RECLAMATION

Managing Water in the West

Colorado River Basin Water Supply and Demand Study

Technical Report D — System Reliability Metrics

U.S. Department of the Interior
Bureau of Reclamation

December 2012

Mission Statements

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

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Acronyms and Abbreviations

2007 Interim Guidelines	*Record of Decision for Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead*
2007 Interim Guidelines Final EIS	*Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead Final Environmental Impact Statement*
af	acre-feet
AMP	Adaptive Management Program
Basin	Colorado River Basin
Basin States	Colorado River Basin States
CAP	Central Arizona Project
cfs	cubic feet per second
CRSS	Colorado River Simulation System
DOI	U.S. Department of the Interior
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
Forum	Colorado River Basin Salinity Control Forum
kaf	thousand acre-feet
kafy	thousand acre-feet per year
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M&I	municipal and industrial
maf	million acre-feet
metrics	system reliability metrics
Mexico	United Mexican States
mg/L	milligram(s) per liter
msl	above mean sea level
MWh	megawatt-hour
NGS	Navajo Generating Station
NWR	National Wildlife Refuge
Partnership	Ten Tribes Partnership
PBO	Programmatic Biological Opinion

Reclamation	Bureau of Reclamation
Recovery Programs	Upper Colorado River Endangered Fish Recovery Program and San Juan River Basin Recovery Implementation Program
ROD	Record of Decision
Secretary	Secretary of the Interior
SNWA	Southern Nevada Water Authority
Study	Colorado River Basin Water Supply and Demand Study
TNC	The Nature Conservancy
tribes	federally recognized tribes
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
Western	Western Area Power Administration

Technical Report D — System Reliability Metrics

1.0 Introduction

The Colorado River Basin Water Supply and Demand Study (Study), initiated in January 2010, was conducted by the Bureau of Reclamation's (Reclamation) Upper Colorado and Lower Colorado regions, and agencies representing the seven Colorado River Basin States (Basin States) in collaboration with stakeholders throughout the Colorado River Basin (Basin). The purpose of the Study is to define current and future imbalances in water supply and demand in the 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 adaptation and mitigation strategies to resolve those imbalances. The Study contains for major phases to accomplish this goal: Water Supply Assessment, Water Demand Assessment, System Reliability Analysis, and Development and Evaluation of Options and Strategies for Balancing Supply and Demand.

Spanning parts of the seven states of Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming, the Colorado River is one of the most critical sources of water in the western United States. The Colorado River is also a vital resource to the United Mexican States (Mexico). It is widely known that the Colorado River, based on the inflows observed over the last century, is over-allocated and supply and demand imbalances are likely to occur in the future. Up to this point, this imbalance has been managed, and demands have largely been met as a result of the considerable amount of reservoir storage capacity in the system, the fact that the Upper Basin States are still developing into their apportionments, and efforts the Basin States have made to reduce their demand for Colorado River water.

Concerns regarding the reliability of the Colorado River system to meet future needs are even more apparent today. The Basin States include some of the fastest growing urban and industrial areas in the United States. At the same time, the effects of climate change and variability on the Basin water supply has been the focus of many scientific studies, which project a decline in the future yield of the Colorado River. Increasing demand, coupled with decreasing supplies, will certainly exacerbate imbalances throughout the Basin.

It is against this backdrop that the Study was conducted to establish a common technical foundation from which important discussions can begin regarding possible strategies to reduce future supply and demand imbalances. The content of this report is a key component of that technical foundation and describes the system reliability metrics identified in the Study. System reliability metrics (metrics) are measures that indicate the ability of the Colorado River system to meet the needs of Basin resources[1] under multiple future conditions. Metrics were used to measure (quantitatively or qualitatively) the potential impacts to Basin resources from current and future water supply and demand imbalances and to measure the effectiveness of options and strategies at resolving those imbalances. These results are described in *Technical Report G – System Reliability Analysis and Evaluation of Options & Strategies.*

[1] Resources include water allocations and deliveries for municipal, industrial, and agricultural use; 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.

This report describes the approach used to develop the system reliability metrics and the set of metrics resulting from implementing that approach. Initially published in June 2011 under Interim Report No. 1 and then updated and reissued in February 2012, this report replaces these two previously published versions. There were no substantial changes or additions to the metrics since February 2012, although several metrics were changed from using a quantitative to qualitative measurement as a result of data and tool limitations and time constraints.

2.0 Approach for Metric Development

Metrics were developed through a collaborative process involving representatives of numerous organizations, including the Reclamation, the Basin States, U.S. Fish and Wildlife Service (USFWS), National Park Service, Western Area Power Administration (Western), federally recognized tribes (tribes), conservation and recreation organizations, water delivery contractors, contractors for the purchase of federal power, and others interested in the Basin. A Metrics Sub-Team, composed of representatives from some of these organizations, was established to carry out the task of metric development. The Metrics Sub-Team coordinated with points of contact designated by the other organizations, who provided data, information, and expertise critical to metric development.

The Metrics Sub-Team members and the points of contact from the other organizations are listed in appendix D1 of this report.

The general approach used to develop the metrics is presented in figure D-1. As shown, metric development was a multi-step process, in which each metric presented in this report was fully defined by applying steps 1 through 7. In the subsequent sub-sections, the individual steps used to develop the metrics are described, and examples are provided to illustrate the development approach.

2.1 Step 1 – Resource Categories

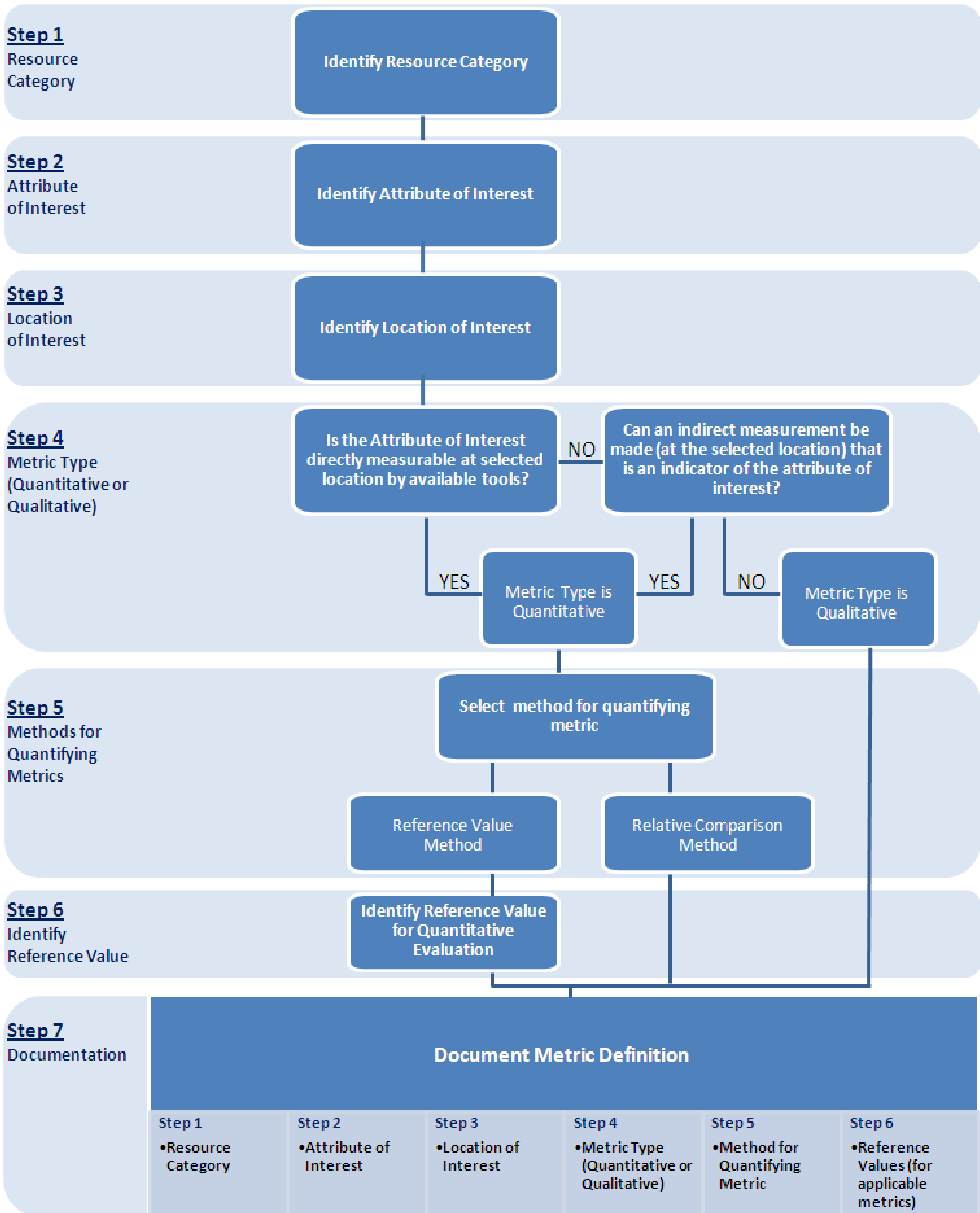
As stated in the *Plan of Study* (see *Study Report, Appendix 1 – Plan of Study*):

> The Study will characterize current and future water supply and demand imbalances in the Basin and assess the risks to Basin resources. 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.

The following resource categories were developed to reflect these groups of identified resources:

- Water Deliveries
- Electrical Power Resources
- Water Quality
- Flood Control
- Recreational Resources
- Ecological Resources

FIGURE D-1
Approach for Metric Development



Socioeconomic impacts were not considered an independent resource category in the Study. Instead, socioeconomic impacts resulting from water supply and demand imbalances were considered within the principal resource categories, as appropriate.

