the Upper Colorado River Basin, Lower Colorado River Mainstem, and tribes served by water provided (directly or pursuant to exchanges) through the Central Arizona Project (CAP) facilities under contracts between tribes and the United States (as listed in section 4.4.6). In addition, Reclamation is working collaboratively with the Ten Tribes Partnership, whose members have landholdings in the Upper and Lower Basins through which the Colorado River and various tributaries flow, as well as the Inter Tribal Council of Arizona (ITCA), whose members are the governments of 20 federally recognized tribes with land in Arizona. Discussions with tribes to quantify future demands are ongoing, the results of which will be incorporated into the Study and will be reflected in subsequent Study reports. Additional information on tribal rights and projected future demand is provided in appendix C9.

2.4 Summary of Trends in Historical Water Use

Historical data presented in *Technical Report C – Water Demand Assessment* (Reclamation, 2011b) demonstrate an increasing trend in Colorado River water use over time. Figure C-2 presents historical Colorado River uses and losses by category. From this figure, trends of increasing M&I water use and stable to decreasing agricultural water use can be seen, consistent with the population and irrigated acreage trends of the Southwest.

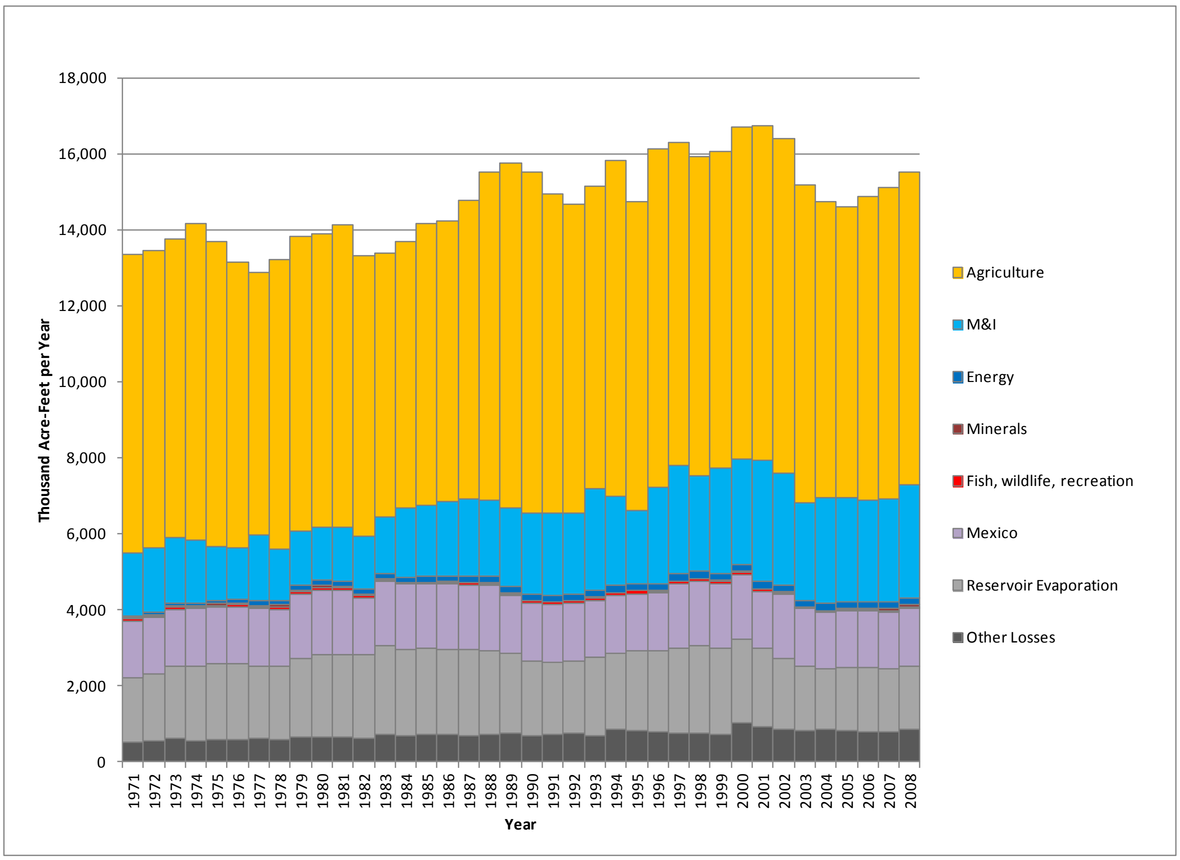
M&I water use has increased over time as a result of continued population growth in the Basin States. The Basin States include some of the most rapidly growing areas of the United States and typically have had growth rates far exceeding the national average. While population growth has slowed in recent years, the projections for the region continue to remain higher than the national average (U.S. Census Bureau, 2010). Significant decreases in per capita water use, largely due to improvements in indoor fixtures and appliances, have partially offset the water demands associated with increases in population.

Agricultural water use has been relatively stable in recent years, with some reductions likely due to the recent drought. Some reductions in irrigated acreage have occurred in the Basin, consistent with trends in the western United States, and appear to be associated with economic conditions, supply limitations, and pressures from urban encroachment due to land use changes and water transfers. Continued population growth is expected to continue these recent pressures on agriculture lands and water use.

Water use for energy purposes has grown over time, generally consistent with population growth. The growth in population has translated into increased energy demands in the Southwest with energy supply importation from other areas and expanding use of renewable energy. This growth in energy demands has been partially mitigated through federal and local energy conservation incentive programs.

For the purposes of reporting historical water uses, the tribal uses have been incorporated into other categories. However, for the projections of future demand, tribal demands are generally considered in a separate category.

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



[1] Excluding consumptive use in Lower Basin tributaries. Distribution of use by category in some adjacent areas was estimated when historical reporting of use within those areas did not contain identical categories as those presented here.

[2] Phreatophyte and operational inefficiency losses.

3.0 Water Demand Scenario Development Approach

3.1 Scenario Planning Approach

A scenario planning approach was implemented to examine the uncertainty in future water supply and demand. Details of this approach are included in *Technical Report A – Scenario Development* (Reclamation, 2011a). Scenarios are alternative views of how the future might unfold and are used to assist in evaluating the effect of key driving forces on future system reliability. Scenarios are not predictions or forecasts of the future. Rather, a set of well-constructed scenarios represents a range of plausible futures.

The scenario planning process involved identifying the key driving forces (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 the driving forces as to their relative importance and relative uncertainty; and associating the highly uncertain and highly important driving forces (critical uncertainties) with either water supply or water demand.

The water demand scenarios were constructed based on alternative views of future demand for the Colorado River, considering the critical uncertainties relating to demand. The following scenarios are considered for assessing the range of future demand:

- Current Projected (A): Continuation of growth, development patterns, and institutions follow long-term trends
- Slow Growth (B): Slow growth with emphasis on economic efficiency
- Rapid Growth (C1 and C2): Economic resurgence (population and energy) and current preferences toward human and environmental values
- Enhanced Environment (D1 and D2): Expanded environmental awareness and stewardship with growing economy

Complete narrative descriptions of the scenarios (storylines) are presented in appendix C1. Under the storylines, two logical branches or directions are considered for the Rapid Growth (C1 and C2) and Enhanced Environment (D1 and D2) scenarios. For example, population growth or increasing energy needs and subsequent water demand could potentially be offset by associated technological innovations influencing water use. The four storylines with these two branches result in six water demand scenarios. The water demand scenario names were recently updated from those presented in *Technical Report C – Water Demand Assessment* (Reclamation, 2011b) to better reflect the interpretations of the storylines.

3.2 Quantification Approach

The scenario planning approach described previously provided the narrative framework for assessing Colorado River demand[2]. Each of the scenarios was subsequently quantified through significant input from the Basin States, with additional input provided by tribes, fish and wildlife refuge managers, and conservation organizations. Demand for each scenario was quantified by

[2] Demand, and in particular Colorado River demand, referred to in this memorandum reflects the potential future demand that could arise due to a given scenario.

estimating values for individual parameters (such as population, irrigated acreage, water use efficiencies, etc.) associated with storylines and specific scenario assumptions.

Each Basin State considers many of these parameters in its evaluation of future demand projections for its state water planning efforts. Although many planning efforts consider alternative scenarios, in most cases those scenarios are not consistent with those considered in the Study. To provide consistent demand assumptions with the scenarios considered in the Study, the Basin States provided estimates of future demand that align with the storylines. These estimates of scenario demand was initially based on existing planning efforts with varying assumptions related to parameters as well as varying planning timeframes considered. The estimates were generally modified to reflect the broader range of plausible conditions desired in the Study.

Consumptive demand for fish and wildlife needs were prepared by the U.S. Fish and Wildlife Service to reflect the range of potential needs for wildlife refuges.

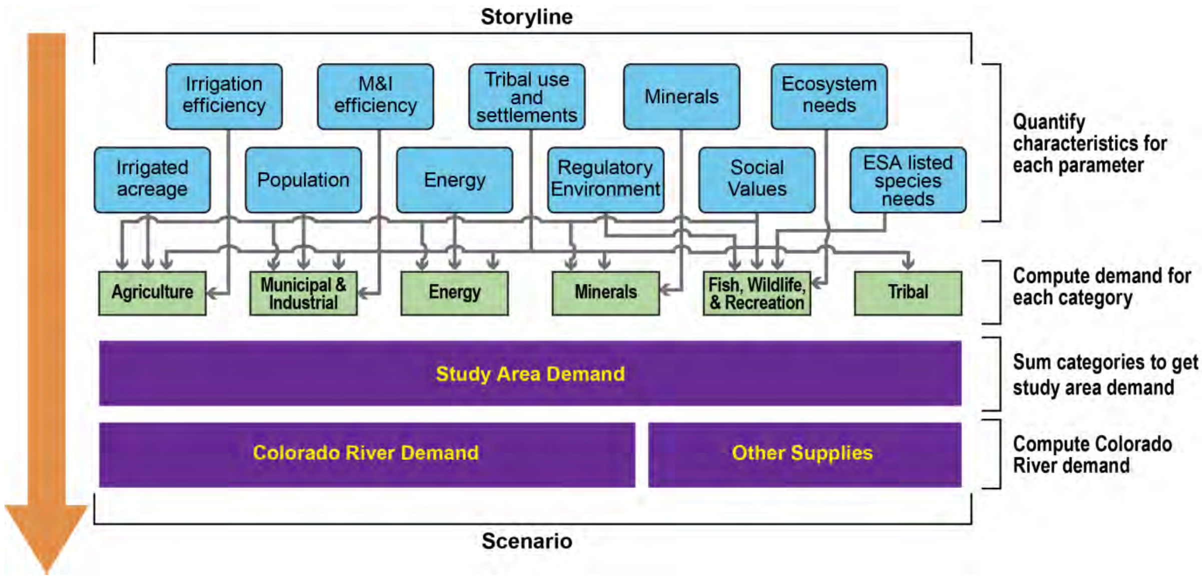
The demand under each scenario was developed for each of six demand categories: agricultural, M&I, energy, mining, fish/wildlife/recreation, and tribal. Demand estimates were developed for specific planning areas within each state and then totaled for all planning areas to represent the Study Area demand for that state.

Demand was first developed for areas that may be served by Colorado River water, independent of the source of supply. This demand is termed Study Area demand in this memorandum. However, for many areas outside of the hydrologic basin, a portion of the Study Area demand is satisfied from other supplies. To develop estimates of the Colorado River demand, the Study Area demand is reduced by estimates of available supply from other sources. The distinction between Study Area demand and Colorado River demand is particularly important for areas such as southern California, portions of Arizona not served by Mainstem Colorado River water, the Front Range of Colorado, Wasatch Front of Utah, San Juan-Chama service areas of New Mexico, and the Cheyenne region in Wyoming (figure C-1). For example, M&I demands in southern California are served by sources such as the State Water Project, Los Angeles Aqueduct, and local surface and groundwater sources that are intermingled with Colorado River water. In these areas, parameters such as irrigated acreage and population are developed and projected based on a specific geographic area rather than by supply source. As such, the specific population potentially served by Colorado River water cannot be determined. Instead, the total population is used to estimate M&I demand for the geography, and information about the availability of other supplies is used to estimate the Colorado River demand. Colorado River demand is not limited to individual state apportionments but rather reflects projected water needs based on change in demand parameters over time.

Figure C-3 shows the general approach to quantifying a demand scenario. The storyline, shown at the top of figure C-3, is required to begin the approach. 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. Colorado River demand can be calculated as the Study Area demand minus demand potentially met by other supplies.

Other factors affecting future water demand, such as Mexico’s allotment and losses such as riparian use and reservoir evaporation, are not explicitly included in the scenario approach. These factors will be included in the modeling supporting the system reliability analysis in the next phase of the Study. Non-consumptive demands are primarily represented through metrics associated with uses such as hydropower, recreation, and ecological resources, further discussed in detail in *Technical Report D – System Reliability Metrics* (Reclamation, 2012b).

FIGURE C-3
Approach to Quantifying Demand Scenarios[1]



[1] Mexico's allotment and losses such as reservoir evaporation, phreatophyte losses, and operational inefficiencies, are not included in this approach but will be included in the modeling supporting the system reliability analysis.

Table C-1 presents the demand categories, their definitions, and associated parameters collected or developed for the Study. The parameter data were collected through communication with and requests to the Basin States, tribes, U.S. Fish and Wildlife Service, and conservation organizations. Information sought included changes in parameter data over time, such as population, that are used to develop demands by category. Where information on alternative futures was lacking, other references were reviewed that provided indications of regional trends.

TABLE C-1
Definition of Demand Categories and Their Associated Parameters

Demand Category	Definition	Parameters
Agriculture	Water used to meet irrigation requirements of agricultural crops, maintain stock ponds, and sustain livestock	Irrigated acreage, irrigation efficiency
Municipal and Industrial	Water used to meet urban and rural population needs, and industrial needs within urban areas	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[1]	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, Endangered Species Act-listed species needs, and ecosystem needs
Tribal	Water used to meet tribal needs and settlement of tribal water rights claims	Tribal use and settlements

[1] This demand category represents the consumptive use portion of demand. Non-consumptive demands are considered in metrics, see Technical Report D – System Reliability Metrics (Reclamation, 2012b).

As part of the scenario quantification process, general relationships were used to relate the expected changes in parameters for each scenario in comparison to the Current Projected (A) scenario consistent with each storyline. These are shown conceptually in table C-2. For example, it is anticipated that population will grow at a greater rate in the Rapid Growth (C1 and C2) scenarios when compared to the Current Projected (A) scenario, but water use efficiency may either remain relatively constant in the Rapid Growth (C1) scenario, or increase over time in the Rapid Growth (C2) scenario. However, the expected change in parameters may have substantial geographic differences. For example, while “Increased Demand” for minerals under the Rapid Growth (C1 and C2) scenarios may be expected in general, some areas may have little or no capacity for minerals development. Therefore, while these general relationships are shown in table C-2, the specific quantification of the scenario includes important geographic differences.

TABLE C-2
Scenario Matrix of Typical Changes in Parameters Compared to the Current Projected (A) Scenario (blue represents a decrease and red represents an increase in the parameter value when compared to the Current Projected (A) scenario)

	Population	M&I Per Capita Use	Self-Served Industrial Demand[1]	Agriculture Irrigated Acreage	Agriculture Efficiency	Energy Demand	Minerals Demand	Fish, Wildlife, Recreation Demand	Tribal Demand
Slow Growth (B)	Slower Growth	No Change	No Change	No Change	Decreased Efficiency	No Change	No Change	No Change	Slower Growth
Rapid Growth (C1)	Rapid Growth	No Change	No Change	Increased Ag Land Use	Decreased Efficiency	Increased Demand	Increased Demand	No Change	Faster Growth
Rapid Growth (C2)	Rapid Growth	Increased Efficiency	Increased Efficiency	Increased Ag Land Use	Increased Efficiency	Decreased Demand	Decreased Demand	Increased Demand	Faster Growth
Enhanced Environment (D1)	No Change	Increased Efficiency	Increased Efficiency	No Change	No Change	Decreased Demand	Decreased Demand	Increased Demand	No Change
Enhanced Environment (D2)	Rapid Growth	Increased Efficiency	Increased Efficiency	No Change	Increased Efficiency	Decreased Demand	Decreased Demand	Increased Demand	Faster Growth

[1] Self-served industrial demand represents the demand of industries in a given area that have water supply systems independent of municipal systems.

