# Appendix G4
# Supplemental Results

# Appendix G4 — Supplemental Results

This appendix provides supplemental discussion and results related to the system reliability analysis presented in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies* for metrics identified in *Technical Report D – System Reliability Metrics.* Results are presented with (portfolios) and without (Baseline) the implementation of options and strategies. The analysis is presented by category and subsequent attributes of interest in a series of six attachments, as follows:

- Attachment A, Water Deliveries Metrics' Results
  - Consumptive Uses and Shortages, Other Water Deliveries
- Attachment B, Electrical Power Resources Metrics' Results
  - Electrical Power Generated, Economic Value of Electrical Power Generated, Available Generation Capacity, Impact on Power Rates, Water Supply System Pumping, Impact on Basin Funds
- Attachment C, Water Quality Metrics' Results
  - Salinity, Sediment Transport, Temperature, Other Water Quality Constituents, Socioeconomic Impacts Related to Salinity
- Attachment D, Flood Control Metrics' Results
  - Flood Control Release, Reservoir Spills, Flooding Risk
- Attachment E, Recreational Resources Metrics' Results
  - Shoreline Public Use Facilities, River and Whitewater Boating, Other Recreational, Socioeconomic Impacts
- Attachment F, Ecological Resources Category Metrics' Results
  - Flows to Support Threatened and Endangered Species, Instream Flow Rights, Cottonwood Recruitment Metric, Flow-Dependent Ecological Systems, Wildlife Refuges and Fish Hatcheries

Results are presented by portfolio with all scenario combinations grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study, all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(1) Box and whisker type plots that show the median, 25th and 75th percentiles and include “whiskers” representing the 10th and 90th percentiles. The statistical data for a given “box” represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each scenario for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

(2) Frequency and magnitude plots showing line plots relating the frequency of occurrence (typically the percentage of years) of an event compared to the magnitude of the event. These plots are also presented over time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

(3) Bar charts are used to display the percent of years that met a desired target or the percent of years that are within a given category. The bars are also presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

Quantitative discussion focuses on either the relative performance or the performance versus a prescribed value for individual indicator metrics. In each case, the performance over time without options and strategies (Baseline) is discussed first and then compared to the performance with options and strategies (portfolios). In many cases, the performance of individual metrics is gauged versus system vulnerabilities. Qualitative discussions generally use quantitative data indirectly to make inferences about potential system performance with respect to the attribute of interest.

**Appendix G4**

# Attachment A
# Water Deliveries Metrics' Results

# Attachment A — Water Deliveries Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics*, were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for both the quantitative and qualitative metrics associated with the Water Deliveries resource category. The Water Deliveries resource attributes of interest are shown in table A-1.

Results are presented by portfolio with all scenario combinations grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(1) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

(2) Frequency and magnitude plots showing line plots relating the frequency of occurrence (typically the percentage of years) of an event compared to the magnitude of the event. These plots are also presented over time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

TABLE A-1
Water Delivery Metrics

| Attribute of Interest | Resource Metric | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|---|
| Consumptive Uses and Shortages | Upper Basin Delivery | 2.1 | Quantitative | Annual | Upper Basin Aggregate | A-1 |
| | Upper Basin Shortage | 2.1 | Quantitative | Annual | Upper Basin Aggregate | A-2 |
| | Lower Basin Shortage | 2.1 | Quantitative | Annual | Lower Basin | A-3 |
| | Lower Basin Delivery | 2.1 | Quantitative | Annual | Lower Basin Aggregate | A-4 |
| | Lee Ferry Deficit | 2.1 | Quantitative | Annual | Colorado River at Lee Ferry, AZ | A-5 |
| | Remaining Demands above Lower Division States' Basic Apportionment | 2.1 | Quantitative | Annual | Lower Basin Aggregate | A-6 |
| | Tribal Water Right Satisfaction | 2.2 | Qualitative | NA | Basin-wide | NA |
| Other Water Deliveries | Navajo Reservoir Pool Elevation | 3 | Quantitative | Monthly | Navajo Reservoir | A-7 |
| | Lake Mead Pool Elevation | 3 | Quantitative | Monthly | Lake Mead | A-8 |
| | Annual Flows at Morelos Diversion Dam Above the 1944 Treaty Delivery | 3 | Quantitative | Annual | Morelos Diversion Dam | A-9 |
| Socioeconomic Impacts of Shortages | Socioeconomic Impacts of Shortages | 4 | Qualitative | NA | Basin-wide | NA |

# 2.0 Metrics for the Consumptive Uses and Shortages Attribute of Interest

## 2.1 Quantitative Consumptive Uses and Shortages Metrics

Consumptive uses and shortages metrics were evaluated at locations throughout the Basin where demand nodes exist within the Colorado River Simulation System (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*).

Upper and Lower Basin delivery and shortage are measures of aggregate CRSS-simulated consumptive use (delivery) and shortage. Increasing delivery results in better realization of full demand and reduction in shortage. Figures A-1 through A-4 show results associated with Upper and Lower Basin shortage and delivery. In addition, figures A-5 and A-6 show the Lee Ferry deficit (defined for purposes of the Study as the amount of flow less than an aggregate of 75 maf over 10 years) and the remaining demand above Lower Division States' basic apportionment.

For the Upper Basin, delivery increases over time under the Baseline as demand increases. However, shortage also increases under the Baseline, reflecting both the increased demand and future supply limitations. Implementation of each portfolio results in both increased delivery and decreased shortage. *Portfolio A* and *Portfolio B* show slightly better performance (increasing delivery and reducing shortage) than the other portfolios, likely due to augmentation. In addition, the range of potential shortage and magnitude of shortage appears to be significantly reduced with each portfolio. Of particular interest is that with the implementation of each portfolio, shortage in the 2041 to 2060 time period is similar to shortages in the 2012 through 2026 (first) time period, even with , in general, future increase in demand and reduction in supply.

Figure A-5 shows the number of years where there is a Lee Ferry deficit and the associated magnitude. Under the Baseline, the deficit increases in both frequency and magnitude over time. Implementation of each portfolio reduces both deficit frequency and magnitude, with markedly better performance under *Portfolio A* and *Portfolio C*. Each of these portfolios includes the implementation of banking through routing conserved water to a conceptual off-stream storage location above Lake Powell.

For the Lower Basin, delivery decreases and shortage increases under the Baseline over time. This reflects future reduced supplies, while demands remain at or above apportionment. Implementation of each portfolio increases delivery over time to near the first time period levels and reduces median shortage to the first time period levels. Although median shortage across the scenarios is near first time period levels, there is potential for a higher magnitude of shortage under more-challenging scenarios. The Lower Division States currently have demands above basic apportionment. Under the Baseline, these demands increase through time. As each portfolio is implemented, these remaining demands above Lower Division States' basic apportionment are reduced over time from the Baseline. Further, by the 2041 through 2060 period, remaining demand above Lower Division States' basic apportionment is reduced well below first time period levels to near zero.