2.2 Step 2 – Attribute of Interest

An attribute is a specific property or trait that can be associated with a resource category. Several attributes were identified in each resource category that are informative when evaluating system reliability for that category. These attributes are presented in table D-1 by resource category.

TABLE D-1
Resource Categories and Attributes of Interest

Resource Category	Attribute of Interest
Water Deliveries	• Consumptive Uses[1] and Shortages[2] • Water Levels Related to Intake Facilities • Socioeconomic Impacts Related to Shortages
Electrical Power Resources	• Electrical Power Generated • Economic Value of Electrical Power Generated • Available Generation Capacity • Impact on Power Rates • Water Supply System Pumping Costs • Impacts on Basin Funds
Water Quality	• Salinity • Sediment Transport • Temperature • Other Water Quality Attributes • Socioeconomic Impacts Related to Salinity
Flood Control	• Flood Control Releases and Reservoir Spills • Critical River Stages Related to Flooding Risk
Recreational Resources	• Shoreline Public Use Facilities • River and Whitewater Boating • Other Recreational Attributes • Socioeconomic Impacts Related to Recreation
Ecological Resources	• Threatened and Endangered Species • Aquatic and Riparian Habitats • Wildlife Refuges and Fish Hatcheries

[1] *Consumptive use* is water used, diminishing the available supply.

[2] *Shortage* is unmet demand.

Note that *Demand* is water needed to meet identified uses.

2.3 Step 3 – Location of Interest

Specific locations were selected where a metric would be evaluated, including several points along the Colorado River, its major tributaries, and at selected facilities such as mainstem reservoirs or power generation facilities. Although at this step any location within the Study Area (the hydrologic boundaries of the Colorado River Basin within the United States, plus the adjacent areas of the Basin States that receive Colorado River water) could have been selected, the spatial and temporal scales of available data (through simulation modeling and other sources) restricted the locations and/or the analysis that could be performed at a specific location.

The Colorado River Simulation System (CRSS) is the primary modeling tool that was used in the Study. It simulates the operation of the major Colorado River system reservoirs on a monthly time step and provides information regarding the projected future state of the system in terms of output variables. Outputs include the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points in the system, the total dissolved solids content, and diversions to and return flows from water users in the system. Twelve Upper Basin and Lower Basin reservoirs are modeled in CRSS: Fontenelle, Flaming Gorge, Starvation (a representation of several reservoirs within the Central Utah Project in western Utah), Taylor Park, Blue Mesa, Morrow Point, Crystal, Navajo, Powell, Mead, Mohave, and Havasu. Approximately 250 diversions and return flows are represented in CRSS. Natural flow is input to the model at 29 locations in the Basin (20 in the Upper Basin upstream of and including the Lees Ferry, Arizona gaging station, and nine below Lees Ferry, Arizona, including the Paria River and other inflow points in the Lower Basin).[2]

2.4 Step 4 – Metric Types (Quantitative or Qualitative)

Metrics were evaluated in either a quantitative or qualitative fashion. A metric was evaluated quantitatively if: a) direct evaluation was possible using output from CRSS or results from post-processing of CRSS output data; or b) an indicator of the attribute of interest at the specified location could be developed, based on output from CRSS or post-processing of CRSS output data.

If a particular attribute of interest could not be represented either directly in CRSS or through the development of an indicator, the potential performance of an attribute under various future scenarios was discussed qualitatively. Qualitative metrics bypass steps 5 and 6 and are documented in step 7.

Qualitative discussion vary in detail depending on the level of information available. In some cases, quantitative model results were used to qualitatively assess the metrics using known system variables, e.g., reservoir elevations or streamflow. Although these metrics were evaluated in a qualitative manner in the Study, information developed in the Study may be used to guide quantitative assessments in future studies.

2.5 Step 5 – Methods for Quantifying Metrics

If a metric was identified as quantitative, a specific method for quantifying that metric was selected. Two methods for quantifying metrics were identified:

1. Reference Value Method: In many cases, comparing the attribute of interest at a particular location to a reference value (that may also be specific to the location of interest) informed the assessment of system reliability. The method used to quantify the reference value then defined the method for quantifying the metric. Because the Study addressed a wide range of Basin resources, no single method for quantifying reference values was applicable to all metrics. Therefore, four different methods for quantifying reference values (and the subsequent metrics) were defined, as outlined below.

[2] Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location. However, CRSS uses historical inflows based on U.S. Geological Survey streamflow records as estimates of natural flows for the Paria, Little Colorado, Virgin and Bill Williams Rivers. In addition, the Gila River is not included in CRSS. See *Technical Report C – Water Demand Assessment, Appendix C11 – Modeling of Lower Basin Tributaries in the Colorado River Simulation System*, for more detail.

2. Relative Comparison Method: In some cases, an informative reference value did not exist for an attribute of interest. In such cases, the attribute of interest was strictly compared across the range of future water supply and demand scenarios. For example, metrics related to flood control releases or spills to manage reservoir levels may not have an associated reference value. In this case, metrics related to flood control releases or spills were quantified through a comparative analysis between future scenarios.

2.6 Step 6 – Identify Reference Value (if appropriate)

If the reference value method was selected in step 5, an appropriate reference value was then selected. As described below, reference values could be based on physical constraints in the Basin, prescribed conditions, estimated resource needs, or historical or simulated conditions.

2.6.1 Physical Constraint

Some metrics were quantified based on physical constraints in the river system. For example, the elevation of a facility's water intake represents a physical constraint and provided the reference value that was used to quantify a metric in the Water Deliveries resource category.

2.6.2 Prescribed Condition

Some metrics were quantified based on specific values that are prescribed in contracts and agreements between resource management agencies, Environmental Impact Statement (EIS) Records of Decision (ROD), Biological Opinions issued by USFWS, and other regulatory actions. For example, recommendations of flows for endangered species (as defined in a Biological Opinion) provided reference values that were used to quantify metrics in the Ecological Resources resource category.

2.6.3 Estimated Condition

Some metrics were quantified using an estimated condition for a water-dependent resource. Estimated conditions typically were developed by interested stakeholders or were defined within published reports and articles. For example, the projected demand for municipal, industrial, and agricultural water at a specific location was used to quantify metrics in the Water Deliveries resource category.

2.6.4 Historical Condition

Some metrics were quantified based on values derived from historical conditions, particularly when it was important to measure the change in the attribute of interest over time. Historical values were based on recorded information, where the period of interest may have covered a relatively short timeframe (such as the last 10 years) or a longer timeframe (such as the last 100 years or longer). For example, the minimum hydroelectric generation data over the past 10 years provided reference values that were used to quantify a metric in the Electrical Power Resources resource category.

2.7 Step 7 – Documentation

Metric definitions developed by applying steps 1 through 6 are documented in tabular fashion. The tables, which appear by attribute of interest throughout the report, list the information shown as step 7 in figure D-1.

2.8 Examples of Using the Step-wise Approach to Metric Development

The following discussion provides examples of the approach to implementing each step for metric development. The examples were specifically selected to show the different paths that may be taken when following the steps shown in figure D-1.

2.8.1 Quantitative Type with Direct Measurement

In the resource category Electrical Power Resources, electrical power generated was identified as an attribute of interest. In step 3, the locations of interest were identified as the major Colorado River Storage Project power plants[3] in the Upper Basin and Hoover Dam and the Parker-Davis project in the Lower Basin. In step 4, it was determined that the attribute of interest is directly measurable at the selected locations (CRSS simulates power generation at each of the identified locations); therefore, a quantitative-type metric was used for this attribute.

In step 5, the reference value method was selected based on stakeholder input as the method for metric quantification. In step 6, the reference values vary by location. For example, the Historical Condition method was used at Hoover with the minimum power generation over the previous 10 years selected as the reference value, whereas the Prescribed Condition method was selected for use in the Upper Basin with the firm power contract utilized as the reference value.

2.8.2 Quantitative Type with Indirect Measurement

In the resource category Ecological Resources, aquatic and riparian habitat was identified as an attribute of interest. In step 3, the locations of interest were identified based on stakeholder input. In step 4, it was determined that this attribute could not be directly measured (CRSS does not represent specific ecological and biological characteristics related to aquatic and riparian habitat). However, flow conditions at the monthly time step simulated in CRSS could be an indication of the functioning of aquatic and riparian habitat, thus providing an indirect measurement for this attribute.

In step 5, the reference value method was chosen at locations where in-stream flow water rights exist (another reference value method was used at several other locations where such rights do not exist). In step 6, the minimum target flows defined by instream flow water rights (such as those held by the Colorado Water Conservation Board) were selected as the reference value using the prescribed conditions method.

2.8.3 Qualitative Type

In the resource category Recreational Resources, socioeconomics related to recreation was identified as an attribute of interest based on stakeholder input. In step 3, the locations of interest were identified throughout the Basin where there is a significant economic benefit from recreation. In step 4, it was determined that this attribute could not be directly measured and furthermore, an indirect measurement was not possible in the Study (an economic analysis would require additional economic data and modeling that are not currently available). Therefore, a qualitative-type metric was selected for this attribute.

[3] Power plants at Lake Powell, Flaming Gorge, Blue Mesa, Morrow Point, and Crystal Reservoirs.

3.0 Sources of Data and Information Used in Metric Development

Data sources used in the development of the system reliability metrics included recently published reports relevant to Basin water resources and data and information provided by representatives of organizations either participating directly in the Metrics Sub-Team or as designated point of contact. The use of these data and information sources was referenced where appropriate, and a list of these sources is provided in the References section of this report.

4.0 Water Deliveries Metrics

The water deliveries attributes of interest are:

- Consumptive uses and shortages
- Other water deliveries
- Socioeconomic impacts related to shortages

4.1 Metrics for the Consumptive Uses and Shortages Attribute of Interest

Consumptive uses and shortages metrics were evaluated at locations throughout the Basin where demand nodes exist within CRSS. All consumptive uses and shortages metrics are quantitative metrics whose reference values are defined by the Estimated Condition quantification method. Specifically, the Estimated Condition reference values are based on demand projections for the particular water demand scenario being modeled (see *Technical Report C – Water Demand Assessment*).