3.2.1 Quantification of Tribal Demand

As previously described, the storylines describe different ways each critical uncertainty, those factors determined to be the most critical and uncertain in determining future demand, may unfold. *Change in water availability due to tribal water use and settlement of tribal water rights claims* was determined to be a critical uncertainty[3]. Table C-3 summarizes the storyline narrative from each demand scenario regarding this critical uncertainty.

TABLE C-3
Storylines Related to Tribal Water Use

Storyline Related to Tribal Water Use	Scenario
Tribal use develops according to quantified rights and current use patterns.	Current Projected (A)
Tribal use continues to develop but at slower than planned rates.	Slow Growth (B)
Tribal use and development occur faster than currently planned. In addition, new tribal claims and settlements are realized.	Rapid Growth (C1)
Tribal use and development occur faster than currently planned. In addition, new tribal claims and settlements are realized.	Rapid Growth (C2)
Tribal use develops according to quantified rights and current use patterns.	Enhanced Environment (D1)
Tribal use and development occurs faster than currently planned. In addition, new tribal claims and settlements are realized.	Enhanced Environment (D2)

The scenario storylines were published in *Technical Report C – Water Demand Assessment (*Reclamation, 2011b), and comments received suggested that the factors driving the trajectory of certain critical uncertainties (for example, changes in water needs for energy or changes in agricultural land use) are different from those that drive the uncertainty related to tribal water use. Specifically, tribal comments pointed out that factors such as increased population and economic development may not be the primary drivers for future tribal demands. Tribal governments exercise direct and immediate control over land use decisions and development on tribal trust lands, and these decisions may be independent of economic drivers. For example, under economic conditions where a private entity might choose to fallow land, a tribal government may keep land in production simply to cover irrigation assessment costs and/or to provide employment. After considering these comments, it was decided to change the storyline narratives related to tribal water use by removing economic factors. For example, the storyline for the Slow Growth (B) scenario was changed from "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," to "Tribal use continues to develop but at slower than planned rates."

In most cases, the quantification of tribal demand relied on information submitted by the Ten Tribes Partnership for use in the *Colorado River Interim Surplus Criteria Final Environmental Impact Statement (EIS)* (Reclamation, 2000) and used in the more recent *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead Final EIS* (Reclamation, 2007). Some revisions to these projections were made and alternative demand scenarios were quantified based on discussions with and information

[3] For a list of all critical uncertainties associated with water demand and an explanation of how those critical uncertainties were developed, see *Technical Report A – Scenario Development* (Reclamation, 2011a).

submitted by individual tribes, the Ten Tribes Partnership, and the ITCA. Appendix C9 describes in more detail the demand projections for each tribe with quantified Colorado River rights.

4.0 Results of Water Demand Scenario Quantification

The quantification of future water demand incorporated a scenario planning approach as described in section 3. This section presents the quantified demands that resulted from implementing this approach. Section 4.1 presents a broad qualitative comparison of the demand scenarios, followed by a quantitative summary of the results in sections 4.2 through 4.4. Section 4.2 presents an overview of Study Area demand and Colorado River demand; section 4.3 presents Colorado River demand by geography (state and Basin level); and section 4.4 presents the Colorado River demand by category. In each of these sections, the demands are presented for the six scenarios. Details of the demand quantification for each state at the planning-area level are presented in appendices C2 through C8. Details of quantification for tribal demands are provided in appendix C9.

4.1 Comparison of Demand Scenarios

This section presents a broad comparison of the demand scenarios across the Study Area. The comparison is presented in terms of the differences among driving forces, summarized at a category level, as described in the storyline for each scenario. The storylines are also provided in appendix C-1 of this memorandum. The driving force categories, Demographics and Land Use, Technological and Economics, and Social and Governance, contain multiple driving forces that were used to explore critical uncertainties that formed the basis of the storyline for each scenario. The development of the driving forces, category groupings, critical uncertainties, and storylines is discussed in more detail in *Technical Report A – Scenario Development* (Reclamation, 2011a).

The storylines discuss the future trajectory of both consumptive and non-consumptive demands. The scenario quantification presented in this memorandum primarily focuses on consumptive demands, expressed through the categories M&I, Agricultural, Energy, Minerals, Fish, Wildlife and Recreation, and Tribal. The results of this quantification are presented in sections 4.2 through 4.4 of this memorandum. Non-consumptive demands described in the storylines are those that support the environment and recreational activities. These are expressed through flow targets and are characterized as metrics in *Technical Report D – System Reliability Metrics* (Reclamation, 2012b). This memorandum does not compare non-consumptive flow targets across scenarios; rather, the impact on flows supporting the environment and recreational activities will be assessed across all scenarios through the evaluation of the ecological and recreational metrics in the next phase of the Study. Ecological resources metrics can be found in tables D-8 and D-9 of *Technical Report D – System Reliability Metrics,* while recreational resources metrics, primarily river and whitewater boating, are defined in table D-7.

The Study Area comparison provides the overarching context supporting the consumptive water demand quantification presented in this memorandum. Relative to water use across sectors, these comparisons reflect differing levels of and interplay among changing societal values, economic drivers, and various types of resource constraints. An exception to this comparison is with respect to tribal demands. It was determined during the quantification process that the factors affecting tribal demands are not particularly well represented by the driving force categories established by the Study. For the most part, tribal demands are based on quantified rights in

Current Projected (A), Slow Growth (B), and Enhanced Environment (D1) scenarios, but consider additional unquantified settlements or claims in tribal demands in the Rapid Growth (C1 and C2) and Enhanced Environment (D2) scenarios. Additionally, it is important to recognize that the quantification of water supply and demand scenarios may compare differently at state and individual planning area levels. State level demands generally follow broad identifiable trends, whereas individual planning areas consider locally relevant information, plans, timelines, and constraints.

4.1.1 Demographics and Land Use

Population growth and changes in land use are driven by economic growth, the continuance of currently planned agricultural water supply projects, conversion of agriculture to urban land, and the phasing out of lower economic-value crops in some areas. Population growth and land use parameters for each state correspond with different reference points based on state and local information and planning efforts reflecting long-term trends.

The Current Projected (A) and Enhanced Environment (D1) scenarios are supported by "best estimate" population projections, whereas more rapid population projections support the Rapid Growth (C1 and C2) and Enhanced Environment (D2) scenarios. The Slow Growth (B) scenario contains slower population projections. Agricultural land use decreases across the entire Basin to varying degrees across all scenarios and at a greater rate under the Rapid Growth (C1 and C2) scenarios. However, in some Upper Basin planning areas both the Current Projected (A) and the Slow Growth (B) scenarios show increases in irrigated agricultural acreage by 2060.

4.1.2 Technology and Economics

The development and adoption of new technology and conservation programs supporting reductions in agricultural, energy, and M&I water demand are driven by investments at the local, state, and federal levels that will be brought about by changing societal values, economic drivers, and resource constraints.

M&I water use becomes more efficient under all scenarios. The increase in efficiency is beyond current water efficiency programs and practices. The lowest increase in M&I water use efficiency occurs under the Slow Growth (B) scenario, and the largest efficiency increase occurs under the Enhanced Environment (D1 and D2) scenarios. Changing social values drive these efficiency increases by fostering a willingness to increase investments at the local, state, and federal levels in water conservation programs. The most modest efficiency increase under the Slow Growth (B) scenario stems from the slower rate at which society embraces additional new conservation programs or lacks resources to develop such programs. Changing social values, federal investment, and subsequent responses focused on conservation efforts results in the largest efficiency increase under the Enhanced Environment (D1 and D2) scenarios.

Agricultural per acre water delivery ranges from a modest increase under the Rapid Growth (C2) scenario to a modest decrease under the Enhanced Environment (D1) scenario. The primary reason for the small decrease under this scenario is favorable economic conditions coupled with changing social values, creating a willingness and incentives to invest in agricultural water conservation. This leads to rapid adoption of new technologies, resulting in decreased agricultural demands due to increased agricultural water use efficiency.

Water needs for energy development increase across all scenarios and range from the most modest increase under the Enhanced Environment (D1 and D2) scenarios to the greatest increase under the Rapid Growth (C1 and C2) scenarios. Water needs for energy expand relative to population growth and results in the highest demand under the Rapid Growth (C1) scenario. Under the Enhanced Environment (D1 and D2) scenarios, an emphasis on renewable energy requirements and investments in technologies that reduce water consumption associated with energy production and new development decreases projected water demands for energy production despite a rapidly growing population featured under the Enhanced Environment (D2) scenario.

4.1.3 Social and Governance

Changes in agricultural and M&I water use efficiency, in addition to the adoption of new programs to support ecological and recreational resources, are influenced by varying rates of institutional and regulatory changes assumed in the scenarios.

Water use efficiency changes range from no significant change relative to present practices to increased efficiency based on social values. No significant change is anticipated in the Current Projected (A) and Slow Growth (B) scenarios. The Enhanced Environment (D1 and D2) scenarios show increased efficiency resulting from social values leading to greater investment, increased governmental regulations, agreements, and incentives promoting greater renewable energy use, and implementation of additional water conservation programs.

All scenarios rely on the continued existence and further successful implementation of existing federal endangered species programs and policies. Additionally, the Enhanced Environment (D1 and D2) scenarios contemplate a future where changing social values drive public support for investments in additional programs and actions: supporting more certain recovery of listed species, keeping them from being re-listed, providing ecological flows sufficient to support a healthy river system, and enhancing recreational use of the river. The ecological flow targets, characterized using the flow metrics for these scenarios, are non-consumptive and modeling will identify shortfalls for quantified flow targets. Options and strategies, including those that increase supply, reduce demand, and/or modify operations, will be considered to address the risks to Basin resources[4].

4.2 Summary Results of Scenario Quantification

Following the approach described in section 3, values were developed for parameters and demands quantified for each of the scenarios. Table C-4 presents summary results for the demand scenarios considered in the Study. The table presents agricultural and M&I demand parameters for the Study Area, which distinguishes the scenarios, the resulting Study Area demand, and finally the Colorado River demand by category.

[4] Resources include water allocations and deliveries consistent with the apportionments under the Law of the River; hydroelectric power generation; recreation; fish, wildlife, and their habitats (including candidate, threatened, and endangered species); water quality including salinity; flow- and water-dependent ecological systems; and flood control.

TABLE C-4
Summary Results of Water Demand Scenario Quantification by 2060

Key Study Area Demand Scenario Parameters							
	2015	2060 Scenario Parameters					
		A	B	C1	C2	D1	D2
Population (millions)	40.0	62.4	49.3	76.5	76.5	62.4	76.5
Change in per capita water usage (%), from 2015	–	-9%	-7%	-9%	-16%	-19%	-17%
Irrigated acreage (millions of acres)	5.5	5.1	5.2	4.6	4.6	4.9	5.0
Change in per-acre water delivery (%), from 2015	–	+1%	+2%	+1%	+3%	-0%	+3%
Study Area Demand (maf)							
Agricultural Demand	16.5	15.2	15.7	13.7	13.8	14.9	14.9
Municipal and Industrial Demand	8.6	12.5	10.2	15.1	13.9	11.0	13.7
Energy Demand	0.35	0.66	0.57	1.01	0.58	0.53	0.56
Minerals Demand	0.1-0.11	0.18	0.18	0.22	0.15	0.15	0.15
Fish, Wildlife, and Recreation Demand	0.16-0.23	0.08	0.08	0.08	0.10	0.16	0.16
Tribal Demand[1]	1.6-1.8	2.0	2.0	2.5	2.4	2.1	2.4
Total Study Area Demand[2]	**27.6**	**30.7**	**28.7**	**32.5**	**30.9**	**28.7**	**31.9**
Colorado River Demand (maf)							
Agricultural Demand	7.2	6.7	6.8	6.6	6.7	6.5	6.8
Municipal and Industrial Demand	3.4	5.1	4.5	6.2	5.2	4.9	5.4
Energy Demand	0.22	0.44	0.38	0.74	0.37	0.34	0.35
Minerals Demand	0.09-0.11	0.17	0.18	0.21	0.14	0.14	0.14
Fish, Wildlife, and Recreation Demand	0.15-0.21	0.06	0.07	0.06	0.08	0.15	0.15
Tribal Demand[1]	1.5-1.7	2.0	1.9	2.4	2.4	2.0	2.4
Total Colorado River Demand[2]	**12.8**	**14.5**	**13.8**	**16.2**	**15.0**	**14.0**	**15.2**

[1] Tribal demand within the state of Colorado is included in other demand categories.

[2] Excludes Mexico's allotment and losses (reservoir evaporation, phreatophytes, and operational inefficiencies). These factors will be included in the modeling supporting the system reliability analysis.

About 40 million people are estimated to be in the Study Area by 2015. This number is expected to increase to between 49 and 77 million by 2060. The highest population growth is associated with the Rapid Growth (C1 and C2) and the Enhanced Environment (D2) scenarios. The Slow Growth (B) scenario has the lowest population growth of the scenarios (49 million by 2060) but still represents a growth of nearly 25 percent over 2015 estimates.

The growing municipal population, however, will continue to be more efficient in its per capita water use than today. Per capita water use, based solely on passive or existing conservation targets, is expected to be 7 to 19 percent less in 2060 than in 2015. These reductions vary considerably across states and scenarios. In some regions, per capita water use rates are expected to drop by over 20 percent by 2060.

Irrigated acreage is projected to continue to decrease through 2060 under all scenarios. Under the Rapid Growth (C1 and C2) scenarios, projected irrigated acreage is reduced by more than 830,000 acres and by roughly 300,000 to 550,000 acres in the other scenarios. Although water use efficiency improvements are anticipated, some of the remaining irrigated land is expected to be more intensely cultivated or fully irrigated, resulting in little overall change in water delivery per acre.

Water demand for energy and mineral categories are projected to increase under all scenarios. The growing need for energy (coal, solar, and oil shale) is projected to increase water demands. The largest increases are anticipated in Arizona, Colorado, and the California desert. Meanwhile, water needs for mineral extraction are projected to significantly increase in Wyoming, Colorado, and Arizona.

Tribal demand is anticipated to increase over time as demand reaches quantified rights (in all scenarios) and demand beyond these quantified rights is realized in the Rapid Growth (C1 and C2) scenarios and the Enhanced Environment (D2) scenario.

The Study Area demand ranges between 28.7 and 32.5 maf by 2060 with Colorado River demand[5] ranging between 13.8 and 16.2 maf. Some of the increase in Study Area demand is projected to be met through increases in other supplies, primarily in Colorado and California. The increase in Colorado River demand from 2015 to 2060 is estimated to be between 1.1 and 3.4 maf, with the Lower Basin making up about 60 percent of the increase. Of the total increase in Colorado River demand, for the growing categories, between 64 and 76 percent of the growth is contributed by the M&I demand category. The growth in energy, tribal, and mineral categories constitutes the remaining demand increase.

Colorado River demand is determined as Study Area demand less the demand projected to be supplied by other sources. The Study and the results presented in this memorandum focus on the resulting Colorado River demand. Figure C-4 presents demands across the initial scenarios in three panels as follows: 1) Study Area demand with other supplies and Colorado River demand identified, 2) Colorado River demand, and 3) change in Colorado River demand by demand category.

From the first panel, it can be seen that Study Area demand increases from about 28 maf in 2015 to up to nearly 33 maf by 2060 in the highest scenario. The range in demand increase across scenarios in 2060, however, is projected to be as low as 1.2 or as high as 4.7 maf. More than half of the Study Area demand is expected to be met by other supplies.