FIGURE A-1
Annual Upper Basin Delivery

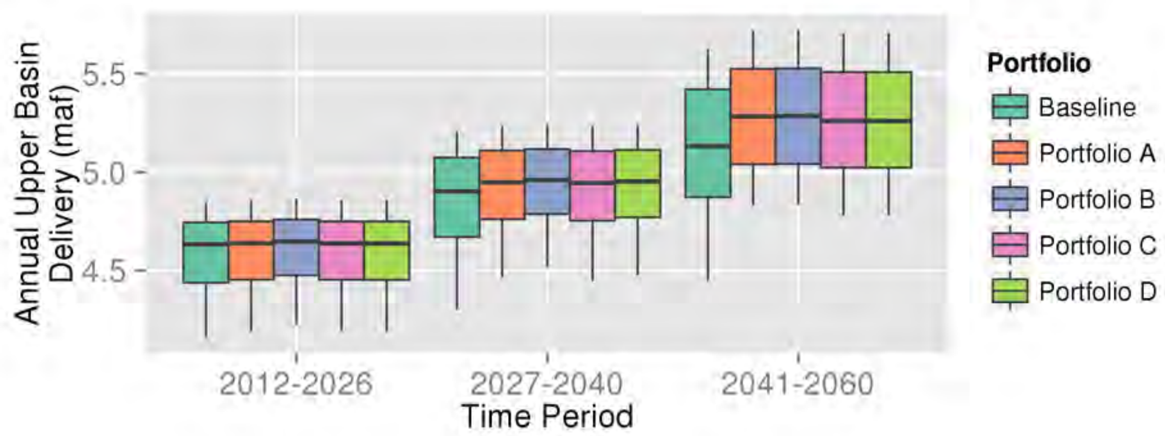



FIGURE A-2
Annual Upper Basin Shortage

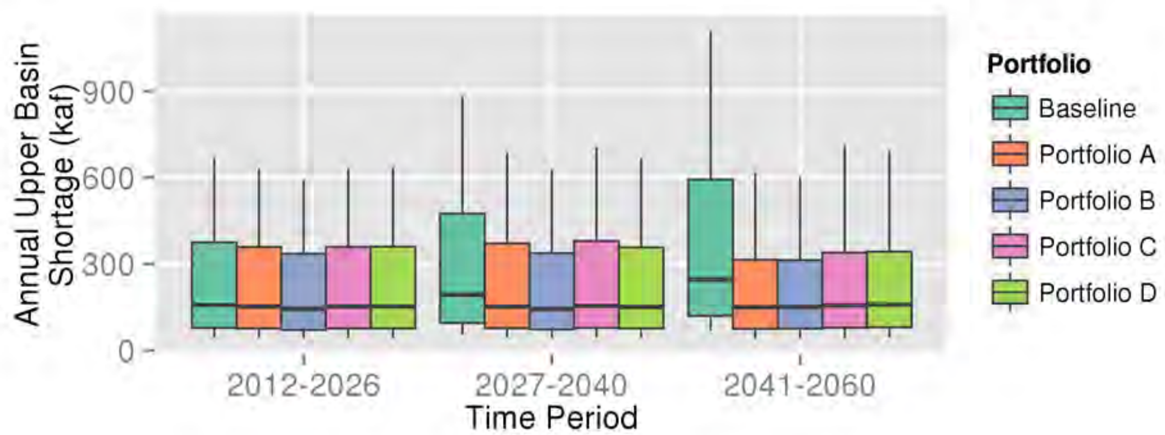



FIGURE A-3
Annual Lower Basin Shortage

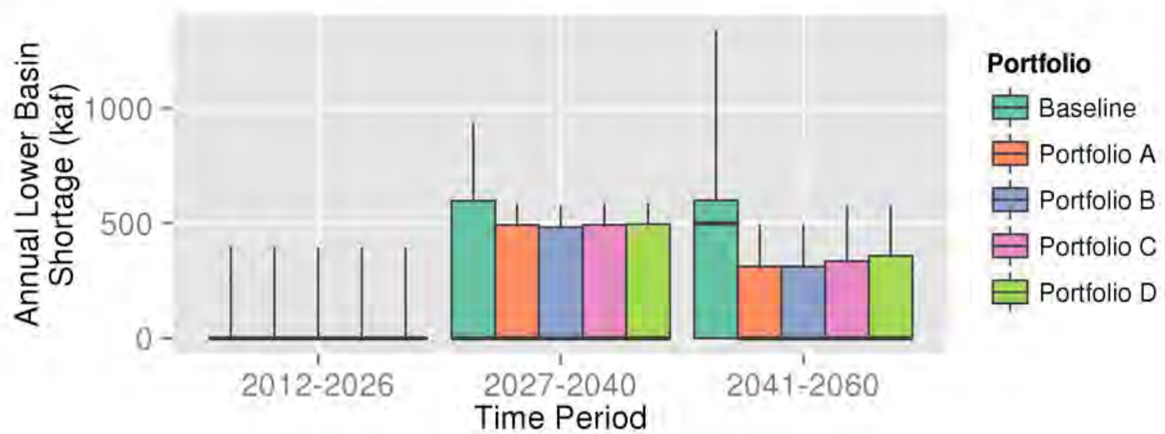


FIGURE A-4
Annual Lower Basin Delivery

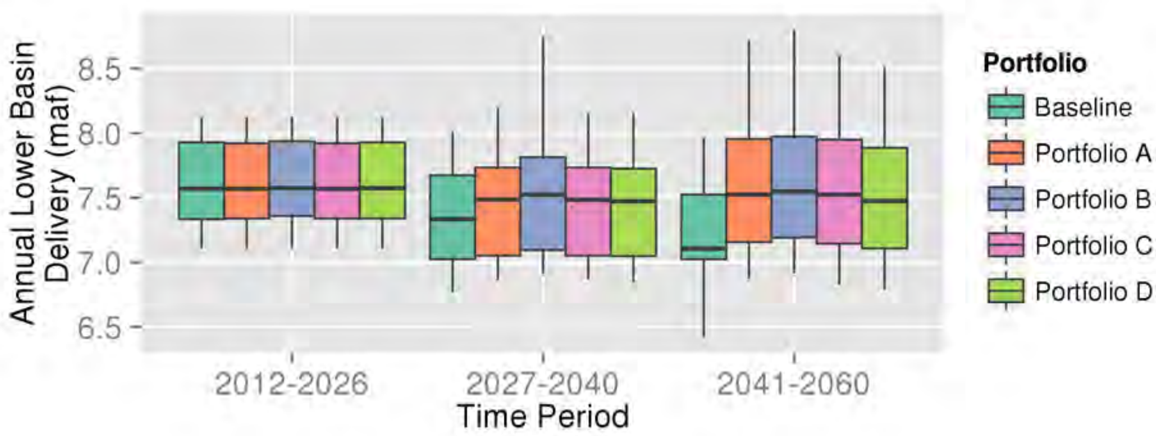



FIGURE A-5
Annual Lee Ferry Deficit (10-year flow volume less than 75 million acre-feet)

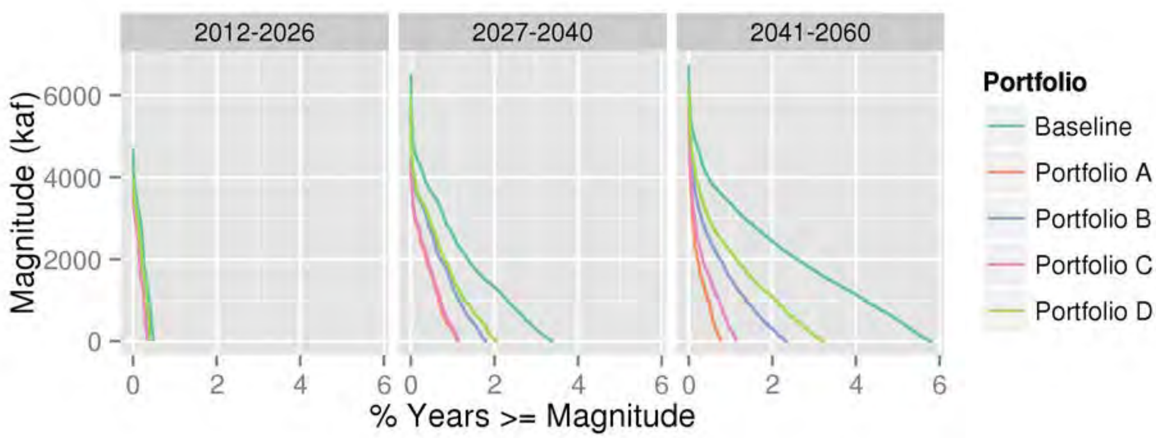
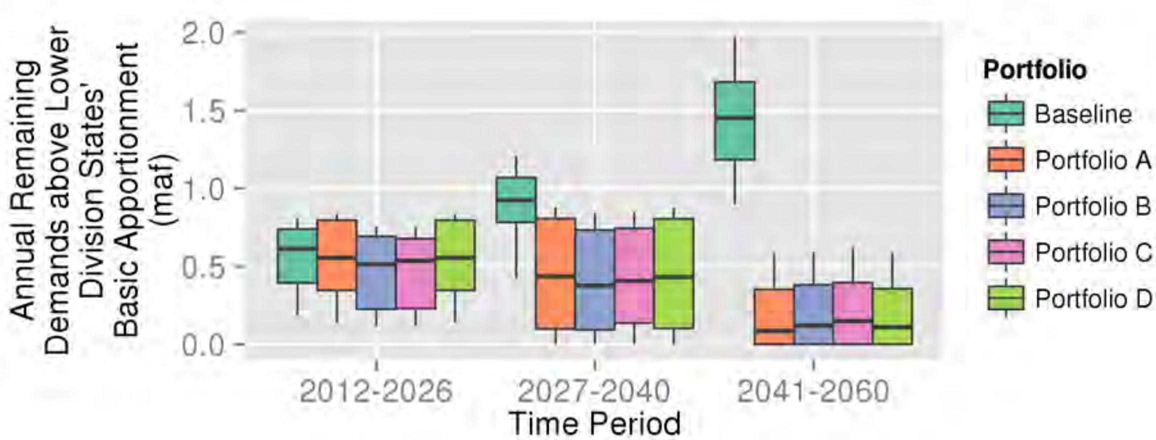



FIGURE A-6
Annual Remaining Demands Above Lower Division States' Basic Apportionment



### 2.2 Tribal Water Right Satisfaction

The assessment of system ability to satisfy tribal water rights, including tribal Central Arizona Project entitlements, was not explicitly evaluated due to CRSS's inability to simulate water rights in the Upper Basin and because CRSS does not include individual Central Arizona Project users. Tribal deliveries will be further analyzed in future studies—see the *Study Report* section on future considerations and next steps for additional details.

## 3.0 Metrics for the Other Water Deliveries Attribute of Interest

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

Figure A-7 shows CRSS simulated monthly Navajo Pool Elevation. In general, the median pool elevation declines over time across the scenarios for the Baseline. In addition, the 10th percentile pool elevations drop by more than 20 feet above msl. Implementation of each portfolio results in higher median pool elevations across the scenarios and an increase in the 10th percentile elevations. Note that the median elevations under Baseline and the portfolios are well above the minimum elevation for Navajo Irrigation Project diversion.

Figure A-8 shows the monthly Lake Mead pool elevation. Under the Baseline there is a marked drop in every month over time in pool elevation. Implementation of each portfolio results in an increase in pool elevation over time across the scenarios. *Portfolio A* appears to produce 2041 through 2060 time period pool elevations at or above the first time period elevations. However, for each of the portfolios, the range in potential elevations increases when compared to the first time period; this reflects increasing differences between scenarios through time.

Figure A-9 presents the annual flows at Morelos Diversion Dam that are above the required 1944 Treaty delivery. Under the Baseline, these flows decrease slightly in both magnitude and frequency over time. Implementation of each of the portfolios results in an increase in magnitude and frequency over time.

FIGURE A-7
Monthly Navajo Reservoir Pool Elevation
*Minimum Pool Elevation for Navajo Irrigation Project Diversion Reference Value Shown as Solid Red Line*

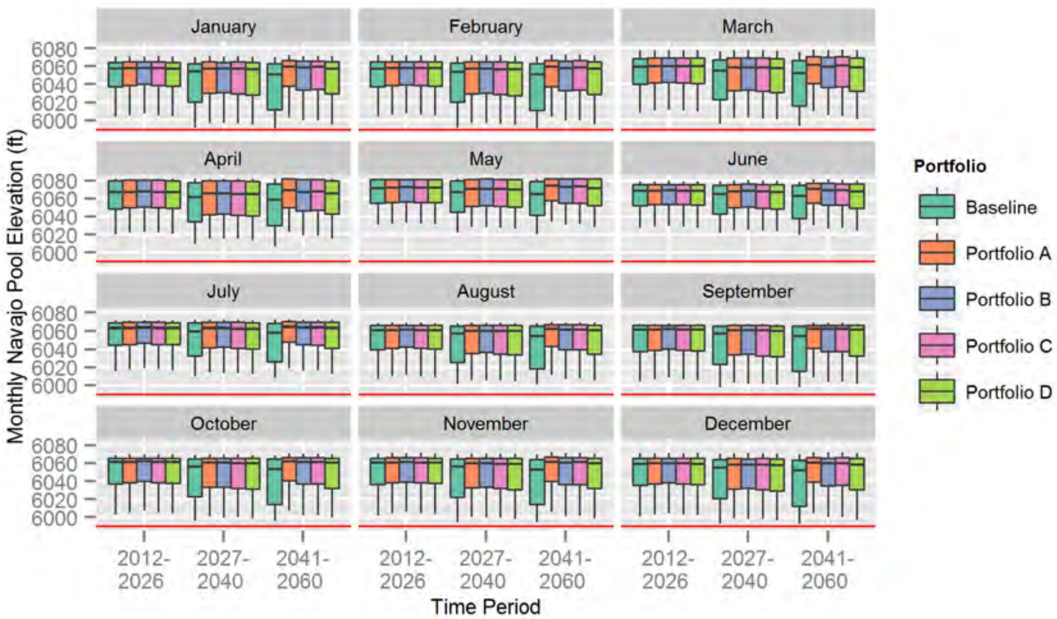



FIGURE A-8
Monthly Lake Mead Pool Elevation
*Elevation 1,000 ft msl Reference Value Shown as Solid Red Line*

