RECLAMATION

Managing Water in the West

February 2012 Update

Colorado River Basin Water Supply and Demand Study

Technical Report D – System Reliability Metrics

U.S. Department of the Interior
Bureau of Reclamation

February 2012

Mission Statements

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

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

February 2012 Update

Colorado River Basin Water Supply and Demand Study

Technical Report D – System Reliability Metrics

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Colorado River Basin Water Supply and Demand Study Study Team

U. S. Department of the Interior
Bureau of Reclamation

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Acronyms/Abbreviations

AMP	Adaptive Management Program
Basin	Colorado River Basin
Basin States	Colorado River Basin States (Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming)
CAP	Central Arizona Project
cfs	cubic feet per second
CRSS	Colorado River System Simulation
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
Forum	Colorado River Basin Salinity Control Forum
FWS	U.S. Fish and Wildlife Service
Interior	U.S. Department of the Interior
kaf	thousand acre-feet
kafy	thousand acre-feet/year
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
M&I	municipal and industrial
mg/L	milligram(s) per liter
msl	mean sea level
MWh/yr	megawatt hours/year
NIB	Northerly International Boundary
NGS	Navajo Generating Station
NWR	National Wildlife Refuge
Reclamation	Bureau of Reclamation
ROD	Record of Decision
SNWA	Southern Nevada Water Authority
Study	Colorado River Basin Water Supply and Demand Study
VIC	Variable Infiltration Capacity
Western	Western Area Power Administration

System Reliability Metrics

1.0 Introduction

The *Plan of Study*, (provided in appendix 1 of the Interim Report No. 1 *Status Report),* states that the purpose of the Colorado River Basin Water Supply and Demand Study (Study) is to define current and future imbalances in water supply and demand in the Colorado River Basin (Basin) and the adjacent areas of the seven Colorado River Basin States[1] (Basin States) that receive Colorado River water over the next 50 years, and to develop options and strategies to resolve those imbalances. The Study contains four major phases to accomplish this goal: Water Supply Assessment, Water Demand Assessment, System Reliability Analysis, and Development and Evaluation of Opportunities for Balancing Supply and Demand.

System reliability metrics (metrics) are measures that indicate the ability of the Colorado River system to meet the needs of Basin resources[2] under multiple future conditions. Metrics will be 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 to remedy those imbalances.

This report describes the approach used to develop the system reliability metrics and the set of metrics resulting from implementing that approach. This report was initially published in June 2011 under Interim Report No. 1 and has been since updated to reflect the comments received on Interim Report No. 1, technical developments and the ongoing input of stakeholders.

Substantive changes made to this report since its first publication as part of Interim Report No. 1 are noted below by section.

- Water Deliveries Metrics (Section 4) – Metrics have been added that measure the ability of the system to satisfy tribal water rights. In addition, a metric has been added to measure flows arriving at Morelos Diversion Dam in excess of the 1944Treaty delivery.
- Water Quality Resources Metrics (Section 6) – Metrics have been added to include the measurement of salinity in the Upper Basin and one additional location in the Lower Basin.
- Recreational Resources Metrics (Section 8) – Metrics have been developed and added that incorporate the concept of “boatable days” under the river and whitewater boating attribute of interest.
- Ecological Resources Metrics (Section 9) – Metrics have been developed and added for all attributes of interest. In particular, two new groups of metrics were added to the aquatic and riparian habitat attribute of interest, cottonwood recruitment and flow-

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

[2] 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.

dependent ecological systems. In addition, metrics described in Interim Report No. 1 were and further refined.

Some of the metrics defined may not prove to be informative, or further analysis may identify the need for other metrics. These types of adjustments will be made throughout the Study's System Reliability Analysis phase.

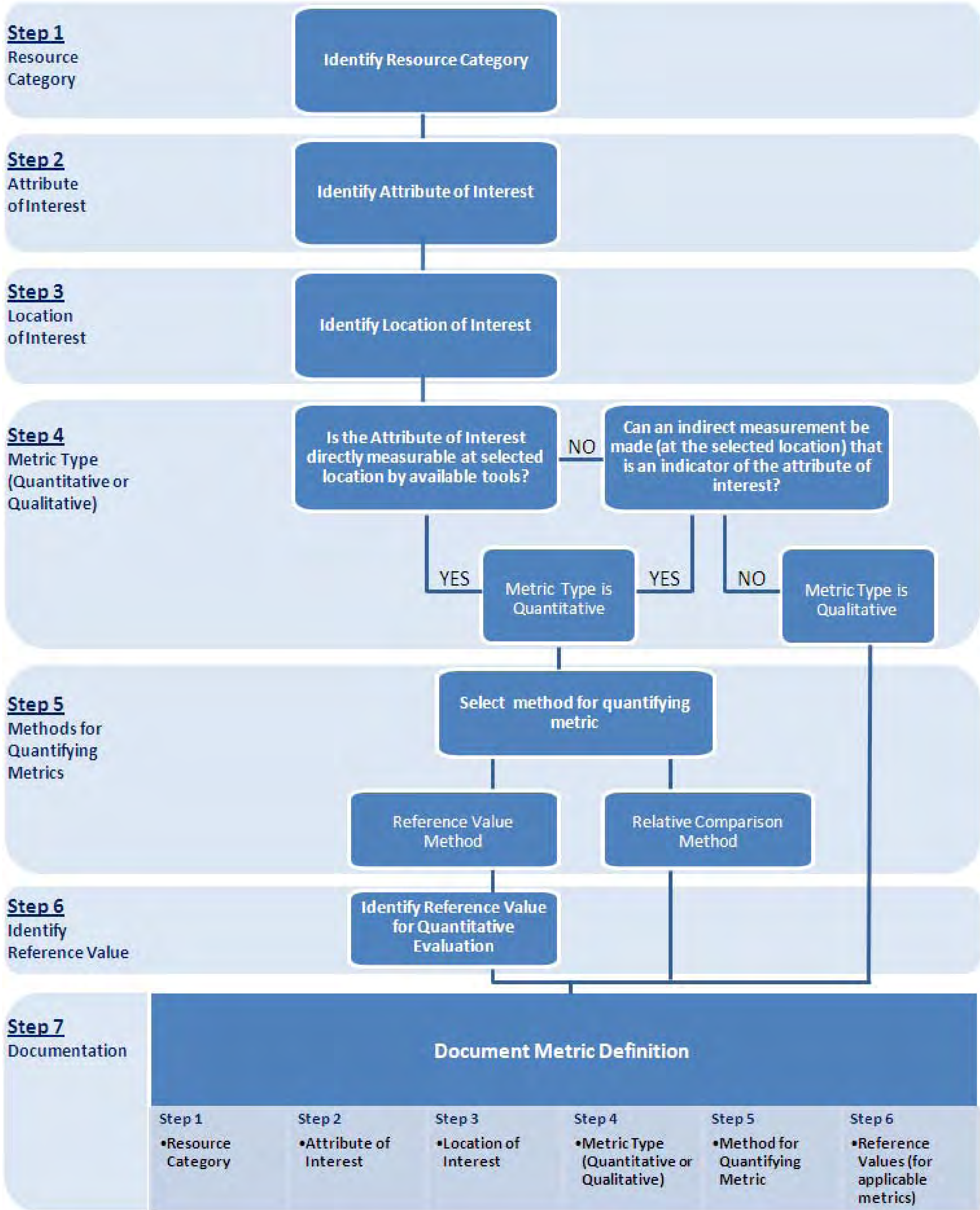
2.0 Approach for Metric Development

Metrics were developed through a collaborative process involving representatives of numerous organizations, including the Bureau of Reclamation (Reclamation), the Basin States, U.S. Fish and Wildlife Service (FWS), National Park Service, Western Area Power Administration (Western), Native American tribes and communities, environmental 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 is a multi-step process, in which each metric presented in this report is 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.

FIGURE D-1
Approach for Metric Development



2.1 Step 1 – Resource Categories

As stated in the *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 Resources
- Flood Control
- Recreational Resources
- Ecological Resources

Socioeconomic impacts are not considered an independent resource category in the Study. Instead, socioeconomic impacts resulting from water supply and demand imbalances are 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

TABLE D-1
Resource Categories and Attributes of Interest

Resource Category	Attribute of Interest
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

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

[2] *Shortage* is unmet demand.
Demand is water needed to meet identified uses.

2.3 Step 3 – Location of Interest

Specific locations were selected where a metric may 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 Basin plus the adjacent areas of the Basin States that receive Colorado River water) may be selected, the spatial and temporal scales of available data (through simulation modeling and other sources) may restrict the locations and/or the analysis that can be performed at a specific location.

The Colorado River Simulation System (CRSS) is the primary modeling tool that will be 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. There are approximately 250 diversions and return flows represented in CRSS in the Basin. 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 in Arizona, and nine below Lees Ferry, Arizona including the Paria River and other inflow points in the Lower Basin).[3]

[3] 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 C5, Modeling of Lower Basin Tributaries in the Colorado River Simulation System*, for more detail.

2.4 Step 4 – Metric Types (Quantitative or Qualitative)

Metrics will be evaluated in either a quantitative or qualitative fashion. A metric will be evaluated quantitatively if: a) direct evaluation is 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 can be developed, based on output from CRSS or post-processing of CRSS output data.

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

Qualitative discussions will vary in detail depending on the level of information available. During the System Reliability Analysis phase of the Study, more information will be available, including model results and results from quantitative analyses. Using this information and other information available from published reports and/or articles, the approach for evaluating each qualitative metric and the level to which a qualitative evaluation can be made will be discussed in future technical updates.

Although several metrics will be 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 is identified as quantitative, the next step is to select a specific method for quantifying that metric. Two methods for quantifying metrics have been 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) informs the assessment of system reliability. The method used to quantify the reference value then defines the method for quantifying the metric. Because the Study is addressing a wide range of Basin resources, no single method for quantifying reference values is applicable to all metrics. Therefore, four different methods for quantifying reference values (and the subsequent metrics) have been defined, as outlined below.

2. Relative Comparison Method: In some cases, an informative reference value may not exist for some attributes of interest. In such cases, the attribute of interest is 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 will be quantified through a comparative analysis between future scenarios.

2.6 Step 6 – Identify Reference Value (if appropriate)

Once the reference value method is selected in step 5, the next step is to select the appropriate reference value. As described below, reference values may 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 may be quantified based on physical constraints in the river system. For example, the elevation of a facility's water intake represents a physical constraint and provides the reference value that can be used to quantify a metric in the Water Deliveries resource category.

2.6.2 Prescribed Condition

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

2.6.3 Estimated Condition

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

2.6.4 Historical Condition

Some metrics may be quantified based on values derived from historical conditions, particularly when it is important to measure the change in the attribute of interest over time. Historical values are based on recorded information, where the period of interest may cover 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 and median hydroelectric generation data over the past 10 years provide reference values that can be used to quantify a metric in the Electrical Power Resources category.

2.7 Step 7 – Documentation

Metric definitions developed by applying steps 1 through 6 (figure D-1) are documented in tabular fashion similar to what is 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 (figure D-1). 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[4] in the Upper Basin and Hoover Dam and the Parker-Davis project in the Lower Basin. In step 4, it was determined that the

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

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 can be 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, two reference values for electrical power generated were selected to be the minimum and median power generation over the previous 10 years, which is an Historical Condition method.

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 cannot 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 is used at several other locations). In step 6, the reference value for prescribed conditions would be the minimum target flows defined by in-stream flow water rights (such as those held by the Colorado Water Conservation Board).

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 at various locations throughout the Basin, particularly where there was a significant economic benefit from recreation. Step 4 determined that this attribute cannot be directly measured and furthermore, an indirect measurement is 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.

3.0 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 points 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 will be 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 [Interior], 2007) through 2026. Beyond 2026, additional modeling assumptions will be made, and the sensitivity of the modeling results to those assumptions will be analyzed. For the Upper Basin, CRSS does not simulate the complex water rights systems in each state that would be 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, additional analysis may be conducted within the System Reliability phase to provide a better estimate of these shortages.

4.1.1 Tribal Water Rights

The ability of the system to satisfy tribal water rights, including tribal Central Arizona Project (CAP) entitlements, will be evaluated where CRSS nodes exist for those tribes and a reference value has been determined. Tribal water rights metrics are quantitative, whose reference values are, for tribes with currently quantified rights, the full amounts of those rights. For tribes without fully quantified rights, the ability to use a reference value and the quantification of that reference value will be determined in coordination with those tribes.

The Southern Ute and Ute Mountain Ute Tribes' demand projections are included in the State of Colorado's demand projections for the San Juan Basin. Their quantified water right entitlements are generally senior to other State of Colorado uses. The ability of the system to satisfy these water rights can be determined based on the ability of the system to satisfy the State of Colorado's proposed demand.

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.

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 are evaluated at locations other than where CRSS demand nodes exist (e.g., reservoir elevations) and have therefore been 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.

CRSS assumes a delivery to Mexico of 1.5 million acre-feet/year with additional deliveries of up to 200,000 acre-feet/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 Shortage EIS.[5] CRSS extends to just south of the Northerly International Boundary (NIB) 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 will be 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 in-stream diversion facilities or reservoir intake structures. Intake structures cannot operate if reservoir water levels are below their respective minimum service elevations. Therefore, the frequency and duration 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 Reservoir was identified as an intake where water level data are critical and will be quantitatively evaluated with a physical constraint of 5,990 feet above mean sea level (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 there are less than 4.5 million acre-feet of water remaining in Lake Mead. Per the 2007 Interim Guidelines, the Secretary of the Interior 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 intake structures in Lake Mead. Currently, 1,000 feet msl is the minimum allowable water level where the intake facilities are still operable. For these reasons, Lake Mead Elevation at 1,000 feet msl will be evaluated quantitatively as a reference value defined by an Estimated Condition. All metrics for the Other Water Deliveries Attribute of Interest are shown in table D-2.

TABLE D-2
Attribute of Interest: Other Water Deliveries

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

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

[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.

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 (FWS, 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 will be 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 and Davis, and Headgate Rock facilities. Metrics have been developed to assess the impact to electrical power generated from these facilities (or an aggregate of) due to their inclusion in CRSS. There are numerous hydropower plants located throughout the Basin. Metrics for these other hydropower facilities will not be developed. However, those 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 here.

Western Area Power Administration (Western) is a power marketing administration responsible for marketing and transmitting electricity from multi-use water projects in the central and western U.S. Western markets power from all Upper Basin power plants as a single power resource, whereas power is marketed separately from each of the hydropower plants in the Lower Basin. Therefore, electrical power generated by Upper Basin facilities is measured by a single aggregate metric. Individual metrics are used to measure electrical power generated at Lower Basin hydropower plants.

Historical hydropower generation conditions at each facility over the previous 10 years were evaluated by Western. Additional reference periods are also under consideration. Hydropower generation in future scenarios will be compared to these historical reference values. 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[3]
Upper Basin Power Plants[1]	Quantitative - Direct	Historical Condition	4,948,780 MWh/yr
Hoover Power Plant			3,426,149 MWh/yr
Parker and Davis Power Plants			1,413,475 MWh/yr
Headgate Rock Power Plant	Quantitative - Indirect[2]		44,207 MWh/yr

NOTES:
[1]Upper Basin power plants include: Fontenelle, Flaming Gorge, Blue Mesa, Morrow Point, Crystal, and Glen Canyon.
[2]Headgate Rock Dam is not explicitly modeled in CRSS. However, because the reservoir behind Headgate Rock Dam is maintained at a relatively constant elevation, an indirect measurement can be made by relating modeled changes in river flows to electrical power generated at the dam.
[3]Reference values are the minimum power generation that occurred during the 10-year reference period of 2000 through 2009 selected by Western.

MWh/yr = Megawatt-hours per year

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 can be used in post-processing analyses to directly calculate economic value. Therefore, the relative difference between the economic value of power produced among scenarios can be evaluated quantitatively using the relative comparison quantification method.

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 will be 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.

TABLE D-4
Attribute of Interest: Available Generation Capacity

Location	Metric Type	Quantitative Method	Reference Value[3] (all values are in MWh/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-Davis			275	213	203	198	224	269	270	317	318	319	318	320
Headgate Rock	Quantitative Indirect[2]		13	11	12	12	13	14	16	7	13	13	15	15

NOTES:
[1]Upper Basin power plants include: Fontenelle, Flaming Gorge, Blue Mesa, Morrow Point, Crystal, and Glen Canyon.
[2]Headgate Rock Dam is not explicitly modeled in CRSS. However, because the reservoir behind Headgate Rock Dam is maintained at a relatively constant elevation, an indirect measurement can be made by relating modeled changes in river flows to available generation capacity at the dam.
[3]Reference values are the minimum available generation capacity that occurred during the selected 10-year reference period of 2000 through 2009.

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 impact power rates, regardless of whether they have firm contract power delivery agreements.

Varying degrees of power generation shortfalls may exist under the various future scenarios to be 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. However, 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 will be included in the Study.

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); the Southern Nevada Water Authority (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 are deemed unnecessary.

Alternatively, wide fluctuations in water levels in Lake Mead and Lake Powell could impact 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, quantitative metrics have been developed for SNWA pumping costs. 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 are 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 may exist under the various future scenarios to be evaluated. Therefore, qualitative metrics will be used to relate power generation shortfalls to increased risk of funding shortfalls.

6.0 Water Quality Resources Metrics

The water quality resources 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 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 million acre-feet 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 have been 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 NIB.

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. Table D-5 summarizes the Basin salinity metrics and the associated quantification methods and reference values.

TABLE D-5
Attribute of Interest: Salinity

Location	Metric Type	Quantification Method	Reference Value[1]
Below Hoover Dam	Quantitative	Prescribed Condition	723 mg/L
Below Parker Dam			747 mg/L
At Imperial Dam			879 mg/L
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			
Colorado River near Grand Canyon, AZ			
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			
Virgin River near Littlefield, AZ			
Green River at Green River, UT			
San Rafael River near Green River, UT	Quantitative	Relative Comparison	Not Applicable
San Juan River near Archuletta, NM			
San Juan River near Bluff, UT			
Colorado River at Lees Ferry, AZ			

NOTES:
[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.

mg/L= milligram(s) per liter

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

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.