Panel two depicts the range of Colorado River demand across scenarios. The Colorado River demand increases from about 12.8 maf in 2015 to between 13.8 and 16.2 maf in 2060 (or 8 percent to 27 percent increase from 2015) depending on the scenario. The range across the

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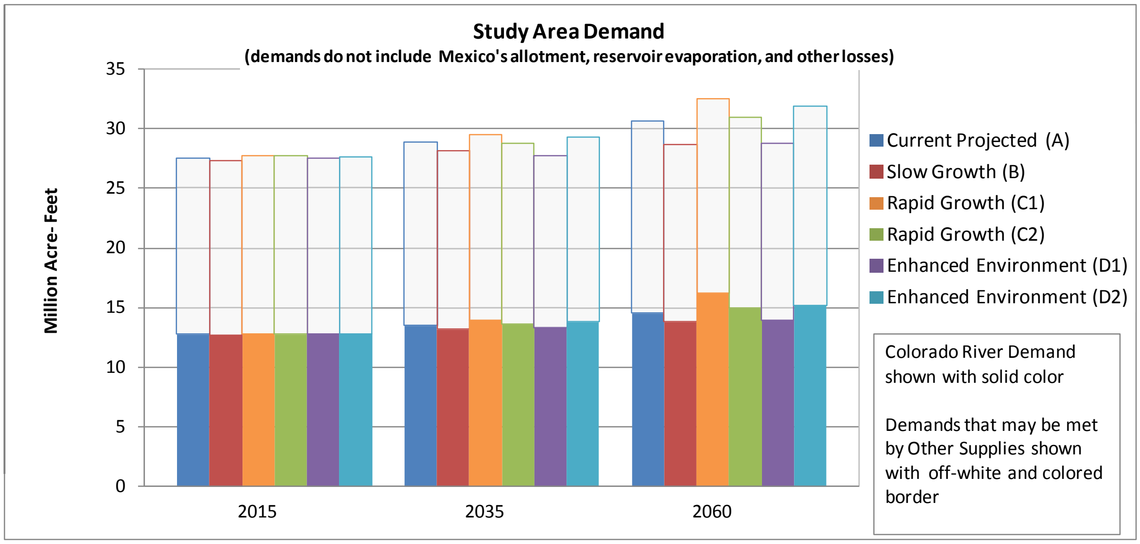
[5] Mexico's allotment and losses such as reservoir evaporation, phreatophyte losses, and operational inefficiencies are not part of this total. These factors will be included in the modeling supporting the system reliability analysis and have been included in figure C-5 to provide a more complete view of the total demand and losses in the Basin.

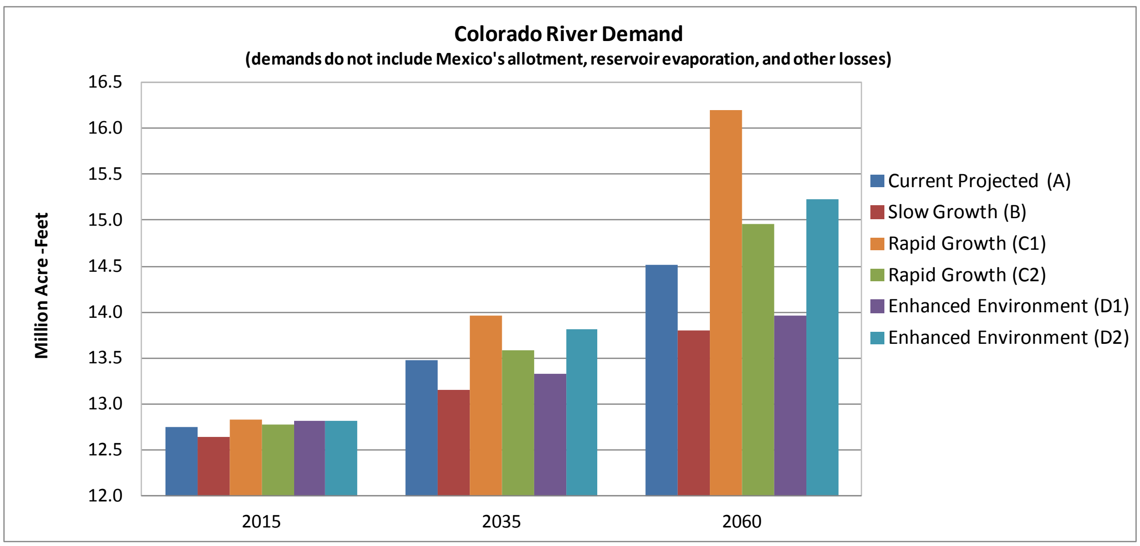
highest and lowest scenarios is about 2.4 maf by 2060 or about a 17 percent spread between the Rapid Growth (C1) and the Slow Growth (B) scenarios.

Panel three shows the projected change in Colorado River demand by specific demand categories for each scenario. Increase in the M&I demand category across all scenarios represents the greatest increase in demand. Tribal and energy demand categories also are projected to grow, while the overall growth in Colorado River demand is projected to be partially offset by decreases in agricultural demand driven by reductions in irrigated acreage.

Figure C-5 shows the historical Colorado River use6 and projected future Colorado River demand by scenario. This figure includes historical and future projected losses (comprised of reservoir evaporation and other losses) and deliveries to Mexico to provide a more complete view of the total demand and losses in the Basin. Factoring in Mexico's allotment and losses, the Colorado River demand increases to between 18.1 and 20.4 maf in 2060. The range across scenarios in 2060 (about 2.4 maf) is easily discernible in the figure, as is the relative similarity of overall demand in the Current Projected (A), Rapid Growth (C2), and Enhanced Environment (D2) scenarios. In addition, it appears that the quantified scenarios track with recent peaks in historical uses that likely represent the least supply limited conditions and could be an indication of historical demand.

FIGURE C-4
Study Area, Colorado River, and Change in Colorado River Demand





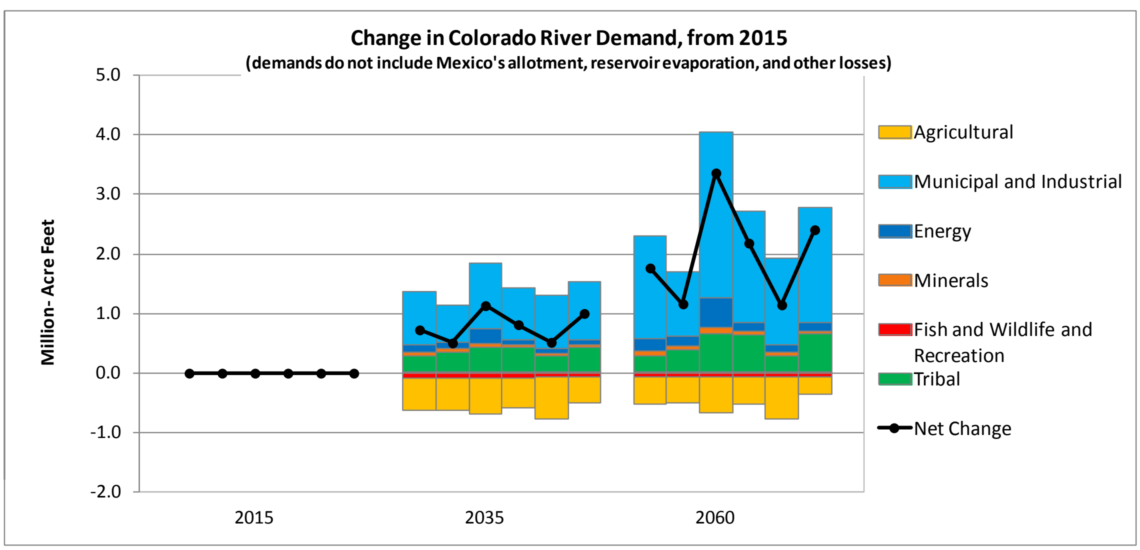
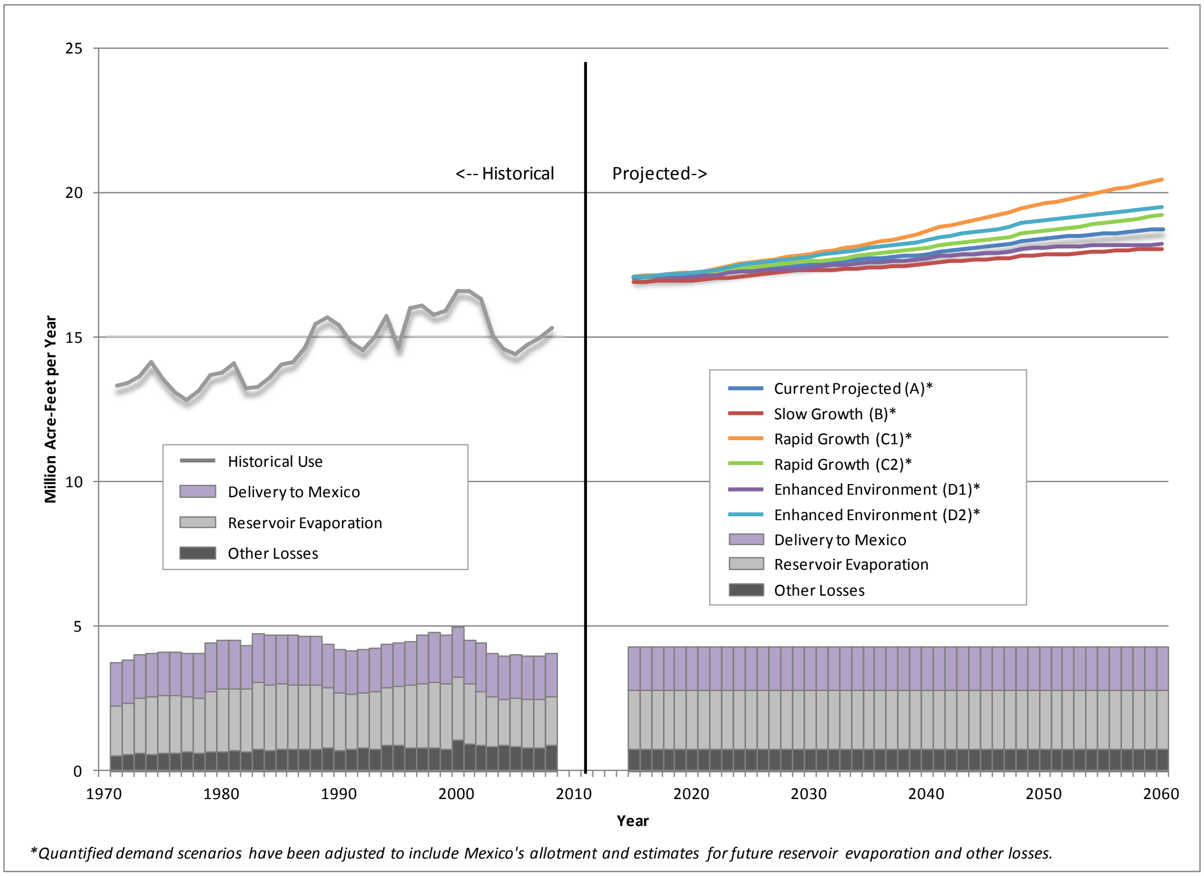


FIGURE C-5
Colorado River Basin Historical Use[1] and Future Projected Demand[1], Delivery to Mexico[2], Reservoir Evaporation[3], and Other Losses[4]



[1] Excluding consumptive use in Lower Basin tributaries.

[2] Assumed 1.5 maf delivery to Mexico 2012-2060. Modeling to support the system reliability analysis will project future deliveries to Mexico in accordance with the 1944 Treaty,

[3] Assumed 1971-2008 average reservoir evaporation of 2.0 maf 2012-2060.

[4] Other losses include phreatophyte and operational inefficiency losses. Future phreatophyte losses are computed by assuming 1995-2008 average of 632 kaf. Future operational inefficiency losses are computed as the sum of 109 kaf (the 1990-2010 average bypass of return flows from the Welton-Mohawk Irrigation and Drainage District to the Cienega de Santa Clara in Mexico) and 7 kaf (computed by assuming the 1964-2010 historical average annual volume of non-storable flows delivered to Mexico [excluding flood years] is reduced by 90 percent due to the operation of Brock Reservoir).

4.3 Colorado River Water Demand by Geography

The Colorado River demand at three geographic levels is presented in figures C-6, C-7, and C-8. These figures show Study Area, Upper and Lower Basin, and individual state demand across the scenarios. The bars at the right in these figures show the relative contribution of each demand category to the total Colorado River demand at a point in time (2015, 2035, or 2060) in the Current Projected (A) scenario. In general, the category proportions remain relatively consistent across the scenarios.

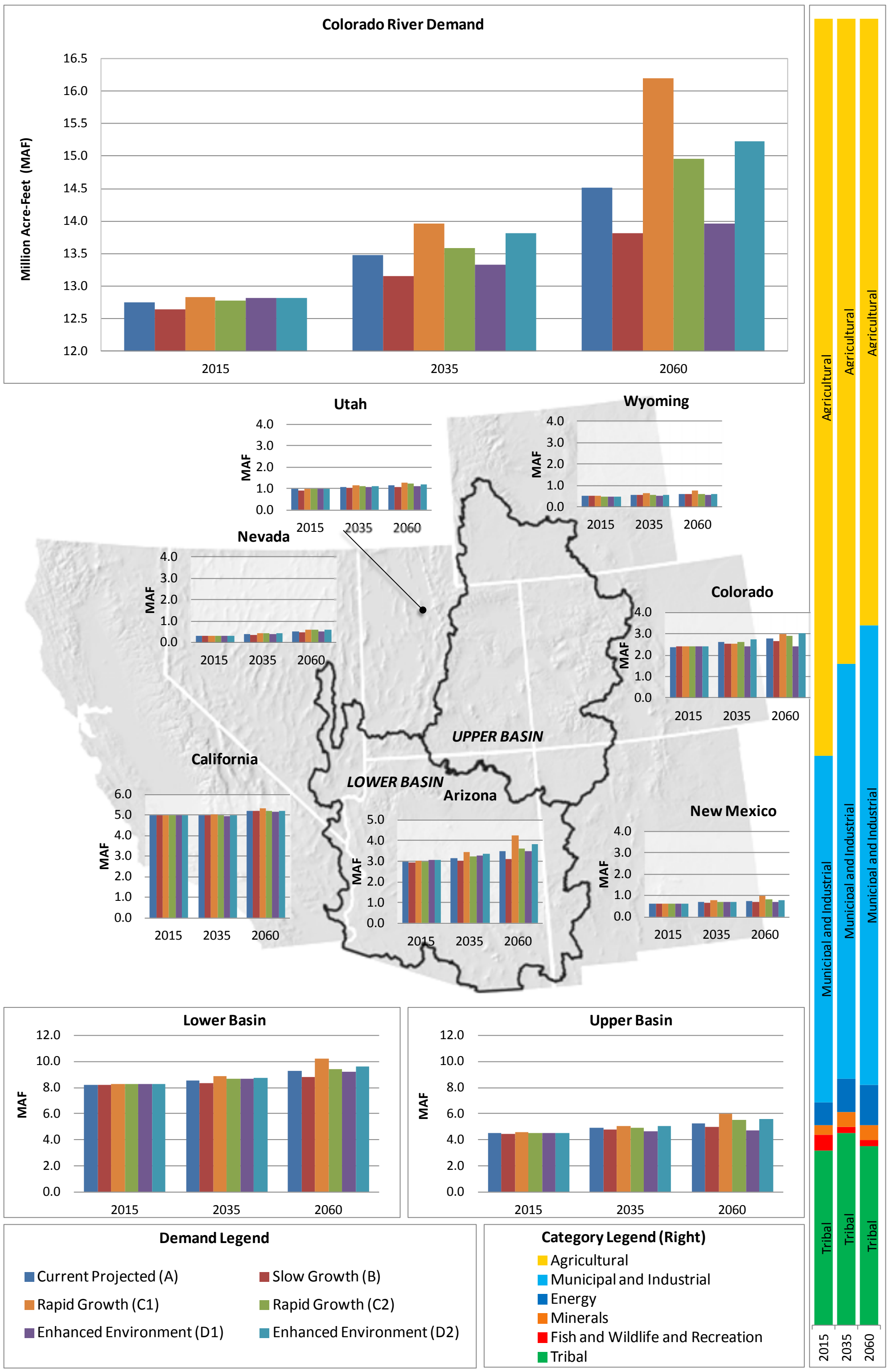
As described in section 3.2, the scenario quantification approach entailed first quantifying the changes in parameters, such as population and agricultural acreage, and then using these quantified parameters to compute demand. For the purposes of the Study, the resulting demand is not limited by the Colorado River Compact apportionments. In this way the demand for Colorado River and tributary water can be assessed in the context of overall Study Area demand and supplies available from other sources.

As shown in figure C-6, the change in both magnitude and percentage of Colorado River demand varies considerably across the states. Colorado and Arizona show the greatest magnitude of overall growth in Colorado River demand from 2015 to 2060 across the scenarios, ranging between about 0.2 and 1.2 maf increase by 2060 in Arizona and 0.04 and 0.64 maf in Colorado. The broad demand range across scenarios in these states is due to substantial growth in M&I demand, particularly in central Arizona and the Front Range of Colorado. Increase in tribal demand is also a significant contributor to the increases in Arizona. Demand in Nevada and California is projected to grow by about 0.2 to 0.35 maf, due to population growth in Nevada and California (supply currently limited by Colorado River Aqueduct capacity). Demand in New Mexico, Utah, and Wyoming grows by about 0.1 to 0.2 maf under most scenarios. However, under the Rapid Growth (C1 and C2) scenarios the growth is about 0.3 maf in Utah, where population is projected to increase by nearly 4 million and per capita water use reductions do not fully offset the rapid growth.