CRSS simulates shortages differently for the Upper and Lower Basin. For the Lower Basin, CRSS computes shortages as specified in the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lakes Powell and Mead* (2007 Interim Guidelines) (U.S. Department of the Interior [DOI], 2007) through 2026. Beyond 2026, additional modeling assumptions were made: 1) the 2007 Interim Guidelines were assumed to extend through 2060, and 2) the operations of Lake Powell and Lake Mead reverted to the No Action Alternative in the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lakes Powell and Mead Final Environmental Impact Statement* (2007 Interim Guidelines Final EIS) (Reclamation, 2007) through 2060. Both assumptions[4] were used in the system reliability analysis.

The quantified demand scenarios in the Lower Basin include demands above the Lower Division states' basic apportionments. As part of the system reliability analysis, select options were implemented to, in part, reduce demands above apportionment. Therefore, the remaining demands above Lower Division States' basic apportionment were included as a metric. For the Upper Basin, CRSS does not simulate the complex water rights systems in each state that are needed to model shortages to individual water right holders. At any particular node (location), the model tracks shortages when the flow is insufficient to meet the local demands. Such a broad simulation greatly underestimates shortages for the major Upper Basin tributaries; however, given the relative comparison nature of the Study, reporting shortages as modeled can still provide insights to benefits or reductions to deliveries within the Upper Basin. An area identified

[4] *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies, Appendix G2 – Colorado River Simulation System Modeling* provides a detailed description of these and other CRSS modeling assumptions used in the system reliability analysis.

for future work after the Study includes enhancements to CRSS to better estimate Upper Basin shortages. Additionally, the 10-year moving aggregate flow volume at Lee Ferry is tracked in CRSS. Anytime the 10-year flow volume is less than 75 million acre-feet (maf), the shortfall is reported as a Lee Ferry deficit.

4.1.1 Tribal Water Rights

The assessment of the ability of the system to satisfy tribal water rights, including tribal Central Arizona Project (CAP) entitlements, was not explicitly evaluated for two reasons. First, model limitations described previously with respect to not simulating water rights in the Upper Basin limited the ability to track deliveries to tribes in the Upper Basin. Second, at the request of the Ten Tribes Partnership (Partnership), opportunities to conduct a future joint planning study with Reclamation that will focus on tribal issues are being explored. It is envisioned that through this future study, coupled with CRSS enhancements, a detailed assessment of the ability of the system to satisfy tribal water rights would be performed.

With respect to tribes with CAP entitlements, CRSS aggregates all deliveries to CAP users into one node, with the exception of the Ak-Chin and Salt River Pima-Maricopa Indian Communities. However, the ability of the system to deliver water to tribes with CAP entitlements could be determined based on CAP's ability to divert a sufficient quantity of water to meet these entitlements. Therefore, a qualitative discussion on the ability of the system to satisfy tribal water rights was included in the Study.

4.2 Metrics for the Other Water Deliveries Attribute of Interest

There are several other attributes of interest related to water deliveries that are important to various stakeholders. These attributes of interest were evaluated at locations other than where CRSS demand nodes exist (e.g., reservoir elevations) and were therefore placed in this category. These include flows arriving at Morelos Diversion Dam, the Navajo Indian Irrigation Project Diversion at Navajo Reservoir, and Lake Mead at elevation 1,000 feet above mean sea level (msl).

CRSS assumes a delivery to Mexico of 1.5 maf per year, with additional deliveries of up to 200,000 acre-feet (af) per year when Lake Mead is in flood control operations. Reductions in deliveries to Mexico are simulated consistent with the modeling assumptions noted in the 2007 Interim Guidelines Final EIS (Reclamation, 2007)[5]. CRSS extends to just south of the Northerly International Boundary to include the Morelos Diversion Dam (Mexico's principal diversion) and accounts for the entire 1944 Treaty delivery at that point. Flows arriving at Morelos Diversion Dam in excess of the 1944 Treaty delivery were tracked as a relative comparison metric under the other water deliveries attribute of interest.

Water is extracted from the Colorado River at numerous locations using instream diversion facilities or reservoir intake structures. Intake structures cannot operate if reservoir water levels are below their respective minimum service elevations. Therefore, the frequency of potential conditions in which water levels drop below minimum intake service elevations are important measures of system reliability. The Navajo Indian Irrigation Project Diversion at Navajo

[5] Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The United States will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Treaty with Mexico through the International Boundary and Water Commission in consultation with the Department of State.

Reservoir was identified as an intake where water level data are critical and was quantitatively evaluated with a physical constraint of 5,990 feet msl. This is the minimum allowable water level where diversion facilities are still operable.

Elevation 1,000 feet msl in Lake Mead is important to water deliveries for multiple reasons. At elevation 1,000 feet msl, there are less than 4.5 maf of water remaining in Lake Mead. According to the 2007 Interim Guidelines (DOI, 2007), the Secretary of the Interior (Secretary) shall consult with the Basin States whenever Lake Mead is below elevation 1,025 feet msl and is projected to fall below 1,000 feet msl, to discuss further measures that may be undertaken at such time. This elevation is also of interest to the operation of the Southern Nevada Water Authority's (SNWA) intake structures in Lake Mead. Currently, 1,000 feet msl is the minimum allowable water level at which the intake facilities are still operable. For these reasons, Lake Mead elevation at 1,000 feet msl was evaluated quantitatively with its reference value defined by an Estimated Condition. All metrics for the other water deliveries attributes of interest are shown in table D-2.

TABLE D-2
Attribute of Interest: Other Water Deliveries

Location	Metric Type	Quantification Method	Reference Value (feet msl)
Morelos Diversion Dam	Quantitative	Relative Comparison	Not Applicable
Navajo Indian Irrigation Project Diversion at Navajo Reservoir		Physical Constraint	5,990
Lake Mead		Estimated Condition	1,000

4.3 Metrics for the Socioeconomic Impacts of Shortages Attribute of Interest

To quantitatively evaluate socioeconomic impacts of shortage conditions, an economic model that relates delivery shortages to employment, income, and tax revenue would be required. This model would need to be regional in nature and have the capability to allocate shortages among agricultural and municipal and industrial (M&I) users. Economic models of this type have been built and used in the past (USFWS, 1994). However, updating these models to evaluate socioeconomic impacts related to delivery shortages is beyond the scope of the Study. For this reason, socioeconomic impacts related to shortages is discussed in a qualitative manner.

5.0 Electrical Power Resources Metrics

The electrical power resources attributes of interest are:

- Electrical power generated
- Economic value of electrical power generated
- Available generation capacity
- Impact on power rates
- Water supply system pumping costs
- Impacts on Basin funds

5.1 Metrics for the Electrical Power Generated Attribute of Interest

Hydroelectric power generation is directly related to the head on the generating units and the quantity of water flowing through the turbines. The net effective head is the difference between the water level elevation of the reservoir behind a dam and in the tail water below the dam. The net effective head and flow are the two variables that influence hydroelectric power generation of the power plant, measured in megawatts.

Hydroelectric power is generated at numerous locations throughout the Basin. Hydropower plants in the Upper Basin that are modeled in CRSS include the Colorado River Storage Project facilities located at the Lake Powell, Flaming Gorge, Blue Mesa, Morrow Point, and Crystal reservoirs, as well as the power plant at Fontenelle. Hydropower plants in the Lower Basin include the Hoover, Parker, Davis, and Headgate Rock facilities. Metrics were developed to assess the impact to electrical power generated from these facilities (or an aggregate of) due to their inclusion in CRSS. Headgate Rock Dam is not explicitly modeled in CRSS. However, because it is located just downstream of Parker Dam, the releases from Parker Dam were used to qualitatively assess the effects on power generation at Headgate Rock Dam using the relative comparison method. There are numerous other hydropower plants located throughout the Basin. Metrics for these other hydropower facilities were not developed; however, readers who have a particular interest in other hydropower plants may be able to use the results from facilities evaluated in the Study as indicators for facilities not evaluated in the Study.

Western is a power marketing administration responsible for marketing and transmitting electricity from multi-use water projects in the central and western United States. Western markets power from all Upper Basin power plants as a single power resource; therefore, electrical power generated by Upper Basin facilities was measured by a single aggregate metric. In the Lower Basin, power is marketed separately for Hoover, the Parker-Davis Project, and Headgate Rock hydropower plants. Individual metrics were used to measure electrical power generated at these three locations. Table D-3 summarizes the metrics related to electric power generated.

TABLE D-3
Attribute of Interest: Electrical Power Generated

Location	Metric Type	Quantification Method	Reference Value Megawatt-hours (MWh) per year
Upper Basin Power Plants[1]	Quantitative – Direct	Prescribed Condition	4,948,780[3]
Hoover Power Plant		Historical Condition	3,426,149[4]
Parker and Davis Power Plants[2]		Relative Comparison	Not Applicable
Headgate Rock Power Plant	Qualitative	Relative Comparison	Not Applicable

[1] Upper Basin power plants include: Fontenelle, Flaming Gorge, Blue Mesa, Morrow Point, Crystal, and Glen Canyon.

[2] Parker and Davis power plants were aggregated for the purposes of the Study. Power marketed through the Parker-Davis Project consists of all of the power generated from Davis plus half the power generated from Parker, but this metric presents the entire power generated from both hydropower facilities.

[3] Reference value is the firm power contract for all Upper Basin power plants.

[4] Reference value is the minimum power generation that occurred during the 10-year reference period of 2000 through 2009 selected by Western.