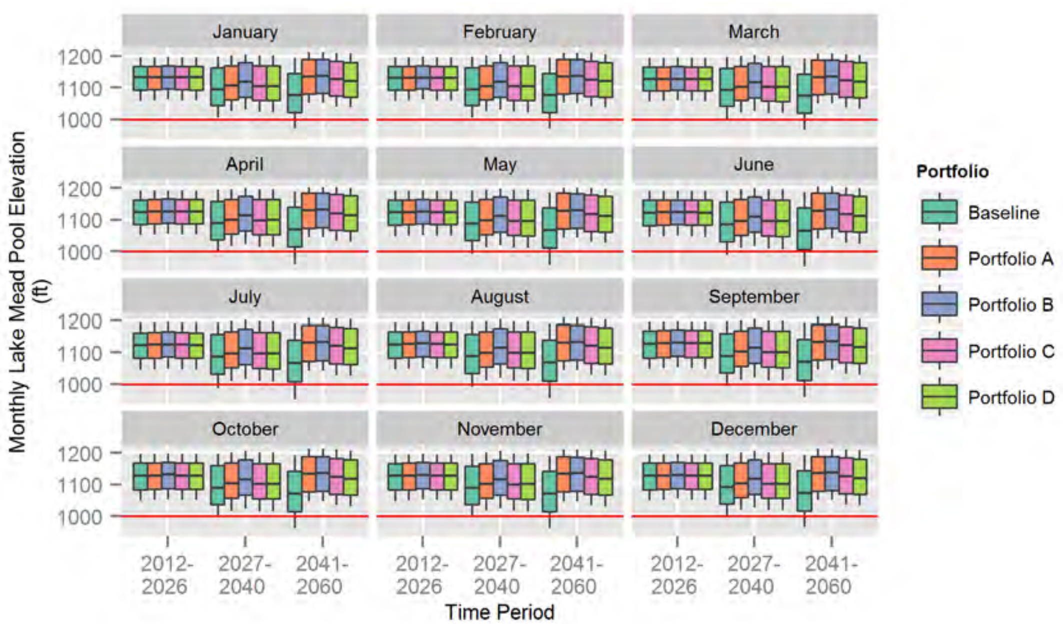
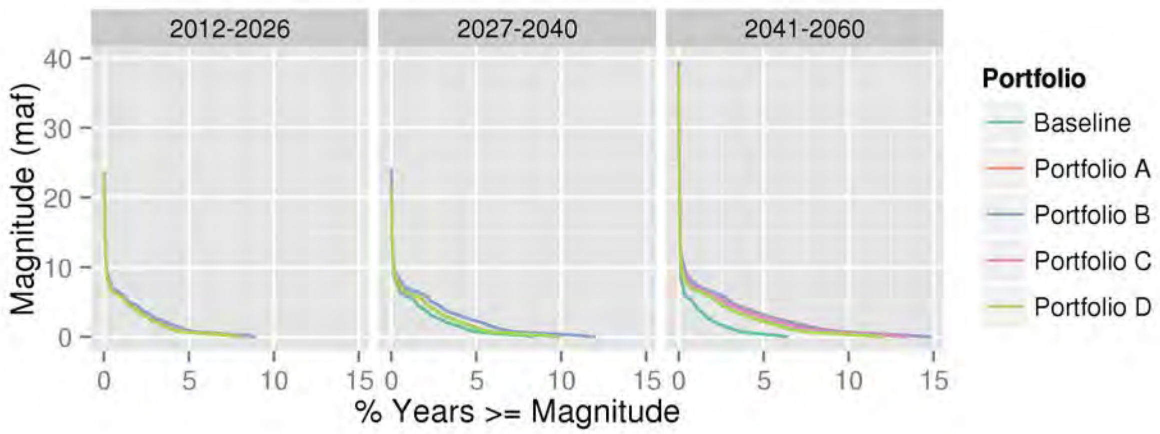


FIGURE A-9
Annual Flows at Morelos Diversion Dam Above the 1944 Treaty Delivery




# 4.0 Metrics for the Socioeconomic Impacts of Shortages Attribute of Interest

To quantitatively evaluate socioeconomic impacts of shortage conditions, an economic model that relates delivery shortages to employment, income, and tax revenue would be required. This model would need to be regional in nature and have the capability to allocate shortages among agricultural and municipal and industrial users. Economic models of this type have been built and used in the past. 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 are discussed qualitatively.

An unsure or stressed water supply could increase the potential for reduced economic activity. Unsure or reduced water supplies could result in new and existing water-reliant industries to locate elsewhere. Frequent shortage could result in reduced agricultural yield, impacting farm income as well as all of the associated industries. Additionally, as discussed in attachment E to appendix G4, reduced reservoir levels and flows could result in a reduction of recreation and associated income.

Figures A-2 and A-3 present Upper and Lower Basin shortage, respectively. As shown, shortage is anticipated to increase in frequency and magnitude over time under the Baseline. Implementation of the portfolios indicates that shortage can be mitigated. For the Lower Basin, median shortage over time is similar to the first time period. However, the range of shortage increases significantly as a result of low flow/high demand scenarios.

Appendix G4

# Attachment B

# Electrical Power Resources Metrics' Results

# Attachment B — Electrical Power Resources Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics,* were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for both the quantitative and qualitative metrics associated with the Electrical Power Resources category. The Electrical Power Resources attributes of interest are shown in table B-1.

Results are presented on a portfolio basis, in which all scenarios are grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(3) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

TABLE B-1
Resource Categories and Attributes of Interest

| Attribute of Interest | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|
| Electrical Power Generated | 2 | Quantitative | Annual | Upper Basin Aggregate | B-1 |
| | | | | Hoover | B-2 |
| | | | | Parker and Davis | B-3 |
| | | Qualitative | | Headgate Rock Power Plant | NA |
| Economic Value of Electrical Power Generated | 3 | Qualitative | NA | Basin-wide | NA |
| Available Generation Capacity | 4 | Quantitative | Monthly and Annual | Upper Basin Aggregate | B-4, B-5 |
| | | | | Hoover | B-6, B-7 |
| | | | | Parker and Davis | B-8, B-9 |
| Impact on Power Rates | 5 | Qualitative | NA | Basin-wide | NA |
| Water Supply System Pumping Costs | 6 | Qualitative | NA | Basin-wide | NA |
| Impact on Basin Funds | 7 | Qualitative | NA | Basin-wide | NA |

# 2.0 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 tailwater 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 Colorado River Basin (Basin). Hydropower plants in the Upper Basin that are modeled in the Colorado River Simulation System (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 facilities.

Figures B-1 through B-3 present the annual electrical power generated as computed in CRSS. Upper Basin electrical power generated can be compared to the associated power generation contract held by Western Area Power Administration (WAPA) of 4,948 terrawatt-hours. Figure B-1 shows annual electrical power generation for the aggregation of all Upper Basin power plants. Median power generation under the Baseline declines through 2060 to near the contract value. Implementation of each portfolio increases power generation to conditions in the 2012 through 2026 (first) time period.

FIGURE B-1
Annual Electrical Power Generated, Upper Basin Aggregate
*Power Generation Reference Value is shown as Solid Red Line.*

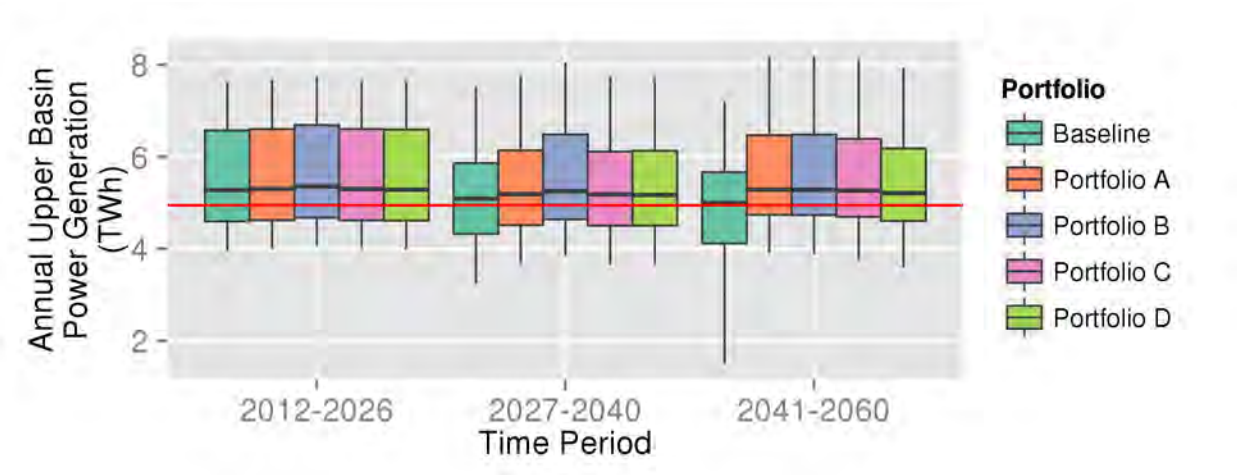



FIGURE B-2
Annual Electrical Power Generated, Hoover
*Power Generation Reference Value is shown as Solid Red Line.*

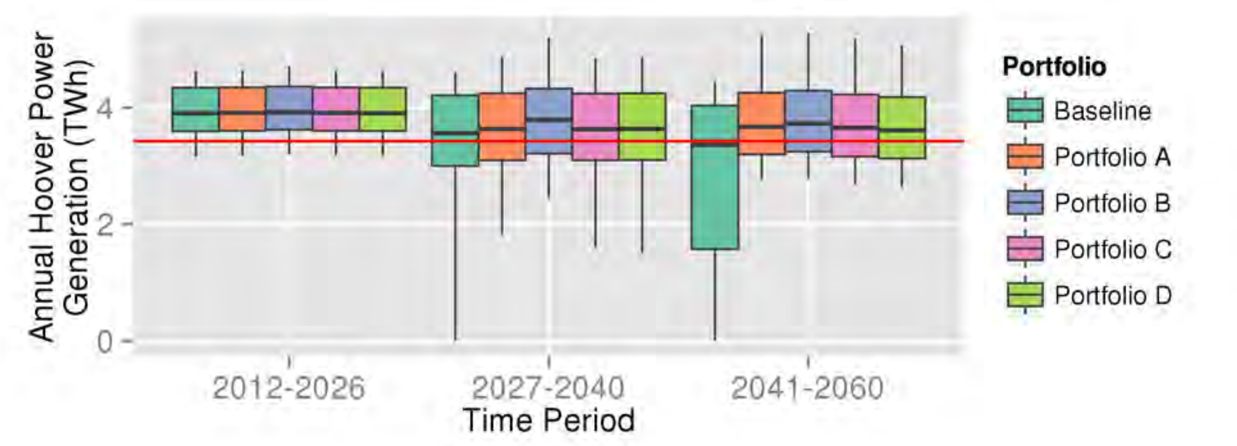


FIGURE B-3
Annual Electrical Power Generated, Parker and Davis

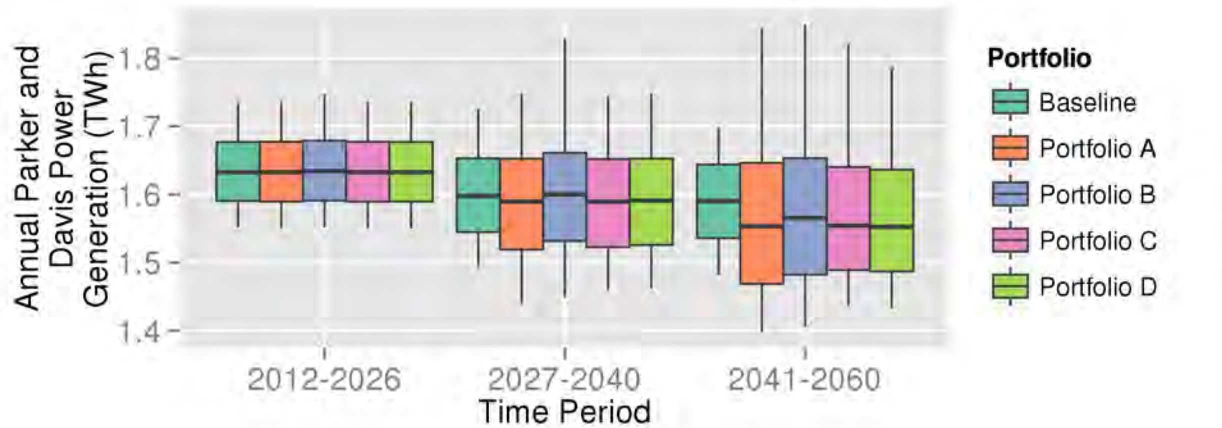



Figure B-2 shows the Hoover plant's power generation. Under the Baseline, median 2041 through 2060 power generation decreases to below the historical 10-year low reference provided by WAPA. Implementation of each portfolio improves power generation. However, historical generation rates are not achieved.