When demand by category is examined in figure C-7, the contribution of demand by category across the Upper and Lower Basins vary, with nearly equal agricultural and M&I demand in the Lower Basin and nearly two-thirds of the demand in the Upper Basin from agriculture. The category contribution to the total demand varies considerably across states as well, with no two states having comparable proportions of categories.

Figure C-8 shows the change in Colorado River demand by category from 2015 for each scenario. In most scenarios, the M&I demand is the major driver contributing to future growth in demand. However, the M&I demand does not increase as significantly in the Enhanced Environment (D1) scenario as per capita water use is assumed to be substantially decreased. Tribal, energy, and minerals demands are also projected to increase in all scenarios, while Basin-wide reductions in agricultural demand are projected. The Upper Basin generally shows growth in all categories but is dominated by demand growth in the M&I category, while the Lower Basin shows dramatic growth in M&I demand (in most scenarios) and a significant reduction of agricultural demand. The reduction in fish and wildlife demand in the Lower Basin is caused by the cessation of mitigation water provided to the Salton Sea in California in accordance with the 2003 Colorado River Water Delivery Agreement, Federal Quantification Settlement Agreement.

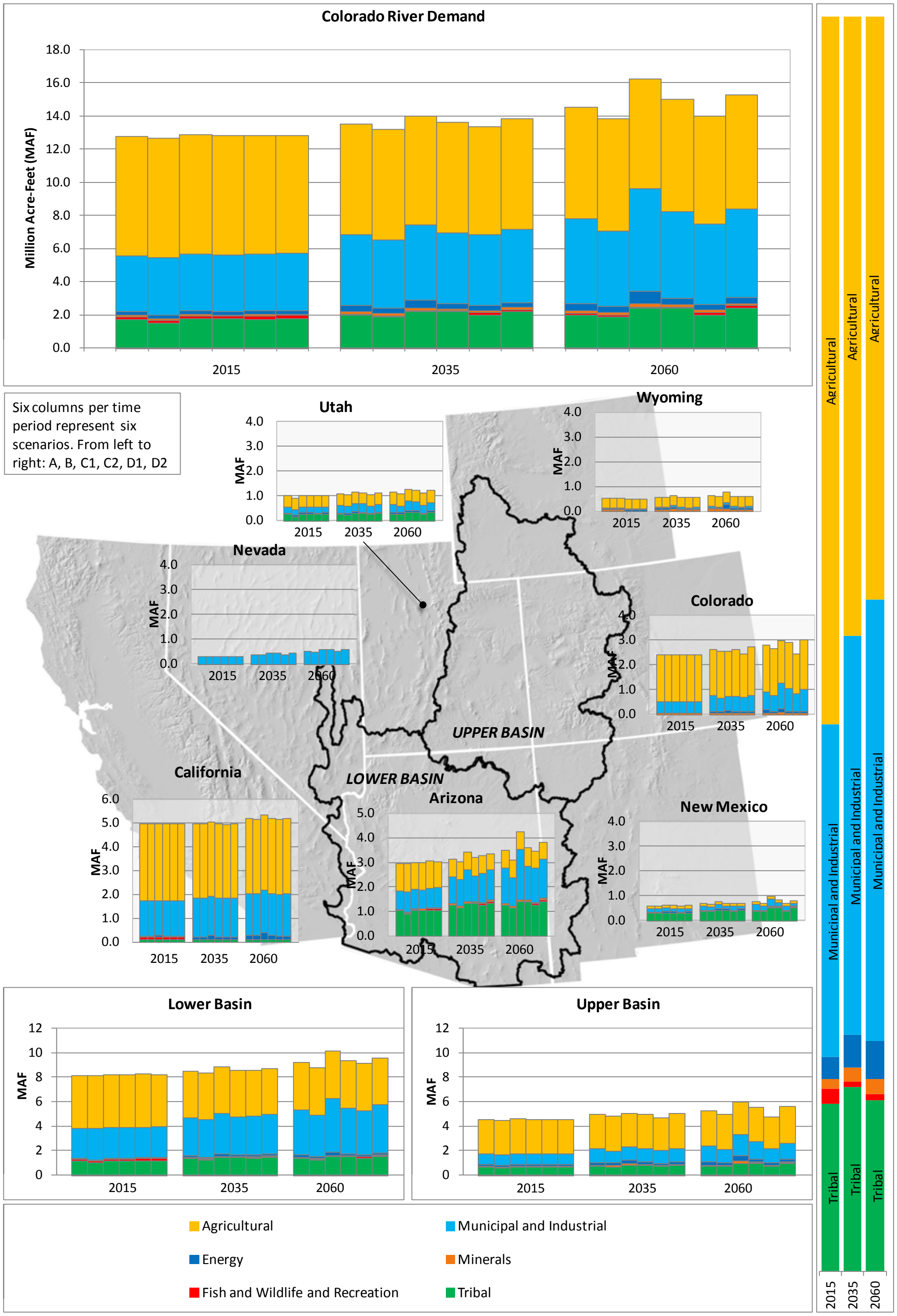
FIGURE C-6
Colorado River Water Demand[1,2]



[1] Demands do not include Mexico's allotment and losses such as reservoir evaporation. These factors will be included in the modeling supporting the system reliability analysis.

[2] Tribal demand within Colorado is not reflected in the tribal category but is included in other categories.

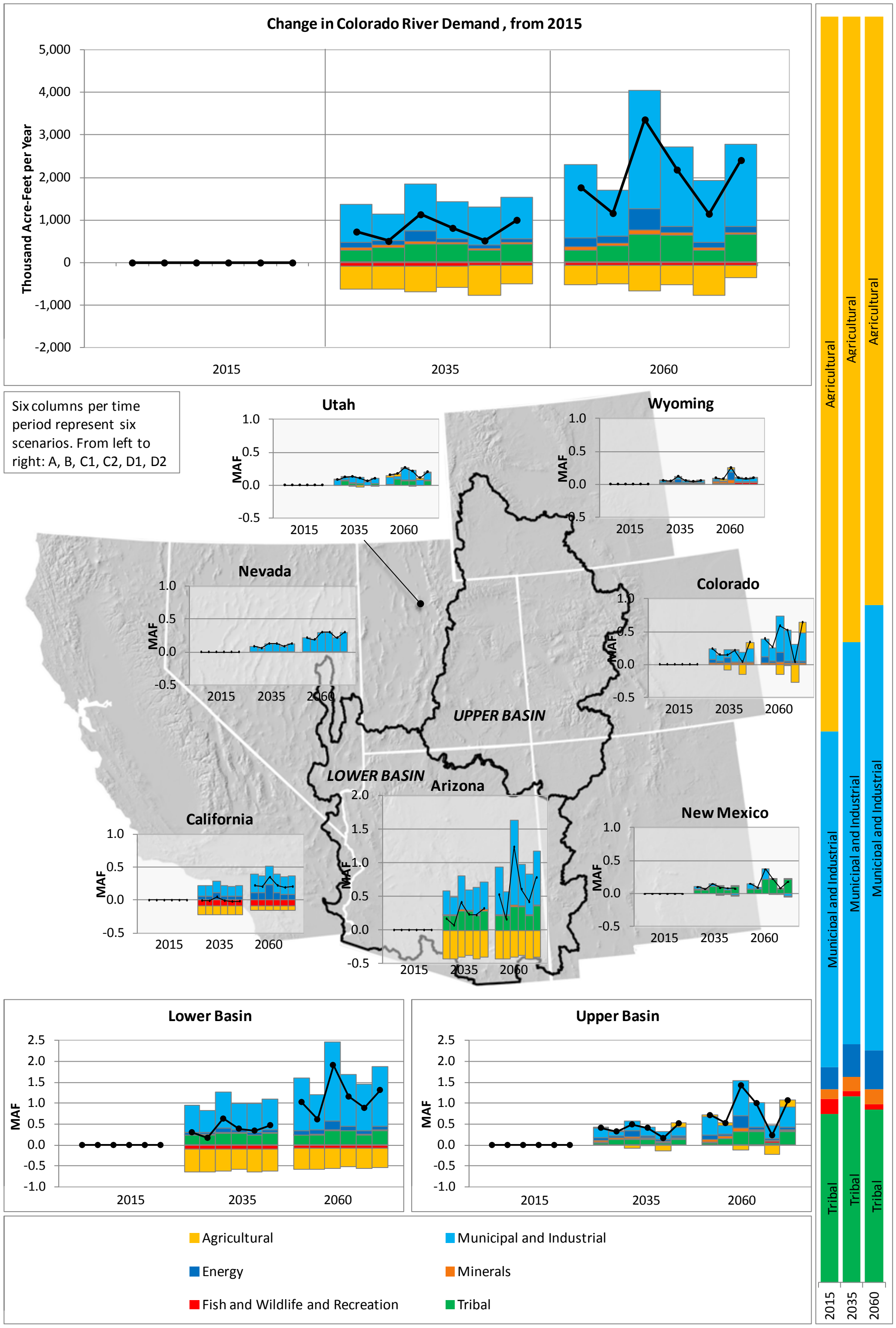
FIGURE C-7
Colorado River Water Demand by Category [1,2]



[1] Demands do not include Mexico's allotment and losses such as reservoir evaporation. These factors will be included in the modeling supporting the system reliability analysis.

[2] Tribal demand within Colorado is not reflected in the tribal category but is included in other categories.

FIGURE C-8
Change in Colorado River Water Demand from 2015 by Category [1,2]



[1] Demands do not include Mexico's allotment and losses such as reservoir evaporation. These factors will be included in the modeling supporting the system reliability analysis.

[2] Tribal demand within Colorado is not reflected in the tribal category but is included in other categories.

4.4 Colorado River Water Demand by Category

4.4.1 Agriculture

Agricultural water demand is primarily driven by the extent of irrigated acreage and per-acre water delivery. Per-acre water delivery is the amount of water diverted per irrigated acre and includes components such as transmission and delivery losses (surface evaporation, riparian demand, and seepage), and on farm losses that are made up of evaporation, tail water (return), and crop irrigation requirements. Each of these factors varies by location (precipitation, growing season, etc.), irrigation method, and crop type.

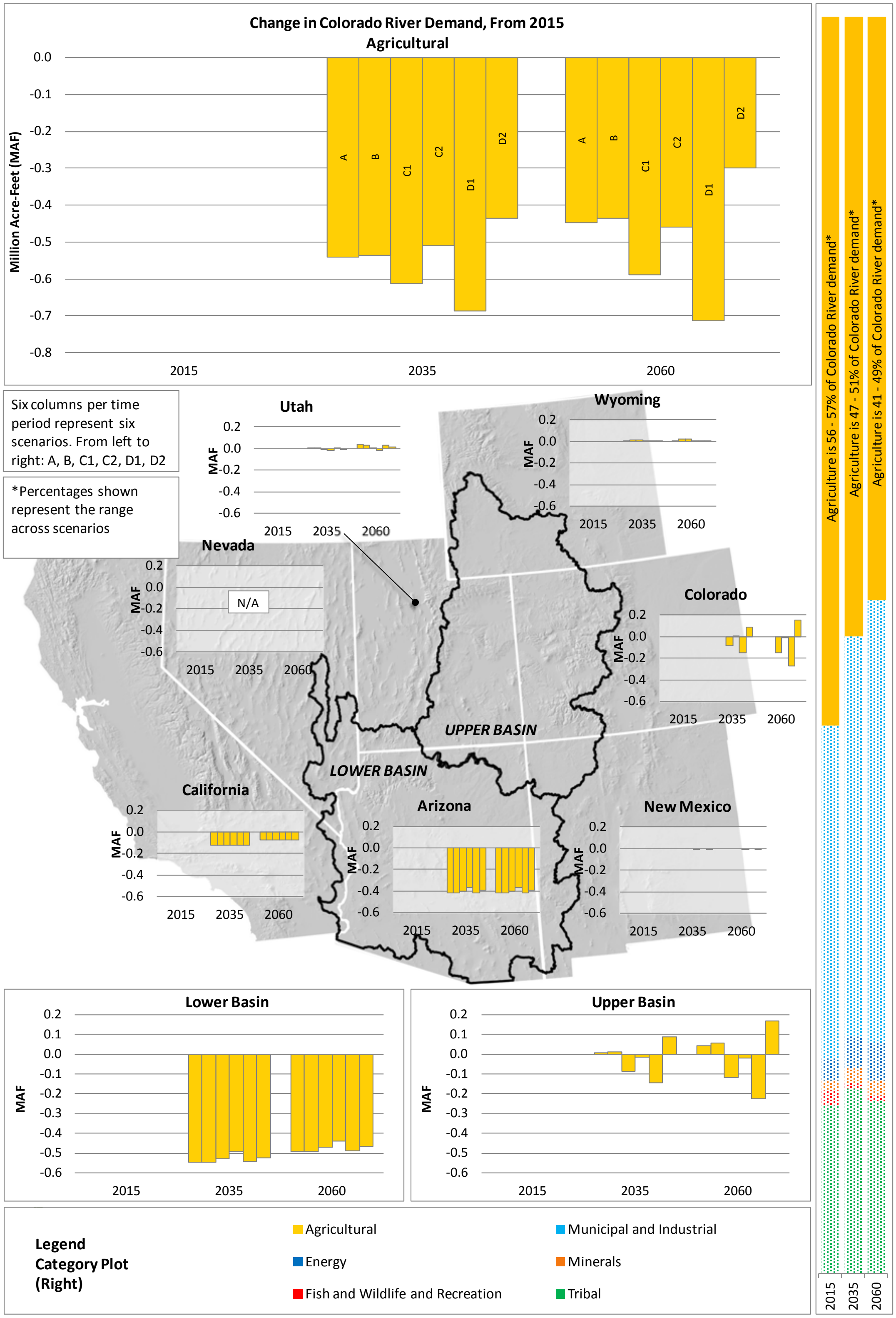
Figure C-7 shows the demand by category and depicts the relative magnitude of the agricultural demand. Figure C-9 presents the change in agricultural demand for the Study Area, by Upper and Lower Basin, and by state. The figure also shows agricultural demand as a proportion of the total Colorado River water demand (right hand stacked bar graph).

As can be seen from figure C-7 and figure C-9, agricultural water demand is the largest component of the Colorado River demand, dropping from about 57 percent in 2015 to between 41 and 49 percent of Colorado River demand in 2060, depending on the scenario. The reduction in the percentage contribution of agricultural demand results from both a decrease in agricultural water demand and an increase in other categories of demand. Total Colorado River demand for agricultural uses decreases through 2060 for all scenarios. The overall decrease in agricultural demand is almost entirely due to a reduction in irrigated acreage as per-acre delivery shows slight increases across all scenarios.

Agricultural demand decreases over time in the Lower Basin, but exhibit some increases in the Upper Basin in several scenarios. For the Lower Basin states, most of the decrease in agricultural demand occurs in Arizona, with a small amount of reduction in demand in California across all scenarios. Nevada does not report any agricultural use in any scenarios. In the Upper Basin, an increase in agricultural demand occurs in most states, with changes in Colorado having the greatest magnitude and being the most notable in the Enhanced Environment (D2) scenario. However, the projected agricultural demand in Colorado decreases in several scenarios due to assumptions of future irrigated acreage. Slight increases in agricultural demand are projected in most scenarios in Utah and Wyoming. New Mexico agricultural demand ranges from no change to a nominal decrease.

A strong driver for loss of agricultural acreage is urbanization, leading to physical loss of acreage and pressure for transfer of water. These factors are particularly important in Colorado and Arizona. Utah and Wyoming are continuing to actively develop agricultural lands under existing plans.

FIGURE C-9
Change in Colorado River Water Demand for Agriculture



4.4.2 Municipal and Industrial

M&I water demand can be estimated from population and per capita water use, with the addition of self-served industrial (SSI) demand. The per capita water use is a measure of the amount of water produced or diverted per person in a given municipality or service area. Because this measure examines all water produced by a given municipality or service area, it often includes industrial, commercial, and institutional demand as well as residential demand. A number of factors may influence the M&I water use of a given community, including the amount of industrial demand, climate, number of institutional facilities, accounting method for reuse, demographics, economic conditions, and number of visitors. These factors make comparisons among different locations challenging.