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. Potential impacts of sediment transport on the health of aquatic species will be qualitatively addressed with metrics in the Ecological Resources category. Also, the relation between beach formation in reservoirs and within river reaches, and the recreational experience will be 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 will not be quantitatively evaluated in the Study. The importance of water temperature to aquatic species will be addressed qualitatively under the Ecological Resources category.

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 will be 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. Using output from this economic model, economic impacts related to elevated salinity levels may be evaluated quantitatively for some future scenarios.

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 may be provided to complement the quantitative 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 the U.S. Army Corps of Engineers and Reclamation in 1984, as prescribed by the *Water Control Manual* of December 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 million acre-feet 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 can be used to quantify the frequency and magnitude of both flood control releases at Lake Mead and reservoir spills. These metrics will be quantified at Fontenelle, Flaming Gorge, Blue Mesa, Navajo, 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 exist downstream of Lake Mead, Navajo Dam, and the Aspinall Unit. Additional analysis of CRSS output data will be performed to estimate flooding potential, and quantitative metrics using the relative comparison method will be applied at these locations. At other critical river reaches, river operations, and flood control will be evaluated qualitatively.

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-6 summarizes the metrics for shoreline access.

TABLE D-6
Attribute of Interest: Shoreline Public Use Facility Access

Location	Metric Type	Quantitative Method	Reference Value[1] (ft above msl)
Flaming Gorge	Quantitative	Physical Constraint	
Cedar Springs Marina and Firehole Boat Ramps, Sunny Cove Swim Beach			6,018
Antelope Flat, Anvil Draw, Buckboard, Sheep Creek, Squaw Hollow Boat Ramps			6,015
Mustang Ridge and Upper Marsh Creek Boat Ramps			6,011
Lucerne Valley Marina, Kingfisher Island Boat Ramp			6,010
Lucerne Valley Boat Ramp			5,994
Blue Mesa			
Elk Creek Boat Ramp			7,433
Lake Fork Boat Ramp			7,443
Iola Boat Ramp			7,433
Stevens Creek Boat Ramp			7,462
Ponderosa Boat Ramp			7,468
Navajo			
Sims Mesa Boat Ramp			6,000
Pine Boat Ramp			5,997
Arboles Boat Ramp			5,978
Lake Powell			
Rainbow Bridge			3,650
Hite Marina, Hite Public Boat Ramp, Castle Rock Cut			3,620

TABLE D-6
Attribute of Interest: Shoreline Public Use Facility Access

Location	Metric Type	Quantitative Method	Reference Value[1] (ft above msl)
Antelope Point Public Boat Ramp	Quantitative	Physical Constraint	3,588
Bull Frog Boat Ramp			3,580
Wahweap, Stateline, Bull Frog Low Water Alternative, Halls Crossing Ramps			3,560
Wahweap, Antelope Point, Bull Frog, Halls Crossing Marinas			3,555
Lake Mead			
Pearce Bay Boat Ramp and Ferry			1,175
Grand Wash Access			1,170
Las Vegas Bay and Government Wash Boat Ramps			1,150
Overton Beach Marina and South Cove Boat Ramp			1,125
Lake Mead Marina			1,112
Lake Mead, Hemenway, Temple Bar Boat Ramps			1,080
Echo Bay Boat Ramp			1,050

NOTE:
[1]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

There are many different recreational activities that 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, limitations exist 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 impact 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-7, for the Colorado River near Cisco, Utah, the range for an acceptable boating experience is from 1,800 to 100,000 cubic feet/second (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 are included in the Study because the information may provide an understanding of the impacts to river and whitewater boating under the multiple future conditions being 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.

Since 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 “boatable 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 “boatable” days in a month where 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-7 lists the locations at which the metric is 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 are used to determine the number of acceptable and optimal boatable days. The number of boatable days is compared across future scenarios. As such, the utility of the metrics described in this section is primarily to understand the relative comparison of boatable days across a wide range of future scenarios.

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

[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.

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 those 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 will be evaluated in the Study. Appendix D2 lists all the locations surveyed by American Whitewater.

TABLE D-7
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

NOTE:
[1]The Cross Mountain segment is a very technical whitewater boating resource, and is defined by a narrow range of boatable flows, as compared to other segments on the Yampa. Because of the technical and advanced nature of the resource, responses from experienced paddlers are 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 will be 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 will be 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 have been 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 have been 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* 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:

- Threatened and endangered species
- Aquatic and riparian habitats
- Wildlife refuges and fish hatcheries

9.1 Metrics for 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

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[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.

these flow recommendations across various scenarios should not be viewed as solely the ability to recover the species.

The 1996 Glen Canyon Dam ROD 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. – 7:00 p.m. and 5,000 cfs from 7:00 p.m.-7:00 a.m. When coupled with the down ramp restrictions of 1,500 cfs/hour (Reclamation, 1996), the minimum average daily release is constrained to 6,438 cfs. The minimum daily release can be converted to a minimum monthly release for Glen Canyon Dam and used as a reference value.

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 of the Interior 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 which 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 is 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 kaf/ 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-8 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 have 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 result 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.

TABLE D-8
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 et al., 2001)
Gunnison River near Grand Junction, CO			Spring peak volumes ranging from about 347–2,090 thousand acre-feet (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 (Fish and Wildlife Service, 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 (Fish and Wildlife Service, 2008)
Green River near Greendale, UT	Quantitative	Prescribed Condition[1]	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			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 et al., 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 Operations Final EIS (Reclamation, 2006a)
Glen Canyon Dam	Quantitative	Prescribed Condition	Minimum average daily release of 6,438 cfs	Glen Canyon Dam ROD (Reclamation, 1996)

TABLE D-8
Attribute of Interest: Flows to Support Threatened and Endangered Species

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

NOTES:
[1]These flow targets are one component of the Upper Colorado River Endangered Fish Cooperative Agreement between Interior and the States of Colorado, Utah, and Wyoming; and several Programmatic Biological Opinions 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 Programmatic Biological Opinions 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 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.

cfs= cubic feet per second

kaf= thousand acre-feet

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. However, 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. While 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 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.

TABLE D-9
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[1]
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[1]
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[1]
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[1]

[1] See appendix D6 for the detailed approach to this reference value.

9.2.1 Instream Flow Rights

The Colorado Water Conservation Board has secured many in-stream 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 will be compared with the in-stream flow right. Table D-9 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 FWS and The Nature Conservancy (TNC), a metric has been developed that incorporates this concept.

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 is dependent 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-9 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, other locations exist 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

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

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 *(see Interim Report 1 – Technical Report C Appendix C5)* 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-9) consider flow needs only during the base flow period. In coordination with the FWS and The Nature Conservancy, metrics were developed for estimated flow conditions at this location in addition to two other locations in the Yampa River Basin. Table D-9 presents the locations and a summary of the reference values for these metrics, while appendix D6 describes the methodology used to develop the metrics.

The White River near Watson, Utah, is another location with documented flow needs (Haines et al., 2004; Lentsch et al., 2000), though they have not been fully prescribed through a biological opinion. A summary of the estimated flow conditions for the White River near Watson are also presented in table D-9. The full set of estimated flow conditions and the methods to develop those flows for the flow-dependent ecological systems attribute of interest are described in appendix D6.

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 D6) is dependent on assumptions behind the hydrologic year-typing. Acknowledging these limitations, the estimated flow conditions in table D-9 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. As such, the utility of the metrics described in this section is primarily to understand the relative comparison these ecological systems across a wide range of future scenarios.

9.3 Metrics for Wildlife Refuges and Fish Hatcheries Attribute of Interest

Table D-10 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 the FWS. 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 D5.

In the Lower Basin, reference values are based on the wildlife refuges' entitlements and historical use and vary by water demand scenario *(see Interim Report 1 – 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 the FWS.

TABLE D-10
Attribute of Interest: Wildlife Refuges and Fish Hatcheries

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

[1] See appendix D5 for monthly flow conditions that vary by hydrologic year type.

[2] Annual diversion and depletion varies across water demand scenarios (*see Interim Report 1 – Technical Report C Water Demand Assessment*). The lower ends represent the average diversion and depletion from 2005-2009 (4,542 acre-feet diversion for Havasu National Wildlife Refuge [NWR]). The upper end represents the refuge entitlement (37,339 acre-feet diversion for Havasu NWR).

[3] This amount reflects Lake Mead National Recreational Area (NRA) 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 NRA.

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.

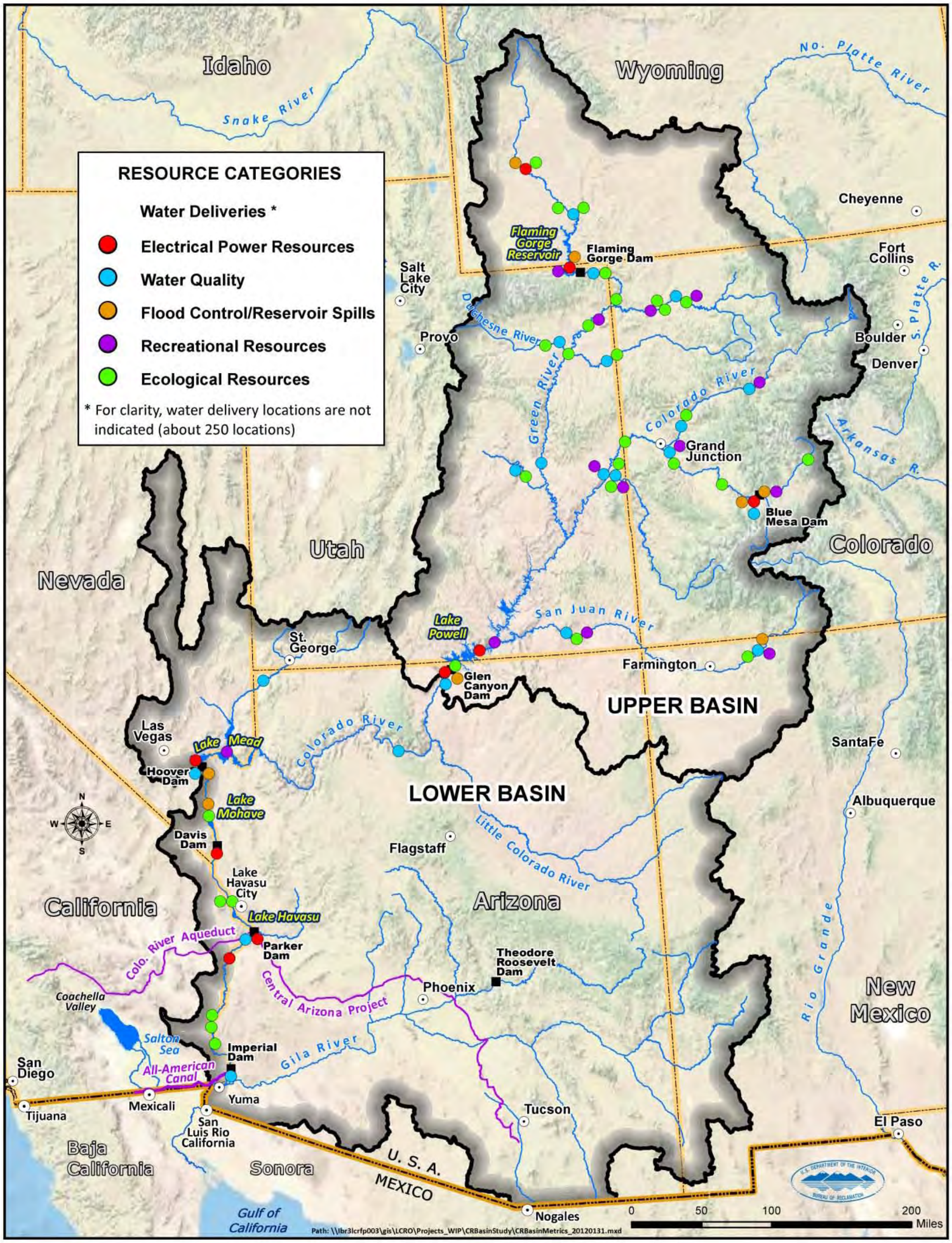
Metrics were developed to assess the impacts to water deliveries, electrical power resources, water quality, flood control, recreational resources, and ecological resources under multiple future conditions. Some metrics use information directly from CRSS (for example, consumptive uses and reservoir releases) while others use indirect measurements using flow to estimate the impact to the resource (for example, aquatic and riparian habitats). Still other metrics, such as socioeconomic impacts, will be 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 will be 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 comprised 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 will indicate whether or not a certain flow condition exists, but does 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.

Every attempt was made to develop appropriate and informative metrics; however, it is possible that some defined metrics may not prove to be informative, or further analysis may identify the need for other metrics. These types of adjustments will be made in the next phase of the Study (System Reliability) and documented in future reports.

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

Nothing in the Study, however, is intended for use against any Basin State, any Native American tribe or community, 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 Native American tribe or community, the Federal Government, or Upper Colorado River Commission as it relates to the law of the river. Furthermore, nothing in this Study is intended to, nor shall this Study be construed so as to, interpret, diminish, or modify the rights of any Basin State, any Native American tribe or community, the Federal Government, or the Upper Colorado River Commission under federal or state law or administrative rule, regulation, or guideline, including without limitation the Colorado River Compact, (45 Stat. 1057), the Upper Colorado River Basin Compact (63 Stat. 31), the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico (Treaty Series 994, 59 Stat. 1219), the United States/Mexico agreement in Minute No. 242 of August 30, 1973, (Treaty Series 7708; 24 UST 1968) or Minute No. 314 of November 26, 2008, or Minute No. 318 of December 17, 2010, the Consolidated Decree entered by the Supreme Court of the United States in Arizona v. California (547 U.S 150 (2006)), the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), the Colorado River Storage Project Act of 1956 (70 Stat. 105; 43 U.S.C. 620), the Colorado River Basin Project Act of 1968 (82 Stat. 885; 43 U.S.C. 1501), the Colorado River Basin Salinity Control Act (88 Stat. 266; 43 U.S.C. 1951), the Hoover Power Plant Act of 1984 (98 Stat. 1333), the Colorado River Floodway Protection Act (100 Stat. 1129; 43 U.S.C. 1600), or the Grand Canyon Protection Act of 1992 (Title XVIII of Public Law 102-575, 106 Stat. 4669). Reclamation and the Basin States continue to recognize the entitlement and right of each State under existing law to use and develop the water of the Colorado River system.[11,12]

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

[12] Reclamation and the Basin States are in the process of modifying this disclaimer based on discussions with Native American tribes and communities.

Appendix D1
Metrics Sub-Team Members

Appendix D1—Metrics Sub-Team Members

The information presented in the *Technical Report D - System Reliability Metrics* is the outcome of a collaborative process involving representatives of numerous organizations.

A list of Metrics Sub-Team members and their affiliations is presented below.

- Carly Jerla, Bureau of Reclamation
- Klint Reedy, Black & Veatch
- Martin Einert, Bureau of Reclamation
- Kara Gillon, Defenders of Wildlife
- Jason John, Navajo Nation
- Jan Matusak, The Metropolitan Water District of Southern California
- Colby Pellegrino, Southern Nevada Water Authority
- John Shields, Wyoming State Engineers Office
- Robert Wigington, The Nature Conservancy
- Alan Butler, Bureau of Reclamation

Points of contact with other organizations that provided additional information are listed below.

- Xavier Gonzalez, Western Area Power Administration
- Sam Loftin, Western Area Power Administration
- David Slick, Salt River Project
- Jack Barnett, Colorado River Basin Salinity Control Forum
- Robert Radtke, Bureau of Reclamation
- Katrina Grantz, Bureau of Reclamation
- Norm Henderson, National Park Service
- Bill Jackson, National Park Service
- Kent Turner, National Park Service
- Janet Bair, U.S. Fish and Wildlife Service
- Andrew Hautzinger, U.S. Fish and Wildlife Service
- Jana Mohrman, U.S. Fish and Wildlife Service
- Tom Chart, U.S. Fish and Wildlife Service
- John Sanderson, The Nature Conservancy
- Mike Roberts, The Nature Conservancy
- Nathan Fey, American Whitewater

Appendix D2
Boatable Days Metrics

Appendix D2—Boatable Days Metrics

1.0 Introduction

This appendix describes the method used to implement the boatable days metric for the river and whitewater boating attribute of interest. Relationships were developed at several Upper Basin locations relating average daily flow to the quality of boating experience. In this context, flow translates to an acceptable, optimal, or other (flows below or above the acceptable thresholds) boating day, depending on the flow magnitude and the survey respondents. The flow-experience relationships (Whittaker et al., 2005) were developed by American Whitewater based on user surveys that asked users to identify flows ranging from totally unacceptable to totally acceptable based on their skill level and craft type. Since the Colorado River System Simulation (CRSS) operates at a monthly time step and the flow-experience relationships are developed based on average daily flows, an additional step is necessary to resolve the time step discrepancy.

Significant uncertainties exist related to the use of approach taken by American Whitewater in the Study as there are several limitations stemming from resource constraints and the Study timeline. Nevertheless, the information resulting from this approach has been included in the Study because it provides a broad view of the impacts to river and whitewater boating under multiple future conditions. However, it is recommended that future efforts carefully consider the limitations and assumptions of this approach if this information is used in future efforts.

The methodology section details the process of performing user surveys and developing flow-experience relationships (section 2.1). Additionally, the procedure that is used to resolve the time step discrepancy between CRSS output and flow-recreation relationships is presented in section 2.2. Section 3 summarizes the results of the user survey procedure. A report developed by American Whitewater describing the User-survey approach and survey results is provided in Attachment A.