Figure B-3 shows power generation at the Parker and Davis power plants. Baseline power generation decreases over time through 2060. Implementation of each portfolio exacerbates this reduction, resulting in nearly twice the reduction of power generation over time. Presumably, this reduction in power generation is due to the implementation of desalination and/or reuse projects and demand reduction. With portfolios in place, options such as desalination and reuse help meet demands below Parker, resulting in reduced Parker releases and decreased energy generation.

The Headgate Rock Power Plant is located in the Lower Basin below Parker Reservoir. It is not explicitly modeled in CRSS. However, because the reservoir is operated to maintain a relatively constant elevation, changes in flow below Parker Reservoir can be used to assess changes in power generation.

Under the Baseline simulation, the median flow below Parker reduces over time, indicating some reduction in energy generated at Headgate Rock. Additionally, as portfolios implement options, there tend to be lower releases from Parker compared to the Baseline, once again indicating a reduction in energy generation at Headgate Rock.

# 3.0 Metrics for the Economic Value of Electrical Power Generated

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

Economic value can be assessed qualitatively by examining electrical power generated and assuming that increases in power result in additional economic value and decreases in power result in a loss of economic value. Figures B-1 through B-3 present electrical power generation for the Upper Basin in aggregate, Hoover Dam, and Parker and Davis. Under the Baseline, power generation declines over time across the scenarios. Implementation of each portfolio results in an improvement in power generation over the Baseline. However, while Upper Basin power generation remains essentially unchanged over time from the first time period, Hoover power generation is slightly reduced, and Parker and Davis power generation appears to be reduced by around 5 percent. In aggregate, these results suggest a slight decrease in economic value.

# 4.0 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. WAPA 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.

Figures B-4 to B-9 show the monthly and annual generation capacity for the Upper Basin, Hoover Dam, and Parker and Davis dams through 2060, as modeled in CRSS. For the Upper Basin aggregate and Hoover Dam, the Baseline generation capacity declines over time, with particularly significant declines to at or near zero in the summer months when peak demands typically occur. Implementation of each portfolio results in significant improvements in available generation capacity over the Baseline, with most portfolios resulting in available generation capacity greater than conditions in the first time period. The portfolios also significantly increase the available power generation capacity in the worst conditions. In CRSS, Parker and Davis are operated to maintain relatively constant pool elevations, which results in a constant generating capacity. Although there is slight variation in the elevations at Parker and Davis across scenarios, it (1) generally does not greatly affect the generation capacity and (2) is not evident at the scale shown in figures B-8 and B-9.

FIGURE B-4
Monthly Available Generation Capacity, Upper Basin Aggregate. Generation Capacity
*Reference Value is shown as Solid Red Line.*

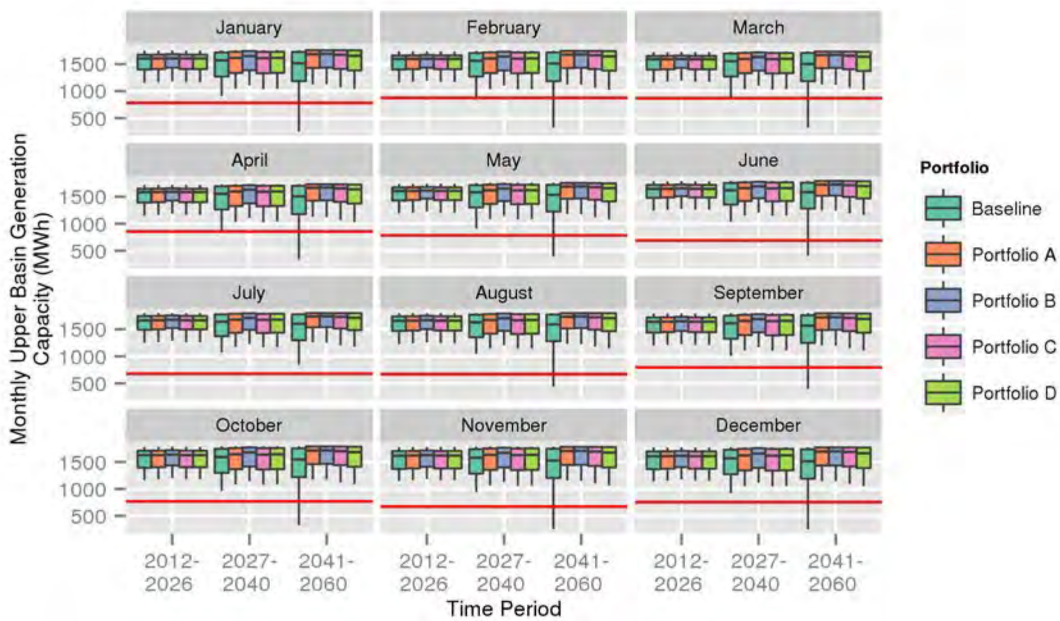



FIGURE B-5
Annual Available Generation Capacity, Upper Basin Aggregate. Generation Capacity
*Reference Value is shown as Solid Red Line.*

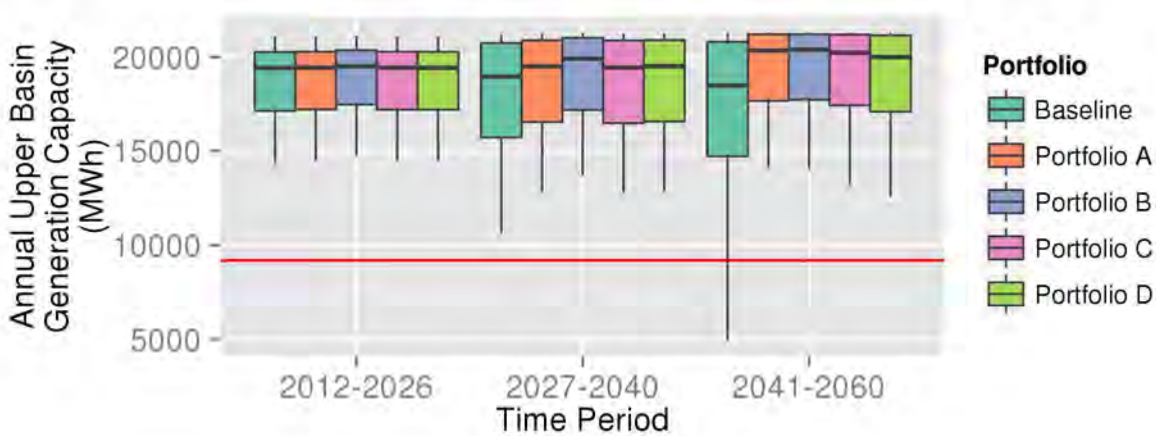


FIGURE B-6
Monthly Available Generation Capacity, Hoover. Generation Capacity
*Reference Value is shown as Solid Red Line.*

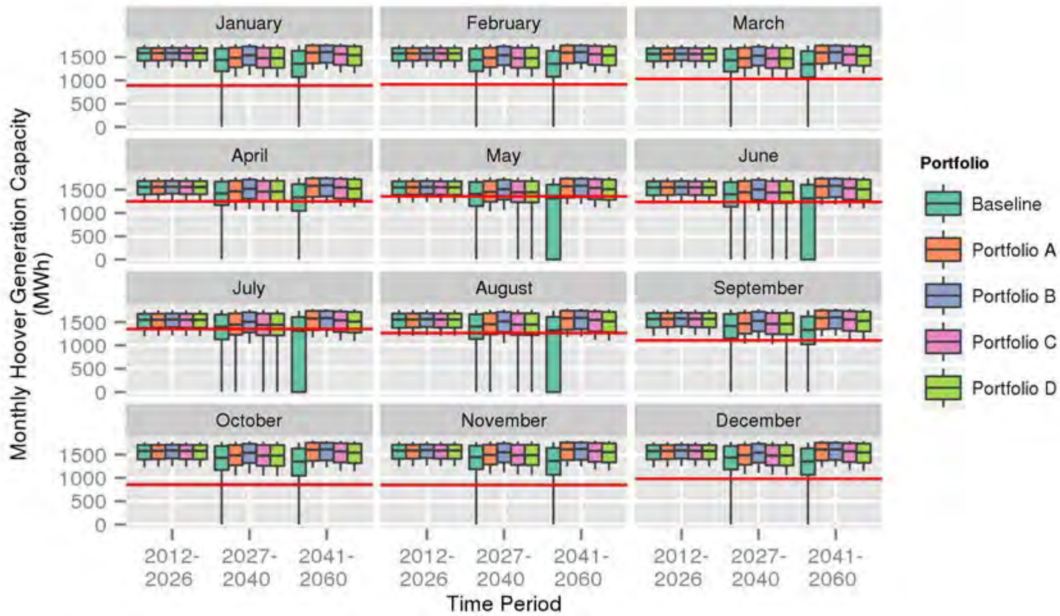



FIGURE B-7
Annual Available Generation Capacity, Hoover. Generation Capacity
*Reference Value is shown as Solid Red Line.*

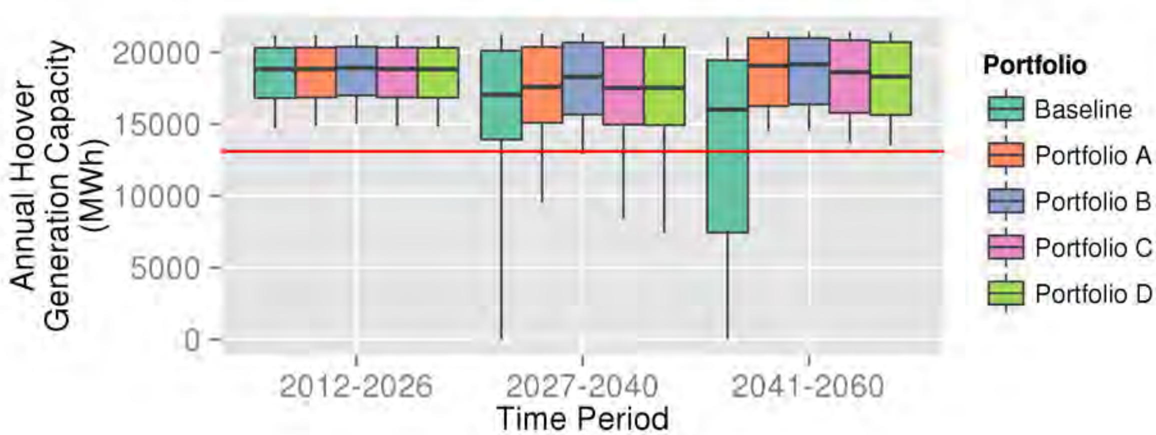


FIGURE B-8
Monthly Available Generation Capacity, Parker and Davis. Generation Capacity
*Reference Value is shown as Solid Red Line.*