The SSI demand represents the demand of industries in a given area that have independent water supply systems. Because these industries have water supplies independent from the other urban areas, the demand is not directly related to population and per capita water use rates assumed for most M&I demand projections.

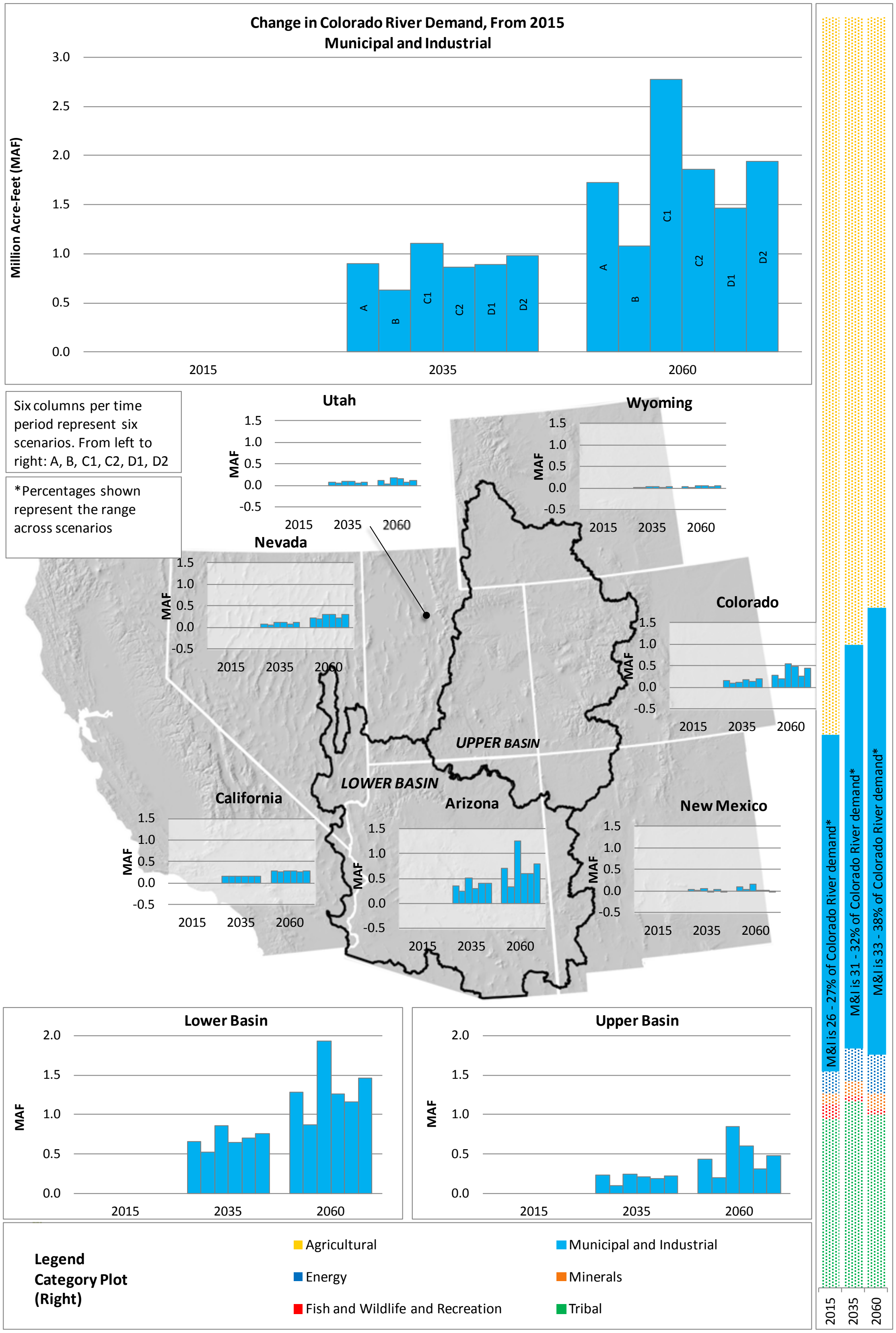
Figure C-7 shows the demand by category and depicts the relative magnitude of the M&I demand. Figure C-10 presents the change in M&I demand for the Study Area, by Upper and Lower Basin, and by state. The figure also shows the M&I demand as a proportion of the total Colorado River water demand (right hand stacked bar graph).

As can be seen from figure C-7 and figure C-10, M&I water demand is the second largest component of Colorado River demand, increasing from about 27 percent in 2015 to between 33 and 38 percent of total Colorado River demand in 2060 depending on the scenario. The M&I demand increases over the Study period for all scenarios. The increase is primarily due to population increase because per capita water use is projected to decrease over time across all scenarios. The self-served industrial demand is less than 10 percent of total M&I demand.

The M&I demand for Colorado River water increases over the Study period in both the Upper and Lower Basin, with about 19 to 32 percent of the increase occurring in the Upper Basin and 68 to 81 percent of the increase occurring in the Lower Basin. In the Upper Basin, most of the increase in M&I demand for Colorado River water is due to projected population growth in the state of Colorado. The remaining increase in Upper Basin M&I demand is primarily in New Mexico and Utah, with only small increases in Wyoming. In the Lower Basin, about 50 percent of the increase in M&I demand occurs in Arizona, with the remaining 50 percent split between California and Nevada across all scenarios.

Population is the most significant driver for increases in M&I demands. In the scenarios, per capita water use rates are projected to decrease in six of the seven Basin States and partially attenuate demand growth due to population increases alone. Per capita water use rates decrease in all states except in Wyoming, where rates increase slightly due to urbanization of rural areas.

FIGURE C-10
Change in Colorado River Water Demand for Municipal and Industrial



4.4.3 Energy

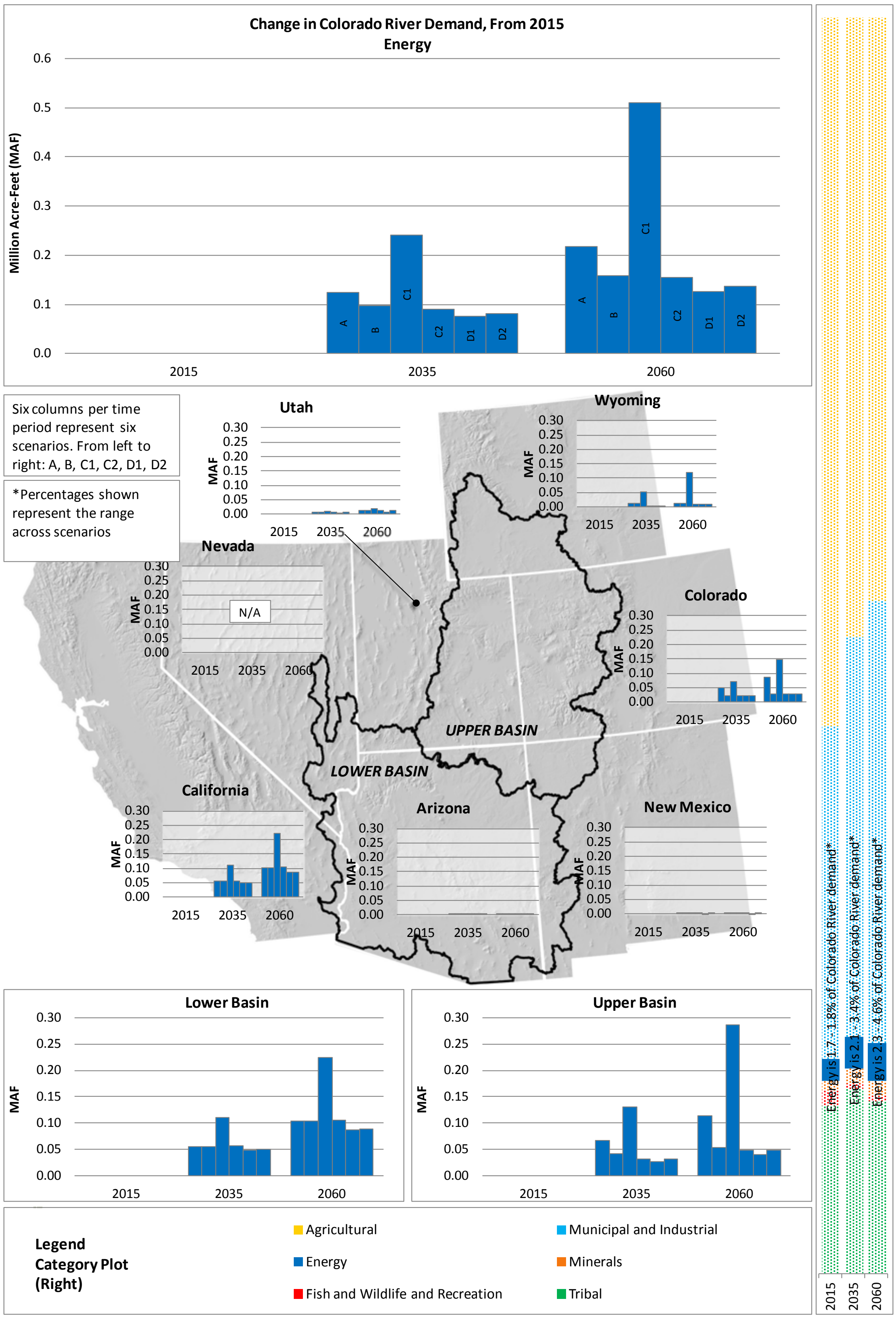
Water demand for energy includes anticipated growth in most types of power generation and associated technologies, including thermoelectric, solar, geothermal, and oil shale. Water demand for energy uses can be estimated through known plans for new power plants or through applying a per capita energy water use factor. Power facilities, however, often serve areas remote from their locations and therefore potentially represent exports or imports of energy and water from the Study Area to meet these distributed needs. Therefore, while the link between population and energy demand exists, the effects on energy water demands are not always experienced in the same planning areas as the growth.

Figure C-7 shows the demand by category and depicts the relative magnitude of the energy water demand. Figure C-11 presents the change in energy demand for the Study Area, by Upper and Lower Basin, and by state. The figure also shows the energy demand as a proportion of the total Colorado River water demand (right hand stacked bar graph).

As can be seen from figure C-7 and figure C-11, energy water demand is a small fraction of total Colorado River demand. The water demand for energy increases from about 1.7 percent of the total demand in 2015 to between 2.3 and 4.6 percent of total demand in 2060, depending on the scenario. Energy demand for Colorado River water increases over the Study period for all scenarios, with notable increases for the Rapid Growth (C1) scenario.

The water demand for energy is projected to increase over the Study period in all scenarios and in both the Upper and Lower Basins. Between 31 and 56 percent of the increase in water demand for energy occurs in the Upper Basin and between 44 and 69 percent of the increase occurs in the Lower Basin. In the Upper Basin, between about 50 to 80 percent of the increase in energy demand over time is due to increases in Colorado, with the remaining increase in demand primarily split between Wyoming and Utah. In the Upper Basin, increases are due to expansion of thermoelectric power plants and oil shale production. In the Lower Basin, virtually all of the growth in water demand for energy occurs in California due to projected expansion of geothermal and solar projects. Projected increases in water demands for energy in Arizona represent only about 1 percent of the Lower Basin increase, and Nevada does not report any energy use in any of the scenarios.

FIGURE C-11
Change in Colorado River Water Demand for Energy



4.4.4 Minerals

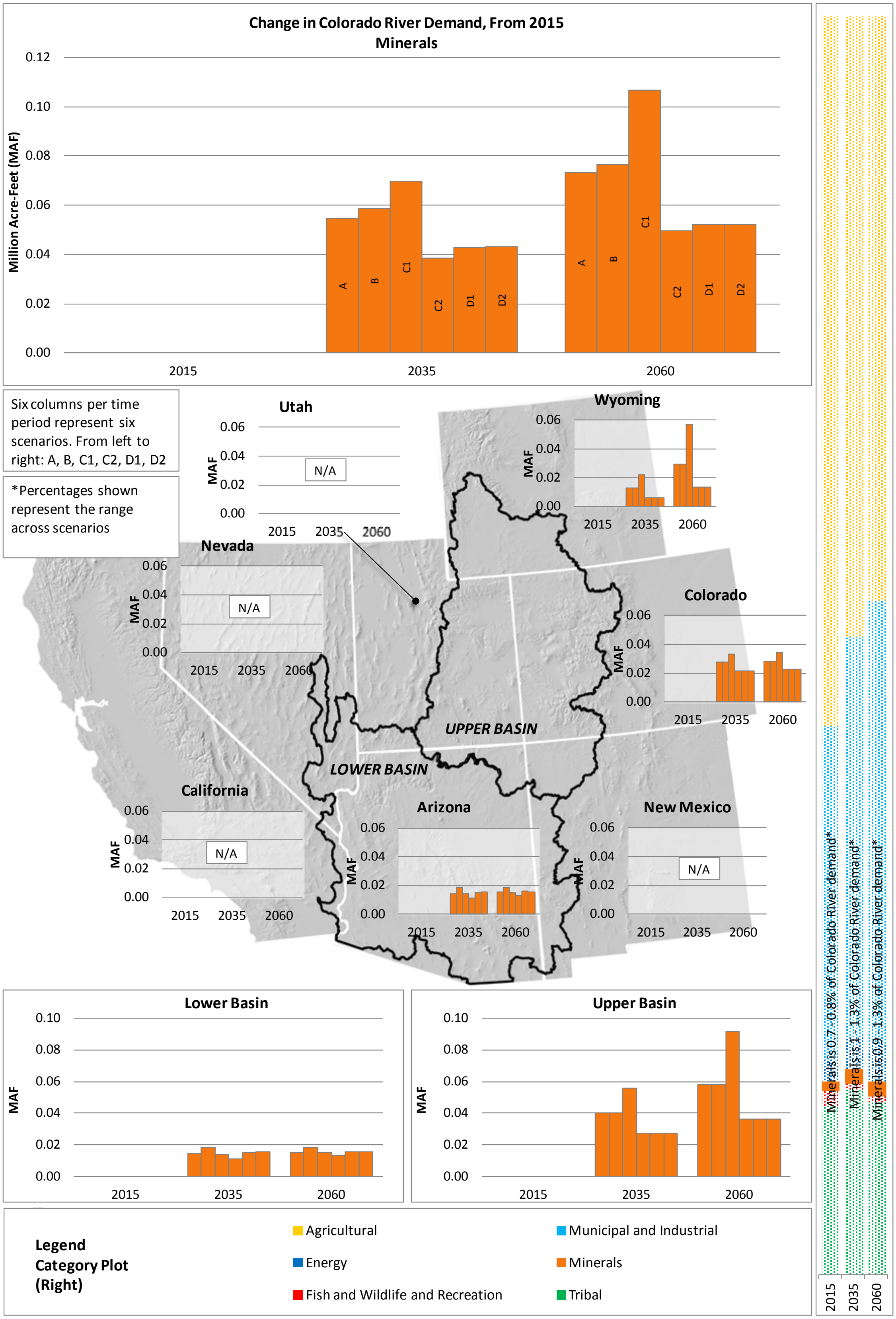
Water demand for mineral production can be estimated through existing uses and known plans for mineral extraction in the Study Area. Water demand for mineral production varies considerably across the Study Area and can fluctuate significantly based on market prices for a given product.

Water demands for mineral extraction represent only a small portion (less than 200,000 afy Basin-wide) of the total demand for Colorado River water. Figure C-12 presents the change in mineral demand for the Study Area, by Upper and Lower Basin, and by state. The figure also shows mineral demand as a proportion of the total Colorado River water demand (right hand stacked bar graph).

As can be seen from figure C-7 and figure C-12, minerals water demand is a small fraction of Colorado River demand, increasing from about 0.7 percent in 2015 to between 0.9 and 1.3 percent of Colorado River demand in 2060, depending on the scenario. The water demand for mineral extraction, however, increases for all scenarios and in both the Upper and Lower Basins. Similar increases in demand occur in the Upper and Lower Basins for Rapid Growth (C2) and Enhanced Environment (D1 and D2) scenarios, between 2015 and 2060. Greater increases in demand occur in the Upper Basin for Current Projected (A), Slow Growth (B), and Rapid Growth (C1) scenarios due to technology adoption assumptions.