2.0 Methodology

2.1 Establish Flow Ranges

To establish flow ranges for survey-based acceptable and optimal recreational opportunities, American Whitewater collected and organized personal evaluations of recreational resource conditions, and recreation-relevant hydrology, consistent with standard methods (Whittaker et al., 2005). An online survey conducted during November and December 2011, involved 382 volunteer paddlers representing a range of experience and skill level. The survey asked respondents to evaluate flows at each location, although few respondents had experience with every segment surveyed.

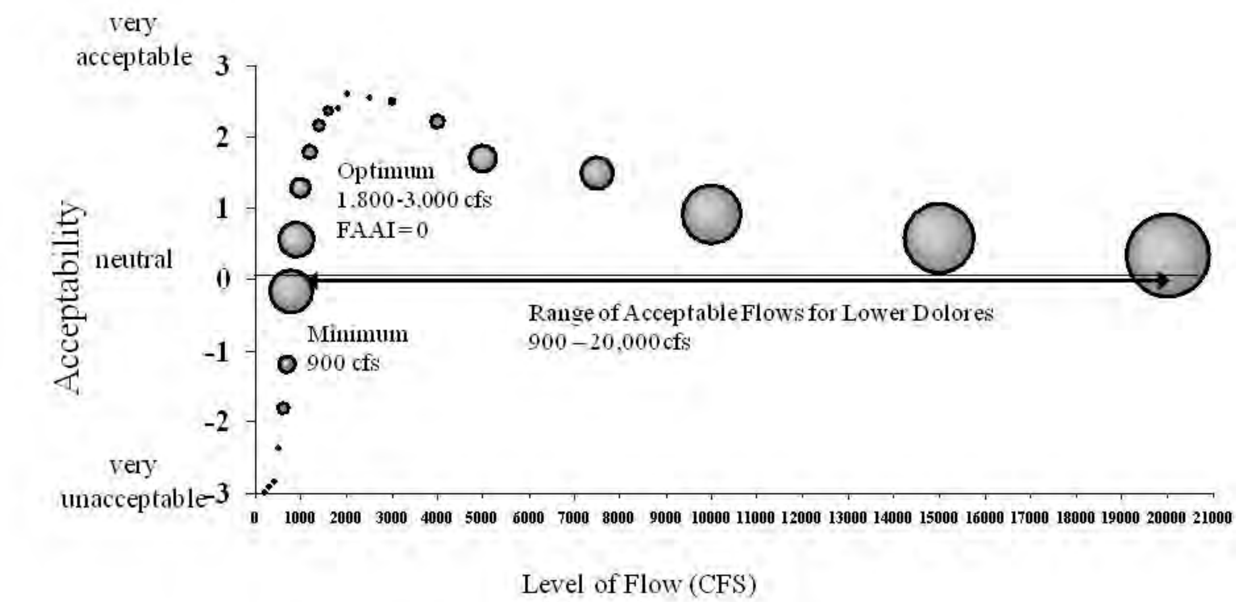
Study respondents were asked to evaluate overall recreation quality for each measured flow at each study segment, using a seven-point “acceptability” scale (ranging from unacceptable -3 to acceptable 3). Using a survey-based normative approach, individual evaluations of flows are aggregated into social norms, which describe the group’s collective evaluation of those same stream flows (Shelby et al., 1996; Whittaker et al., 1993). Structural norm characteristics were used to graphically represent the range of acceptable flows for whitewater boating opportunities.

Mean evaluation for each flow condition is plotted graphically to create the social norm or flow-acceptability curves (see figure D2-1 for an example). These curves are analyzed in terms of certain characteristics, including:

1) Acceptable Flows, the range of flows represented above the neutral line of the curve starting at the minimum acceptable flow

2) Optimal Flows, flows that are represented by the peak of the curve

FIGURE D2-1
Example flow acceptability agreement index curve. The size of symbols represents the variability within the responses *(smaller symbols represent greater relative agreement among respondents).*



Impact Acceptability Curves and the Flow Acceptability Agreement Index (Potential for Conflict Index, or FAAI) were used to help determine minimum acceptable, optimal, and the range of acceptable flows, and respondent agreement regarding the acceptability of each specific flow level. A detailed report on the methods used to determine the flow ranges is included as attachment A.

2.2 Obtaining Boatable Days from CRSS Output

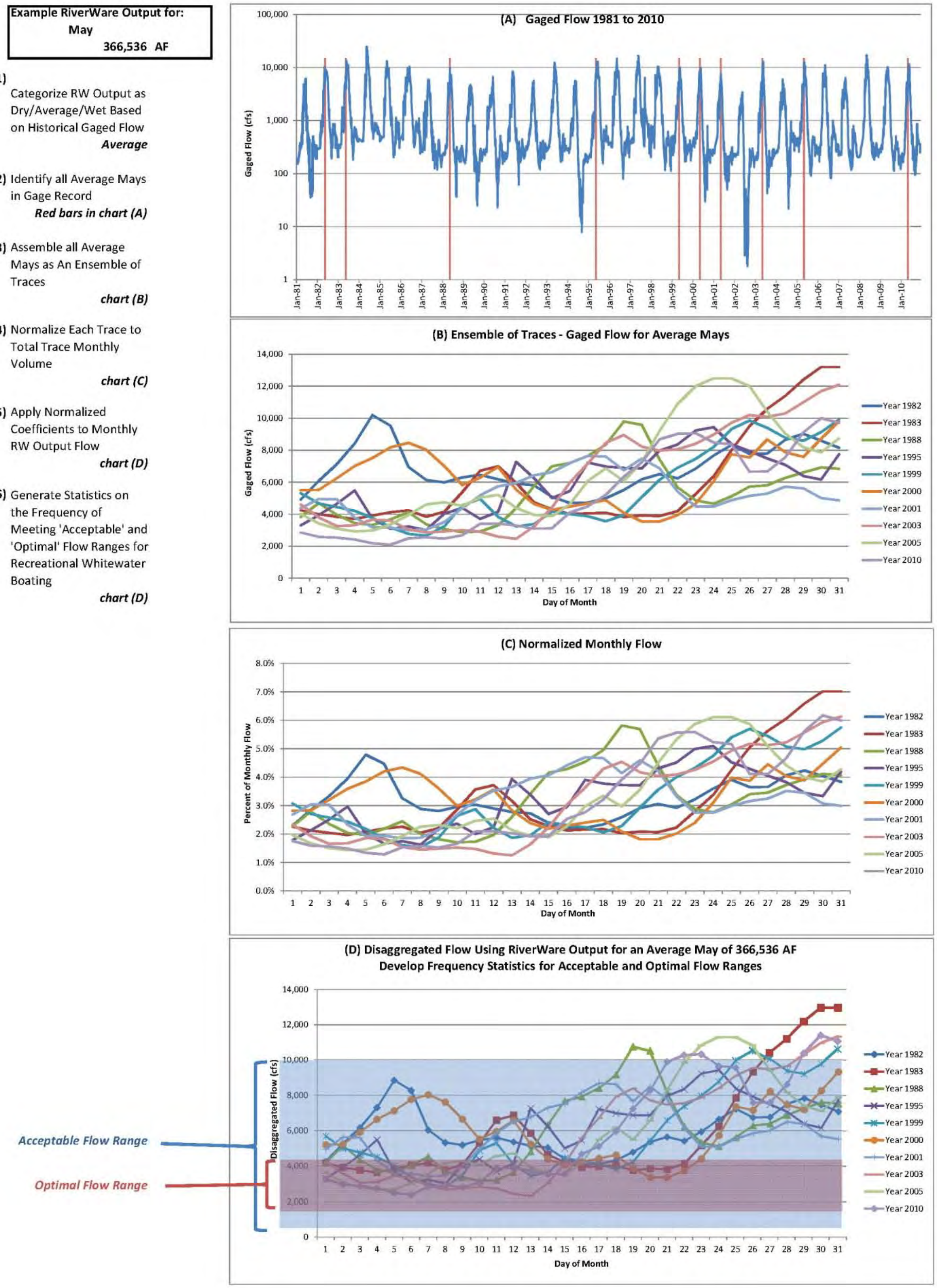
CRSS is operated on a monthly time step with flow outputs reported as average monthly flow or as monthly volumes. However, during the course of a month, the daily flow rates may change considerably and have a significant impact on the recreational whitewater resource. Therefore, the metric requires a temporal disaggregation of modeled monthly flow volumes to daily average flow rates before computing the number of acceptable, optimal, and other boating days in a month. The disaggregated flow rates are then compared to the acceptable and optimal flow ranges for each location to develop statistics on the number of acceptable and optimal boating days in each month.

The daily disaggregation of flow is performed external to the CRSS model using software developed specifically for this metric. The disaggregation technique uses historical patterns of flow variability from observed gage data and applies the variability to the modeled monthly flow volume. Stream gages used to develop the historical patterns were evaluated for significant changes in upstream operations. Gages with significant changes over the past 30 years or that were projected to have significantly different flow patterns in the future (e.g., re-operation of upstream reservoir) were screened from further consideration.

Figure D2-2 shows the overall process of the temporal disaggregation using an example CRSS model output for an average May flow of 366,536 acre-feet. Each month of the past 30 years of gage data at each location was classified as dry, average, or wet months (e.g., driest 10, middle 10, and wettest 10 Mays; figure D2-2A). Hydrologically similar months were combined as an ensemble of traces (i.e., dry July months, wet October months, etc.) with each ensemble containing 10 daily flow patterns (figure D2-2B). Each trace was then normalized by its monthly volume to develop ensemble coefficients that represent the historical pattern of variability (figure D2-2C). The ensembles of coefficients are then applied to the simulated monthly flow to produce an ensemble of plausible daily flows (figure D2-2D). The daily flows patterns are then compared to the desired flow ranges for the specific location to develop statistics on the number of acceptable and optimal boating days in the month.

The boatable days statistics generated from any model scenario can be compared against statistics from other model simulations to assess the relative change in the number of boatable days and assess the effects of the different scenarios on the recreational whitewater resource.

FIGURE D2-2
Example steps for computing number of boatable days from CRSS monthly output.



3.0 Summary

Table D2-1 summarizes the number of respondents for each surveyed location and the acceptable and optimal flow ranges as identified by the user surveys. Locations immediately below Taylor Reservoir and the Aspinall Unit were excluded from the process due to the current representation of the operating logic of these reservoirs in CRSS. The Colorado River near Cameo, Colorado; Colorado River near the Colorado/Utah Stateline, Green River near Green River, Wyoming; White River near Watson, Utah; Gunnison River near Grand Junction, Colorado; and the Green River at Green River, Utah were not included as metrics because there was not adequate user response to the surveys at these locations. Whittaker et al., 1993 recommends approximately 30 respondents for statistical significance. For all other locations, high levels of agreement on optimal flows were recorded and minimum acceptable flows were identified for each segment by the respondents. For many segments, respondents reported no maximum acceptable flow, defining a wide range of acceptable flows, up to 100,000 cubic feet/second (cfs) for certain high volume runs.

The boatable days metric makes it possible to quantify the relative trade-offs among recreation opportunities and between recreation and other resources during the System Reliability Analysis. 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 boatable days in a month where the utility is in the relative comparison of the metric between scenarios.

TABLE D2-1
Summary of the surveyed locations, respondent numbers, and acceptable and optimal flow ranges.

Attribute Location	Whitewater Boating Resource	Acceptable Flow Range (cfs)	Optimal Flow Range (cfs)	Respondent Numbers
Colorado River at Glenwood Springs, CO	GW Playpark South Canyon	1,600-50,000	7,000-20,000	42 Responses – 328 Skipped
Colorado River near Cameo, CO	Big Sur	20,000-50,000	27,500-50,000	26 Responses – 364 Skipped
Colorado River near CO/UT Stateline	Ruby-Horsethief Westwater	n/a	n/a	No data
Gunnison River near Grand Junction, CO	Lower Gunnison Dominguez-Escalante	900-15,000	2,000-12,500	7 Responses – 383 Skipped
Dolores River near Cisco, UT	Lower Dolores	900-20,000	1,800-3,000	48 Responses – 342 Skipped
Colorado River near Cisco, UT	Hittle Bottom Moab Daily	1,800-100,000	4,000-15,000	35 Responses – 355 Skipped
Green River near Green River, WY	Green River Whitewater park	n/a	n/a	6 Responses – 384 Skipped
Green River near Greendale, UT	Lodore Canyon	1,000-12,000	2,000-8,000	93 Responses - 199 Skipped
Yampa River near Maybell, CO	Little Yampa Canyon Cross Mountain Canyon	800-10,000	1,700-4,500	22 Responses - 270 Skipped 51 Responses - 241 Skipped
Yampa River at Deerlodge Park, CO	Yampa Canyon	1,500-20,000	5,000-15,000	102 Responses - 190 Skipped
Green River at Jensen, UT	Split Mountain Canyon	1,200-50,000	2,500-25,000	32 Responses - 358 Skipped
White River near Watson, UT	Lower White	n/a	n/a	2 Responses – 388 Skipped
Green River at Green River, UT	Gray, Desolation, Labyrinth & Stillwater Canyons	1,600-50,000	3,000-20,000	26 Responses – 364 Skipped
San Juan River near Bluff, UT	Lower San Juan	800-50,000	1,400-7,500	37 Responses – 353 Skipped

4.0 References

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Appendix D2

Attachment A
American Whitewater Draft Report

DRAFT SUMMARY REPORT

Evaluating Recreational Flow-Needs in the Upper Colorado River Basin

Defining Low, Acceptable, and Optimal Flows for Whitewater Boating

Nathan Fey
American Whitewater

Evan Stafford
CK Consulting

Abstract:

Effects of in-stream flows on river-based recreational attributes, such as whitewater boating, have profound impacts on recreation opportunities. In many watersheds, streamflows necessary to provide the full range of whitewater boating opportunities are often not clearly defined - presenting a challenge to resource managers seeking to balance water supply and demand strategies. In this study, an online survey was designed and conducted to allow whitewater enthusiasts to evaluate flows for whitewater boating on rivers within the Upper Colorado River basin, and identify low, acceptable and optimum flows for 10 targeted river segments. Flow Acceptability Agreement Index curves summarizes the quality of boating opportunities for each measured stream-flow. Respondents also reported flows that provide certain recreation experiences, from technical low water to challenging high water trips. American Whitewater conducted this study to provide information on flows needed to sustain the whitewater boating resource in the Upper Colorado River basin. This information is being reported with the express intent of developing a quantitative metric for evaluating impacts to existing recreational flow-needs under various management opportunities currently being investigated under the US Bureau of Reclamation's Colorado River Basin Study.

Contents

I. Introduction

Whitewater boating is a flow dependent recreational use of rivers, and considerable work evaluating flow-recreation relationships has occurred over the last several decades (Brown et al., 1991; Shelby, Brown, & Taylor, 1992; Whittaker and Shelby, 2002). Many of the flow-recreation studies focus on whitewater boating, such as rafting, kayaking, and canoeing, as flow often determines whether people have opportunities to take a trip and what level of challenge or social value is provided (Whittaker & Shelby, 2000). Different flow levels provide for varied whitewater boating opportunities. As flows increase from zero, different paddling opportunities and challenges exist within ranges of flows on a spectrum: too low, minimal acceptable, technical, optimal, high challenge, and too high. Standard methodologies are used to define these flow ranges based on individual and group flow-evaluations. The various opportunities provided by different flow ranges are described as occurring in "niches" (Shelby et al., 1997).

Whitewater Boating is enjoyed in different crafts, such as canoes, kayaks, and rafts. Different craft types provide different opportunities for river-based recreation, from individual or small group trips, to large group multi-day excursions. Flows that provide greater social value for one type of craft, such as canoes, may not provide equivalent social value for rafting. Changes in streamflow can have direct effects on the quality of whitewater boating, for every craft type. Direct effects may change quickly as flows change, such as safety in running rapids, number of boat groundings, travel times, quality of rapids, and beach and camp access (Brown, Taylor, & Shelby, 1991; Whittaker et al., 1993; Whittaker & Shelby, 2002). Indirectly, flow effect wildlife viewing, scenery, fish habitat, and riparian vegetation over the long term as a result of changes in flow regime (Bovee, 1996; Richter et al., 1997; Jackson & Beschta, 1992; Hill et al., 1991).

Streamflow is often manipulated through controlled reservoir releases, unanticipated spills from dams, and in-channel diversions. Additional scenarios, such as climate change and drought, water rights development, or conservation and the associated decreases in water demands, can all impact flows and recreation quality. Decision-makers within land and resource management and regulatory agencies, are increasingly interested in assessing the impacts of flow regimes on recreation resources. This has been most notable in the Federal Energy Regulatory Commission's (FERC) relicensing process, and where decision-makers, resource managers, and interest groups consider the extent that flow regimes can be managed to provide desirable recreational resource conditions. Appendix C lists a subset of projects where Whitewater Boating Flows have been analyzed. In these decision-making settings, specific evaluative information on how flow affects recreation quality is critical, particularly where social values are often central to decision-making (Kennedy and Thomas 1995).

Researchers collecting and organizing evaluative information, often employ a normative approach using survey-based techniques. This approach is particularly useful for developing thresholds, or standards, that define low, acceptable, and optimal resource conditions for whitewater boating. Thresholds are crucial elements in any effective management or decision-making process (Shelby et al. 1992). The approach examines individuals' evaluations of a range of conditions (personal norms). Social Norms, defined by aggregate personal norms, describe a group's collective evaluation of resource conditions. This approach has been used to understand streamflows for whitewater boating on the Grand Canyon (Shelby et al. 1992), as well as several others rivers in Colorado (Vandas et al. 1990, Shelby & Whittaker 1995, Fey & Stafford 2009, Fey & Stafford 2010).

American Whitewater designed and conducted this study to collect evaluative information on whitewater boating attributes for 10-targeted recreational resources in the Colorado River Basin. Using overall flow-evaluation data, we developed flow-evaluation curves that identify low, acceptable, and optimum flows for whitewater boating. In addition, specific flow evaluations were collected to aid in "calibrating" points along each curve. The present paper integrates both types of information in order to assist the Protect the Flows Campaign and the U.S. Bureau of Reclamation, in the development of quantitative recreational System Reliability Metrics that can be implemented in the Colorado River Basin Study.