5.2 Metrics for the Economic Value of Electrical Power Generated Attribute of Interest

Western markets power and administers power contracts for power produced at Reclamation-owned and -operated hydropower facilities. The economic value of electrical power produced by these facilities is an important measure of system reliability. CRSS calculates the quantity of electrical power generated, and this information could be used in post-processing analyses to calculate economic value. However, the necessary steps to compute the economic value of the electrical power generated was beyond the scope of the Study. Therefore, a qualitative analysis of the economic value was included in the Study.

5.3 Metrics for the Available Generation Capacity Attribute of Interest

Available generation capacity is a measure of the maximum amount of power that could be produced based on reservoir level and the physical design capacity of the hydropower facility. The available generation capacity affects hydropower ramping operations and overall power system reliability. Ramping is the change in water release from the reservoir that passes through the turbine to meet the electrical load. Both scheduled and unscheduled ramping occur to meet variations in real-time electrical loads. Western depends on ramping operations to ensure electrical service reliability and an uninterrupted power supply. The higher the available generation capacity, the more flexibility is available in the ramping operations. Therefore, available generation capacity is an important attribute of electrical power resources.

Historical information about available generation capacity (by month) was evaluated. Available generation capacity in future scenarios was compared to this historical reference, both monthly and annually (computed by summing the monthly values). Table D-4 summarizes the metrics related to available generation capacity.

5.4 Metrics for the Impact on Power Rates Attribute of Interest

Western has contracts in place to deliver specified amounts of power to its customers in the Upper Basin. If Upper Basin hydroelectric power facilities cannot produce the contracted power during any given month, Western must buy energy at the market rate to make up these shortfalls. The amount of power that must be purchased at the market rate directly affects the long-term power rates to contract customers. In the Lower Basin, firm contract power delivery agreements are limited to the Parker-Davis Project. Although Western does not have firm contract power delivery agreements for power produced from the Hoover power plant, decreased power plant production would require increased purchases of market rate power by contract customers. Therefore, power generation at all power plants could affect power rates, regardless of whether they have firm contract power delivery agreements.

Varying degrees of power generation shortfalls would occur under the various future scenarios evaluated. Understanding the impacts of potential generation shortfalls (which may occur with or without the implementation of options and strategies) to power rates is an attribute of interest for electrical power resources. Power rates paid by contract customers are not directly measurable by CRSS, and updating third-party models to perform this analysis is outside the scope of the Study. Therefore, a qualitative evaluation of the relationship between generation shortfalls and power rates was included in the Study.

TABLE D-4
Attribute of Interest: Available Generation Capacity

Location	Metric Type	Quantitative Method	Reference Value[2] (all values are in MWh per month)											
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Upper Basin[1]	Quantitative – Direct	Historical Condition	769	672	757	781	874	869	856	783	688	677	670	795
Hoover			856	848	982	889	913	1,029	1,248	1,357	1,233	1,353	1,265	1,107
Parker and Davis			275	213	203	198	224	269	270	317	318	319	318	320

[1] Upper Basin power plants include: Fontenelle, Flaming Gorge, Blue Mesa, Morrow Point, Crystal, and Glen Canyon.
[2] Reference values are the minimum available generation capacity that occurred during the selected 10-year reference period of 2000 through 2009.

5.5 Metrics for the Water Supply System Pumping Costs Attribute of Interest

Utilities that pump water to their service areas may be affected by increased energy requirements for pumping associated with lower water levels in source water reservoirs. Examples include the Salt River Project, which extracts cooling water from Lake Powell for the Navajo Generating Station (NGS); SNWA, which diverts water from Lake Mead; the Metropolitan Water District of Southern California, which diverts water from Lake Havasu through the Colorado River Aqueduct; and the Central Arizona Water Conservation District, which also diverts water from Lake Havasu to supply the CAP delivery area. Current operating practices maintain relatively constant lake levels in Lake Havasu regardless of hydrologic conditions. Pumping costs for the Colorado River Aqueduct and CAP, therefore, do not fluctuate significantly with hydrologic conditions. For this reason, quantitative metrics at these locations were deemed unnecessary.

Alternatively, wide fluctuations in water levels in Lake Mead and Lake Powell could affect pumping costs for water providers that pump from these reservoirs. For example, SNWA uses variable-speed pumping equipment that has the ability to adjust power usage with varying lake levels. Therefore, the effects of varying lake levels on SNWA pumping costs were included as a qualitative metric. Conversely, the Salt River Project uses constant speed pumping equipment for the NGS, which is lower-cost equipment, but does not have the ability to adjust power usage with lake levels. Therefore, electrical costs for pumping water to the NGS will not fluctuate significantly with hydrologic conditions. For this reason, metrics for the NGS were deemed unnecessary.

5.6 Metrics for the Impact on Basin Funds Attribute of Interest

A portion of the revenue from the sale of power generated at hydropower facilities is used to finance Basin funds, which include the Upper Colorado River Basin Fund, Lower Colorado River Basin Development Fund, Colorado River Dam Fund, and the Parker-Davis Account. These funds provide revenue for a variety of uses, including the operation and maintenance of hydroelectric facilities and associated dams and/or repayment of specific Basin projects or programs. Western is responsible for marketing and collecting payment for power and transfer of revenues to Basin funds. A change in the amount of available capacity or energy generation could potentially affect the revenue derived from the sale of power and the contributions to the Basin funds.

The impact to Basin funds depends on numerous factors, including amount of power sold, economic value of that power, and revenue allocation agreements. CRSS does not directly calculate any of these quantities. However, it does calculate hydropower generation, and varying degrees of hydropower generation shortfalls would occur under the various future scenarios evaluated. Therefore, qualitative metrics were used to relate power generation shortfalls to increased risk of funding shortfalls.

6.0 Water Quality Metrics

The water quality attributes of interest are:

- Salinity
- Sediment transport
- Temperature

- Other water quality attributes
- Socioeconomic impacts related to salinity

6.1 Metrics for the Salinity Attribute of Interest

The U.S. Environmental Protection Agency (EPA) suggested the development of water quality criteria for salinity in the Basin following passage of the Federal Water Pollution Control Act (Clean Water Act) of 1972. In response, the Basin States formed the Colorado River Basin Salinity Control Forum (Forum) to develop numeric salinity criteria and an implementation plan to ensure compliance while allowing the Basin States to continue to develop their Compact-allocated water. The Forum recommends, the States adopt, and EPA approves the flow-weighted average annual numeric salinity criteria for three locations on the lower Colorado River (table D-5). The criteria, first established in 1975, are reviewed every 3 years; the latest review was completed in 2011.

Minute No. 242 of the International Boundary and Water Commission provides that the United States shall adopt measures to ensure that the approximately 1.36 maf delivered to Mexico upstream of Morelos Dam have an annual average salinity of no more than 115 parts per million ±30 parts per million over the average annual salinity of Colorado River waters which arrive at Imperial Dam. Real-time water operations ensure that the salinity differential is met each year.

CRSS performs salinity calculations for select locations in the Lower Basin, including below Hoover Dam, below Parker Dam, and at Imperial Dam. Therefore, quantitative metrics for salinity were identified at these locations based on the Forum-developed numeric salinity criteria. CRSS does not include the complex surface water/groundwater interactions in the Yuma, Arizona region from Imperial Dam to the Northerly International Boundary.

Although numeric salinity criteria in the Upper Basin and at other locations in the Lower Basin have not been developed, salinity levels are monitored at 17 locations throughout the Basin by the Colorado River Basin Salinity Control Program[6] in cooperation with the U.S. Geological Survey, with 15 of those locations being in the Upper Basin. These locations are represented in CRSS and are used as relative comparison metrics to compare salinity levels across scenarios. Table D-5 summarizes the Basin salinity metrics and the associated quantification methods and reference values.

6.2 Metrics for the Sediment Transport Attribute of Interest

Reservoirs behind dams throughout the Basin retain the vast majority of the inflowing sediment. Following the completion of the dams, large sediment deltas formed near the inflow areas. When the reservoirs are drawn down during droughts, rivers cut new channels through the sediment deltas to reach the reservoirs. Generally the greater the reservoir drawdown, the greater the sediment delta headcut and the finer the sediment exposed. The resuspended sediments have a significant oxygen demand and also temporarily release nutrients, which can result in greater algal growth.

[6] Authorized through Public Laws 93-320, 98-569, 104-20, 104-127, 106-459, 107-171, and 110-246.

TABLE D-5
Attribute of Interest: Salinity

Location	Metric Type	Quantification Method	Reference Value[1] milligram(s) per liter (mg/L)
Below Hoover Dam	Quantitative	Prescribed Condition	723
Below Parker Dam			747
At Imperial Dam			879
Colorado River near Glenwood Springs, CO	Quantitative	Relative Comparison	Not Applicable
Colorado River near Cameo, CO			
Gunnison River near Grand Junction, CO			
Dolores River near Cisco, CO			
Colorado River near Cisco, CO			
Green River at Green River, WY			
Green River near Greendale, UT			
Yampa River near Maybell, CO			
Duchesne River near Randlett, UT			
White River near Watson, UT			
Green River at Green River, UT			
San Rafael River near Green River, UT			
San Juan River near Archuleta, NM			
San Juan River near Bluff, UT			
Colorado River at Lees Ferry, AZ			
Colorado River near Grand Canyon, AZ			
Virgin River near Littlefield, AZ			

[1] For locations with numeric criteria developed by the Forum, salinity is measured as flow-weighted average annual total dissolved solids at designated locations on the Colorado River.

Riverine sediment transport, therefore, can have recreation and biological resource impacts. Sediment transport in the Basin is not modeled by CRSS. Although sediment transport models exist for some locations, there is no Basin-wide sediment transport model. The relation between beach formation in reservoirs and within river reaches, and the recreational experience was addressed qualitatively in the Recreational Resources resource category.