All increases in water demand for mineral production are due to increases in Colorado, Wyoming, and Arizona.

FIGURE C-12
Change in Colorado River Water Demand for Mineral Production



4.4.5 Fish, Wildlife, and Recreation

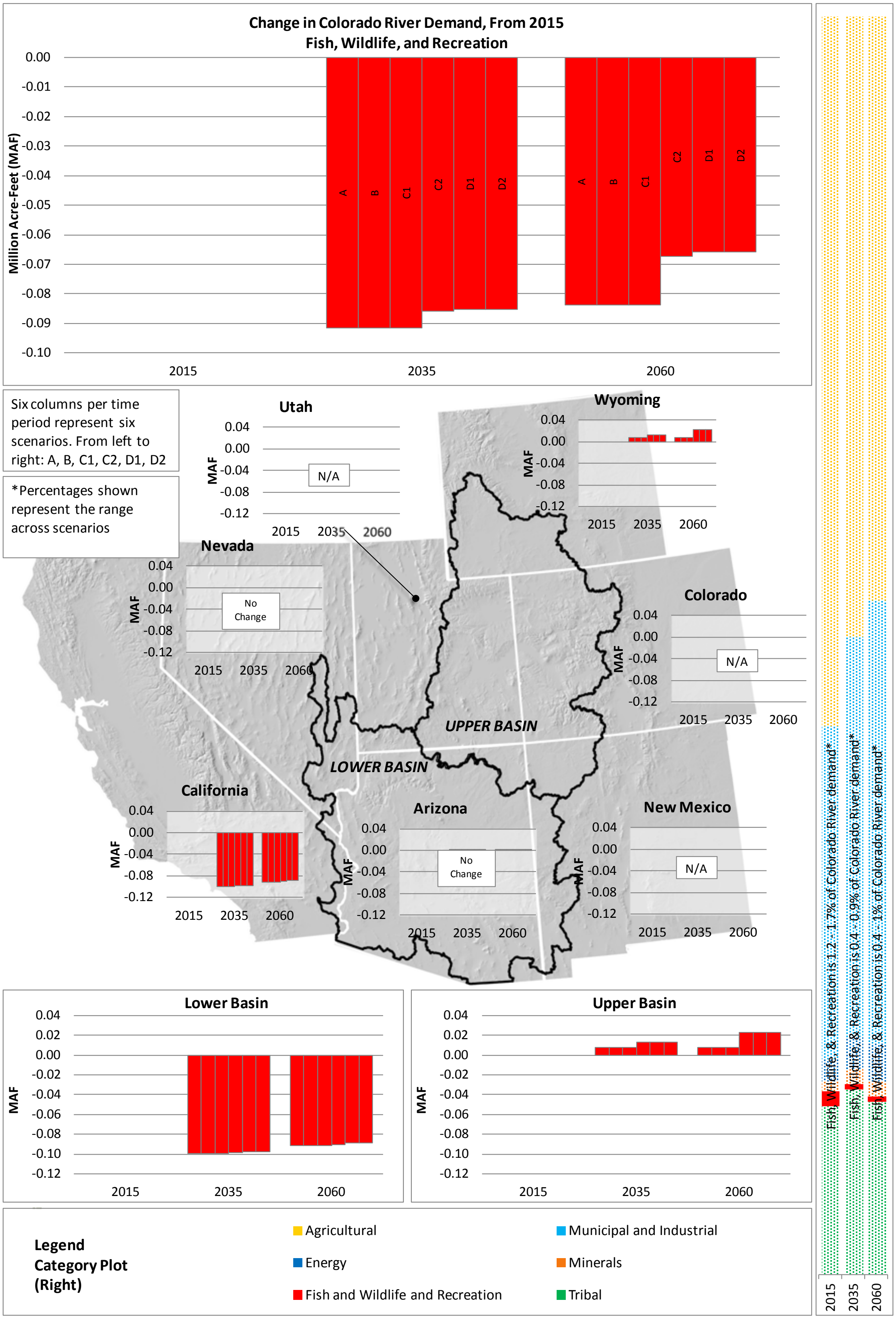
Water demand for fish, wildlife, and recreation is estimated from existing agreements or known consumptive uses associated with this demand category. The demands in this category largely represent water needs for wildlife refuges, fish hatcheries, recreational facilities, and obligations for water delivery to the Salton Sea under the 2003 Colorado River Water Delivery Agreement, Federal Quantification Settlement Agreement. In the Lower Basin, the Cibola National Wildlife Refuge (NWR), Imperial NWR, Havasu NWR, and Lake Mead National Recreation Area have consumptive water rights and largely comprise the fish, wildlife, and recreation demand in the Lower Basin. Non-consumptive demands associated with fish, wildlife, and recreation, including in-stream flow requirements, are represented through the metrics portion of the Study as presented in *Technical Report D – System Reliability Metrics* (Reclamation, 2012b).

Figure C-7 shows the demand by category and depicts the relative magnitude of the fish, wildlife, and recreation water demand. Figure C-13 presents the change in fish, wildlife, and recreation demand for the Study Area, by Upper and Lower Basin, and by state. The figure also shows the fish, wildlife, and recreation demand as a proportion of the total Colorado River water demand (right hand stacked bar graph).

As can be seen from figure C-7 and figure C-13, fish, wildlife, and recreation water demand is a small fraction of Colorado River demand, decreasing from about 1.4 percent in 2015 to about 0.4 to 1 percent of Colorado River demand in 2060 across all scenarios. The overall decrease in demand for Colorado River water for fish, wildlife, and recreation is driven by the terms of an exhibit of the 2003 Colorado River Water Delivery Agreement, Federal Quantification Settlement Agreement, which phases out Salton Sea delivery obligations over time.

Fish, wildlife, and recreation demand increases over time in the Upper Basin and decreases over time in the Lower Basin. The Upper Basin makes up about 30 percent of the fish, wildlife, and recreation demand in 2060, with the Lower Basin making up about 70 percent of demand. In the Upper Basin, all of the increase in fish, wildlife, and recreation water demand over time is due to increases in this category in Wyoming. Colorado, New Mexico, and Utah do not report any fish, wildlife, and recreation consumptive use in any of the scenarios. In the Lower Basin, all of the decrease in fish, wildlife, and recreation demand occurs in California. Arizona includes fish, wildlife, and recreation demand that varies by scenario but is constant over time. Nevada includes small fish, wildlife, and recreation demand that is constant over time and across scenarios.

FIGURE C-13
Change in Colorado River Water Demand for Fish, Wildlife, and Recreation



4.4.6 Tribal

Tribal water demand in the Study is largely based on the quantified rights and entitlements of tribes to Colorado River water as well as their anticipated future rate of use and development. A number of tribes in the Basin have unquantified rights and claims (Navajo Nation, Ute Mountain Ute Indian Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Pascua Yaqui Tribe, San Carlos Apache Tribe, San Juan Southern Paiute Tribe, Tohono O'odham Nation, Tonto Apache Tribe, and Yavapai-Apache Nation), and although the demand for this water is considered to be a factor impacting Basin-wide water availability, specific numbers may not be available for technical and political reasons. With the exception of the Navajo Nation, unquantified rights and claims are not a component of the demands presented below.

For the Study, tribes with quantified rights to Colorado River water were organized into three categories, presented in table C-5, based on location: Upper Colorado River Basin tribes, Lower Colorado River Mainstem tribes, and tribes served by water provided through the CAP. Figure C-14 displays the lands in the hydrologic Basin where tribes have rights or claims to Colorado River water.

TABLE C-5
Upper Colorado River Basin Tribes, Lower Colorado River Mainstem Tribes, and Tribes Served by Water Provided through the CAP

Upper Colorado River Basin Tribes	
Jicarilla Apache Nation	New Mexico
Navajo Nation	Arizona, New Mexico, and Utah
Southern Ute Indian Tribe	Colorado
Ute Indian Tribe of the Uintah and Ouray Reservation	Utah
Ute Mountain Ute Tribe	Colorado, New Mexico, and Utah
Lower Colorado River Mainstem Tribes[1]	
Chemehuevi Indian Tribe	California
Cocopah Indian Tribe	Arizona
Colorado River Indian Tribes	Arizona and California
Fort Mojave Indian Tribe	Arizona, Nevada, and California
Hopi Tribe	Arizona
Quechan Indian Tribe	Arizona and California
Tribes served through the Central Arizona Project	
Ak-Chin Indian Community	Arizona
Fort McDowell Yavapai Nation	Arizona
Gila River Indian Community	Arizona
Pascua Yaqui Tribe	Arizona
Salt River Pima-Maricopa Indian Community	Arizona
San Carlos Apache Tribe	Arizona
Tohono O'odham Nation	Arizona
Tonto Apache Tribe	Arizona
White Mountain Apache Tribe	Arizona
Yavapai-Apache Nation	Arizona
Yavapai-Prescott Tribe	Arizona

[1] The Zuni Indian Tribe has rights to Little Colorado River water in Arizona and the Moapa Band of Paiutes has rights to water in the Muddy River, Nevada. The modeling of these tributaries assume future demand to be consistent with historic demand on these rivers. See Technical Report C—Water Demand Assessment, appendix C5 (Reclamation, 2011b) for more information on the modeling of Lower Basin tributaries.

FIGURE C-14
Colorado River Basin Tribes

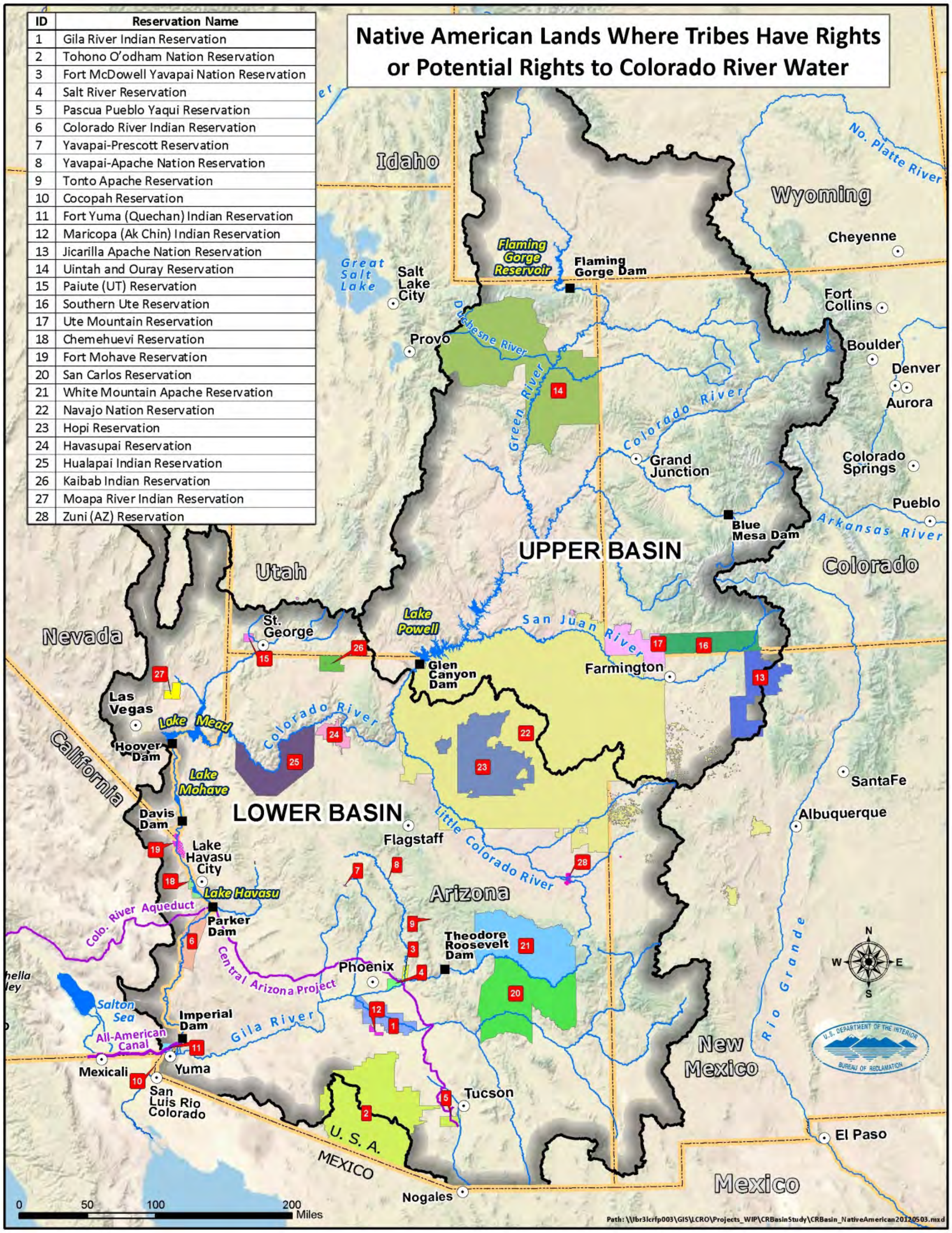


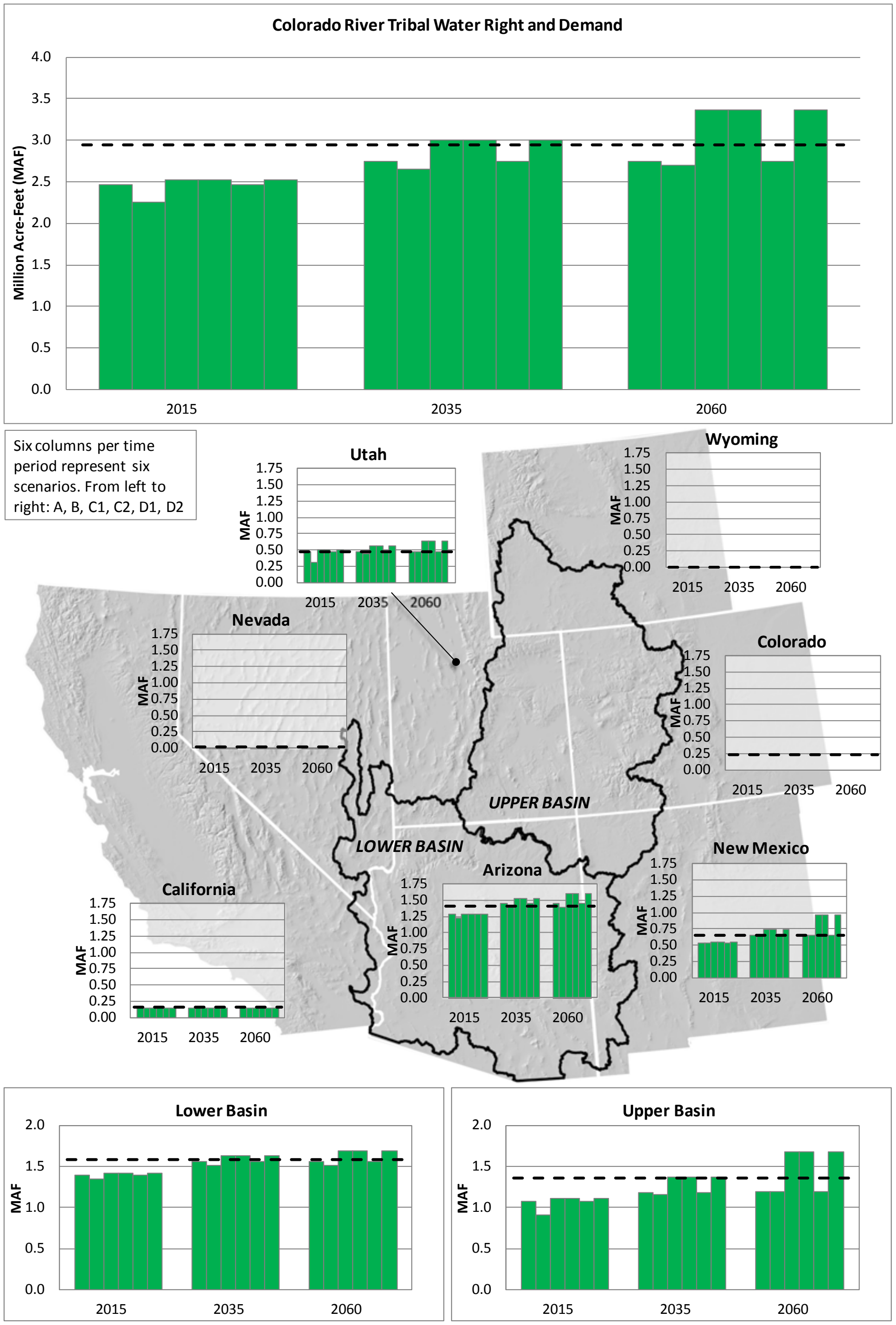
Figure C-15 summarizes Basin-wide, by Upper and Lower Basins, and by state, both the quantified Colorado River rights held by tribes as well as the tribal demand as a portion of those rights. Tables C-6 and C-7 present, by state, tribal diversion, depletion, and acreage entitlement as appropriate, as well as 2015, 2035, and 2060 projected tribal diversion and depletion, along with total state depletion under each scenario. It is important to note that in Figure C-15 both tribal demand and rights are presented in terms of diversion and not depletion. This presentation was chosen to facilitate a comparison between demand and quantified rights for the Mainstem tribes in the Lower Basin whose rights are quantified in terms of diversion entitlements. For a more detailed description of the rights and demands by tribe, see appendix C9.