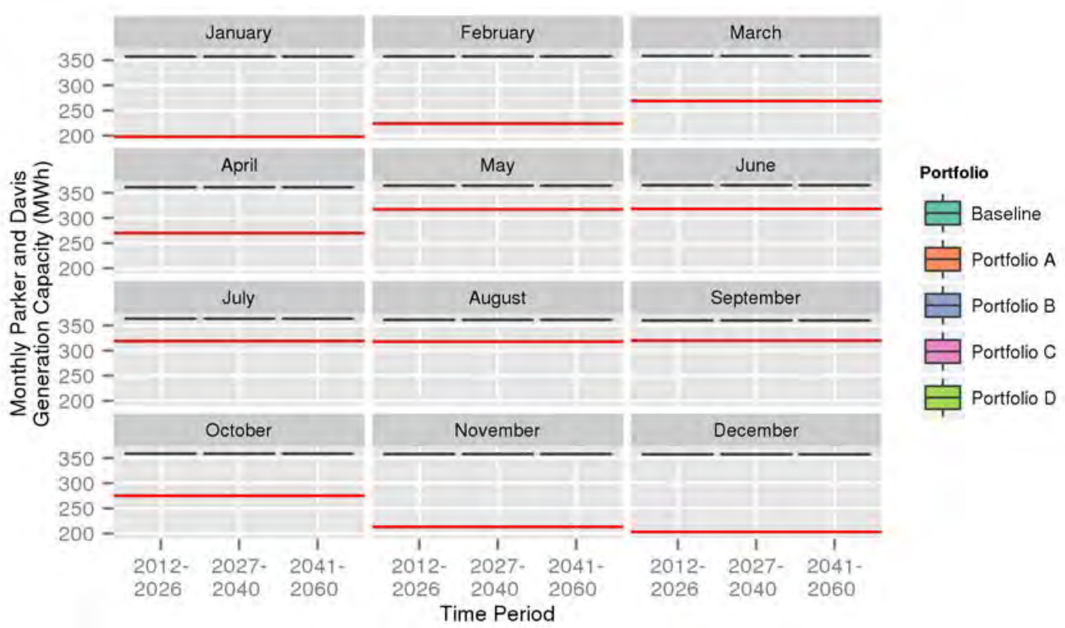
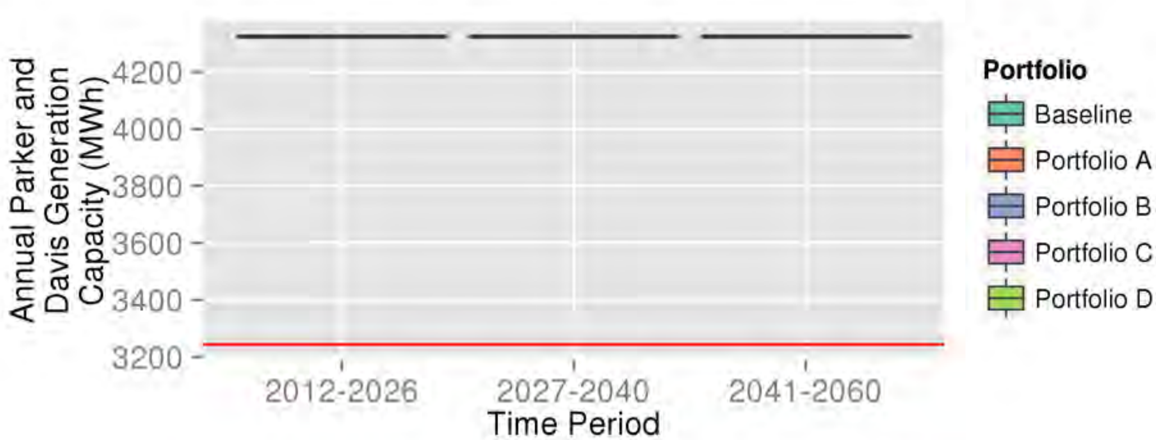



FIGURE B-9
Annual Available Generation Capacity, Parker and Davis. Generation Capacity
*Reference Value is shown as Solid Red Line.*




# 5.0 Metrics for the Impact on Power Rates Attribute of Interest

For the Upper Basin, WAPA has firm delivery contracts in place. When WAPA cannot meet these contract amounts, power must be purchased on the open market at substantially higher rates. Projected increased demand and reduced supplies will likely result in increased frequency of these power buys, potentially increasing the overall rate for power. As shown in figure B-1, CRSS simulations indicate significantly reduced power generation by 2060 for the Baseline. Improvement in power generation occurs with each of the portfolios. Implementation of each portfolio results in power generation similar to generation in the first time period, with slightly worse performance under *Portfolio D*. Implementation of each portfolio would likely result in little to no change in power rates due to changes in power generation.

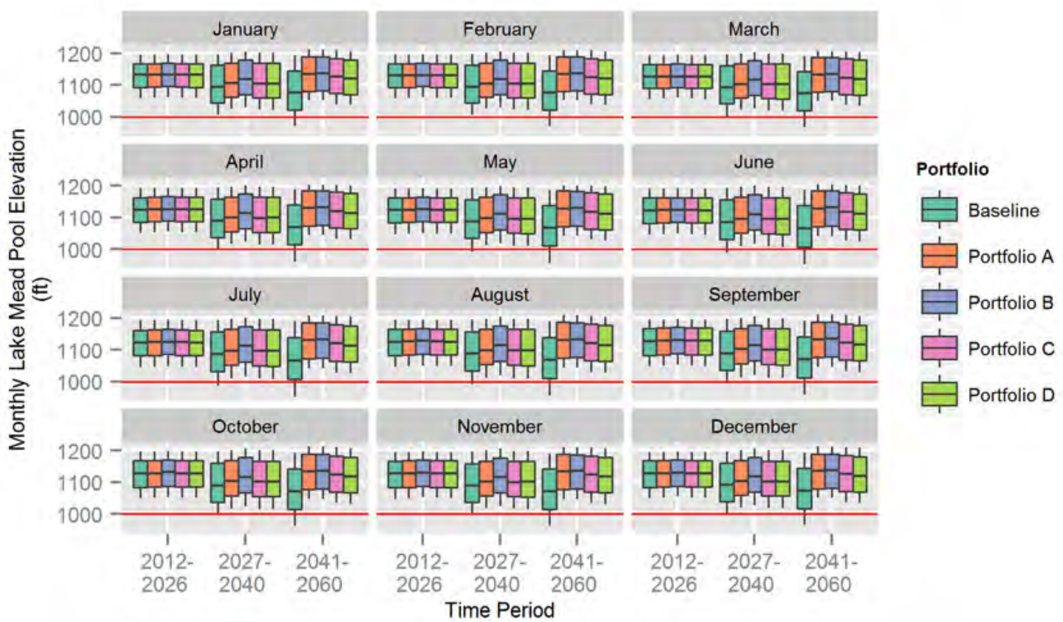
Reduced power generation in the Lower Basin will likely require power purchases on the open market. This increased demand on the market will likely result in an overall increase in market rates. As noted in figure B-2, median power generation at Hoover Dam decreases over the long term. Each of the portfolios reduces this decrease, with *Portfolio B* resulting in the best long-term power generation from Hoover Dam and overall generation only slightly reduced from generation in the first time period. This result implies that there may be the need for some additional power buys in the Lower Basin with some associated increase in power rates.

# 6.0 Metrics for the Water Supply System Pumping Costs Attribute of Interest

Lower water levels in reservoirs may affect pumping power requirements for some entities. Examples include the Salt River Project, which extracts cooling water from Lake Powell for the Navajo Generating Station; 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 Central Arizona Project delivery area. Based on current reservoir operations and typical utility equipment and procedures, there should be little effect on power costs due to changing reservoir levels for most of these utilities. However, because SNWA uses variable speed pumps, changing Lake Mead levels could impact pumping costs.

As shown in figure B-10, CRSS simulations indicate that the median Lake Mead elevation under the Baseline is significantly reduced over time. This reduced elevation would likely result in increased pumping costs for SNWA. All of the portfolios improve Lake Mead elevation and reduce the range of variability in elevations through 2060 compared to Baseline results. *Portfolio A* results in the most improvement of Lake Mead elevations through 2060. All of the portfolios except for *Portfolio D* result in 2060 median Lake Mead elevations higher than recent elevations, suggesting potential future decreased relative pumping costs for SNWA.

FIGURE B-10
Monthly Lake Mead Pool Elevation
*Elevation 1,000 ft msl Reference Value shown as Solid Red Line*




## 7.0 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. 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. Reduced power generation will likely result in a loss of revenue, potentially impacting the noted revenue uses.

As shown in figures B-1 to B-3, CRSS simulations indicate significantly reduced power generation and subsequent likely loss of revenue by 2060 for the Baseline.  Improvement in power generation occurs with each of the portfolios.  Power generation is essentially maintained at or near first time period levels in the Upper Basin and at Hoover Dam, with significant reductions at Parker and Davis Dam. These results suggest a likely reduction in overall revenue and impact to Basin Funds.

**Appendix G4**

# Attachment C
# Water Quality Metrics' Results

# Attachment C — Water Quality Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics*, were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for both the quantitative and qualitative metrics associated with the Water Quality resource category. The Water Quality resource attributes of interest are shown in table C-1.