6.3 Metrics for the Temperature Attribute of Interest

Impounding water in reservoirs affects the water temperature of dam releases as a result of thermal stratification. During the summer, the surface layers of the reservoirs are typically warm as the result of inflows, ambient air temperature, and solar radiation. Conversely, lower reservoir layers remain cooler year-round. For these reasons, water temperatures downstream of reservoirs are influenced by reservoir water level, release facility location, and release volumes.

Water temperature can affect the health of flow- and water-dependent species in the Basin. Water temperature is not modeled by CRSS and therefore was not quantitatively evaluated in the Study.

6.4 Other Water Quality Attributes of Interest

Numerous other water quality attributes are of interest to various stakeholders. Water quality attributes such as selenium, dissolved oxygen, nutrients, algae, metals, perchlorate, and emerging contaminants were qualitatively addressed in the Study.

6.5 Metrics for Socioeconomic Impacts Related to Salinity Attribute of Interest

Economic impacts of elevated salinity levels in the Colorado River and its tributaries are not calculated by CRSS. Reclamation and the Forum use the Lower Colorado Salinity Damage Model to estimate economic damages that result from elevated salinity levels in the Basin. Economic damages estimated by this model include changes to crop yields related to agricultural water use and impacts due to M&I water use, such as reduced useful life of water-dependent appliances, increased use of water-softening chemicals, and increased purchase of bottled water. The necessary steps to run this economic model using all of the Study's results is beyond the scope of the Study. Therefore, the economic effects due to salinity levels were included as a qualitative metric. In addition, EPA has set voluntarily guidelines for salinity levels in drinking water supplies with a target of less than 500 mg/L, measured as total dissolved solids. Some water providers, notably the Metropolitan Water District of Southern California, blend Colorado River water with other water supplies that have lower salinity in an attempt to meet these guidelines. When salinity levels are elevated in the Colorado River, the ability of M&I water suppliers to meet their target blended salinity is diminished. Qualitative discussions of this item were provided in addition to the discussion of economic damages.

7.0 Flood Control Metrics

The flood control attributes of interest are:

- Flood control releases and reservoir spills
- Critical river stages related to flooding risk

7.1 Metrics for the Flood Control Releases and Reservoir Spills Attribute of Interest

The term "flood control releases" is unique to the operation of Hoover Dam because Lake Mead's annual release is governed by strict flood control regulations. The current flood control regulations were implemented under the Field Working Agreement between Reclamation and the U.S. Army Corps of Engineers (USACE) for Flood Control Operation of Hoover Dam and Lake Mead, signed February 8, 1984 as prescribed by the 1982 *Water Control Manual for Flood Control, Hoover Dam and Lake Mead, Colorado River* (USACE, 1982). Under this agreement, criteria are set forth to meet system space requirements from August through December and to determine reservoir releases from January through July. During all months of the year, the top 1.5 maf of space (the space above elevation 1,219.6 feet msl) is reserved exclusively for flood control purposes. Lake Mead is considered to be under flood control operations when releases in excess of those necessary to meet water use demands are required to make this flood control space available.

Reclamation also makes "spill avoidance" decisions at other reservoirs that it manages and operates. The primary objective of spill avoidance is to minimize the amount of water that does not pass through hydropower facilities. Reclamation typically defines a spill as any amount of water that does not pass through the hydropower facilities, including water that is diverted around the dam through bypass piping, as well as water that physically passes over the dam spillway.

CRSS was used to quantify the frequency and magnitude of both flood control releases at Lake Mead and reservoir spills. These metrics were quantified at Fontenelle, Flaming Gorge, Blue Mesa, Lake Powell, and Lake Mead using the relative comparison quantification method.

7.2 Metrics for the Critical River Stages Related to Flooding Risk Attribute of Interest

CRSS does not directly calculate water levels (stages) in river reaches. In select locations, empirical relationships between river flow and river stage can be used to assess the potential for flooding. Specifically, empirical relationships between flow and flood risk (safe channel capacity) exist downstream of Lake Mead, Navajo Dam, and the Aspinall Unit. Additional analysis of CRSS output data was performed to estimate flooding potential. Table D-6 summarizes the metrics for the critical river stages related to flooding risk.

TABLE D-6
Attribute of Interest: Critical River Stages Related to Flooding

Location	Metric Type	Quantitative Method	Reference Value[1] cubic feet per second (cfs)	Reference
Gunnison River at Delta, Colorado	Quantitative	Estimated Condition	15,000	Water Control Manual Blue Mesa Dam and Reservoir (USACE, 1988)
San Juan River below Navajo Dam			5,000	Water Control Manual Navajo Dam and Reservoir (USACE, 1970)
San Juan River near Farmington, New Mexico			12,000	
Colorado River below Hoover Dam			28,000	Water Control Manual Hoover Dam and Lake Mead (USACE, 1982)

[1] Maximum safe channel capacity

8.0 Recreational Resources Metrics

The recreational resources attributes of interest are:

- Shoreline public use facilities
- River and whitewater boating
- Other recreation attributes
- Socioeconomic impacts related to recreation

8.1 Metrics for the Shoreline Public Use Facilities Attribute of Interest

Access to boat launch ramps and marinas is directly related to reservoir water levels. CRSS calculates water levels for all major Basin reservoirs, so access to shoreline facilities can be evaluated directly with CRSS output. Low reservoir levels can also limit reservoir boating navigation and affect ferry service. Table D-7 summarizes the metrics for shoreline access.

TABLE D-7
Attribute of Interest: Shoreline Public Use Facility

Location[1]	Metric Type	Quantitative Method	Reference Value[2] (feet msl)
Flaming Gorge	Quantitative	Physical Constraint	
Firehole Boat Ramp			6,019
Cedar Springs Marina			6,018
Antelope Flat, Anvil Draw, Buckboard, Sheep Creek, Squaw Hollow Boat Ramps			6,015
Lucerne Valley Marina			6,010
Mustang Ridge and Upper Marsh Creek Boat Ramps			6,000
Lucerne Valley Boat Ramp			5,994
Blue Mesa			
Ponderosa Boat Ramp			7,468
Stevens Creek Boat Ramp			7,462
Lake Fork Marina and Boat Ramp			7,440
Iola and Elk Creek Boat Ramps			7,433
Navajo			
Arboles Boat Ramp			6,025
Sims Mesa Boat Ramp			6,000
Pine Boat Ramp			5,997
Lake Powell			
Hite Public Boat Ramp			3,620
Castle Rock Cut			3,613
Antelope Point Public Boat Ramp			3,588
Wahweap, Stateline, Bull Frog Low Water Alternative, Halls Crossing Ramps			3,560
Wahweap, Antelope Point, Bull Frog, Halls Crossing Marinas			3,555

TABLE D-7
Attribute of Interest: Shoreline Public Use Facility

Location[1]	Metric Type	Quantitative Method	Reference Value[2] (feet msl)
Lake Mead			
Pearce Bay Boat Ramp and Ferry			1,175
Las Vegas Bay and Government Wash Boat Ramps			1,150
Overton Beach Marina, Callville and South Cove Boat Ramps			1,125
Overton Boat Ramp			1,110
Lake Mead Marina			1,100
Lake Mead, Hemenway, Temple Bar Boat Ramps			1,080
Echo Bay Boat Ramp			1,050

[1] Other locations, such as boat access camp sites, swim beaches, and natural features, are recognized as attractions but not included as reference values for the shoreline public use facilities attribute of interest.

[2] Minimum reservoir levels required for use of designated shoreline public use facilities. Below these levels, facilities would have to be extended, closed, or relocated.

8.2 Metrics for the River and Whitewater Boating Attribute of Interest

Many different recreational activities are supported by rivers and streams throughout the Basin. The river and whitewater boating attribute of interest was designed to measure the impact to one of those activities, specifically river and whitewater boating.

River and whitewater boating experiences vary with flow conditions, as well as with other non-flow related factors. For use in the Study, American Whitewater developed relationships that relate flow conditions to the quality of the boating experience by applying methodology developed by Whittaker et al. (2005). Under this methodology used by American Whitewater, flow translates to an “acceptable” or “optimal” boating day, depending on the flow condition and user survey responses. While this approach has been used in other Federal Energy Regulatory Commission-related studies, significant uncertainties exist related to its use in the Study. Additionally, it should be recognized that there are alternative study options to the one applied here that relate flow and recreation quality. The inclusion of the results from this particular approach should not be construed as an endorsement of this method by the Basin States or Reclamation.

A key component of this methodology is user surveys that ask the recreational boating community to identify flows ranging from totally unacceptable to totally acceptable based on their skill level and craft type. American Whitewater independently conducted these surveys and due to resource constraints and the Study timeline, these surveys were conducted over a much shorter timeframe (1 month) than others typically conducted by American Whitewater. As such, there are limitations in the data collected by these surveys, in particular related to low response numbers and non-response bias. Non-response bias can result when surveys are only filled out by a small percentage of the people who were asked to fill out the survey, and has the potential to skew results (Whittaker et al., 1993)[7].

Survey limitations affect the flow-experience relationships derived from these surveys. Correspondingly, the flow ranges that define these relationships also contain limitations. Some of these are quite obvious given the extremely broad range of acceptable flows at some locations. For example, as shown in table D-8, for the Colorado River near Cisco, Utah, the range for an acceptable boating experience is from 1,800 to 100,000 cfs. The results of the user survey, as well as the methods applied to develop acceptable and optimal flow ranges, are described in detail in appendix D2.

Notwithstanding these limitations, information retained from these surveys and the subsequent analysis resulting in estimated flow conditions to support the boating experience were included in the Study because the information may provide an understanding of the impacts to river and whitewater boating under the multiple future conditions assessed in the Study. This information provides a useful broad view of these impacts; however, it is recommended that future efforts that incorporate this information carefully consider the limitations described here and in further detail in appendix D2.