As seen in figure C-15, quantified tribal diversion rights comprise about 2.9 maf in the Basin, with about 1.36 maf of those rights in the Upper Basin and 1.58 maf in the Lower Basin. Quantified tribal rights are assumed to not vary by scenario or throughout the Study period. The majority of quantified rights are within Arizona, totaling approximately 1.4 maf. Tribal demands in Colorado, at the request of the Southern Ute Indian and Ute Mountain Ute Tribes, are not broken out from other categories in the state. Consequently, only the quantified right for these tribes (not the demand) is shown in these figures. There are no tribal rights or claims to Colorado River water in Wyoming. The figure also shows the tribal demand in terms of depletion as a proportion of the total Colorado River demand (right hand stacked bar graph).

Tables C-6 and C-7 show that in some states, tribal demand is already equal to (or in some cases above) the quantified right in 2015 under all scenarios. Demand beyond the quantified rights, as seen under the Rapid Growth (C1 and C2) scenarios and the Enhanced Environment (D2) scenario in Arizona, New Mexico, and Utah, include unquantified rights and claims provided by the Navajo Nation. In those states that include scenarios where tribal demand is less than the right (Arizona, Utah, and New Mexico) the demand grows to reach the right by 2060. Under all scenarios for all states, with the exception of Colorado where tribal demand is not separated from other demands within the state, tribal demand has met or surpassed the quantified tribal right by 2060.

These tables also demonstrate the importance of tribal water in state demand. Tribal demand in the Basin lags behind only M&I and agricultural demand.

FIGURE C-15
Colorado River Basin Tribal Diversion Rights (dotted line) and Diversion-Based Demand[1,2,3]



[1] Tribal demand in Colorado, at the request of the Southern Ute Indian and Ute Mountain Ute Indian Tribes, is not broken out from other categories in the state.

[2] The diversion and depletion associated with demand for the Ute Indian Tribe of the Uintah and Ouray Reservation is dependent upon the re-ratification of the Revised Ute Indian Compact of 1990 by the Tribe and the state of Utah.

[3] Demands provided by the Navajo Nation include both quantified and unquantified rights and claims. See appendix C9 for more detail.

TABLE C-6
Upper Colorado River Basin Tribal Rights and Tribal and State Future Demands

State	Tribal Diversion Entitlement (Water Right) (afy)	Tribal Depletion Entitlement (Water Right) (afy)	Scenario	Tribal Demand (Diversion) 2015 (afy)	Tribal Demand (Depletion) 2015 (afy)	State Demand (Depletion) 2015 (afy)	Tribal Demand (Diversion) 2035 (afy)	Tribal Demand (Depletion) 2035 (afy)	State Demand (Depletion) 2035 (afy)	Tribal Demand (Diversion) 2060 (afy)	Tribal Demand (Depletion) 2060 (afy)	State Demand (Depletion) 2060 (afy)
CO	225,448	125,399	All Scenarios	Tribal demand in Colorado is embedded in other demand categories within the state.								
NM[1]	652,343	359,865	Current Projected (A)	543,280	299,470	600,020	652,926	359,730	703,035	658,546	363,195	754,100
			Slow Growth (B)	543,280	299,470	600,020	652,926	359,730	673,386	658,546	363,195	692,615
			Rapid Growth (C1)	554,904	305,710	606,260	745,316	409,775	757,963	961,439	525,795	979,209
			Rapid Growth (C2)	554,904	305,710	605,005	745,316	409,775	694,229	961,439	525,795	830,724
			Enhanced Environment (D1)	543,280	299,470	597,509	652,926	359,730	684,477	658,546	363,195	682,604
			Enhanced Environment (D2)	554,904	305,710	602,586	745,316	409,775	678,361	961,439	525,795	784,559
UT[1]	480,594	258,943	Current Projected (A)	480,594	258,943	999,059	480,594	258,943	1,081,531	480,594	258,943	1,153,500
			Slow Growth (B)	316,354	170,451	910,566	447,747	241,245	1,032,775	480,594	258,943	1,084,253
			Rapid Growth (C1)	506,798	272,045	1,012,161	560,470	298,881	1,141,323	637,286	337,289	1,277,455
			Rapid Growth (C2)	506,798	272,045	1,011,093	560,470	298,881	1,116,488	637,286	337,289	1,222,092

TABLE C-6 (CONTINUED)
Upper Colorado River Basin Tribal Rights and Tribal and State Future Demands

State	Tribal Diversion Entitlement (Water Right) (afy)	Tribal Depletion Entitlement (Water Right) (afy)	Scenario	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)
				2015 (afy)			2035 (afy)			2060 (afy)		
UT[1]	480,594	258,943	Enhanced Environment (D1)	480,594	258,943	997,295	480,594	258,943	1,059,226	480,594	258,943	1,109,080
			Enhanced Environment (D2)	506,798	272,045	1,010,397	560,470	298,881	1,111,176	637,286	337,289	1,211,531
WY	0	0	All Scenarios	No tribal entities in Wyoming receive Colorado River water.								
AZ[1]	0	0	Current Projected (A)	49,125	47,987	45,610	49,207	47,707	45,610	49,207	47,707	45,610
			Slow Growth (B)	49,125	47,987	45,610	49,207	47,707	45,610	49,207	47,707	45,610
			Rapid Growth (C1)	43,437	42,431	40,054	61,088	59,226	57,129	77,621	75,255	68,768
			Rapid Growth (C2)	43,437	42,431	40,054	61,088	59,226	57,129	77,621	75,255	68,768
			Enhanced Environment (D1)	49,125	47,987	45,610	49,207	47,707	45,610	49,207	47,707	45,610
			Enhanced Environment (D2)	43,437	42,431	40,054	61,088	59,226	57,129	77,621	75,255	68,768

[1] Demands provided by the Navajo Nation include both quantified and unquantified rights and claims. See appendix C9 for more detail.

[2] The diversion and depletion associated with the demand for the Ute Indian Tribe of the Uintah and Ouray Reservation is dependent upon the re-ratification of the Revised Ute Indian Compact of 1990 by the Tribe and the state of Utah.

TABLE C-7
Lower Colorado River Mainstem Tribal Rights and Tribal and State Future Demands

State	Tribal Diversion Entitlement (Water Right) (afy)	Scenario	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)	Tribal Demand (Diversion)	Tribal Demand (Depletion)	State Demand (Depletion)
			2015 (afy)			2035 (afy)			2060 (afy)		
AZ[1]	1,411,968	Current Projected (A)	1,226,804	991,458	2,971,627	1,389,573	1,154,227	3,139,792	1,389,573	1,154,227	3,498,169
		Slow Growth (B)	1,173,590	875,250	2,954,401	1,336,359	1,038,019	3,023,966	1,336,359	1,038,019	3,113,250
		Rapid Growth (C1)	1,243,260	1,007,533	3,062,675	1,463,628	1,226,025	3,474,004	1,516,340	1,277,130	4,294,372
		Rapid Growth (C2)	1,243,047	1,007,384	3,047,165	1,463,415	1,225,876	3,279,575	1,516,127	1,276,981	3,649,521
		Enhanced Environment (D1)	1,226,804	991,458	3,060,138	1,389,573	1,154,227	3,281,506	1,389,573	1,154,227	3,478,115
		Enhanced Environment (D2)	1,243,047	1,007,384	3,094,136	1,463,415	1,225,876	3,415,447	1,516,127	1,276,981	3,871,117
CA	156,522	Current Projected (A)	156,522	91,995	4,979,059	156,522	91,995	4,973,679	156,522	91,995	5,203,358
		Slow Growth (B)	156,522	91,995	4,976,814	156,522	91,995	4,966,166	156,522	91,995	5,182,190
		Rapid Growth (C1)	156,522	91,995	4,987,463	156,522	91,995	5,038,886	156,522	91,995	5,335,818
		Rapid Growth (C2)	156,522	91,995	4,979,179	156,522	91,995	4,970,671	156,522	91,995	5,203,263
		Enhanced Environment (D1)	156,522	91,995	4,975,136	156,522	91,995	4,955,416	156,522	91,995	5,167,686
		Enhanced Environment (D2)	156,522	91,995	4,977,225	156,522	91,995	4,961,821	156,522	91,995	5,184,353
NV	12,534	Current Projected (A)	12,534	9,000	300,000	12,534	9,000	385,309	12,534	9,000	517,042
		Slow Growth (B)	12,534	9,000	300,000	12,534	9,000	356,568	12,534	9,000	489,668
		Rapid Growth (C1)	12,534	9,000	300,000	12,534	9,000	426,713	12,534	9,000	600,049
		Rapid Growth (C2)	12,534	9,000	300,000	12,534	9,000	426,713	12,534	9,000	600,049
		Enhanced Environment (D1)	12,534	9,000	300,000	12,534	9,000	385,309	12,534	9,000	517,042
		Enhanced Environment (D2)	12,534	9,000	300,000	12,534	9,000	426,713	12,534	9,000	600,049

[1] Demands provided by the Navajo Nation include both quantified and unquantified rights and claims. See appendix C9 for more detail.

5.0 Mexico's Allotment

Mexico has an allotment to Colorado River water under Article 10 of the 1944 Treaty (United States and Mexico, 1944 [T.S. 994]). Article 10 of the 1944 Treaty states the following:

"Of the waters of the Colorado River, from any and all sources, there are allotted to Mexico:

(a) A guaranteed annual quantity of 1,500,000 acre-feet (1,850,234,000 cubic meters) to be delivered in accordance with the provisions of Article 15 of this Treaty.

(b) Any other quantities arriving at the Mexican points of diversion, with the understanding that in any year in which, as determined by the United States Section, there exists a surplus of waters of the Colorado River in excess of the amount necessary to supply uses in the United States and the guaranteed quantity of 1,500,000 acre-feet (1,850,234,000 cubic meters) annually to Mexico, the United States undertakes to deliver to Mexico, in the manner set out in Article 15 of this Treaty, additional waters of the Colorado River system to provide a total quantity not to exceed 1,700,000 acre-feet (2,096,931,000 cubic meters) a year. Mexico shall acquire no right beyond that provided by this subparagraph by the use of waters of the Colorado River system, for any purpose whatsoever, in excess of 1,500,000 acre-feet (1,850,234,000 cubic meters) annually.

In the event of extraordinary drought or serious accident to the irrigation system in the United States, thereby making it difficult for the United States to deliver the guaranteed quantity of 1,500,000 acre-feet (1,850,234,000 cubic meters) a year, the water allotted to Mexico under subparagraph (a) of this Article will be reduced in the same proportion as consumptive uses in the United States are reduced.

The quantification of demand scenarios does not include the assessment of future demand for Colorado River water within Mexico. Future deliveries to Mexico in accordance with the 1944 Treaty will be included in the System Reliability Analysis phase of the Study to assess future imbalances within the Study Area.

6.0 Reservoir Evaporation and other Losses

Water loss categories have also been defined for the Study; these are reservoir evaporation (water lost due to evaporation from reservoirs), phreatophyte use (water lost due to evapotranspiration by riparian vegetation along the Colorado River in the Lower Basin), and operational inefficiency[6] (water unavailable for delivery due to operational inefficiencies in the Lower Basin).

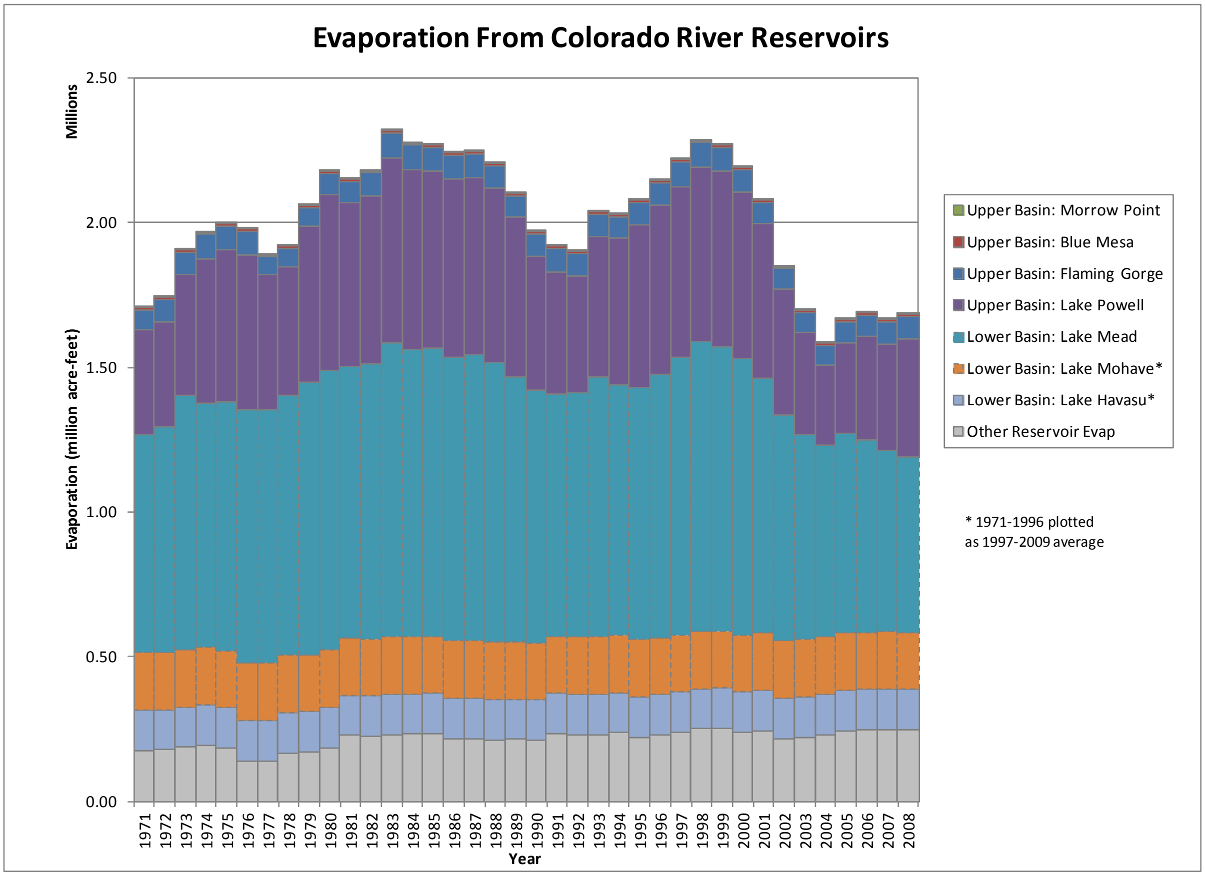
Losses for a number of the large Mainstem reservoirs are directly calculated by CRSS. Other reservoirs and phreatophyte use will be accounted for in the analysis by using an average of historical use.

[6] 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.

6.1 Reservoir Evaporation

Reservoir evaporation varies annually, based on the surface area of a given reservoir and climactic conditions. Annual evaporation for the larger Basin reservoirs (Lower Basin: Lake Mead, Lake Mohave, and Lake Havasu; Upper Basin: Morrow Point, Blue Mesa, Crystal, Fontenelle, Flaming Gorge, Navajo, and Lake Powell) is calculated monthly through model simulation based on simulated conditions. Evaporation from other reservoirs in the Basin States is estimated from historical losses. Figure C-16 presents historical losses due to reservoir evaporation. Average annual evaporative losses between 1971 and 2008 are about 1.8 maf and 1.5 maf between 2000 and 2008. Declining evaporative losses can be attributed to lower average reservoir storage.