Results are presented on a portfolio basis, in which all scenarios are grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(4) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the baseline as well as each scenario for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

(5) Frequency and magnitude plots showing line plots relating the frequency of occurrence (typically the percentage of years) of an event compared to the magnitude of the event. These plots are also presented over time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

TABLE C-1
Water Quality Metrics

| Attribute of Interest | Section | Quantitative or Qualitative | Plot Type | Locations | Figure Number |
|---|---|---|---|---|---|
| Salinity | 2 | Quantitative | Annual | Colorado River Below Hoover Dam | C-1 |
| | | | | Colorado River Below Parker Dam | C-2 |
| | | | | Colorado River At Imperial Dam | C-3 |
| | | | | Colorado River near Glenwood Springs, CO | C-4 |
| | | | | Colorado River near Cameo, CO | C-5 |
| | | | | Gunnison River near Grand Junction, CO | C-6 |
| | | | | Dolores River near Cisco, CO | C-7 |
| | | | | Colorado River near Cisco, CO | C-8 |
| | | | | Green River at Green River, WY | C-9 |
| | | | | Green River near Greendale, UT | C-10 |
| | | | | Yampa River near Maybell, CO | C-11 |
| | | | | Duchesne River near Randlett, UT | C-12 |
| | | | | White River near Watson, UT | C-13 |
| | | | | Green River at Green River, UT | C-14 |
| | | | | San Rafael River near Green River, UT | C-15 |
| | | | | San Juan River near Archuleta, NM | C-16 |
| | | | | San Juan River near Bluff, UT | C-17 |
| | | | | Colorado River at Lees Ferry, AZ | C-18 |
| | | | | Colorado River near Grand Canyon, AZ | C-19 |
| | | | | Virgin River near Littlefield, AZ | C-20 |
| Sediment Transport | 3 | Qualitative | NA | Basin-wide | NA |
| Temperature | 4 | Qualitative | NA | Basin-wide | NA |
| Other Water Quality constituents | 5 | Qualitative | NA | Basin-wide | NA |
| Socioeconomic Impacts Related To Salinity | 6 | Qualitative | NA | Basin-wide | NA |

# 2.0 Metrics for the Salinity Attribute of Interest

In order to comply with the Clean Water Act, the Colorado River Basin Salinity Control Forum (Forum) develops numeric salinity criteria for water below Hoover and Parker dams and at Imperial Dam. The most recent criteria are 723, 747, and 879 milligrams per liter[1], respectively and were developed in 2011. In addition, Minute No. 242 of the International Boundary and Water Commission provides that the United States ensure that waters 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 that arrive at Imperial Dam.

Colorado River Simulation System (CRSS) output for these locations, along with 17 additional monitoring locations, is shown in figures C-1 to C-20. Due to modeling limitations, the results shown include only the Observed Resampled and the Paleo Resampled supply scenarios. In examining these results the following broad observations are made:

1. **Negative concentrations –** Negative concentrations were reported in some simulations for the locations shown in figures C-12 and C-15, which is clearly unrealistic. CRSS models water quality improvements projects (WQIPs), which remove salinity from the system, using a constant mass removal. A negative concentration results if, in any given month, the salinity mass in the reach is less than the WQIP's set removal amount. This modeling limitation will be addressed in the future.
2. **Prescribed conditions** (Hoover, Parker, and Imperial, figures C-18 to C-20) – Salinity increases under the Baseline, likely due to the increasing demand coupled with reduced supply. The increases are less than 10 percent and do not approach the prescribed concentrations. Implementation of each of the portfolios reduces salinity concentrations from the Baseline but does not reduce to 2012 through 2026 concentrations.
3. **Lower concentrations –** Three of the locations—Delores River near Cisco, CO (figure C-7), Duchesne River near Randlett, UT (figure C-12), and San Rafael River near Green River, UT (figure C-15)—result in future salinity concentration reductions under the Baseline. The decrease in Baseline salinity may be due to decreases in demand resulting in more available flow for dilution. Implementation of each portfolio results in small future reductions from the Baseline. At these locations *Portfolio B* tends to reduce concentrations more than the other portfolios.
4. **Same concentrations –** In two cases, the White River near Watson, UT (figure-C-13) and the Virgin River near Littlefield, AZ (figure C-20), there is little to no change in salinity concentration under the Baseline or with implementation of each portfolio. For the White River near Watson, UT, consistent concentrations appear to be due to relatively small changes in demand or supply from the Baseline scenario. For the Virgin River near Littlefield, AZ, this effect is due to the fact that this location only considers natural flow and is outside of the locations that demands are specifically modeled.
5. **Higher concentrations –** For the remaining locations, salinity steadily increases under the Baseline and is significantly reduced with the implementation of each portfolio. These decreases are due to either demand reduction and/or augmentation, resulting in

[1] Flow-weighted average annual salinity.

greater overall flow and subsequently more dilution and lower salinity concentrations. Two distinct patterns emerge in comparing future portfolio performance related to location. These distinctions are represented by the Colorado River near Glenwood Springs, CO and by the Green River at Green River, WY. For the Colorado River near Glenwood Springs, CO, the salinity is reduced from the Baseline but appears to increase from *Portfolio A* to P*ortfolio D*. This effect is likely due to varying degrees of increased dilution in *Portfolio A* and *Portfolio B* due to the inclusion of importation options. For the Green River at Green River, WY, salinity is reduced from the Baseline, but *Portfolio A* and P*ortfolio C* appear to perform better with respect to salinity concentration. This effect is likely due to the inclusion of banking in these portfolios which routes conserved water to a conceptual off-stream storage location above Lake Powell. The routing increases flow in the reaches resulting in increased dilution.

FIGURE C-1
Annual Salinity, Colorado River below Hoover Dam
*Numeric Salinity Criteria Reference Value Shown as Solid Red Line.*

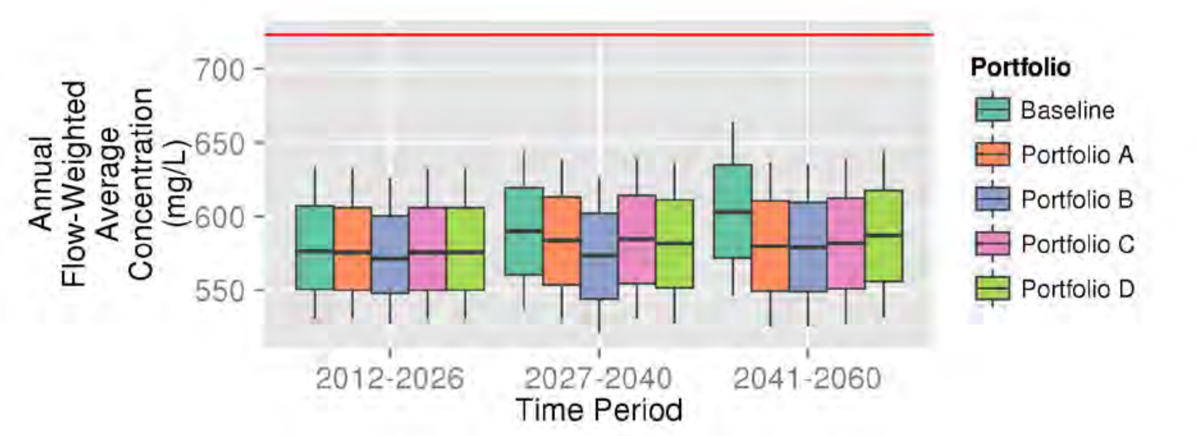


FIGURE C-2
Annual Salinity Colorado River below Parker Dam
*Numeric Salinity Criteria Reference Value Shown as Solid Red Line.*

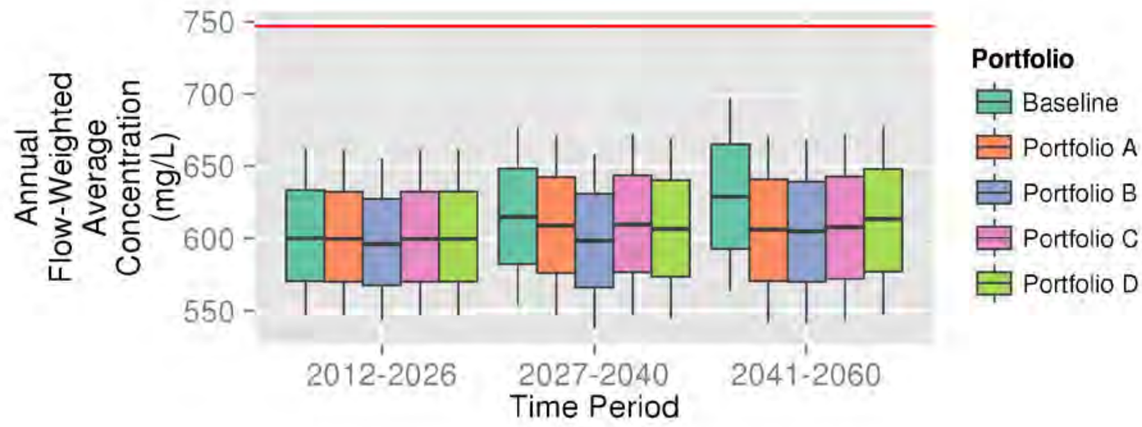



FIGURE C-3
Annual Salinity, Colorado River at Imperial Dam
*Numeric Salinity Criteria Reference Value Shown as Solid Red Line.*