Because CRSS operates at a monthly time step and the flow-experience relationships are developed based on average daily flows, a method was developed that uses the flow-experience relationships for the Study. This method develops daily flow patterns that translate monthly volumes projected by CRSS into “boating flow days” using the flow-experience relationships developed through user surveys. The daily flow patterns are not meant to predict actual daily flows in the future; rather, they are an intermediate step in obtaining the number of boating flow days in a month. The number of boating flow days is compared across future scenarios. As such, the utility is in the relative comparison of the metric between scenarios. A detailed description of this method is provided in appendix D2.

Table D-8 lists the locations at which the metric was evaluated (locations explicitly modeled in CRSS), the corresponding recreational boating reach, and the estimated range of “acceptable” and “optimal” flows for boating as determined from the user surveys. It is important to note that these flow ranges are estimated to support river and whitewater boating and do not necessarily support other recreational activities, for example, fishing. The acceptable and optimal ranges listed in this table are not the metrics’ reference value; rather, they were used to calculate the number of acceptable and optimal boating flow days.

In cases where CRSS does not explicitly represent the recreational boating reach of interest, the nearest downstream location represented in CRSS was chosen as an indirect approximation of the location of interest. The locations were selected by evaluating three criteria: 1) the proximity of a location explicitly represented in CRSS to a whitewater boating resource; 2) an assessment of the CRSS ability to model flow at the desired locations; and 3) an acceptable number of respondents (30 per Whitaker et al. [1993]) for the user surveys. It should be recognized that the locations in table D-7 are not a complete list of locations that are important to the recreational boating community. Rather, they are the locations surveyed by American Whitewater and fit the evaluation criteria previously described and were evaluated in the Study. Appendix D2 lists all the locations surveyed by American Whitewater.

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[7] Whittaker et al. (1993) suggests that non-response bias may be an issue if the survey response rate is less than 65 percent. In the surveys conducted by American Whitewater, the response rates were typically much lower than 65 percent.

TABLE D-8
Attribute of Interest: River and Whitewater Boating

Location	Whitewater Boating Resources	Acceptable Range (cfs)	Optimal Range (cfs)
Colorado River at Glenwood Springs, CO	GW Play Park, South Canyon	1,600–50,000	7,000–20,000
Dolores River near Cisco, UT	Lower Dolores	900–20,000	1,800–3,000
Colorado River near Cisco, UT	Hittle Bottom, Moab Daily	1,800–100,000	4,000–15,000
Green River near Greendale, UT	Lodore Canyon	1,000–12,000	2,000–8,000
Yampa River near Maybell, CO[1]	Little Yampa Canyon, Cross Mountain Canyon	800–10,000	1,700–4,500
Yampa River at Deerlodge Park, CO	Yampa Canyon	1,500–50,000	2,500–25,000
Green River at Jensen, UT	Split Mountain Canyon	1,200–50,000	2,500–25,000
San Juan River near Bluff, UT	Lower San Juan Canyon	800–50,000	1,400–7,500

[1] The Cross Mountain segment is a very technical whitewater boating resource, and is defined by a narrow range of boating flows, as compared to other segments on the Yampa. Because of the technical and advanced nature of the resource, responses from experienced paddlers were less than 30.

8.3 Other Recreational Attributes of Interest

Sediment transport affects the recreational experience along Basin rivers and in Basin reservoirs. Significant additional analyses (beyond CRSS) are required to model sediment transport. Therefore, in lieu of detailed quantitative analyses, qualitative evaluations relating sediment transport to river flows were provided as part of the Study.

8.4 Metrics for the Socioeconomic Impacts Attribute of Interest

A reduction in the number of recreational visitors as a result of limited shoreline access could adversely affect local socioeconomics. Rough estimates that relate reservoir levels or flow conditions to socioeconomic impacts exist for some areas in the Basin. Significant additional analyses (beyond CRSS) are required to model the socioeconomic impacts related to reduced recreational use. For this reason, socioeconomic impacts related to reduced recreational use of Basin water resources were evaluated qualitatively.

9.0 Ecological Resources Metrics

Colorado River ecosystems support a wide array of native species, each with diverse needs. To assess the response of these ecosystems to changed conditions under future scenarios, extensive data and models that examine the complex interactions of the physical environment and specific species' needs are required. This detailed level of assessment is beyond the scope of the Study; however, metrics that approximate the flow-based conditions to support these resources were developed to facilitate the understanding of how these hydrologic conditions vary under future conditions.

The locations at which these metrics are applied do not represent all of the ecologically important locations in the Basin. Rather, they represent locations that are both explicitly modeled in CRSS and have ecological relevance. Many limitations exist with respect to the tools and data that can be reasonably used given the Study's time and resources. Acknowledging these limitations, metrics that approximate the location and estimate the flow conditions to support ecological resources were developed for the purpose of the Study. As such, the utility of the metrics described in this section is primarily to understand the relative comparison within an attribute of interest across a wide range of future scenarios[8].

Ecological resources specified in the *Plan of Study* (see *Study Report, Appendix 1 – Plan of Study*) include fish, wildlife, and their habitats; candidate, threatened, and endangered species; and flow- and water-dependent ecological systems. The ecological resources attributes of interest are:

- Flows to support threatened and endangered species
- Aquatic and riparian habitats
- Wildlife refuges and fish hatcheries

9.1 Metrics for Flows to Support Threatened and Endangered Species Attribute of Interest

The Upper Colorado River Endangered Fish Recovery Program and San Juan River Basin Recovery Implementation Program (Recovery Programs) are designed to help recover several fish species listed as endangered under the federal Endangered Species Act (the Colorado pike minnow, the razorback sucker, the bonytail, and the humpback chub), while allowing water development to continue in the Upper Colorado and San Juan River Basins. The Recovery Programs provide water for these endangered fish species in accordance with all applicable laws through means that include the modification of operations at federal and non-federal facilities, conservation, and the development of additional supplies. Flow recommendations[9] are defined as part of the Recovery Programs; therefore, flows are used as indicators for metrics for these fish species, and the Recovery Programs' recommendations provide the reference values. Providing flows is only one part of the recovery efforts that include activities such as habitat development, non-native fish control, and monitoring and research. The combination of flow and non-flow recovery actions is anticipated to increase endangered fish populations to achieve recovery. As such, the relative difference in achieving these flow recommendations across various scenarios should not be viewed as the sole means to recover the species.

The 1996 Glen Canyon Dam ROD (Reclamation, 1996) guides the operations of Glen Canyon Dam regarding downstream ecological resources. The ROD sets very specific limits on daily operations (ramp rates and fluctuation limits). Most sub-monthly constraints cannot be effectively modeled in CRSS; however, the ROD specifies minimum allowable releases of 8,000 cfs from 7:00 a.m. to 7:00 p.m. and 5,000 cfs from 7:00 p.m. to 7:00 a.m. When coupled with the down-ramp restrictions of 1,500 cfs per hour (Reclamation, 1996), the minimum average daily release is constrained to 6,438 cfs. The minimum daily release was converted to a minimum monthly release for Glen Canyon Dam and used as a reference value.

[8] For example, metrics for riparian habitat, under the aquatic and riparian habitats attribute of interest, should be used to show that scenario "X" meets the estimated flow conditions for cottonwood recruitment 95 percent of the time and scenario "Y" meets the criteria 98 percent of the time, so scenario "Y" is relatively better at meeting the flow conditions. An incorrect interpretation of the metric would be to infer that if scenario "X" is realized, cottonwood recruitment will not exist 5 percent of the time because data and tool limitations inhibit that level of detail.

[9] The flow recommendations were developed based on the best available information at the time. They are subject to change based on continued research and adaptive management processes integral to the ongoing recovery efforts.

The ROD also established the Glen Canyon Dam Adaptive Management Program (AMP) to monitor the effects of Glen Canyon Dam operations on the downstream ecological resources. The AMP is responsible for making recommendations to the Secretary regarding ways to fulfill the resource protection requirements of the Grand Canyon Protection Act while complying with all applicable federal laws. Each year the AMP recommends flows that the Secretary may adopt for these purposes. At times these have included changes in monthly release patterns; however, this is done annually on an ad hoc basis and therefore was not included as a metric.

In the Lower Basin, the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) provides Endangered Species Act compliance for specific federal ongoing and future flow and non-flow related actions in the Lower Basin through 2055, as well as the conservation plan for a non-federal section 10(a)(1)(B) permit over the same period of time. The LCR MSCP-covered activities include changes in points of diversion that could result in reduced flows in amounts up to 845 thousand acre-feet per year (kafy) in the reach below Hoover Dam to Davis Dam, up to 860 kafy in the reach below Davis Dam to Parker Dam, and up to 1,574 kafy in the reach below Parker Dam to Imperial Dam. Reductions in flow may occur from actions such as water transfers, conservation activities, and shortages to Lower Basin water users (Reclamation, 2004). The flow reduction values at these locations provide the reference values for metrics associated with threatened and endangered species in the Lower Basin.

Table D-9 summarizes the metrics related to flows to support threatened and endangered fish, including the location, flow target(s), and reference document from which these flows were taken. Many of the Recovery Program flow recommendations are for average daily flow rates, whereas CRSS operates at the monthly time step; however, recent research and development efforts resulted in the ability to evaluate daily flow targets below Navajo and Flaming Gorge Reservoirs. For other locations, monthly volumetric targets were developed based on the Recovery Program’s flow recommendations. Appendix D3 details the methods used to develop these monthly approximations. Assumptions (e.g., hydrologic period of record chosen for year type determination) were made to develop those approximations that in some cases resulted in flows different than those specified in the reference documents and that exist for regulatory purposes. The inclusion of these approximated flows in the Study should not in any way change or affect the flow recommendations that are used for regulatory purposes.