II. Recreational Flow Assessment – Locations and Methods

To define normative standards for whitewater boating flows in the Upper Colorado River basin, American Whitewater collected and organized personal evaluations of recreational resource conditions, and recreation-relevant hydrology, consistent with NPS methodologies[1]. Using a web-based survey tool[2], American Whitewater designed two sets of questions asking respondents to evaluate flows for ten rivers, relative to specific U.S. Geological Survey streamflow gage locations and Colorado River Simulation System Nodes.

Table A: Recreational Whitewater Attribute Locations

Whitewater Resource Location	USGS Gage	Whitewater Boating Attribute
Colorado River At Glenwood Springs	9072500	Glenwood Springs Playpark & South Canyon
Colorado River Near Cameo – CO	9095500	Big Sur
Gunnison River Near Grand Junction	9152500	Lower Gunnison (Dominguez-Escalante)
Dolores River Near Cisco - UT	9180000	Lower Dolores River
Colorado River Near Cisco – UT	9180500	Hittle Bottom & Moab Daily
Green River Near Green River - WY	9217000	Green River Whitewater Park
Green River at Jensen – UT	9261000	Split Mountain Canyon
White River Near Watson – UT	9306500	Lower White River
Green River At Green River – UT	9315000	Desolation-Gray, Labyrinth & Stillwater Canyons
San Juan River Near Bluff - UT	9379500	Lower San Juan

An online approach to the flow comparison survey was used in this study for several reasons:
- The study timeframe was too short to use other approaches, such as mail-in surveys or in-person ballots.
- Many whitewater boaters that have taken trips on these target rivers hail from around the United States. An online approach makes it easier to access this knowledge base.
- Electronic announcements and links to the survey website facilitate broader participation and higher respondent numbers.

The Flow-Evaluation Survey was based on the normative approach discussed above. One set of survey questions was used to develop overall flow-evaluations curves, and another set of questions helped identify and explain various points on those same curves. Overall Flow evaluation questions asked respondents to evaluate overall recreation quality for specific measured flows on each study segment, using a seven-point "acceptability" scale (unacceptable -3 and acceptable 3). This type of Survey contrasts with surveys that evaluate a single flow, or surveys conducted while flows are manipulated by controlled releases over a short period of time (Whittaker et al. 1993).

Another set of six specific flow evaluation questions asked respondents to report: 1) the minimum whitewater flow, 2) lowest preferred whitewater flow, 3) technical whitewater flow, 4) optimal whitewater flow, 5) high whitewater flow, and 6) highest safe whitewater flow. Each respondent reported flows with respect to their preferred craft-type. A copy of the online Flow-

[1] Whittaker, D., B. Shelby, J. Gangemi. 2005. Flows and Recreation, A guide to studies for river professionals. US Department of Interior, National Park Service, Anchorage, AK

[2] www.surveymonkey.com

Evaluation Survey, including both sets of questions, is attached as Appendix A.

An announcement of the flow-evaluation study was sent to over 5,000 American Whitewater members, including a link to the online survey website. The announcement was also posted to several online river-related discussion forums and various regional paddling club websites. The online format allowed whitewater boaters of all skill-levels and craft-types to report personal evaluations. The survey sample included outfitters currently permitted to operate commercially on targeted rivers, and non-commercial boaters. Because there were few differences between these groups, the data was combined in the analysis.

In all, 382 volunteer paddlers responded to the survey, although very few respondents had experience with every segment in the study. Table B summarizes the number of survey responses for each study segment. For this study, 93% of respondents identified themselves as private paddlers, 78% of respondents identified themselves as advanced or expert paddlers, and 73% reported paddling at least 20+ days per season. A wide-range of craft types was surveyed, with rafters (23%), kayakers (72%), canoeists (5%) all represented.

Most respondents (42%) reported living in six Colorado basin states, such as Wyoming, Colorado, Utah, New Mexico, Arizona, and Nevada, though paddlers from 38 states participated in the survey. 65% of respondents felt “very comfortable” estimating flows in cfs (cubic feet per second) on targeted river segments, while no respondents reported feeling “uncomfortable” or even “somewhat uncomfortable” estimating flows on their favorite stretch.

Table B:
Recreational Whitewater Attribute Locations and Respondent Numbers

Whitewater Boating Location	USGS Gage	Whitewater Boating Attribute	Respondent Numbers
Colorado River At Glenwood Springs	9072500	Glenwood Springs - South Canyon	42 Responses
Colorado River Near Cameo	9095500	Colorado River - Big Sur	26 Responses
Gunnison River Near Grand Junction	9152500	Lower Gunnison Dominguez-Escalante	7 Responses
Dolores River Near Cisco	9180000	Lower Dolores	48 Responses
Colorado River Near Cisco	9180500	Hittle Bottom- Moab Daily	35 Responses
Green River Near Green River WY	9217000	Green River Whitewater Park	6 Responses
Green River at Jensen	9261000	Split Mountain Canyon	32 Responses
White River Near Watson	9306500	Lower White	2 Responses
Green River At Green River UT	9315000	Desolation-Gray, Labyrinth & Stillwater Canyons	26 Responses
San Juan River Near Bluff	9379500	Lower San Juan	37 Responses

For most segments studied, responses provided sufficient information to proceed with data analysis and organization. For both the Green River Whitewater Park, and Lower White River Attributes, not enough information was provided to develop FAAI curves. While responses for the Lower Gunnison River were less than 10 in aggregate, most evaluations show a high level of agreement, and supported flow-curve development.

III. Results and Discussion

A. Overall Flow Evaluations

Mean responses from the overall flow evaluation questions were plotted for each flow level, and connected to create a curve. In most cases, the curves show inverted U shapes where low flows and high flows provide low quality recreation conditions, while medium flows provide more optimal conditions. Utilizing Flow Acceptability Agreement Index (FAAI) curves, the range of acceptable and optimal flows for whitewater boating were identified for most segments. Table B summarizes overall flow-evaluations for whitewater boating, including all craft-types.

Table C: *Acceptable and Optimal Flows for Whitewater Boating*

Whitewater Boating Attribute	Minimum Flow (cfs)	Optimal Flows (cfs)	Acceptable Flows (cfs)
Glenwood Springs Playpark & South Canyon	1600	7,000-20,000	1,600-50,000
Big Sur	20,000	27,500-50,000	20,000-50,000
Lower Gunnison (Dominguez-Escalante)	900	2,000-12,500	900-15,000
Lower Dolores River	900	1,800-3,000	900-20,000
Hittle Bottom & Moab Daily	1800	4,000-15,000	1,800-100,000
Green River Whitewater Park		Insufficient data	
Split Mountain Canyon	1200	2,500-25,000	1,200-50,000
Lower White River		Insufficient data	
Desolation-Gray, Labyrinth & Stillwater Canyons	1600	3,000-20,000	1,600-50,000
Lower San Juan	800	1,400-7,500	800-50,000

For two study reaches (Green River Whitewater Park (WY), and Lower White River (UT)), response numbers were too low and did not provide sufficient data for curve development. For all other study segments, where evaluations of higher flows never drop below the neutral line, recreation quality may decline but may not drop below acceptable levels. Open response questions, discussed in Section B, were used to help identify flows that provide minimum, optimal, and high acceptable flows for each segment.

The Flow Acceptability Agreement Index determines respondent agreement regarding the acceptability of each specific flow level (Figures and Tables 1-8, Appendix B). FAAI statistics show extremely high agreement levels for optimal flows (FAAI statistics range between 0 complete agreement, to 1 complete disagreement) while some level of disagreement between respondents exists in regard to the range of acceptable flows. The level of disagreement can be attributed to variability between craft types, although other factors likely play a role including preferred experience and skill levels of respondents. Results show that for most study segments, acceptable flows for kayaks may not provide equal value for rafts.

Table D lists acceptable and optimal flows for both rafts and kayaks to illustrate the variability by craft-type.

Table D
Colorado River Basin Segments FAAI Summary
Minimum, Optimal and Acceptable Flows by Craft-Types

Colorado River Basin Segment		Minimum Flow (CFS)	Optimal Flows (CFS)	Acceptable Flow (CFS)
Glenwood Park & South Canyon	Raft	1000	2800-16000	1000-25000
	Kayak	1600	12000-25000	1600-50000
Big Sur	Raft	NA	NA	NA
	Kayak	20000	25000-50000	20000-50000
Lower Gunnison	Raft	800	2000-12500	800-20000
	Kayak	NA	NA	NA
Lower Dolores	Raft	1000	2000-4000	1000-20000
	Kayak	800	1400-2500	800-20000
Moab Daily	Raft	1800	5000-40000	1800-100000
	Kayak	1800	5000-20000	1800-100000
Split Mountain	Raft	1200	4000-25000	1200-50000
	Kayak	1000	2000-20000	1000-50000
Desolation/Gray	Raft	1600	5000-20000	1600-50000
	Kayak	1400	4000-30000	1400-50000
Lower San Juan	Raft	1000	2000-7500	1000-20000
	Kayak	800	1800-1000	800-20000

For most study segments, respondents reported flows for both rafts and kayaks. Results show that for most segments, kayaks identify lower flows as more acceptable than similar flows for rafts. These results are typical for smaller craft-types where lower flows are sufficient for acceptable whitewater boating opportunities, while low flows do not provide enough flow for larger crafts, like rafts. Results for Glenwood Whitewater Park and South Canyon do not show similar results between craft types. Empirical data describe kayak evaluations as targeting key experiences at the Glenwood Wave, while rafting flows were evaluated for a longer downriver experience, where lower flows are sufficient for floating through South Canyon.

B. Specific Flow Evaluation

In order to further refine the overall flow-evaluation curves, a second set of single-flow evaluations were presented to survey respondents. For each study segment, survey respondents reported a single flow value that provides a distinct paddling experience or “niche” along a spectrum: minimum, low, technical, optimal, high challenge, and highest safe flow. These “niches” relate stream flow to the full range of whitewater boating opportunities and aid in refining the flow-recreation relationship described in each Flow-Curve. Overlaying the specific and overall flow-evaluation results is a helpful approach to analyzing the results of specific flow-evaluations.

With single preference norms reported as specific flow evaluations, measures of central tendency, such as the mean and median, are useful representations of the flow in question. Median flow evaluations for each study segment are described in Table E. For comparison, mean flow evaluations are summarized in Table F.

Table E

MEDIAN Minimum, Low, Technical, Optimal, High and Maximum Flows

Whitewater Boating Attribute	Minimum Flow (CFS)	Low Flow (CFS)	Technical Flow (CFS)	Optimal Flow (CFS)	High Flow (CFS)	Maximum Flow CFS)
1) Glenwood Springs & South Canyon	1000	2000	1500	4000	20000	30000
2) Big Sur	20000	20000	20000	22000	30000	30000
3) Lower Gunnison (Dominguez-Escalante)	700	900	800	3000	9000	15000
4) Lower Dolores River	700	1000	800	1500	3500	5000
5) Hittle Bottom & Moab Daily	1200	2000	1600	4000	20000	40000
- Green River Whitewater Park	-	-	-	-	-	-
6) Split Mountain Canyon	900	1300	1100	3000	20000	30000
- Lower White River	-	-	-	-	-	-
7) Desolation-Gray, Labyrinth & Stillwater Canyons	1200	2200	1100	5000	20000	35000
8) Lower San Juan	650	1000	900	2000	7000	20000

Table F

MEAN Minimum, Low, Technical, Optimal, High and Maximum Flows

Whitewater Boating Attribute	Minimum Flow (CFS)	Low Flow (CFS)	Technical Flow (CFS)	Optimal Flow (CFS)	High Flow (CFS)	Maximum Flow CFS)
1) Glenwood Springs & South Canyon	2281	3412	2502	6009	17624	29175
2) Big Sur						
3) Lower Gunnison (Dominguez-Escalante)	686	1286	1083	2743	9167	14833
4) Lower Dolores River	783	1048	847	1549	3978	6788
5) Hittle Bottom & Moab Daily	1379	2588	2029	5372	23933	42306
- Green River Whitewater Park	-	-	-	-	-	-
6) Split Mountain Canyon	1053	1745	1346	3843	14603	19089
- Lower White River	-	-	-	-	-	-
7) Desolation-Gray, Labyrinth & Stillwater Canyons	1354	2757	1633	6631	20857	38181
8) Lower San Juan	709	1070	930	2594	8050	15432

Note: mean flow-values have been rounded to the nearest whole number.

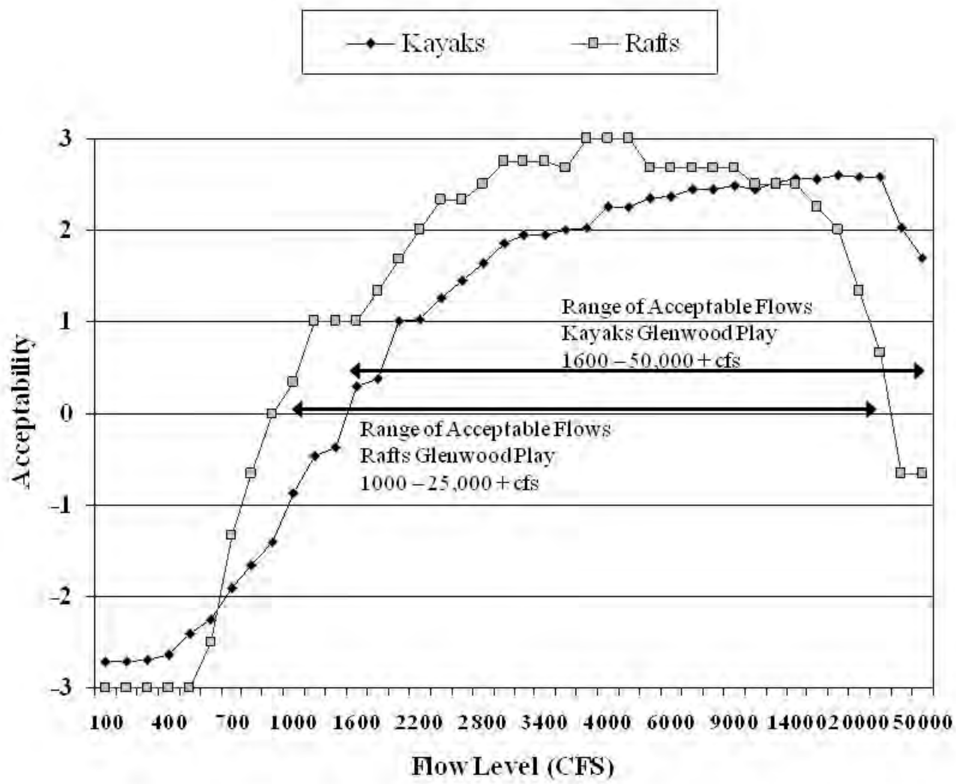
C. Discussion

For most segments, single-flow evaluations are shown to closely mimic relative values identified by the FAAI curves for minimum acceptable, optimal, and maximum acceptable flows. While differences between mean and median flow evaluations for open-ended responses have been established, these values help describe specific flow-dependant “niches” for whitewater boating experiences along each FAAI curve. For the Green River Whitewater Park and Lower White River attributes, insufficient data provided during the study period precluded analysis of FAAI curves, and did not provide enough data to analyze specific flow-evaluations for those attributes.

Overlaying the specific and overall flow-evaluation results is a helpful approach to analyzing the results of the study. An example of this integration, using the Glenwood Springs and South Canyon Attribute is provided in Figure A. Following along the curves for both kayaks and rafts, the mean flow identified for minimum whitewater boating, for both craft-types is 1000 cfs (average of both flow-curves). This is close to the point on the overall flow-evaluation curve (Figure 1, Appendix B) where the neutral line between un-acceptable and acceptable valuation is crossed. Integrating results from both overall and specific flow-evaluation questions provides more information than either format by itself. For more on integrating the results from Overall and Specific Flow Evaluations, refer to the Final Report of our Flow-Evaluation Study.

Figure A

Flow Acceptability Curves for Kayaks and Rafts - Glenwood Wave and South Canyon



IV. Conclusion

To establish flow ranges for acceptable and optimal recreational opportunities, American Whitewater collected and organized personal evaluations of recreational resource conditions, and recreation-relevant hydrology, consistent with standard methodologies. An online survey conducted in 2011, involved 382 volunteer paddlers representing a range of experience and skill level.

Study respondents were asked to evaluate overall recreation quality for each measured flow at each study segment, using a seven-point “acceptability” scale. Using a survey-based normative approach, individual evaluations of flows are aggregated into social norms, which describe the group’s collective evaluation of those same stream flows. Impact Acceptability Curves and the Flow Acceptability Agreement Index were used to help determine minimum, optimal and the range of acceptable flows, and respondent agreement regarding each specific flow level. For each of the river segments surveyed, high levels of agreement on optimal flows were recorded. Minimum acceptable flows were identified for each segment. For many segments, respondents reported no maximum acceptable flow; defining a wide range of acceptable flows, up to 100,000 cfs for certain high volume runs.

Good whitewater conditions require higher flows than those identified as providing minimum boatable flows. Good whitewater conditions for each target river segment have been identified in this study. For each study segment, the median response for minimum whitewater corresponds to the point where the overall flow-evaluation crosses the neutral line. The median response for optimal flows however corresponds with the peak of the curve where ratings are highest. Overall Flow-evaluation curves are relatively flat at the top of most segments, which is attributed to the multiple tolerance norms captured in the study results.

Whitewater flow-preferences described in this summary report make it possible to analyze and evaluate the impacts to whitewater boating under future water supply scenarios being developed under the U.S. Bureau of Reclamation's Colorado River Basin Study. A quantitative metric of "boatable days" can be developed using the reported flow-evaluations from this study. This metric can aid in developing a relative comparison (boatable days) to quantify effects of flow manipulation under various scenarios for future supply and demand scenarios in the Colorado River basin.