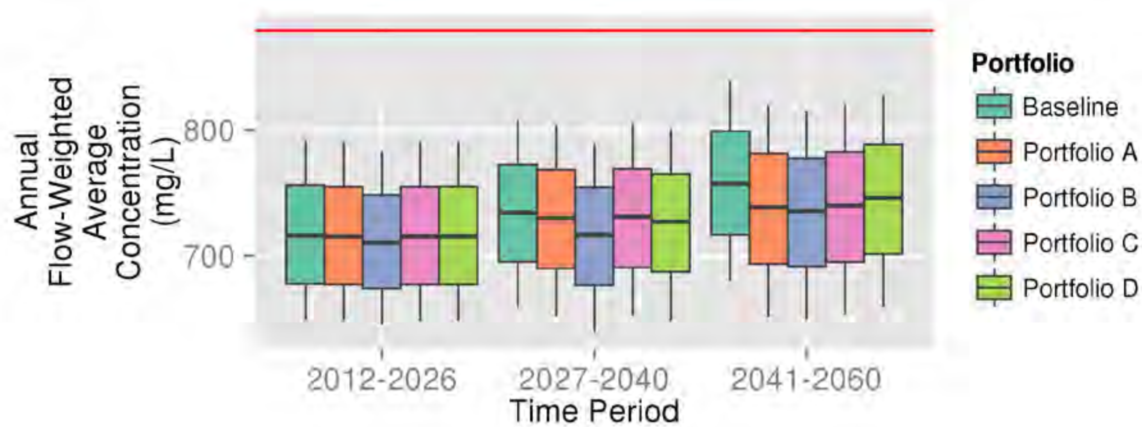



FIGURE C-4
Annual Salinity, Colorado River near Glenwood Springs, CO

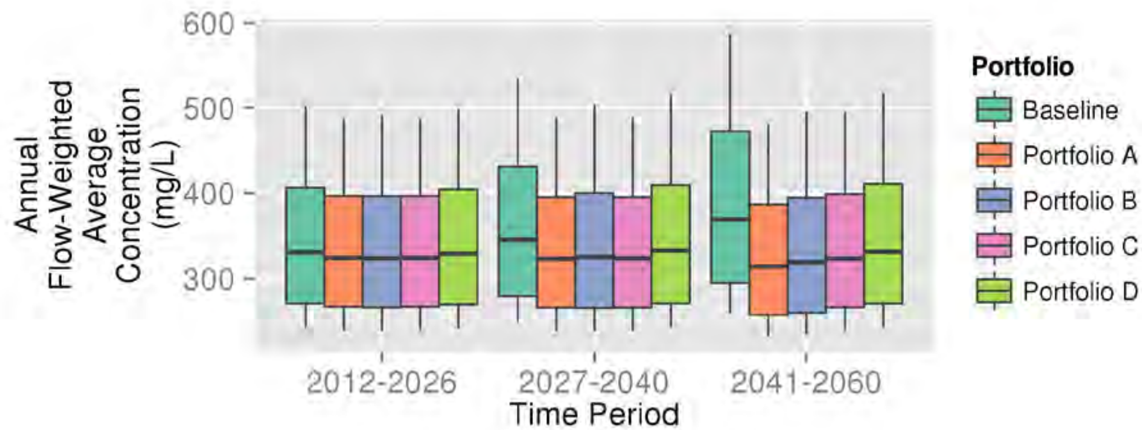


FIGURE C-5
Annual Salinity, Colorado River near Cameo, CO

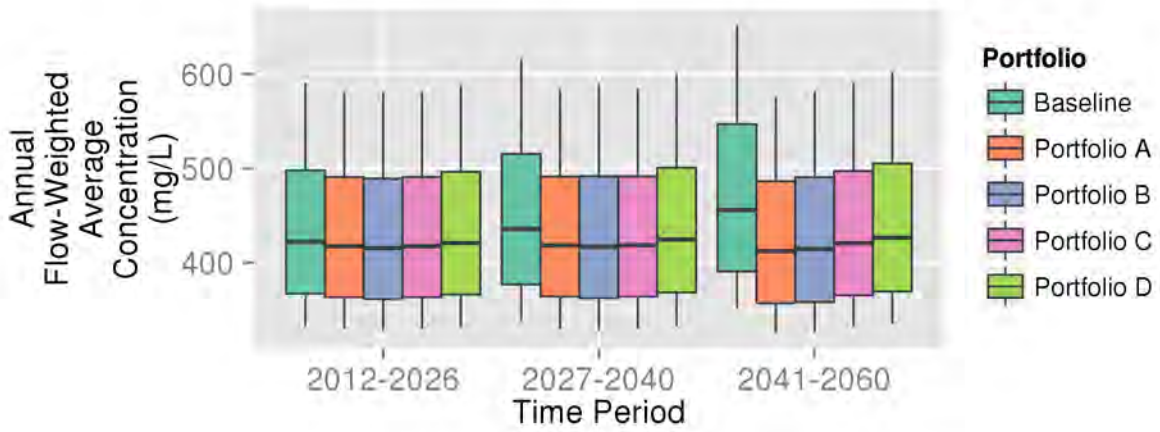



FIGURE C-6
Annual Salinity, Gunnison River near Grand Junction, CO

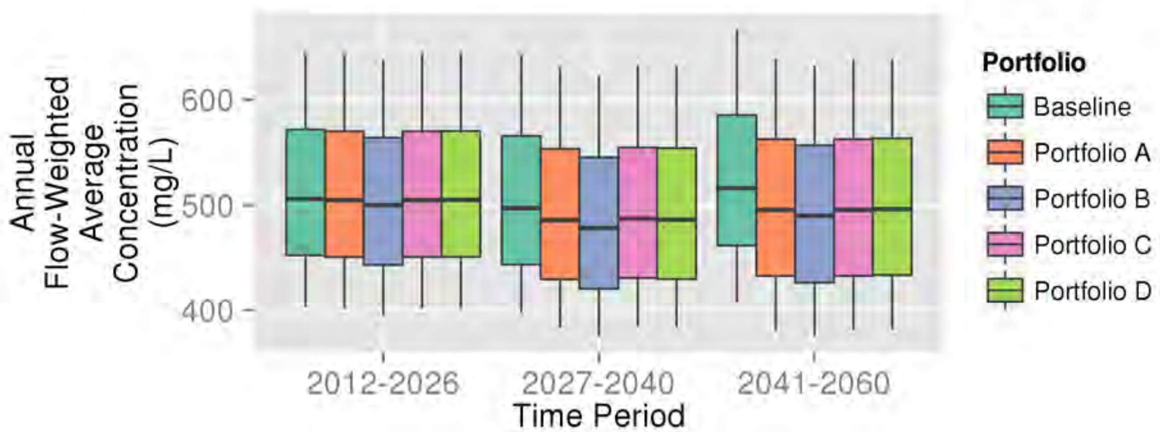



FIGURE C-7
Annual Salinity, Dolores River near Cisco, CO

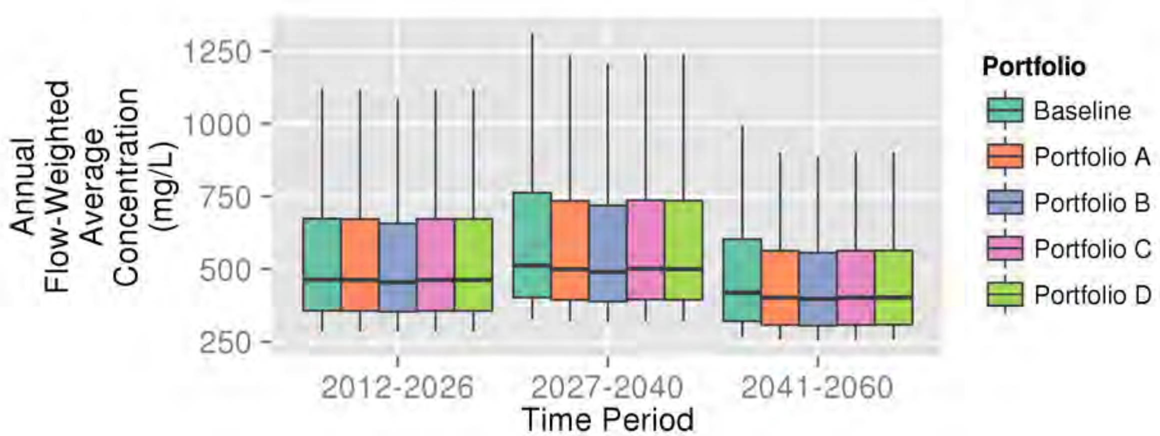


FIGURE C-8
Annual Salinity Colorado River near Cisco, CO

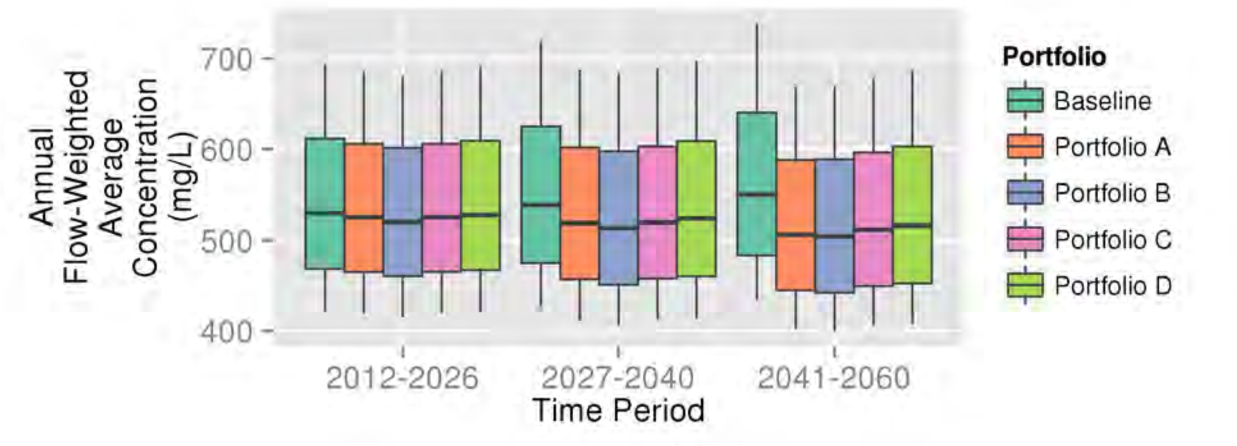



FIGURE C-9
Annual Salinity, Green River at Green River, WY

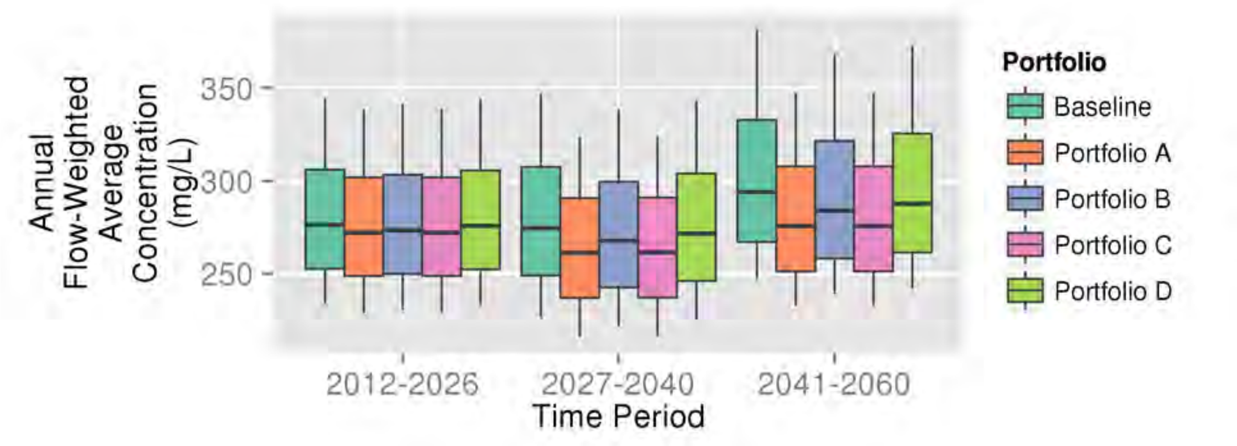



FIGURE C-10