9.2 Metrics for Aquatic and Riparian Habitat Attribute of Interest

At some locations of interest, specific habitat needs have not been expressed in terms of flow recommendations for endangered fish recovery. Nonetheless, there is interest in examining how aquatic and riparian habitat for species not currently threatened or endangered may change with time under varying future scenarios. Although flow is not the only variable that influences changes to the aquatic and riparian habitat, it is the main output variable of CRSS. The flow conditions represent an indirect measurement of how the habitats could function in the future. Metrics for this attribute of interest were developed under each of the following groups:

- Instream flow rights
- Cottonwood recruitment conditions
- Flow-dependent ecological systems

TABLE D-9
Attribute of Interest: Flows to Support Threatened and Endangered Species

Location	Metric Type	Quantitative Method	Reference Value[2]	Reference
Colorado River near Cameo, CO	Quantitative	Prescribed Condition[1]	Average monthly flows ranging from about 1,560–17,160 cfs, depending on month and hydrologic year type	Recovery Program (Osmundson, 2001)
Gunnison River near Grand Junction, CO			Spring peak volumes ranging from about 347–2,090 kaf and summer through winter base flows ranging from 42–154 kaf, depending on hydrologic year type	Recovery Program (McAda, 2003) Final Gunnison River Programmatic Biological Opinion (PBO) (USFWS, 2009)
Colorado River near the Colorado-Utah Stateline			Spring peak volumes ranging from 871–5,271 kaf and summer through winter base flows ranging from 100–369 kaf, depending on hydrologic year type	Recovery Program (McAda, 2003)
Yampa River near Maybell, CO			Base flow of 120 cfs	Recovery Program (USFWS, 2008)
Green River near Greendale, UT			Summer through winter base flows ranging from 800–1,800 cfs, depending on hydrologic year type	Flaming Gorge Operations Final EIS (Reclamation, 2005)
Green River at Jensen, UT			Spring peak flows ranging from 8,300–26,400 cfs and summer through winter base flows ranging from 900–3,000 cfs, depending on hydrologic year type	Flaming Gorge Operations Final EIS (Reclamation, 2005)
Green River at Green River, UT	Quantitative	Prescribed Condition[1]	Spring peak volumes ranging from 1,092–4,700 kaf and summer through winter base flows ranging from 80–289 kaf, depending on hydrologic year type	Flaming Gorge Operations Final EIS (Reclamation, 2005)
Duchesne River near Randlett, UT			Spring peak volumes ranging from 47.6–535 kaf and summer through winter base flows ranging from 2.8–7.1 kaf, depending on hydrologic year type	Recovery Program (Modde and Keleher, 2003)
San Juan River near Bluff, UT[3]			Spring peak flows ranging from 2,500–10,000 cfs and summer through winter base flows ranging from 500–1,000 cfs	Navajo Reservoir Operations Final EIS (Reclamation, 2006a)
Glen Canyon Dam			Minimum average daily release of 6,438 cfs	Glen Canyon Dam ROD (Reclamation, 1996)

TABLE D-9
Attribute of Interest: Flows to Support Threatened and Endangered Species

Location	Metric Type	Quantitative Method	Reference Value[2]	Reference
Hoover Dam to Davis Dam			Flow reductions up to 845 kafy	LCR MSCP (Reclamation, 2004)
Davis Dam to Parker Dam			Flow reductions up to 860 kafy	
Parker Dam to Imperial Dam			Flow reductions up to 1,574 kafy	

[1] These flow targets are one component of the Upper Colorado River Endangered Fish Cooperative Agreement between DOI and the States of Colorado, Utah, and Wyoming; and several PBOs and EISs that are based on that agreement and the underlying program. These flow targets may change in the future as a result of new information or changes in this Recovery Program or the underlying PBOs and EISs.

[2] If the Recovery Programs' flow recommendations are in terms of monthly flows or are at locations that daily flows can be evaluated using CRSS, the reference values are directly from the referenced document. Otherwise, the reference values are monthly approximations of the flow recommendations from the supplied references.

[3] CRSS does not presently have the appropriate resolution to measure base flow recommendations at the precise locations specified in the Navajo Reservoir Operations ROD (Reclamation, 2006b). Methods have been developed, in collaboration with Navajo Reservoir operators, to provide a quantitative approximation of the Navajo ROD flow recommendations that assume the recommendations are measured at the San Juan River near Bluff, Utah.

Table D-10 summarizes the metrics (both the locations and the reference values) considered under each of the above groups. The following sections describe these metrics in further detail.

9.2.1 Instream Flow Rights

The Colorado Water Conservation Board has secured many instream flow rights[10] to benefit the aquatic and riparian habitat across Colorado. Many of these locations are on tributaries that are not modeled in CRSS; however, where the locations coincide with gage locations in CRSS, the modeled flow was compared with the in-stream flow right. Table D-10 presents the locations and their reference values.

9.2.2 Cottonwood Recruitment Metric

Healthy cottonwood stands are an indicator of healthy riparian systems and the many species that depend on them. The recruitment of new cottonwoods is important in maintaining the cottonwood stands, and thus a healthy riparian system. The metric is based on the biological premise that conditions that could lead to a successful cottonwood recruitment event, should occur approximately once every 10 years, to sustain the cottonwoods and the many riparian facultative species depending on them. In coordination with the USFWS and The Nature Conservancy (TNC), a metric was developed that incorporates this concept.

[10] Available at: http://cwcb.state.co.us/environment/instream-flow-program/Pages/main.aspx.

TABLE D-10
Attribute of Interest: Aquatic and Riparian Habitat

Location	Metric Type	Quantification Method	Reference Value
Instream Flow Rights			
Taylor River near Taylor Park, CO	Quantitative	Prescribed Condition	100 cfs in May through September and 50 cfs in October through April.
Gunnison River below Crystal Reservoir, CO			300 cfs in January through December
Cottonwood Recruitment Metric			
Dolores River near Cisco, UT	Quantitative	Estimated Condition	Positive conditions occurring once every 10 years[1]
San Juan River near Archuleta, NM			
Green River below Fontenelle Reservoir, WY			
Green River near Green River, WY			
San Rafael near Green River, UT			
Colorado River near Cisco, UT			
Flow-Dependent Ecological Systems			
Yampa River near Maybell, CO	Quantitative	Estimated Condition	Spring peak volumes ranging from 369–1,459 kaf and summer through winter base flows ranging from 7.1–73 kaf, depending on hydrologic year type[2]
Little Snake River near Lily, CO			Spring peak volumes ranging from 100–531 kaf and summer through winter base flows ranging from 0.36–33.7 kaf, depending on hydrologic year type[2]
Yampa River at Deerlodge Park, CO			Spring peak volumes ranging from 458–1,994 kaf and summer through winter base flows ranging from 7.1–118 kaf, depending on hydrologic year type[2]
White River near Watson, UT			Spring peak volumes ranging from 120–504 kaf and summer through winter base flows ranging from 12.3–36.9 kaf, depending on hydrologic year type[2]

[1] See appendix D4 for the detailed approach to this reference value.

[2] See appendix D5 for the detailed approach to this reference value.

The metric employs the cottonwood recruitment box model (Mahoney and Rood, 1998), which has been applied in many western river systems, including the Bill Williams River (Shafroth et al., 1998) and the Sacramento River (ESSA Technologies Ltd., 2007). As described in Mahoney and Rood (1998), a successful recruitment event depends on four variables: timing of peak flow, the river stage corresponding to the peak flow, the rate of decline from when the peak flow occurs to when the peak has attenuated, and a flood large enough to create the appropriate seed beds. The metric is an estimated condition quantification method; it is estimated that positive recruitment conditions should occur once every 10 years to maintain healthy cottonwood stands. All the above conditions are required to create the opportunity for a successful recruitment event. The approach to determine whether or not these conditions have occurred using CRSS is described in appendix D4. Table D-10 provides the locations at which the cottonwood metric is evaluated.

The locations selected for the cottonwood recruitment method have not necessarily had site-specific surveys to relate flow to floodplain inundation. Detailed site-specific surveys are necessary to recommend flows for cottonwood recruitment. However, the adopted method relies on documented rules of thumb to approximate positive recruitment conditions and is appropriate for a relative comparison across scenarios. Furthermore, the locations have been selected at existing gage sites, which may not be precisely located where ideal conditions exist for cottonwood growth; however, this approximation was necessary given CRSS spatial limitations. These assumptions are useful in providing a general understanding of the relative comparison of cottonwood recruitment under multiple future conditions; however, it is recommended that future efforts that incorporate this information carefully consider these limitations.

Additionally, there are other locations in the Basin where this metric would be appropriate; however, current modeling limitations have limited the inclusion of those locations. In particular, the Bill Williams River has existing flow recommendations (U.S. Geological Survey, 2006), has operations and hydraulic models applied to it for ecological flow needs (Shafroth et al., 2010), and had the cottonwood recruitment box model applied to it in previous efforts (Shafroth et al., 1998). It would be beneficial to include similar metrics on the Bill Williams River; however, this inclusion is limited by the treatment of the Lower Basin tributaries within CRSS *(Technical Report C – Water Demand Assessment, Appendix C11 – Modeling of Lower Basin Tributaries in the Colorado River Simulation System)* in that there is little variation projected on the Bill Williams River between future scenarios.

9.2.3 Flow-Dependent Ecological Systems

Metrics were developed to consider flow-dependent ecological systems (aggregation of fish health and riparian and aquatic habitat) for locations throughout the Basin that are important ecologically but for which no prescribed flow conditions exist. For example, the recommended flows for the Yampa River (described in table D-10) consider flow needs only during the base flow period. In coordination with the USFWS and TNC, metrics were developed for estimated flow conditions at this location in addition to two other locations in the Yampa River Basin. The White River near Watson, Utah, is another location with documented flow needs (Haines et al., 2004; Lentsch et al., 2000), although they have not been fully prescribed through a biological opinion. Table D-10 presents the locations and a summary of the reference values for these metrics, while appendix D5 describes the full set of estimated flow conditions and the methods to develop those flows for the flow-dependent ecological systems attribute of interest.