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Appendix A- Online Flow-Evaluation Survey

Appendix A presented screen shots of the online flow-evaluation surveys. To save paper, the screen shots have not been reprinted. The survey can be viewed online at http://www.americanwhitewater.org/content/Article/view/articleid/31219/.

Appendix B – Overall Flow Evaluation Results

Figure 1

Flow Acceptability Agreement Index Curve for Glenwood Springs and South Canyon
(Flows represented are at the USGS Colorado River At Glenwood Springs, CO*)*

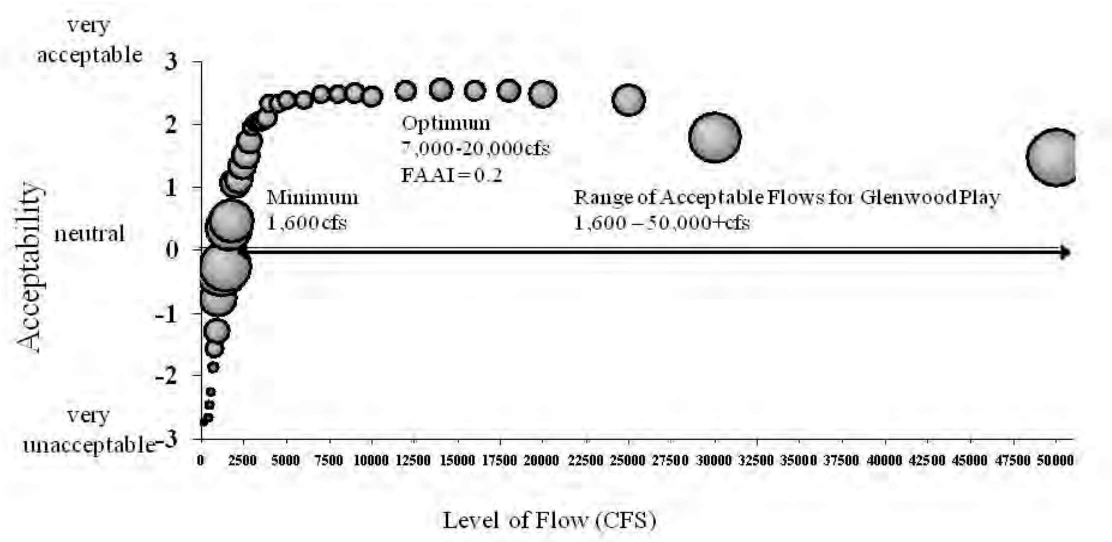


Table 1

Glenwood Springs and South Canyon

Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-2.74	0.06
200	-2.74	0.06
300	-2.71	0.06
400	-2.66	0.08
500	-2.46	0.08
600	-2.26	0.08
700	-1.86	0.11
800	-1.56	0.20
900	-1.29	0.27
1000	-0.77	0.38
1200	-0.34	0.53
1400	-0.26	0.55
1600	0.35	0.50
1800	0.46	0.46
2000	1.06	0.31
2200	1.12	0.30
2400	1.35	0.29
2600	1.51	0.30
2800	1.73	0.27
3000	1.95	0.19
3200	2.03	0.19
3400	2.03	0.19
3600	2.06	0.21
3800	2.11	0.21
4000	2.32	0.18
4500	2.32	0.19
5000	2.38	0.18
6000	2.39	0.19
7000	2.47	0.19
8000	2.47	0.19
9000	2.5	0.20
10000	2.45	0.22
12000	2.53	0.23
14000	2.55	0.24
16000	2.53	0.23
18000	2.53	0.25
20000	2.47	0.29
25000	2.39	0.33
30000	1.78	0.54
50000	1.47	0.61

Figure 2

Flow Acceptability Agreement Index Curve for Big Sur

(Flows represented are flow levels at USGS Colorado River near Cameo, CO*)*

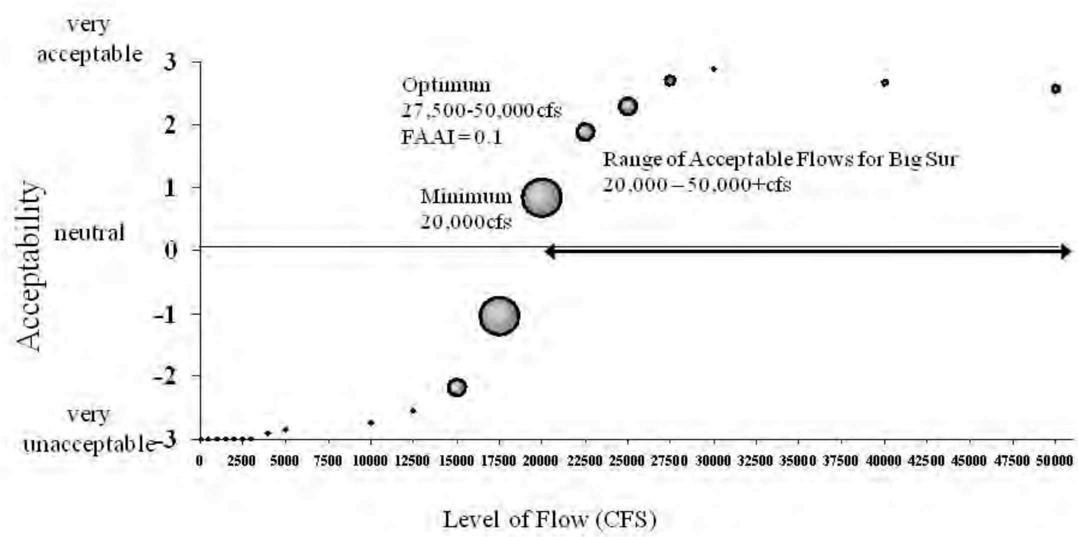


Table 2

Big Sur Mean Acceptability Scores and

Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
500	-3	0.00
1000	-3	0.00
1500	-3	0.00
2000	-3	0.00
2500	-3	0.00
3000	-3	0.00
4000	-2.91	0.00
5000	-2.86	0.00
10000	-2.73	0.00
12500	-2.55	0.03
15000	-2.18	0.18
17500	-1.04	0.41
20000	0.83	0.42
22500	1.88	0.19
25000	2.29	0.18
27500	2.71	0.11
30000	2.88	0.04
40000	2.67	0.06
50000	2.57	0.08

Figure 3

Flow Acceptability Agreement Index Curve for Lower Gunnison

(Flows represented are at the USGS Gunnison River Near Grand Junction, CO*)*

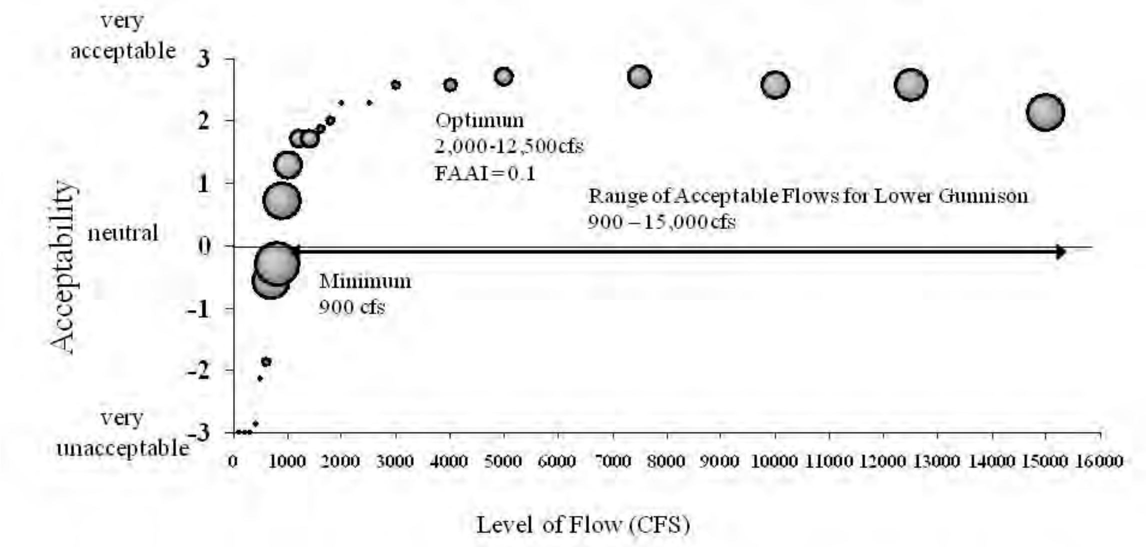


Table 3

Lower Gunnison

Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
200	-3	0.00
300	-3	0.00
400	-2.86	0.00
500	-2.14	0.00
600	-1.86	0.10
700	-0.57	0.38
800	-0.29	0.48
900	0.71	0.38
1000	1.29	0.29
1200	1.71	0.19
1400	1.71	0.19
1600	1.86	0.10
1800	2	0.10
2000	2.29	0.00
2500	2.29	0.05
3000	2.57	0.10
4000	2.57	0.14
5000	2.71	0.19
7500	2.71	0.24
10000	2.57	0.29
12500	2.57	0.33
15000	2.14	0.38

Figure 4

Flow Acceptability Agreement Index Curve for Lower Dolores (Flows represented are flow levels at the USGS Dolores River Near Cisco, CO*)*

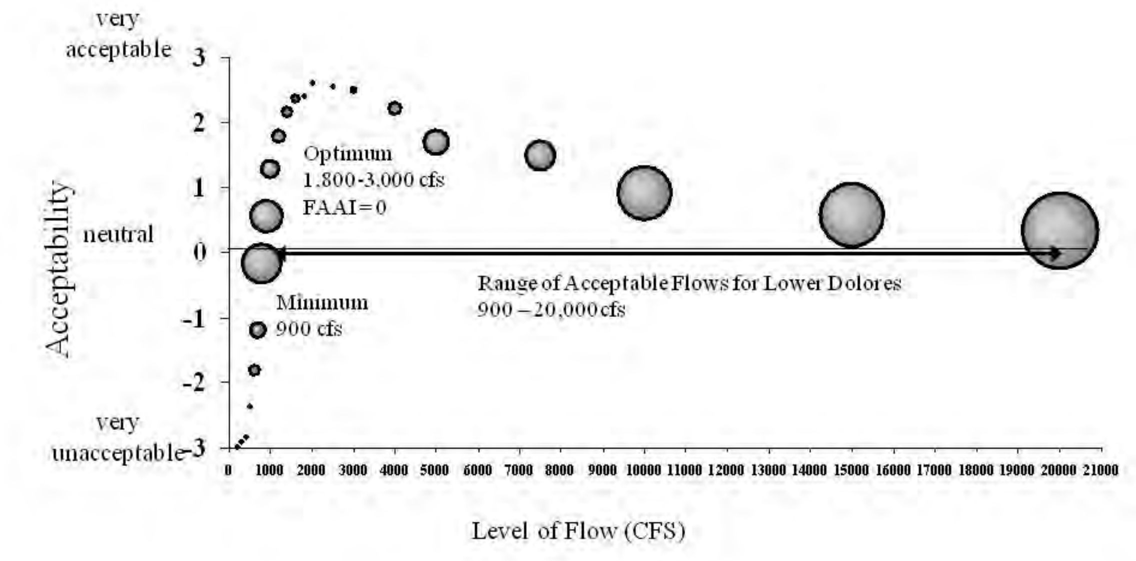


Table 4

Lower Dolores

Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
200	-2.98	0.00
300	-2.9	0.00
400	-2.83	0.02
500	-2.37	0.05
600	-1.8	0.11
700	-1.2	0.16
800	-0.16	0.42
900	0.56	0.34
1000	1.28	0.19
1200	1.79	0.14
1400	2.16	0.11
1600	2.36	0.08
1800	2.4	0.05
2000	2.6	0.03
2500	2.56	0.04
3000	2.5	0.06
4000	2.22	0.14
5000	1.69	0.27
7500	1.5	0.32
10000	0.92	0.56
15000	0.58	0.68
20000	0.34	0.79

Figure 5

Flow Acceptability Agreement Index Curve for Colorado River above Moab

(Flows represented are flow levels at the USGS Colorado River Near Cisco, CO*)*

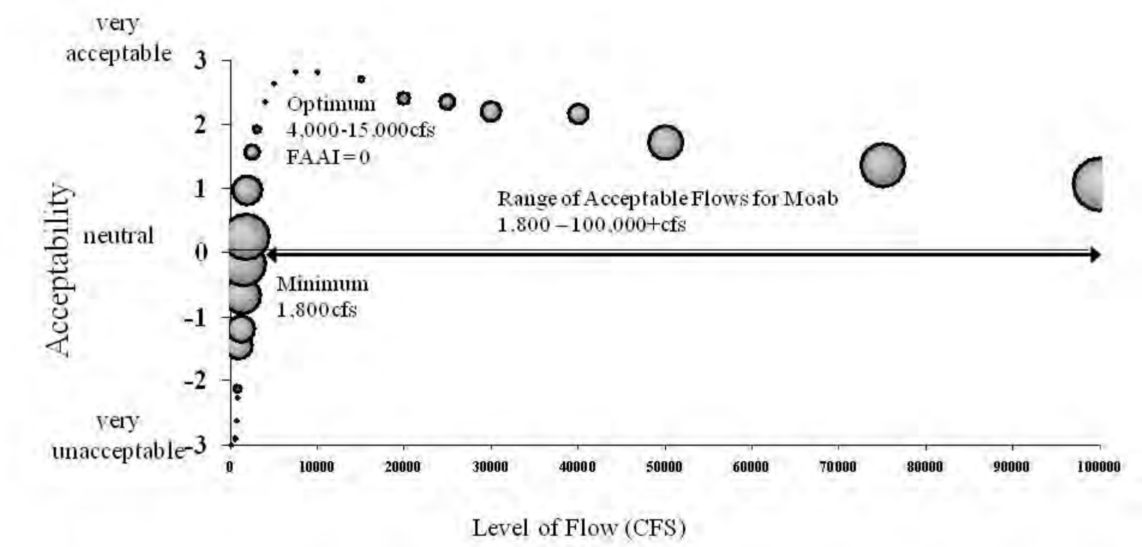


Table 5

Colorado River above Moab

Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
500	-2.91	0.00
700	-2.63	0.00
900	-2.13	0.08
1000	-1.45	0.28
1200	-1.19	0.29
1400	-0.67	0.40
1600	-0.18	0.46
1800	0.24	0.48
2000	0.97	0.31
2500	1.56	0.16
3000	1.91	0.08
4000	2.35	0.04
5000	2.62	0.01
7500	2.82	0.02
10000	2.82	0.03
15000	2.71	0.06
20000	2.41	0.13
25000	2.34	0.17
30000	2.19	0.22
40000	2.16	0.22
50000	1.72	0.38
75000	1.36	0.48
100000	1.07	0.58

Figure 6
Flow Acceptability Agreement Index Curve for Split Mountain
(Flows represented are flow levels at USGS Green River at Jensen, UT*)*

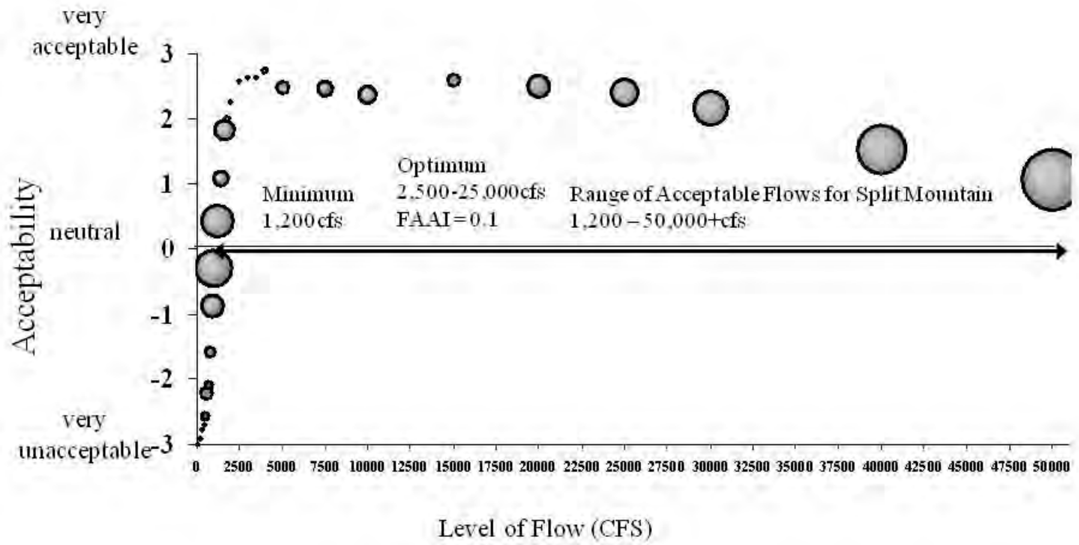


Table 6
Split Mountain
Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
300	-2.78	0.00
500	-2.57	0.09
700	-2.09	0.09
900	-0.87	0.23
1000	-0.29	0.39
1200	0.43	0.35
1400	1.08	0.17
1600	1.83	0.22
1800	2	0.06
2000	2.25	0.03
2500	2.58	0.04
3500	2.63	0.04
4000	2.74	0.06
5000	2.48	0.15
7500	2.46	0.15
10000	2.36	0.20
15000	2.59	0.15
20000	2.5	0.25
30000	2.16	0.37
40000	1.53	0.51
50000	1.06	0.65

Figure 7

Flow Acceptability Agreement Index Curve for Desolation and Gray Canyons
(Flows represented are flow levels at USGS Green River at Green River, UT*)*