FIGURE C-16
Reservoir Evaporative Losses



6.2 Phreatophyte Losses

Phreatophytes are defined as deep-rooted plants that obtain water from the water table or in the vadose zone just above the water table. Phreatophyte losses are estimated for portions of the Lower Basin along the Colorado River Mainstem 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.

Since 1995, Reclamation has updated Lower Basin phreatophyte areas by comparing the current year Landsat summer satellite images to the previous year's images (spectral change detection methods). Reclamation field checks areas of spectral change to confirm that the change is actually due to change in land cover. The areas of land cover change are then mapped, and these maps are used to update the phreatophyte database. Reference evapotranspiration is calculated using the Penman-Monteith equation and applied to the phreatophyte database to arrive at a water demand. Further details can be found in the Lower Colorado River Accounting System reports (Reclamation, 2009).

Before 1996, Davis Dam to Imperial Dam Lower Basin phreatophyte acreage was estimated, and the Blaney-Criddle model was used to estimate demand from 1971 to 1990 and a linear interpolation was employed from 1991 to 1994. Imperial Dam to Northerly International Boundary Lower Basin phreatophyte demand from 1971 to 1994 was estimated based on a 1995 to 2008 linear relationship between phreatophyte demand at Davis Dam to Imperial Dam versus Imperial Dam to Northerly International Boundary.

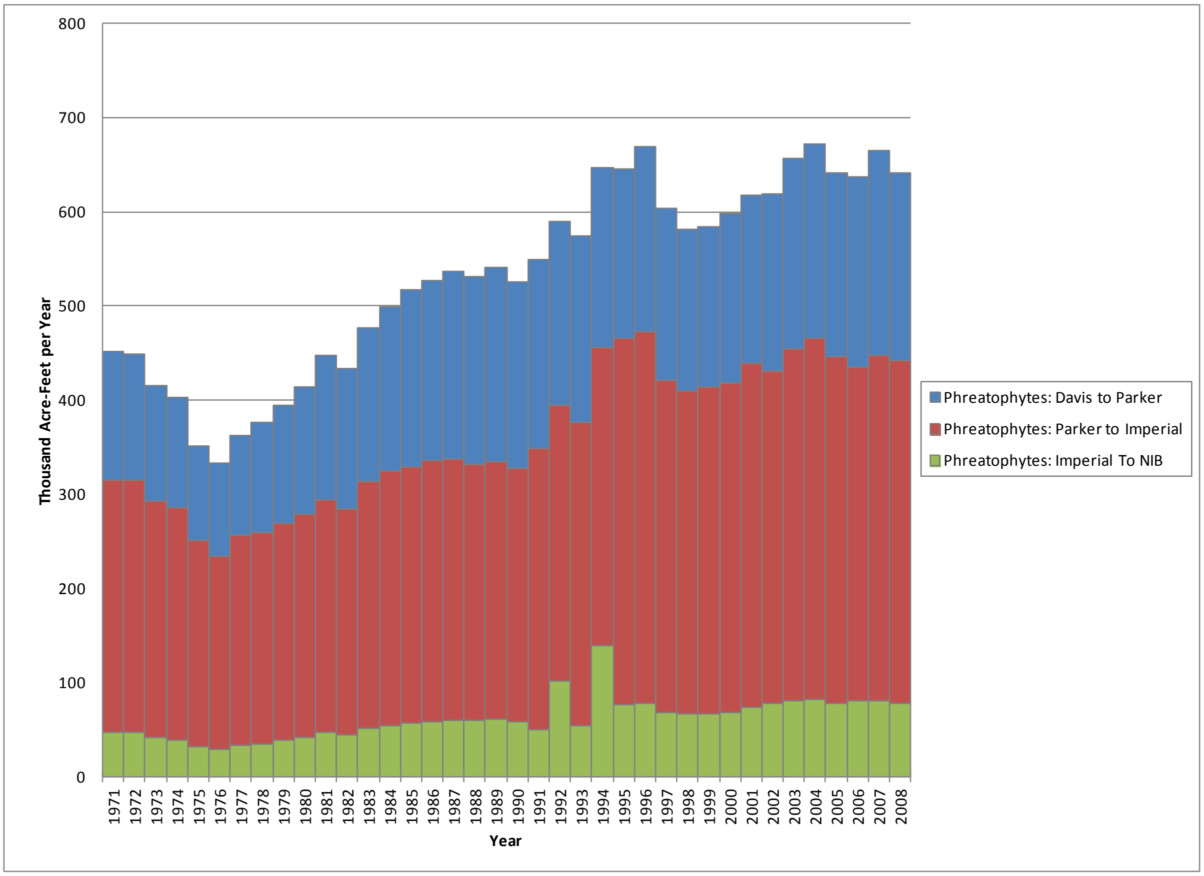
Historical and current phreatophyte use averaged about 0.53 maf per year from 1971 to 2008 and 0.64 maf per year from 2000 to 2008. Figure C-17 shows historical Lower Basin phreatophyte use.

6.2.1 Operational Inefficiencies

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.

Non-storable flows that were delivered to Mexico in excess of the 1944 Treaty over the period of 1964 to 2009 averaged 74,000 afy, excluding years when flood control releases were made from Lake Mead or flooding on the Gila River. The construction of Brock Reservoir is expected to reduce this quantity by about 90 percent to 7,000 afy.

FIGURE C-17
Historical Lower Basin Phreatophyte Use 1971–2008



7.0 Approach for Incorporating Climate Change Effects on Demands

Technical Report A – Scenario Development (Reclamation, 2011a) identified “changes in stream flow variability” and “trends and changes in climate variability” (for example, temperature, precipitation, etc.) as the most important and most uncertain of the critical uncertainties. Because of their importance, these critical uncertainties are considered separately from other driving forces and are considered across all future demand scenarios when matched with the Downscaled General Circulation Model Projected water supply scenario. Future demands may be affected by climate change, primarily due to changes in ambient temperature and the amount and distribution of precipitation. The Study addresses possible effects of changing temperature and precipitation on evapotranspiration, which affects agriculture and outdoor M&I demand, and phreatophyte and reservoir evaporation losses.

As noted, projection of future climate conditions is uncertain, and these uncertainties are further described in *Technical Report B – Water Supply Assessment* (Reclamation, 2012a). There are varying methods for projecting future climate conditions and new science and methods are continually being 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.

7.1 Climate Change Effects on Evapotranspiration

Reclamation has historically used an empirically based approach, the Blaney-Criddle or modified Blaney-Criddle method, for calculating consumptive uses and losses in the Basin. As part of the hydrologic modeling for the Study, a more physically based method, Penman-Monteith, has been used to estimate potential evapotranspiration (PET) under varying climatic conditions. A detailed analysis of these two methods and a description of the approach for incorporating climate information for adjusting demands are presented in appendix C10.

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. A report on this work is included in *Technical Report C – Water Demand Assessment, Appendix C4* (Reclamation, 2011c). 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 Fahrenheit increase in temperature, and by approximately 1 percent for each 5 percent reduction in precipitation.

Reclamation uses the Variable Infiltration Capacity (VIC) hydrologic model to estimate hydrologic responses in the Basin for the purposes of estimating water supply. The VIC model incorporates the Penman-Monteith method for estimating PET in the daily water balance calculations. PET results are available from each of these (TSC’s Blaney-Criddle, and Reclamation’s VIC modeling) sources for use in the Study in estimating the effects of climate change on demand. PET estimates may vary widely among the various methods, but the Penman-Monteith method has been shown to estimate actual ET from lysimeter and field studies most accurately (American Society of Civil Engineers, 2005; Jensen et al., 1990; and Hill et al., 1983). Different PET methods might produce different results under similar climate change assumptions (McKenney and Rosenberg, 1993; Kingston et al., 2009; Bormann, 2011). It was found that the Blaney-Criddle method produced the highest PET sensitivity to climate warming (greatest increase in PET per degree of warming) compared to four other methods for computing PET. The Penman-Monteith method produced changes in PET of approximately 2 to 3 percent per degree Celsius warming. This sensitivity was larger than that estimated under the Priestly-Taylor method and lower than that under the Hargreaves method; however, results were generally within 1 percent of these two methods. Conversely, the Blaney-Criddle method, when simulated under identical meteorological conditions, suggests a change of almost double that in the other methods.

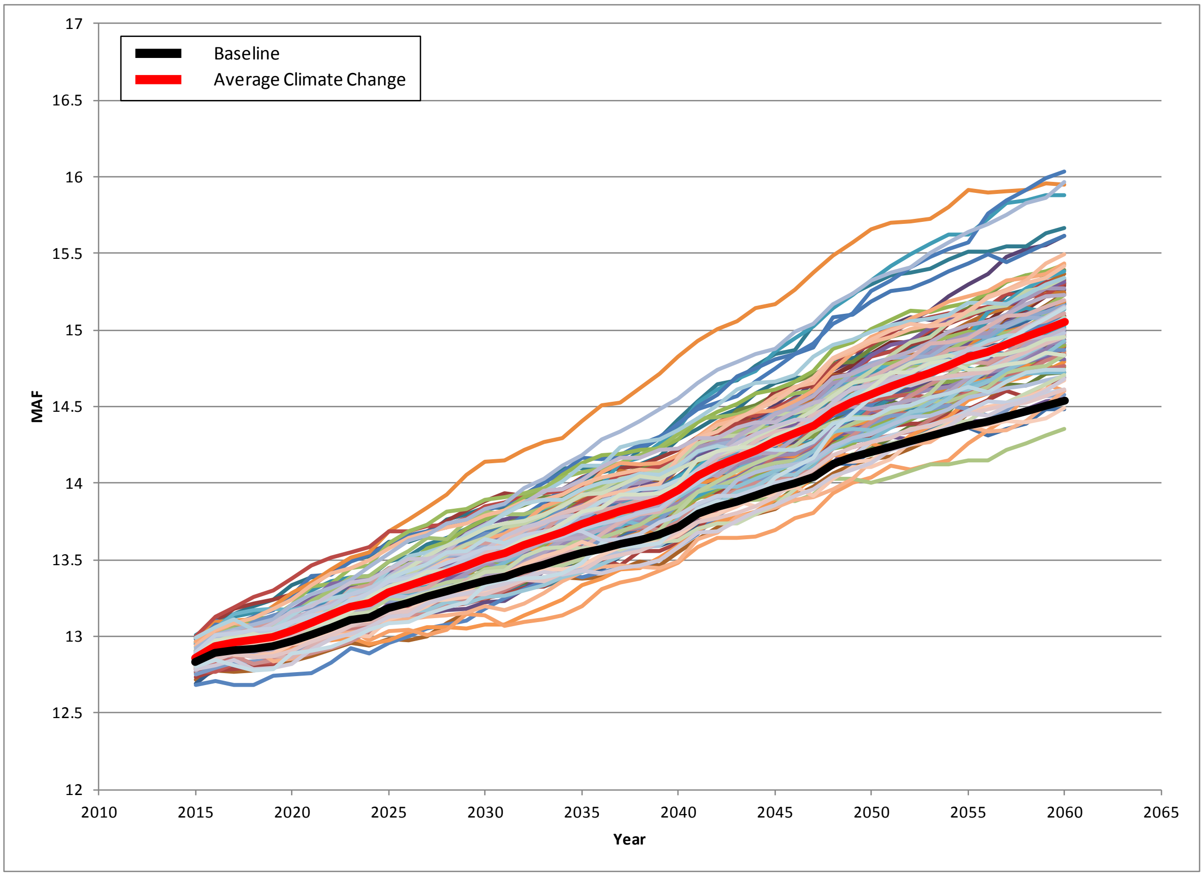
In order to be consistent between the calculations used to generate water supply scenarios, the Penman-Monteith method, as implemented in the VIC model, was proposed to adjust agricultural, outdoor M&I demands, phreatophyte losses, and reservoir evaporation rates due to climate change. Details on the methods used to construct the climate index factors for adjusting demands and losses under climate change are included in appendix C-10. The mean change in evapotranspirative demand is on the order of 4 percent by 2060 as compared to demands without changes in climate. Using the methods described in appendix C-10 and applying the projected changes to all agricultural, outdoor M&I, and phreatophyte demands results in a total demand increase of over 500 kaf/year by 2060. These changes will evolve over time with a warming climate, and could be higher or lower depending on the climate projection, but the magnitude of the climate impact to demands is expected to be substantial.

Figure C-18 presents the factors as applied to the Current Projected (A) scenario demands excluding Mexico's allotment, reservoir evaporation[7], and other losses[8] (corresponding with the Colorado River demand shown in table C-4). The thick red line represents the average annual demand as adjusted for the climate change scenarios. This line can be compared to the unadjusted demands (thick black line). The thinner lines represent the adjustments associated with individual climate traces.

[7]Climate change effects on reservoir evaporation are adjusted dynamically through CRSS simulations.

[8] Phreatophytes are included in the "other losses" category. Losses due to phreatophytes are adjusted for climate change using similar methods as those proposed for agricultural irrigation .

FIGURE C-18
Current Projected (A) Scenario Demands Adjusted for Future Climate Change



7.2 Climate Change Effects on Reservoir Evaporation

Reservoir evaporation will be affected by changes in temperature and rainfall in a similar manner to that for PET. Evaporation from Mainstem reservoirs is calculated by estimating reservoir surface area and applying monthly unit net evaporation rates (evaporation minus precipitation). For the supply scenario representing climate change, projections of open water surface evaporation rates and precipitation will be used from the VIC model (see *Technical Report B – Water Supply Assessment* [Reclamation, 2012a]) to adjust historical evaporation rates to reflect the changes in climate. The details of the climate factors that will be used to modify reservoir evaporation are described in appendix C10.

8.0 Limitations and Next Steps

8.1 Limitations

The projection of future demands for Colorado River water is inherently uncertain. Many factors influence the demand for water in each of the categories described in this memorandum. Population, water use efficiency, agricultural markets, policy and regulations, social values, availability of other supplies, and other factors will all change in the future. This memorandum describes the uncertainty in projecting future conditions through the use of alternative scenarios.

The scenarios capture a view of future demands under only "external" factors and do not include activities by water management entities that may affect demand. Actual demands in the future (as in the past) will be the result of both external factors and more-direct, active management. Active management will be considered in the options and strategies phase of the Study.

The quantification of scenarios relied predominantly on state-provided information guided by the storylines. Each state projects water demands in a slightly different manner and level of complexity, and relies on different data sources. The demands presented in this memorandum are a compilation of this information in the most consistent form possible. However, there are areas of difference with respect to treatment of data, reference points, assumptions, and computation methods. Evaluations were performed as part of the Study, and it is known that areas of difference continue to exist due to planning approach differences.

Although these limitations exist, the Study represents comprehensive, Basin-wide evaluation of future demands for the Colorado River Basin. Future planning efforts will improve upon these methods and limitations.

8.2 Next Steps

Scenarios have been developed for both water supply and water demand, focusing on key factors of future uncertainty, including the potential effects of future climate change. The water demand scenarios, coupled with water supply scenarios (see *Technical Report B – Water Supply Assessment* [Reclamation, 2012a]) will be used to analyze the future reliability of the Colorado River system with and without options and strategies to mitigate future water supply and demand imbalances. Next steps include compiling the demand scenarios, as quantified in this memorandum, into the necessary form for inclusion into CRSS modeling to perform this analysis. Results of this analysis will be made available in subsequent Study reports.

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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 the 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, any federally recognized tribe, 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, any federally recognized tribe, Federal government or Upper Colorado River Commission as it relates to the law of the river. Furthermore, nothing in the Study is intended to, nor shall the Study be construed so as to, interpret, diminish or modify the rights of any Basin State, any federally recognized tribe, 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) as amended, the Hoover Power Plant Act of 1984 (98 Stat. 1333), the Colorado River Floodway Protection Act (100 Stat. 1129; 43 U.S.C. 1600), the Grand Canyon Protection Act of 1992 (Title XVIII of Public Law 102-575, 106 Stat. 4669), or the Hoover Power Allocation Act of 2011 (Public Law 112-72). In addition, nothing in the Study is intended to, nor shall the Study be construed so as to, interpret, diminish or modify the rights of any federally recognized tribe, pursuant to Federal Court Decrees, State Court Decrees, treaties, agreements, executive orders and federal trust responsibility. Reclamation and the Basin States continue to recognize the entitlement and right of each State and any federally recognized tribe under existing law, to use and develop the water of the Colorado River system.[9]

[9] 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.