Several limitations exist with respect to the estimation of these flow conditions. First, these ecological systems are supported by many non-flow parameters (for example water quality, temperature, etc.) that are not considered in the estimated flow-based conditions. Secondly, these flow conditions must be aggregated to a monthly time step to meet that of CRSS. Additionally, the methodology used to develop these flow conditions (appendix D5) depends on assumptions behind the hydrologic year-typing. Acknowledging these limitations, the estimated flow conditions shown in table D-10 have been adopted for the purpose of the Study because they provide a general understanding of the relative comparison of these specific ecological systems; however, it is recommended that future efforts that incorporate this information carefully consider these limitations.

9.3 Metrics for Wildlife Refuges and Fish Hatcheries Attribute of Interest

Table D-11 summarizes wildlife refuge and fish hatcheries in the Basin that have water rights and their reference values. The determination of the reference values was done in coordination with USFWS. In the Upper Basin, reference values are based on both the associated water right within the state and historical diversion records and vary by hydrologic year type. A description of the computation of these reference values can be found in appendix D6.

In the Lower Basin, reference values are based on the wildlife refuges' entitlements and historical use and vary by water demand scenario *(Technical Report C – Water Demand Assessment)*. Under a specific water demand scenario, the reference value may be less than or equal to the refuges' entitlement. It is recognized that a refuge's demand for water is not necessarily limited to that refuge's entitlement; however, the quantification of that demand remains an ongoing effort within USFWS.

TABLE D-11
Attribute of Interest: Wildlife Refuges and Fish Hatcheries

Location	Metric Type	Quantification Method	Reference Value (af)
Colorado			
Browns Park National Wildlife Refuge	Quantitative	Estimated Condition	Monthly flows up to 2,520 af, depending on month and hydrologic year type[1]
Wyoming			
Seedskadee National Wildlife Refuge	Quantitative	Estimated Condition	Monthly flows up to 5,700 af, depending on month and hydrologic year type[1]
Utah			
Ouray National Wildlife Refuge	Quantitative	Estimated Condition	Monthly flows up to 8,800 af, depending on month and hydrologic year type[1]
Arizona			
Havasu National Wildlife Refuge	Quantitative	Estimated Condition	Annual depletions ranging from 4,542–37,339 af and annual diversions ranging from 37,850–41,839 af[2]
Cibola National Wildlife Refuge			Annual depletions ranging from 8,822–16,793 af and annual diversions ranging from 14,230–27,000 af[2]
Imperial National Wildlife Refuge			Annual depletions ranging from 1,039–23,000 af and annual diversions ranging from 1,676–28,000 af[2]
Willow Beach Fish Hatchery	Quantitative	Estimated Condition	Annual depletions of about 290 af[3]

[1] See appendix D6 for monthly flow conditions that vary by hydrologic year type.

[2] Annual diversion and depletion varies across water demand scenarios (*Technical Report C – Water Demand Assessment*). The lower ends represent the average diversion and depletion from 2005–2009 (4,542 af diversion for Havasu National Wildlife Refuge. The upper end represents the refuge entitlement (37,339 af diversion for Havasu National Wildlife Refuge).

[3] This amount reflects Lake Mead National Recreational Area annual depletion, which includes Temple Bar, Katherine, and Willow Beach. CRSS does not represent these locations explicitly and treats them as one diversion by the Lake Mead National Recreational Area.

10.0 Summary and Limitations

Many metrics have been defined, and descriptions of these metrics have been provided in this report. The map shown in figure D-2 displays the Study Area and denotes the locations of the metrics that have been defined. The locations of the water deliveries metrics are not denoted because there are more than 200 locations throughout the Study Area.

Metrics were developed to assess the impacts to water deliveries, electrical power resources, water quality, flood control, recreational resources, and ecological resources under multiple future conditions. Some metrics used information directly from CRSS (for example, consumptive uses and reservoir releases), while others used indirect measurements using flow to estimate the impact to the resource (for example, aquatic and riparian habitats). Still other metrics, such as socioeconomic impacts, were evaluated qualitatively.

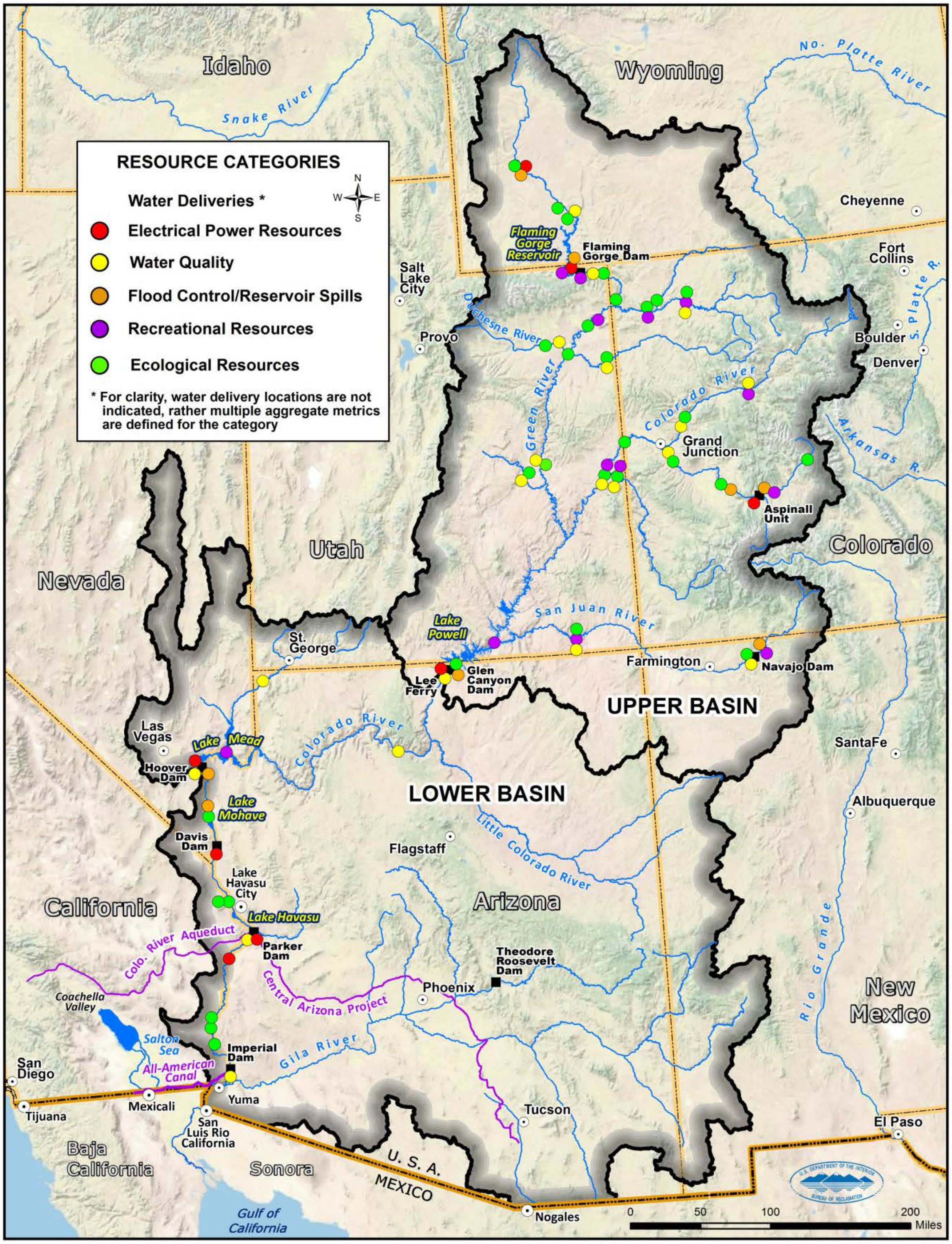
The ability to assess impacts to Basin resources is limited by the spatial and temporal detail of CRSS. For example, CRSS tracks shortages in the Upper Basin when the flow is insufficient to meet the local demands, as opposed to simulating the complex water rights system in each state that would be needed to appropriately model shortages to individual water rights holders. This representation affects the ability of the Study to assess the impacts to deliveries in the Upper Basin.

Another example is that several ecological resources metrics were evaluated through approximations at larger spatial scales and longer time steps, e.g., monthly versus daily, than preferred because of model limitations. Additionally, ecosystems are composed of complex interactions influenced by many variables besides flow, e.g., sediment transport, water quality, temperature, etc. The ecological resource metrics developed for the Study are flow-based, which indicate whether or not a certain flow condition exists, but do not indicate that the expected impact on a species will be realized. Likewise, the flow-based metric may indicate lesser achievement, but other habitat measures not directly measured in the Study may improve, resulting in the improvement of the overall ecosystem.

Despite these limitations, the metrics described in this report represent a good first step towards the identification of a comprehensive set of metrics to measure the potential impacts to Basin resources. Using these metrics and through the development of system vulnerabilities, *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies* presents the projected impacts to these Basin resources and the effectiveness of various options and strategies at mitigating these impacts.

In efforts beyond the Study, additional CRSS developments and enhancements to improve the model’s ability to simulate the system under future conditions will occur. These improvements will help to further the understanding of the potential future impacts to Basin resources in future studies.

FIGURE D-2
Study Area with Locations of Defined Metrics



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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 was constrained by funding, timing, and technological and other limitations, and in some cases presented 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 developed and incorporated assumptions to further complete the Study. Where possible, a range of assumptions was typically 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, or Minute No. 319 of November 20, 2012, 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.