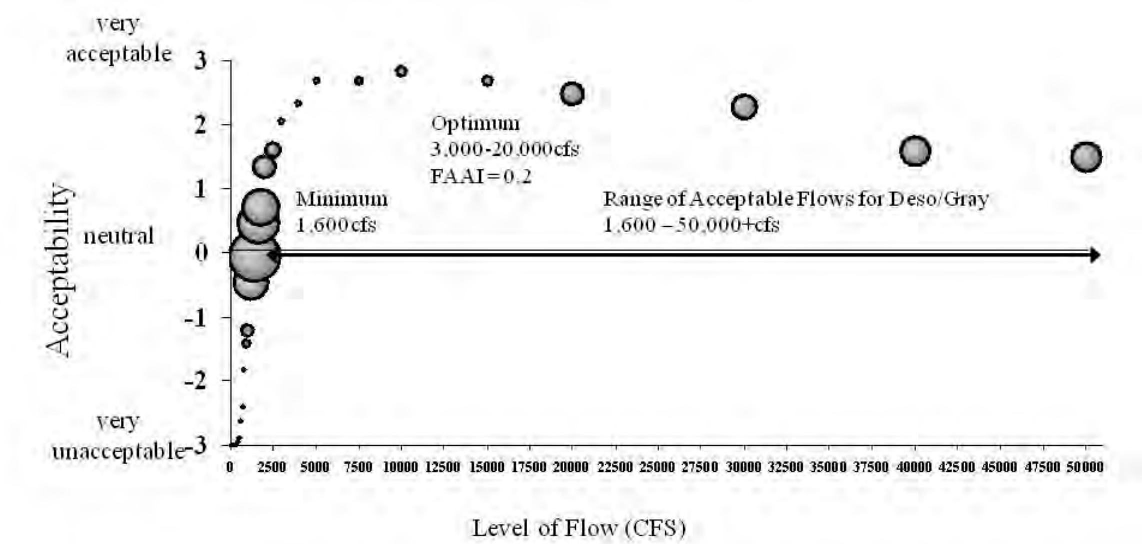


Table 7

Desolation and Gray Canyons
Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
300	-3	0.00
400	-2.94	0.00
500	-2.88	0.00
600	-2.63	0.00
700	-2.41	0.00
800	-1.82	0.04
900	-1.41	0.08
1000	-1.22	0.15
1200	-0.47	0.36
1400	-0.06	0.56
1600	0.47	0.46
1800	0.71	0.39
2000	1.35	0.24
2500	1.61	0.17
3000	2.05	0.07
4000	2.33	0.06
5000	2.68	0.07
7500	2.68	0.09
10000	2.84	0.11
15000	2.68	0.12
20000	2.47	0.245614
30000	2.28	0.2777778
40000	1.59	0.3137255
50000	1.5	0.3125

Figure 8

Flow Acceptability Agreement Index Curve for Lower San Juan

(Flows represented are flow levels at the USGS San Juan River Near Bluff, CO*)*

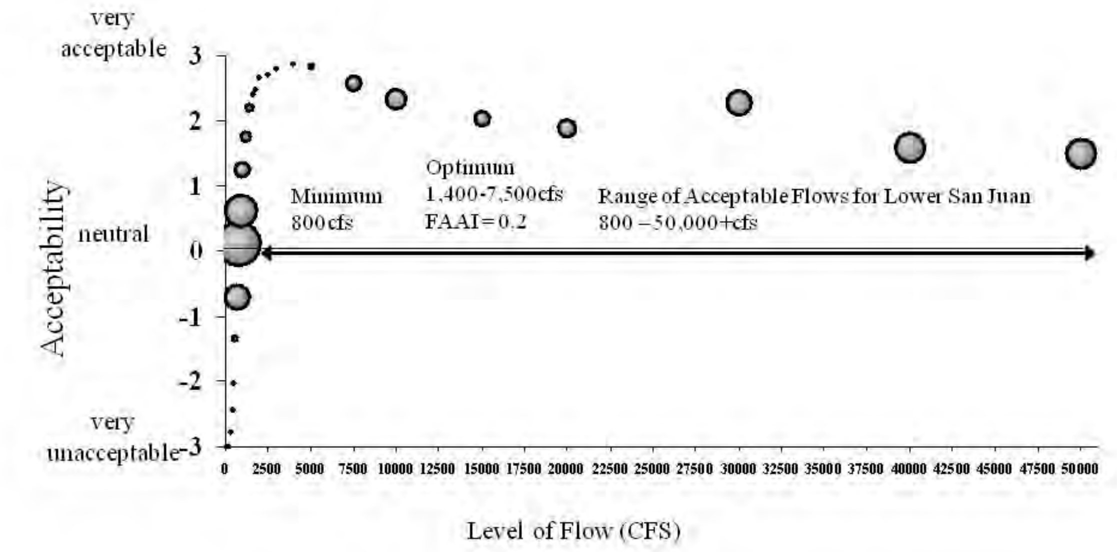


Table 8

Lower San Juan

Mean Acceptability Scores and Flow Acceptability Agreement Index

Specific Flow CFS	Mean Acceptability	FAAI
100	-3	0.00
300	-2.77	0.00
400	-2.45	0.00
500	-2.03	0.02
600	-1.35	0.06
700	-0.71	0.26
800	0.12	0.46
900	0.61	0.34
1000	1.25	0.17
1200	1.75	0.13
1400	2.19	0.09
1600	2.4	0.04
1800	2.48	0.04
2000	2.67	0.02
2500	2.7	0.03
3000	2.8	0.02
4000	2.87	0.03
5000	2.84	0.06
7500	2.57	0.15
10000	2.32	0.21
15000	2.04	0.17
20000	1.88	0.19
30000	2.28	0.28
40000	1.59	0.31
50000	1.5	0.31

Appendix C

A subset of FERC regulated hydropower projects at which discrete usable boating days have been scheduled and/or provided as mitigation for impacts to whitewater boating, and/or analyzed as part of a whitewater flow study.

River	Project Name	State	FERC Project #
COOSA RIVER	JORDAN DAM	AL	00618
COOSA RIVER	MITCHELL	AL	00082
BUTTE CREEK	FORKS OF BUTTE	CA	06896
FEATHER RIVER	FEATHER RIVER	CA	02100
KERN RIVER	BOREL	CA	00382
KERN RIVER	ISABELLA	CA	08377
KERN RIVER	KERN CANYON	CA	00178
KERN RIVER	KERN RIVER NO 1	CA	01930
KERN RIVER	KERN RIVER NO 3	CA	02290
KINGS RIVER	PINE FLAT	CA	02741
MIDDLE FORK AMERICAN R	MIDDLE FORK AMERICAN RIVER	CA	02079
MIDDLE FORK STANISLAUS RIVER	BEARDSLEY/DONNELLS	CA	02005
N FK KINGS R	HAAS-KINGS RIVER	CA	01988
NORTH FORK FEATHER RIVER	POE	CA	02107
NORTH FORK FEATHER RIVER	ROCK CREEK-CRESTA	CA	01962
NORTH FORK FEATHER RIVER	UPPER NORTH FORK FEATHER RIVER	CA	02105
NORTH FORK MOKELUMNE RIVER	MOKELUMNE RIVER	CA	00137
PIRU CREEK	SANTA FELICIA	CA	02153
PIT RIVER	MCCLOUD-PIT	CA	02106
PIT RIVER	PIT 3, 4, & 5	CA	00233
PIT RIVER	PIT NO. 1	CA	02687
SAN JOAQUIN R	KERCKHOFF	CA	00096
SAN JOAQUIN RIVER	BIG CREEK NO 3	CA	00120
SAN JOAQUIN RIVER	BIG CREEK NO 4	CA	02017
SAN JOAQUIN RIVER	BIG CREEK NO.1 & NO.2	CA	02175
SOUTH FORK AMERICAN R	UPPER AMERICAN RIVER	CA	02101
SOUTH FORK AMERICAN RIVER	CHILI BAR	CA	02155
SOUTH FORK FEATHER RIVER	SOUTH FEATHER POWER	CA	02088
SOUTH FORK OF THE AMERICAN RIVER	EL DORADO	CA	00184
SOUTH YUBA RIVER	DRUM-SPAULDING	CA	02310
SOUTH YUBA RIVER	YUBA-BEAR	CA	02266
STANISLAUS R MIDDLE FORK	SAND BAR	CA	02975
STANISLAUS RIVER	SPRING GAP-STANISLAUS	CA	02130
WEST BRANCH FEATHER RIVER	DESABLA-CENTERVILLE	CA	00803
TALLULAH RIVER	NORTH GEORGIA	GA	02354
BEAR RIVER	BEAR RIVER	ID	00020

DEAD RIVER	FLAGSTAFF STORAGE	ME	02612
KENNEBEC RIVER	INDIAN POND	ME	02142
MAGALLOWAY RIVER	AZISCOHOS [?]	ME	04026
RAPID RIVER	UPPER & MIDDLE DAMS STORAGE	ME	11834
S BR PENOBSCOTT R	CANADA FALLS	ME	
W BR PENOBSCOT R	PENOBSCOT	ME	02458
W BR PENOBSCOT R	RIPOGENUS	ME	02572
SWAN RIVER	BIGFORK	MT	02652
WEST ROSEBUD CREEK	MYSTIC LAKE	MT	02301
PIGEON RIVER	WALTERS	NC	00432
TUCKASEGEE RIVER	DILLSBORO	NC	02602
WEST FORK TUCKASEGEE RIVER	WEST FORK	NC	02686
NANTAHALA RIVER	NANTAHALA	NC	02692
EF TUCKASEGEE	EAST FORK	NC	02698
ANDROSCOGGIN RIVER	PONTOOK	NH	02861
PEMIGEWASSET RIVER	AYERS ISLAND	NH	02456
HOOSIC RIVER	HOOSIC	NY	02616
MONGAUP RIVER	RIO	NY	09690
MOOSE RIVER	MOOSE RIVER	NY	04349
RAQUETTE RIVER	[STONE VALLEY REACH]	NY	
RAQUETTE RIVER	PIERCEFIELD	NY	07387
SACANDAGA RIVER	STEWARTS BRIDGE	NY	02047
SALMON R	SALMON RIVER	NY	11408
SARANAC RIVER	SARANAC RIVER	NY	02738
BEAVER RIVER	BEAVER FALLS	NY	02593
BEAVER RIVER	BEAVER RIVER	NY	02645
BLACK RIVER	GLEN PARK	NY	04796
BEAVER RIVER	LOWER BEAVER FALLS	NY	02823
BLACK RIVER	WATERTOWN	NY	02442
KLAMATH RIVER	KLAMATH	OR	02082
SOUTH FORK ROGUE RIVER	PROSPECT NO 3	OR	02337
SUSQUEHANNA RIVER	HOLTWOOD	PA	01881
SALUDA RIVER	SALUDA	SC	00516
WATEREE RIVER	CATAWBA-WATEREE	SC	02232
LITTLE TENNESSEE RIVER	TAPOCO	TN	02169
DEERFIELD RIVER	DEERFIELD RIVER	VT	02323
LITTLE RIVER	WATERBURY	VT	02090
LAKE CHELAN	LAKE CHELAN	WA	00637
SPOKANE RIVER	SPOKANE RIVER	WA	02545
SULLIVAN CREEK	SULLIVAN LAKE (STORAGE)	WA	02225
SULTAN RIVER	HENRY M JACKSON (SULTAN)	WA	02157
TIETON RIVER	TIETON DAM	WA	03701
BLACK RIVER	HATFIELD	WI	10805
CHIPPEWA RIVER	JIM FALLS	WI	02491
GAULEY RIVER	SUMMERSVILLE	WV	10813

Appendix D3
Threatened and Endangered Species Metrics

Appendix D3—Threatened and Endangered Species Metrics

1.0 Introduction

This appendix describes the methods used to formulate the metrics for the threatened and endangered species attribute of interest. The following locations were selected based on existing flow recommendations and their compatibility with existing modeling capabilities: the Colorado River near Cameo, CO (Cameo); Gunnison River near Grand Junction, CO (Grand Junction); Colorado River near the Colorado-Utah Stateline (Stateline); Yampa River near Maybell, CO (Maybell); Green River near Greendale, UT (Greendale); Green River at Jensen, UT (Jensen); Green River at Green River, UT (Green River, UT); Duchesne River near Randlett, UT (Randlett); and San Juan River near Bluff, UT (Bluff).

All selected locations have existing flow recommendations that specify suggested flows varying by month/season and hydrologic year type. The hydrologic year type varies based on the hydrologic conditions in the sub-basin as indicated by some reference value, for example, the forecasted inflow into a reservoir or the projected flow at a gage. In general, the recommendations include a base flow period and a spring peak flow period. In most cases, the recommendations are specified at the daily time step, though there are recommendations for average monthly flows at several locations. The distinction between the two is important. If the recommendations are stated in terms of average monthly flows, they can be directly incorporated into the Colorado River System Simulation (CRSS); only Cameo and Maybell have these direct monthly recommendations. Though CRSS operates at a monthly time step, recent modifications to the model allow for plausible daily flow sequences to be generated at certain gage locations. At Greendale, Jensen, and Bluff, the daily recommendations can be directly compared to the stochastically generated daily flow sequences. At the remaining locations (Grand Junction, Stateline, Green River, UT, and Randlett), the daily flow recommendations are approximated by monthly volumes to evaluate the metrics in CRSS.

The methodology section details how the quantified flow targets are estimated. In the quantified flow targets section, the target monthly volumes that were developed are presented.

2.0 Methodology

2.1 Direct Use of Monthly Recommendations

The flow recommendations for Cameo (Osmundson, 2001) and Maybell (Modde & Smith, 1995) are stated in terms of average monthly flow rates; thus, they can be directly incorporated into a monthly time step model without any additional modifications. Section 3.1 in this appendix presents the recommendations.

2.2 Monthly Approximations of Daily Recommendations

At locations where flow recommendations are expressed as daily values and where CRSS does not have the ability to produce daily flow sequences, historical gage data were used to create an estimated daily flow sequence. This daily flow sequence was then converted to a monthly volume as described in detail below.

While the details of the flow recommendations vary between locations, they have many common elements. The flow recommendations are expressed as target ranges for the rate and/or the duration of flow, for example, 7 to 10 days at 3,000 to 3,500 cubic feet/second (cfs). Low and high target volumes were developed, which use the lower and upper bounds of the ranges, respectively. Additionally, flow recommendations define different hydrologic year types. Typically, the hydrologic year types are defined by the exceedance probability of the current year's conditions compared to the historical record[1]. The flow recommendations vary between year types to resemble the natural variability, so for each location low and high target volumes exist for every month and every hydrologic year type. Since the timing of the peak runoff varies between years, the monthly targets for April–July are combined together for an overall spring target volume. The peak flow recommendations are typically for 1–4 weeks of the April–July period, so historical gage data are used as the pattern for the ascending and descending limbs of the hydrograph. The following outlines the steps to develop the monthly flow targets, which are repeated at each location.

1. Obtain all historical, daily gage data.
2. Rank each year based on annual (water year) volume.

Compute the exceedance for each year as:

$$Exceedance = \frac{m}{n+1}$$

where m = rank and n = the number of years in the record

3. Categorize each year based on the exceedance percentages of each hydrologic year type.
4. Depending on location, between 4 and 6 year types can exist.[2]
5. Compute the average daily flow for each hydrologic year type from April 1–July 31.
6. Assign a daily flow rate for each day as follows:
   a. If during the base flow period, assign the minimum target base flow from the respective flow recommendation (Figure D3-1).
   b. Using the peak flow date as the center of the hydrograph, assign each day's flow as the minimum target flow for the minimum number of days in the respective flow recommendation:
      i. Denote the start day of this peak target as P_{start} and the ending day as P_{end} (Figure D3-1).

[1] The year types are dependent on the length of the historical record. As such, the flows presented here may differ from the flow recommendations that exist for regulatory purposes. The inclusion of these approximated flows should not in any way change or affect the flow recommendations that are used for regulatory purposes.

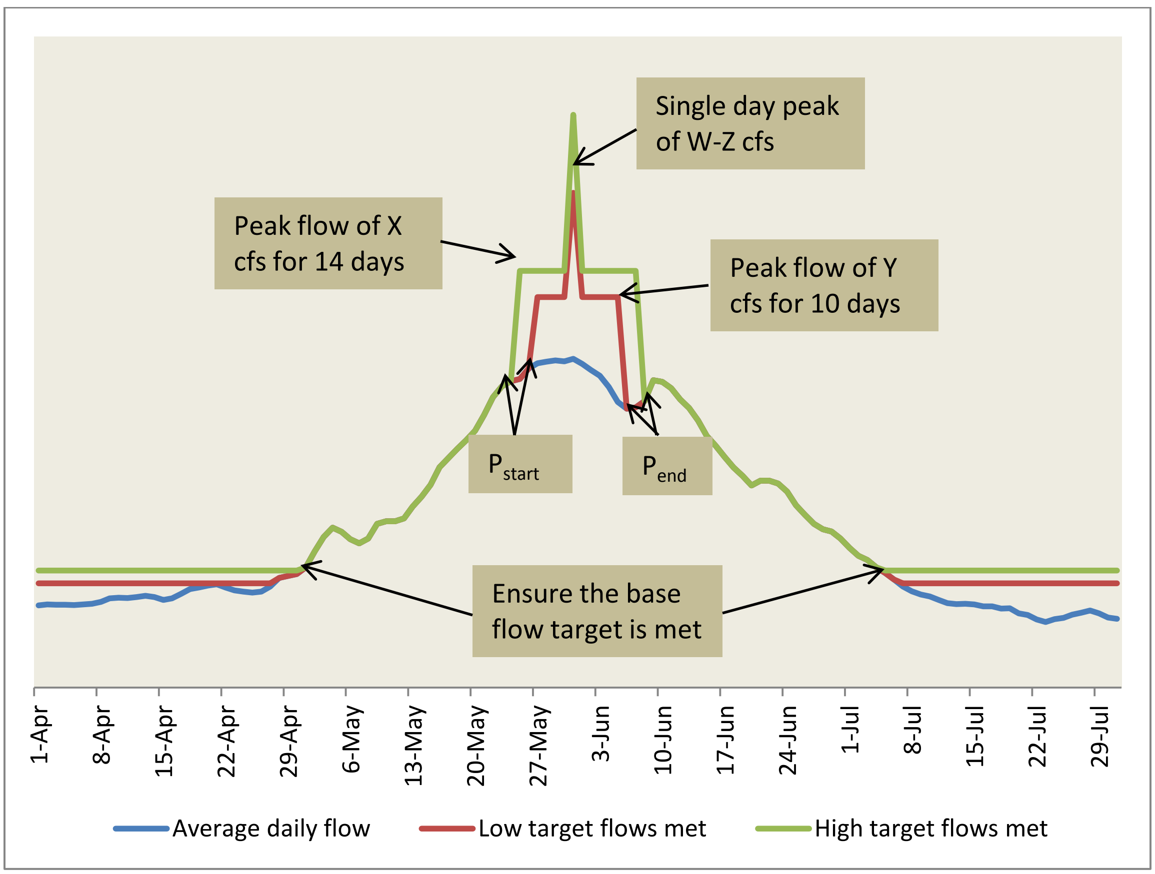
[2] The number of year types varies among locations because the respective flow recommendation documents do not use the same number of year types at all locations. The method here uses the same year types as the respective documentation.

c. Starting on April 1 and going through P_{start}, assign each daily flow as the maximum of the base flow target and the average daily flow (from step 5) for the current day:

i. Repeat for P_{end} through July 31.

7. Sum the daily flows for each month.
8. Sum the monthly volumes for April–July.
9. This results in the “low” target monthly and seasonal volumes.
10. Repeat steps 6-8 selecting the maximum target flows and the maximum number of days at the target flows to compute the “high” monthly targets.
11. Repeat steps 6-10 for each hydrologic year type.

FIGURE D3-1
Schematic showing how the average daily flow from the historical gage record is modified to meet the low and high base flow and peak flow recommendations.
The peak flow recommendations are centered on the single day peak of the average daily flow.



2.3 Direct Use of Daily Recommendations

Model upgrades allow for daily flow recommendations to be directly used as metrics at several locations within the Basin. The operating rules within CRSS for Flaming Gorge and Navajo were updated to reflect the recent Records of Decision (Bureau of Reclamation, 2006a, 2006b) which modify the reservoir operations to help meet the respective flow recommendations below both reservoirs. The peak flow targets below both reservoirs are daily in nature, for example, 7 days at 18,600 cfs. Thus, to adequately reflect the true operations of the reservoirs, CRSS aggregates daily operations to a total monthly volume released from the reservoirs. In doing so, the daily releases are stored in the CRSS results and can be compared with the daily flow recommendations, during the peak flow period. Additionally, the flow requirements below both reservoirs are for locations that aggregate reservoir releases with other tributary inflows. Daily tributary flows are stochastically generated from monthly volumes in the model to produce a plausible daily tributary flow sequence for the peak flow period (April–July). When the tributary flows are combined with the reservoir releases, this total flow can be directly compared to the daily flow recommendations (Butler, 2011). The daily flow sequences are not intended to be predictive; rather in the framework of the probabilistic nature of CRSS, they produce a plausible daily flow sequence and provide variability in the daily flows for each model run. Average monthly releases are used during the base flow periods (August–March) since the reservoir releases are relatively constant during these periods.

3.0 Quantified Flow Targets

For the direct use of monthly flow recommendations and the direct use of daily flow recommendations, the target flows are provided in the following sections 3.1 and 3.3, respectively. For the monthly approximations of daily recommendations, the computed monthly volumes are provided in section 3.2.

3.1 Direct Use of Monthly Recommendations

The flow recommendations from Osmundson (2001) are used directly for the threatened and endangered species metric at Cameo. Table D3-1 presents these recommendations.

TABLE D3-1
Average monthly flow recommendations, in cfs, for the Colorado River near Cameo, CO (Osmundson, 2001).

Category	Dry	Below Average	Above Average	Wet
Rate	**20%**	**30%**	**25%**	**25%**
Exceedance	**81-100%**	**51-80%**	**26-50%**	**0-25%**
January	1,555	1,600	1,600	1,600
February	1,555	1,600	1,600	1,600
March	1,555	1,600	1,600	1,600
April	3,010	3,410	3,590	4,360
May	8,710	9,160	10,530	12,170
June	8,350	12,850	15,750	17,160
July	2,980	4,650	6,870	8,560
August	2,460	2,890	3,280	3,280
September	2,460	2,890	3,280	3,280
October	2,460	2,890	3,280	3,280
November	1,555	1,600	1,600	1,600
December	1,555	1,600	1,600	1,600

For the Yampa River near Maybell, CO, Modde & Smith (1995) and the subsequent Yampa River Programmatic Biological Opinion (U.S. FWS, 2005 and 2008) recommend baseflows ranging from 120 cfs to 134 cfs throughout the year. Given the spatial and temporal scale of CRSS, the model will not be able to meaningfully distinguish between this range. For this reason, the Study will assume a baseflow target of 120 cfs for this metric.

3.2 Monthly Approximations of Daily Recommendations

After following the procedure in section 2.2 for Grand Junction, Stateline, Green River, UT, and Randlett, the following volumetric targets were developed. The low targets for Grand Junction were developed from the U.S. Fish and Wildlife Service (2009) while the high targets were developed from the upper bounds found in McAda (2003); the Grand Junction targets are presented in table D3-2. Table D3-3 presents the high and low targets for Stateline, both of which were developed from McAda (2003). Table D3-4 shows the high and low targets for Green River, UT, which were developed based on the ranges in Bureau of Reclamation (2005). Table D3-5 presents the monthly approximations for the Randlett flow recommendations from Modde & Keleher (2003). The goal of aggregating the April–July flow targets was to capture the runoff volume in one target. The historical data show that the runoff tends to occur earlier in drier years than in the wetter years for the Duchesne near Randlett. To reflect this, the runoff volume is aggregated from March through June in dry and average years while the wet and extremely wet years are aggregated from April through July.

TABLE D3-2
Low and high monthly approximations (acre-feet) of flow recommendations for the Gunnison River near Grand Junction, CO.

Year Type Exceedance	Dry 90–100%		Moderately Dry 70–90%		Average Dry 50–70%	
	Low	**High**	**Low**	**High**	**Low**	**High**
January	46,116	64,562	46,116	64,562	64,562	122,975
February	41,653	58,314	41,653	58,314	58,314	111,074
March	48,575	64,562	48,575	64,562	64,562	122,975
April–July	346,518	349,836	652,198	718,906	920,874	971,017
August	54,724	64,562	64,562	64,562	64,562	122,975
September	52,959	62,479	52,959	62,479	62,479	119,008
October	48,575	64,562	48,575	64,562	64,562	122,975
November	47,008	62,479	47,008	62,479	62,479	119,008
December	46,116	64,562	46,116	64,562	64,562	122,975
Year Type Exceedance	**Average Wet 30–50%**		**Moderately Wet 10–30%**		**Wet 0–10%**	
	Low	**High**	**Low**	**High**	**Low**	**High**
January	64,562	122,975	64,562	153,719	64,562	153,719
February	58,314	111,074	58,314	138,843	58,314	138,843
March	64,562	122,975	64,562	153,719	64,562	153,719
April–July	1,320,185	1,339,779	1,621,987	1,734,757	1,800,077	2,091,909
August	64,562	122,975	92,231	153,719	92,231	153,719
September	62,479	119,008	62,479	148,760	62,479	148,760
October	64,562	122,975	64,562	153,719	64,562	153,719
November	62,479	119,008	62,479	148,760	62,479	148,760
December	64,562	122,975	64,562	153,719	64,562	153,719

TABLE D3-3
Low and high monthly approximations (acre-feet) of flow recommendations for the Colorado River near the Colorado-Utah Stateline.

Year Type Exceedance	Dry 90–100%		Moderately Dry 70–90%		Average Dry 50–70%	
	Low	**High**	**Low**	**High**	**Low**	**High**
January	110,678	110,678	153,719	245,950	153,719	245,950
February	99,967	99,967	138,843	222,149	138,843	222,149
March	110,678	110,678	153,719	245,950	153,719	245,950
April–July	870,512	882,380	1,511,575	1,727,954	2,102,851	2,240,154
August	110,678	110,678	153,719	245,950	153,719	245,950
September	107,107	107,107	148,760	238,017	148,760	238,017
October	110,678	110,678	153,719	245,950	153,719	245,950
November	107,107	107,107	148,760	238,017	148,760	238,017
December	110,678	110,678	153,719	245,950	153,719	245,950
Year Type Exceedance	**Average Wet 30–50%**		**Moderately Wet 10–30%**		**Wet 0–10%**	
	Low	**High**	**Low**	**High**	**Low**	**High**
January	184,463	295,140	184,463	295,140	184,463	368,926
February	166,612	266,579	166,612	266,579	166,612	333,223
March	184,463	295,140	184,463	295,140	184,463	368,926
April–July	3,008,537	3,228,714	4,095,964	4,220,322	4,843,930	5,270,515
August	184,463	295,140	184,463	295,140	184,463	368,926
September	178,512	285,620	178,512	285,620	178,512	357,025
October	184,463	295,140	184,463	295,140	184,463	368,926
November	178,512	285,620	178,512	285,620	178,512	357,025
December	184,463	295,140	184,463	295,140	184,463	368,926

TABLE D3-4
Low and high monthly approximations (acre-feet) of flow recommendations for the Green River at Green River, UT.

Year Type Exceedance	Dry 90–100%		Moderately Dry 70–90%		Average 30–70%	
	Low	High	Low	High	Low	High
January	79,934	159,868	92,231	209,058	110,678	258,248
February	72,198	144,397	83,306	188,826	99,967	233,256
March	79,934	159,868	92,231	209,058	110,678	258,248
April–July	1,092,416	1,144,000	1,728,100	1,755,882	2,827,360	2,893,744
August	79,934	159,868	92,231	209,058	110,678	258,248
September	77,355	154,711	89,256	202,314	107,107	249,917
October	79,934	159,868	92,231	209,058	110,678	258,248
November	77,355	154,711	89,256	202,314	107,107	249,917
December	79,934	159,868	92,231	209,058	110,678	258,248
Year Type Exceedance			**Moderately Wet 10–30%**		**Wet 0–10%**	
			Low	**High**	**Low**	**High**
January			166,017	288,992	196,760	288,992
February			149,950	261,025	177,719	261,025
March			166,017	288,992	196,760	288,992
April–July			3,813,639	3,813,639	4,699,530	4,699,530
August			166,017	288,992	196,760	288,992
September			160,661	279,669	190,413	279,669
October			166,017	288,992	196,760	288,992
November			160,661	279,669	190,413	279,669
December			166,017	288,992	196,760	288,992

TABLE D3-5
Monthly approximations (acre-feet) of flow recommendations for the Duchesne River near Randlett, UT.

<table>
<tr><th>Year Type
Exceedance</th><th>Dry
70–100%</th><th>Average
40–70%</th><th>Wet
10–40%</th><th>Extremely Wet
0–10%</th></tr>
<tr><td>January</td><td>3,074</td><td>3,074</td><td>7,071</td><td>7,071</td></tr>
<tr><td>February</td><td>2,777</td><td>2,777</td><td>6,387</td><td>6,387</td></tr>
<tr><td>March</td><td rowspan="4">47,619</td><td rowspan="4">173,642</td><td>7,071</td><td>7,071</td></tr>
<tr><td>April</td><td rowspan="4">368,554</td><td rowspan="4">534,897</td></tr>
<tr><td>May</td></tr>
<tr><td>June</td></tr>
<tr><td>July</td><td>3,074</td><td>3,074</td></tr>
<tr><td>August</td><td>3,074</td><td>3,074</td><td>7,071</td><td>7,071</td></tr>
<tr><td>September</td><td>2,975</td><td>2,975</td><td>6,843</td><td>6,843</td></tr>
<tr><td>October</td><td>3,074</td><td>3,074</td><td>7,071</td><td>7,071</td></tr>
<tr><td>November</td><td>2,975</td><td>2,975</td><td>6,843</td><td>6,843</td></tr>
<tr><td>December</td><td>3,074</td><td>3,074</td><td>7,071</td><td>7,071</td></tr>
</table>

3.3 Direct Use of Daily Recommendations

The flow targets for Greendale, Jensen, and Bluff are presented in this section. Because CRSS can produce daily flow values at these sites, the tables presented are identical to those in the documents that establish the recommended flows. Table D3-6 presents both the base flow and peak flow recommendations for Greendale, while Table D3-7 presents the recommendations for Jensen. Table D3-8 presents the peak flow recommendations for Bluff. The base flow recommendations below Navajo are stated to be 500–1,000 cfs using a three-gage average (Bureau of Reclamation, 2006c). Due to modeling constraints, Bluff is the only gage available below Navajo. It is assumed that if the base flow is met at Bluff, then the base flow recommendation is met (Butler, 2011).

TABLE D3-6
Flow recommendations for Green River near Greendale, UT (Bureau of Reclamation, 2005).

<table>
<tr><th>Year Type
Exceedance</th><th>Dry
90–100%</th><th>Moderately Dry
70–90%</th><th>Average
30–70%</th><th>Moderately Wet
10–30%</th><th>Wet
0–10%</th></tr>
<tr><td>Maximum Spring Peak Flow (cfs)</td><td>4,600</td><td>4,600</td><td>4,600</td><td>4,600</td><td>8,600</td></tr>
<tr><td>Peak Flow Duration</td><td colspan="5">Depends on inflows into the Green River and the flows needed to achieve recommended flows at Jensen and Green River, UT</td></tr>
<tr><td>Summer-to-Winter Base Flow (cfs)</td><td>800–1,000</td><td>800–1,300</td><td>800–2,200</td><td>1,500–2,600</td><td>1,800–2,700</td></tr>
</table>

TABLE D3-7
Flow recommendations for Green River near Jensen, UT (Bureau of Reclamation, 2005).

Year Type	Dry 90–100%	Moderately Dry 70–90%	Average 30–70%	Moderately Wet 10–30%	Wet 0–10%
Max Spring Peak Flow (cfs)	8,300	8,300	18,600[1]; 8,300[2]	20,300	26,000
Peak Flow Duration	Flows greater than 8,300 cfs should be maintained for 2 days or more except in extremely dry years (98% exceedance)	Flows greater than 8,300 cfs should be maintained for at least 1 week	Flows greater than 18,600 cfs should be maintained for 2 weeks in at least 1 of 4 average years	Flows greater than 18,600 cfs should be maintained for 2 weeks or more	Flows greater than 22,700 cfs should be maintained for 2 weeks or more and flows greater than 18,600 cfs for 4 weeks or more
Summer-to-Winter Base Flow (cfs)	900–1,100	1,100–1,500	1,500–2,400	2,400–2,800	2,800–3,000

[1] Recommended flows: 18,600 cfs in 1 of 2 average years.
[2] Recommended flows: 8,300 cfs in other average years.

TABLE D3-8
Peak flow recommendations for the San Juan River near Bluff, UT (Bureau of Reclamation, 2006b).

Target Peak Flow (cfs)	Minimum Duration (days)	Frequency	Maximum interval between occurrences (years)
> 10,000	5	20%	11
> 8,000	10	33%	7
> 5,000	21	50%	5
> 2,500	10	80%	3

4.0 Summary

The flow targets presented here will be included in CRSS to track the threatened and endangered species attribute of interest at the discussed locations. The monthly approximations of the daily flow targets (sections 2.2 and 3.2) are neither prescriptive in nature nor an interpretation of a flow need. They are coarse approximations of the cited flow recommendations developed to fit into the available modeling resources. All target flows are well suited to compare how flow metrics perform across scenarios, though they are not meant to identify specific years in the future that flow targets are/are not met.

5.0 References

Bureau of Reclamation. 2005. Operation of Flaming Gorge Dam Final Environmental Impact Statement. Salt Lake City, UT.

Bureau of Reclamation. 2006a. Record of Decision Operation of Flaming Gorge Dam Final Environmental Impact Statement.

Bureau of Reclamation. 2006b. Record of Decision for the Navajo Reservoir Operations, Navajo Unit - San Juan River New Mexico, Colorado, Utah Final Environmental Impact Statement.

Bureau of Reclamation. 2006c. Final Environmental Impact Statement Navajo Reservoir Operations. Grand Junction, CO.

Butler, R. A. 2011. Modeling Techniques to Assess Long-term Reliability of Environmental Flows in Basin Scale Planning. University of Colorado.

McAda, C. 2003. Flow Recommendations to Benefit Endangered Fishes in the Colorado and Gunnison Rivers. Grand Junction, CO.

Modde, T., & Keleher, C. 2003. Flow Recommendations for the Duchesne River with a Synopsis of Information Regarding Endangered Fishes. Vernal, UT.

Modde, T., & Smith, G. 1995. Flow Recommendations for Endangered Fishes in the Yampa River. Denver, CO.

Osmundson, D. B. 2001. Flow Regimes for Restoration and Maintenance of Sufficient Habitat to Recover Endangered Razorback Sucker and Colorado Pikeminnow in the Upper Colorado River: Interim Recommendations for the Palisade-to-Rifle Reach. Grand Junction, CO.

U.S. Fish and Wildlife Service. 2005. Final Programmatic Biological Opinion on the Management Plan for Endangered Fishes in the Yampa River Basin. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Denver, CO.

U.S. Fish and Wildlife Service. 2008. Rationale for Management of Water Releases from the Elkhead Reservoir Endangered Fish Pool to Augment August-October Base Flows in the Yampa River.

U.S. Fish and Wildlife Service. 2009. Final Gunnison River Basin Programmatic Biological Opinion. Denver, CO.

Appendix D4
Cottonwood Recruitment Metrics

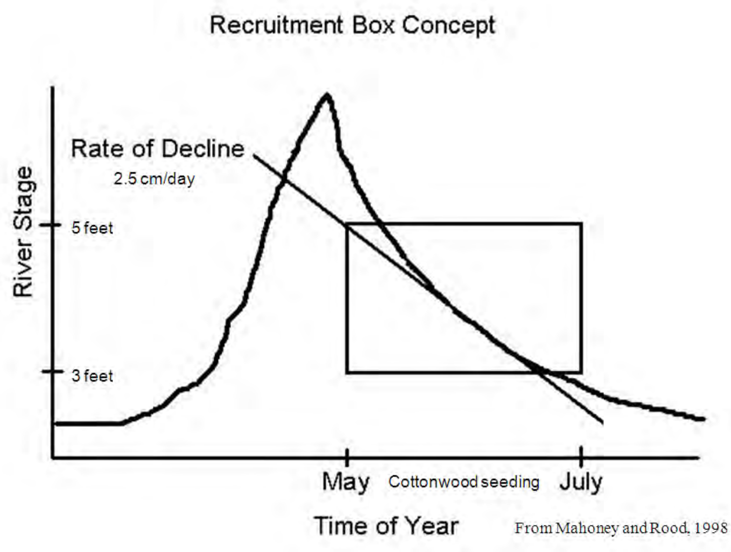
Appendix D4—Cottonwood Recruitment Metrics

1.0 Introduction

This appendix describes the method used to implement the cottonwood recruitment metric for the aquatic and riparian habitats attribute of interest. The metric is used since healthy cottonwood stands are an indicator of healthy riparian systems and the many species that depend on them; recruitment of new cottonwoods is important in maintaining cottonwood stands as older trees die. As described in Mahoney & Rood (1998), a successful recruitment event is dependent on four main 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 magnitude large enough to create appropriate seed beds for the cottonwood seeds. It is also estimated that a recruitment event should occur about once every 5–10 years to maintain a healthy cottonwood stand. Each of these variables has biological importance in the recruitment process and the metric aims to represent these criteria.

For cottonwood recruitment to take place, many processes must properly align. The recruitment events rely on hydrological processes to prepare the seed beds and maintain proper water levels for the growing seedlings. A large flood magnitude creates the appropriate seed beds: bare, moist sites above the base flow stage of the river (Scott et al., 1997). Research suggests that a 1 in 5-year to 1 in 10-year flood event is associated with successful recruitment in the Rocky Mountain region (Mahoney & Rood, 1998). Figure D4-1 depicts each of the remaining criteria. The peak flow should also properly coincide with seed dispersal (late May–July in most of the western United States) and reach a stage high enough to wet the elevation at which cottonwoods grow. Typically, cottonwood stands are established about 2–5 feet above the base flow stage elevation of the stream. Finally, the receding limb should decline slow enough that a seedling's growing roots maintain contact with the water table or more specifically, with freely available water in the phreatic zone and capillary fringe above this zone as both recede through the summer. Studies document cottonwoods surviving with the water table dropping about 1 inch per day. The occurrence of all the above conditions are required to create the opportunity for a successful recruitment event. The following section describes the translation of these criteria to parameters that can be modeled as best as possible given current limitations posed by the monthly time-step in the Colorado River System Simulation (CRSS). The approach described below cannot replace a site-specific study on a reach. The recruitment process is complex and site-specific studies are important to accurately identify the conditions that support recruitment at each individual location.

FIGURE D4-1
The timing, stage height, and rate of decline criteria for positive recruitment conditions (Mahoney & Rood, 1998).



2.0 Methodology

The four criteria that must be met for cottonwood recruitment to be possible were approximated for use in CRSS. The following lists the four approximate criteria that are used to identify positive conditions and the process they represent:

- April–July volume with a 5-year return period:
  - Assumed from the 1 in 5-year to 1 in 10-year range
  - The 5-year flood event was determined based on the April–July volume for each year from historical gage data. Though peak instantaneous flow is typically used to characterize the 5-year flood (Scott et al., 1997), only monthly data is available in CRSS.
- The peak monthly volume should occur in May or June:
  - Since the peak instantaneous flow typically occurs in the month with the peak monthly volume, this approximates that the peak occurs when seeds are dispersed.
- The stage must reach at least 4 feet above the average base flow stage elevation:
  - Assumed from the 2–5 feet range.
- Stage should drop by no more than 2.5 feet /month:
  - 1 inch/day converted to a monthly rate.

Using the above criteria that must be met, the following lists the procedures for determining if all four criteria are met within the CRSS modeling framework:

1. Compute $\bar{S}_{low}$ (the average base flow stage) from historical gage data and a stage-flow table.
2. Compute Q_5: the magnitude of an April–July volume with a return period of 5 years.
3. Check that the peak monthly volume occurs in May or June.
4. If it does not, the remaining criteria do not need to be checked.
5. Is $q_{Apr-Jul}$ (modeled April-July volume) $\geq Q_5$?
6. If it is not, the remaining criteria do not need to be checked.
7. Is $S_{current}$ (the modeled stage in the current month) $\geq \bar{S}_{low} + 4'$?
8. If it is not, the remaining criterion does not need to be checked.
9. Is $S_{current+1\,month} \geq S^{max} - 2.5'$ and $S_{current+2months} \geq S_{current+1\,month} - 2.5'$?
10. If (3), (5), (7), and (9) are all true, then positive conditions exist for cottonwood recruitment.

    Note that whenever stage is referenced, the modeled flow is converted to an elevation using a stage-flow table.

The above procedures identify which years have positive conditions. It is estimated that these positive conditions should occur approximately once every 10 years. The frequency which the positive conditions occur will be compared across scenarios and to the estimated need of occurring once every 10 years.

3.0 Summary

The biological processes that are necessary for cottonwood recruitment had to be approximated for use in a monthly time-step, basin-scale, planning model. When all four conditions are met, the conditions are such that recruitment could take place, though recruitment is not guaranteed. Therefore, the metric should not be used to identify specific years in the future that recruitment will occur; rather it will be used to compare the frequency with which the recruitment could take place across scenarios. Furthermore, the variability (or lack of) in the metric's results could be as much due to the coarseness of approximations as the differences between scenarios. That is, that if the metric shows that there is no change to the frequency of the favorable recruitment conditions between two scenarios, it is unclear if there are truly no differences between scenarios, or if the metric is not sensitive enough to the subtle differences between scenarios. Furthermore, this approach does not replace the benefits of site-specific studies on these reaches. The recruitment process is complex and site-specific studies are important to accurately identify the conditions that support recruitment at each individual location.

4.0 References

Mahoney, J. M., Rood, S. B. 1998. Streamflow Requirements for Cottonwood Seedling Recruitment—An Integrative Model. Wetlands, 18(4), 634-645. DOI:10.1007/BF03161678.

Scott, M. L., Auble, G. T., Friedman, J. M. 1997. Flood Dependency of Cottonwood Establishment along the Missouri River, Montana, USA. Ecological Applications, 7(2), 677-690. doi:10.1890/1051-0761(1997)007[0677:FDOCEA]2.0.CO; 2.

Appendix D5
Estimated Conditions for Flow-Dependent Ecological Systems

Appendix D5—Estimated Conditions for Flow-Dependent Ecological Systems

1.0 Introduction

The Nature Conservancy (TNC) developed approximations of flow conditions to support ecological systems for the Yampa River near Maybell, CO (Maybell), Yampa River near Deerlodge Park, CO (Deerlodge Park), and the Little Snake River near Lily, Colorado (Lily). These quantifications are based on TNC's interpretation of how the Yampa River Programmatic Biological Opinion (PBO) (U.S. Fish and Wildlife Service [FWS], 2005) could be expanded to quantify flow conditions for the full flow regime for Maybell and two additional locations in the Yampa River Basin: Deerlodge Park and Lily. It should be noted that these quantifications are not required under the PBO.

Additionally, TNC developed approximations of flow conditions to support ecological systems at White River near Watson, UT. These quantifications include estimated flow conditions based on FWS flow recommendations that are currently under development through the Upper Colorado River Endangered Fish Recovery Program (Recovery Program).

The methodology section describes how the monthly flow conditions were quantified while the results of these quantifications are presented in the section on estimated flow conditions.

2.0 Methodology

2.1 Yampa River Basin

The PBO covers specified levels of future increases in water use through 2045 within the Yampa River Basin. The methodology described here assumes that depletions from the Yampa River expand to these levels by the year 2045. The range of simulated future flows in the river, assuming historical hydrology and the specified future depeltions, are the basis for computing the esimated flows for ecological systems. The additional depletions specified in the PBO include 23,428 acre-feet above Lily and 30,104 acre-feet above Maybell for a total of 53,532 acre-feet above Deerlodge Park. The year round flows are estimated for the entire Yampa River Basin (at the Maybell, Lily and Deerlodge Park gages), while ensuring that the base flow target at Maybell (FWS, 2008) is met. The method used to develop the estimated flow targets is detailed below.

TNC used the 2009 update to the State of Colorado's Statemod[1] to simulate future flows within the Yampa River Basin which formed the basis of estimating the year round flows for ecological systems. The model was run using data representing the depletions specified in the PBO (2045-level demands) and assumed future flows according to the historical 84-year period 1922-2005[2] to simulate flows in the year 2045. The following steps were then taken to develop flow targets based on model results from the Statemod simulations:

1. Sum all simulated monthly flows in 2045 at Deerlodge to compute annual total volumes. Rank the annual volumes to determine the probability of exceedance

[1] Statemod is the State of Colorado's surface water allocation and accounting model.

[2] Statemod results are sensitive to the chosen period of record and as such, any resulting estimated flow condition would require further analysis to quantify this sensitivity.

and classify each year as shown in table D5-1. The years are separated by exceedance level to allow the flow targets to vary based on hydrologic year type.

TABLE D5-1
Probability of Exceedance

Year Type	Probability of Exceedance
Wet	0-10%
Moderately Wet	10-30%
Average	30-70%
Moderately Dry	70-90%
Dry	90-100%

2. Retrieve the simulated shortages in 2045 above each gage
3. Adjust the simulated flow in 2045 to assume no shortages will occur (for each month at each gage) as: 2045 simulated flow at the gage minus the 2045 shortage from (2) above the gage.[3] Adjusted flow must be > 0.
4. Further adjust monthly flows computed in (3) to ensure that base flows at Maybell are at least equal to 120 cfs[4].
5. Average all simulated then further adjusted flows (4) within a given year type, then aggregate the April-July flows to a total runoff-season target. Targets for a particular month do not always increase from dry to wet year types due to the elimination of negatives in (3).

2.2 White River

The Recovery Program is in the process of developing flow recommendations for the White River near Watson, Utah. The current draft flow recommendations include daily targets. These draft recommendations were aggregated to monthly flow targets consistent with methods used for the monthly approximations of daily recommendations for the threatened and endangered species attribute of interest (appendix D3).

3.0 Estimated Flow Conditions

The monthly estimated flow conditions for Maybell, Lily, and Deerlodge Park are presented in tables D5-2, D5-3, and D5-4, respectively. Table D5-5 lists the targets for the White River near Watson. The purpose of aggregating the April–July flow targets was to capture the runoff volume in one target value.

[3] Shortages are subtracted to follow the assumption in the PBO that they will be satisfied in 2045 and decrease the remaining flow.
[4] See appendix D3 for the simplification of the base flow targets at Maybell. The base flow targets at Maybell are assumed to extend downstream to Deerlodge Park in this quantification.

TABLE D5-2
Estimated flow conditions (acre-feet) for the Yampa River near Maybell, Colorado.

Category Exceedance	Dry 90-100%	Moderately Dry 70-90%	Average 30-70%	Moderately Wet 10-30%	Wet 0-10%
January	9,248	10,915	13,635	14,374	22,341
February	13,489	13,684	16,243	16,548	25,824
March	25,180	40,997	36,046	44,670	73,206
April–July	368,981	604,472	870,646	1,179,492	1,458,585
August	7,379	7,379	8,438	16,316	31,482
September	7,141	7,141	7,141	7,141	23,472
October	8,320	13,101	15,444	17,028	31,916
November	11,895	15,588	16,541	16,913	30,254
December	8,580	12,960	14,819	15,687	22,470

TABLE D5-3
Estimated flow conditions (acre-feet) for the Little Snake River near Lily, Colorado.

Category Exceedance	Dry 90-100%	Moderately Dry 70-90%	Average 30-70%	Moderately Wet 10-30%	Wet 0-10%
January	2,758	3,983	5,330	6,065	7,823
February	4,121	5,236	6,054	7,517	10,938
March	12,416	22,196	19,732	26,924	33,688
April–July	100,287	199,559	318,873	444,742	530,698
August	564	1,146	2,386	2,240	6,320
September	361	900	1,230	2,277	6,492
October	1,288	3,824	6,145	7,635	11,981
November	3,813	4,833	7,170	8,469	11,153
December	3,752	4,809	6,258	7,155	8,399

TABLE D5-4
Estimated flow conditions (acre-feet) for the Yampa River near Deerlodge Park, Colorado.

Category Exceedance	Dry 90-100%	Moderately Dry 70-90%	Average 30-70%	Moderately Wet 10-30%	Wet 0-10%
January	11,861	13,865	17,671	19,068	31,769
February	17,891	17,449	21,844	22,255	39,675
March	34,061	56,019	49,568	61,300	118,118
April–July	457,535	772,084	1,150,079	1,570,554	1,993,638
August	7,379	7,379	11,635	22,697	44,258
September	7,141	7,141	7,141	8,248	29,901
October	11,900	18,890	21,818	24,363	44,280
November	16,910	21,537	23,487	24,244	44,678
December	12,307	17,989	20,964	22,272	32,739

TABLE D5-5
Estimated flow conditions (acre-feet) for the White River near Watson, Utah.

Category Exceedance	Dry 90-100%	Moderately Dry 70-90%	Average 30-70%	Moderately Wet 10-30%	Wet 0-10%
January	18,447	18,453	19,051	22,605	25,365
February	16,661	19,128	18,656	25,483	28,397
March	18,447	21,521	24,595	30,744	36,777
April–July	120,233	203,189	237,841	362,771	503,589
August	12,348	19,005	21,916	30,437	36,893
September	16,618	18,926	19,122	27,537	35,703
October	18,447	21,521	22,608	30,623	35,860
November	17,852	20,803	20,377	27,409	32,372
December	18,284	18,797	18,878	24,223	25,021

4.0 References

U.S. Fish and Wildlife Service. 2005. Final Programmatic Biological Opinion on the Management Plan for Endangered Fishes in the Yampa River Basin. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Denver, CO.

U.S. Fish and Wildlife Service. 2008. Rationale for Management of Water Releases from the Elkhead Reservoir Endangered Fish Pool to Augment August-October Base Flows in the Yampa River.

Appendix D6
Estimated Conditions for
Upper Basin Wildlife Refuges

Appendix D6—Estimated Conditions for Upper Basin Wildlife Refuges

1.0 Introduction

The Seedskadee, Browns Park, and Ouray National Wildlife Refuges (NWRs), located in the Upper Basin, hold water rights that help to preserve the health of those refuges. The refuges' water rights are typically diversion rights and the Colorado River Simulation System (CRSS) has the ability to track whether or not the requested diversion amount is present in reaches approximating the locations of the Upper Basin NWRs. The following sections present the method to estimate the flow conditions for the NWRs and the resulting conditions.

2.0 Methodology

Historically, the NWRs' diversions vary annually based on hydrologic conditions, thus for each refuge the conditions vary with hydrologic year type. The estimated diversions were developed based on the NWRs' state water rights and historical diversion records. Approximately 20 years of annual water usage reports from the refuges maintained by the U.S. Fish and Wildlife Service were used to develop the estimated diversions. Monthly diversion records or a total annual diversion amount were reported in the water usage reports depending on refuge and year. The full record of annual diversion amounts were ranked and then separated by exceedance probability to come up with diversion needs that vary with hydrologic year type. Wet, moderately wet, average, and dry year types were defined as 0–10 percent, 10–30 percent, 30–70 percent, and 70–100 percent exceedance probabilities, respectively. The full diversion right was used as the annual need in wet years. For other year types, the annual diversion amount was determined based on the middle exceedance probability for that year type, for example, the year with a 20 percent exceedance probability for the average wet year. Monthly needs were then computed based on the average historical monthly diversion pattern.

3.0 Estimated Conditions

The estimated conditions for Seedskadee, Browns Park, and Ouray NWR are listed in tables D6-1, D6-2, and D6-3, respectively.

TABLE D6-1
Estimated conditions (acre-feet/month) for the Seedskadee National Wildlife Refuge.

Year Type Exceedance	Dry 100-70%	Average 70-30%	Moderately Wet 30-10%	Wet 10-0%
January	250	300	360	700
February	250	300	360	700
March	1,300	1,700	1,900	3,650
April	1,600	2,000	2,300	4,450
May	2,060	2,550	2,700	5,700
June	1,640	2,040	2,330	4,600
July	900	1,150	1,300	2,500
August	700	850	1,200	2,200
September	850	1,000	1,200	2,200
October	450	570	650	1,300
November	0	0	0	0
December	0	0	0	0
Annual	10,000	12,460	14,300	28,000

TABLE D6-2
Estimated conditions (acre-feet/month) for the Browns Park National Wildlife Refuge.

Year Type Exceedance	Dry 100-70%	Average 70-30%	Moderately Wet 30-10%	Wet 10-0%
January	90	130	200	320
February	90	130	200	310
March	460	680	1,100	1,615
April	560	830	1,300	1,970
May	720	1,070	1,700	2,520
June	570	850	1,340	2,020
July	320	480	750	1,130
August	240	360	570	855
September	220	330	520	800
October	230	340	520	810
November	0	0	0	0
December	0	0	0	0
Annual	3,500	5,200	8,200	12,350

TABLE D6-3
Estimated conditions (acre-feet/month) for the Ouray National Wildlife Refuge.

Year Type Exceedance	Dry 100-70%	Average 70-30%	Moderately Wet 30-10%	Wet 10-0%
January	0	0	0	0
February	0	0	0	0
March	600	1,100	1,500	2,000
April	800	1,200	1,100	2,300
May	2,500	4,500	6,500	8,800
June	800	1,200	1,500	2,200
July	600	1,100	1,500	2,100
August	600	1,100	1,500	2,050
September	600	1,100	1,500	2,000
October	600	1,100	1,500	2,000
November	0	0	0	0
December	0	0	0	0
Annual	7,100	12,400	16,600	23,450