Annual Salinity, Green River near Greendale, UT

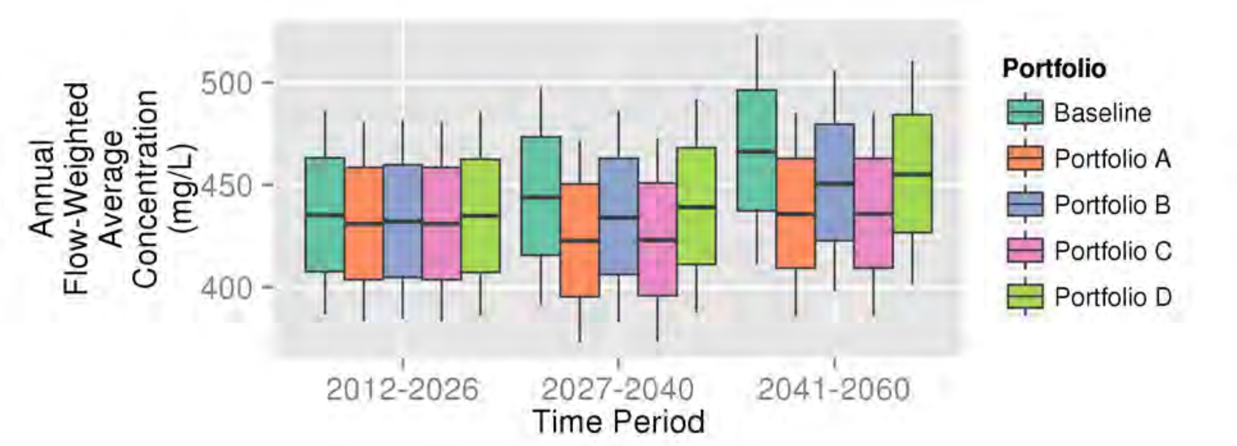


FIGURE C-11
Annual Salinity, Yampa River near Maybell, CO

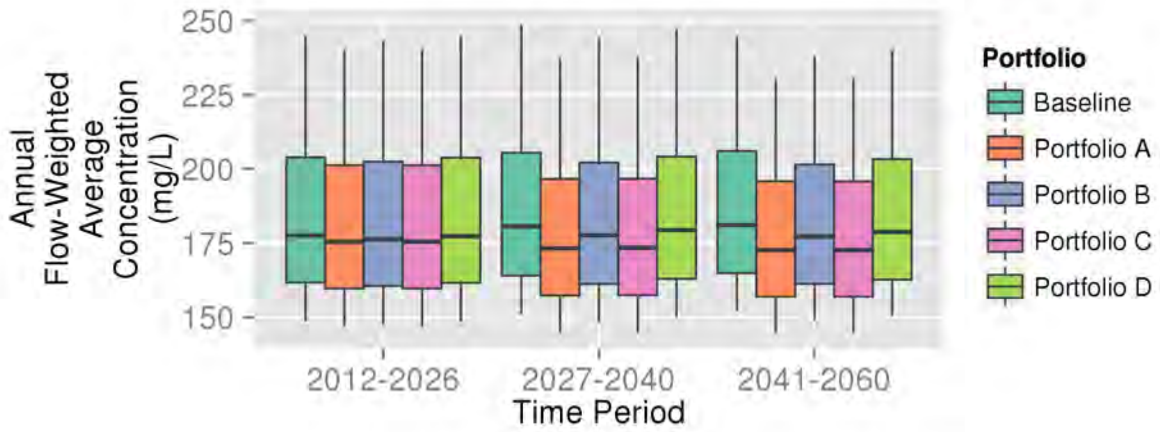



FIGURE C-12
Annual Salinity, Duchesne River near Randlett, UT

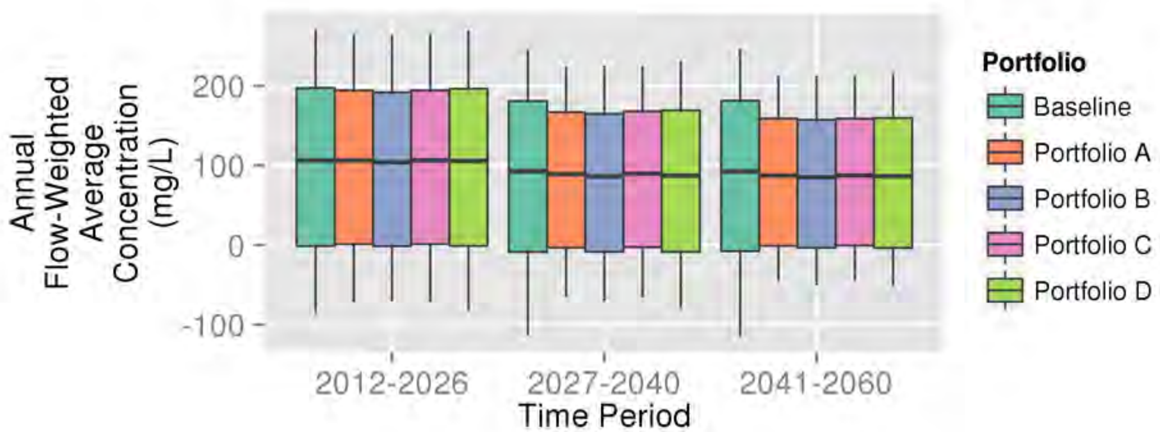



FIGURE C-13
Annual Salinity, White River near Watson, UT

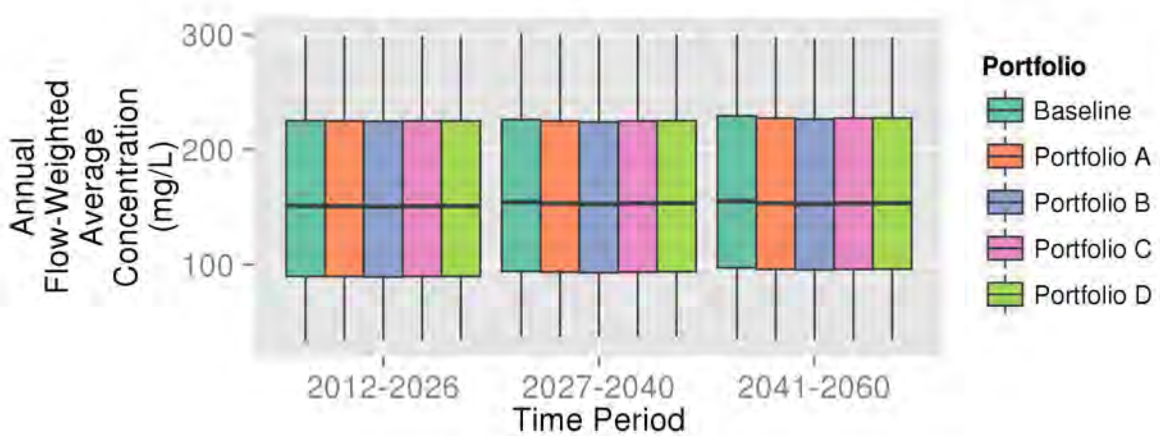


FIGURE C-14
Annual Salinity, Green River at Green River UT

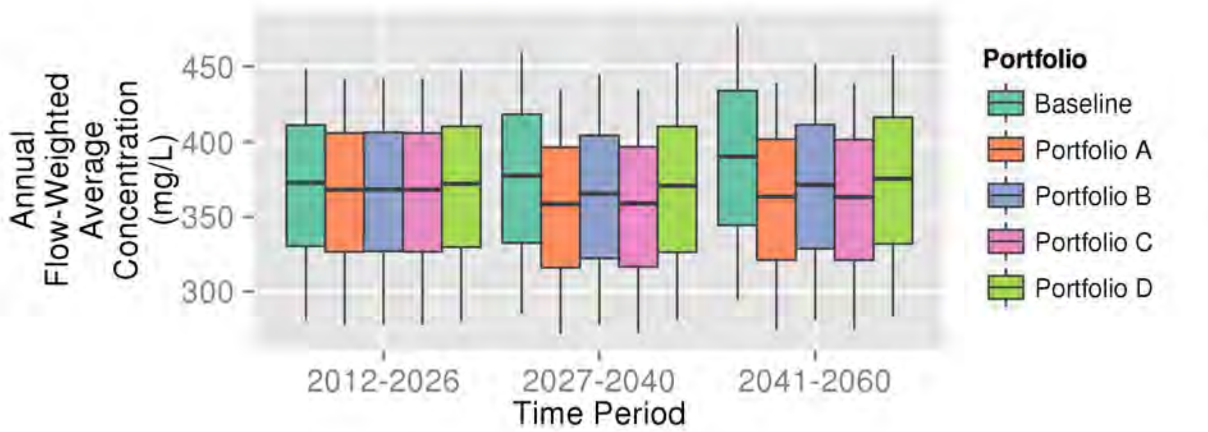



FIGURE C-15
Annual Salinity, San Rafael River near Green River, UT

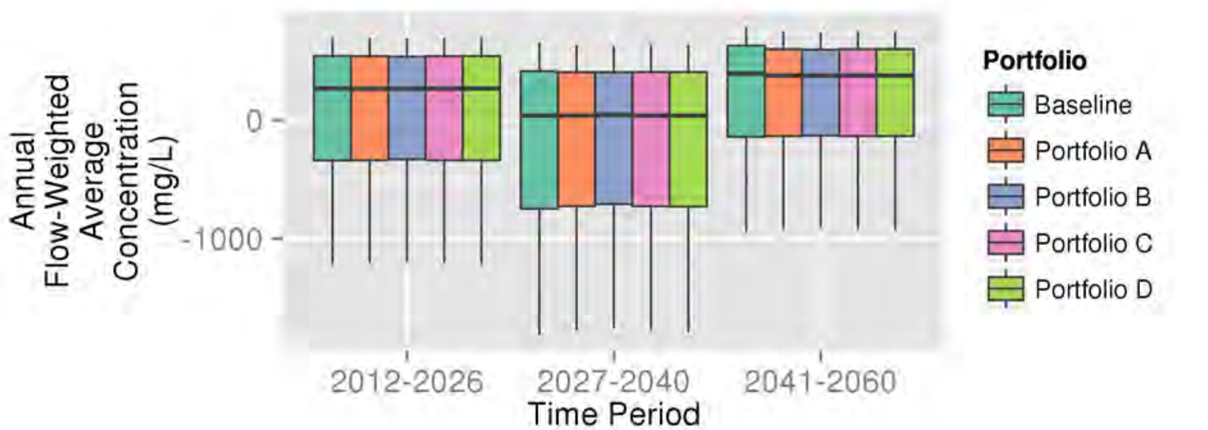



FIGURE C-16
Annual Salinity, San Juan River near Archuleta, NM

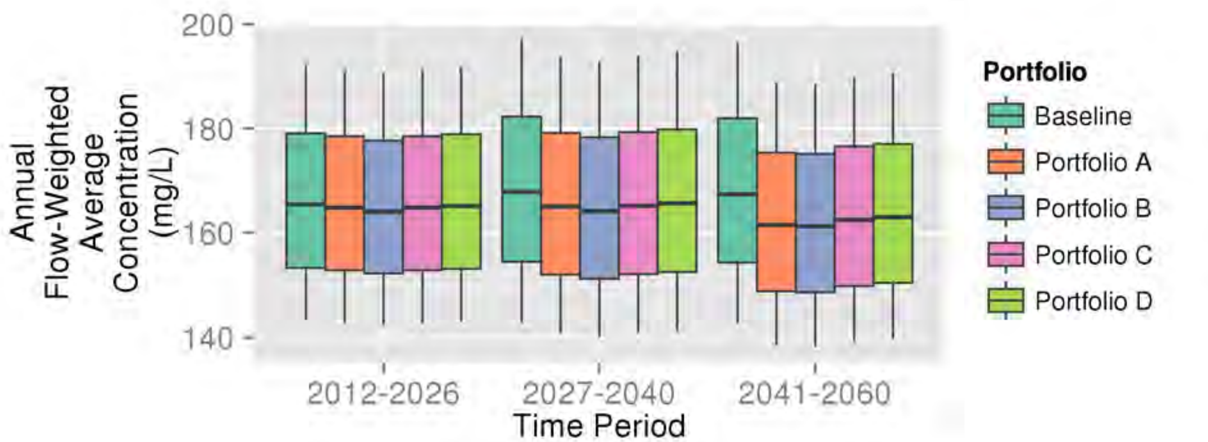


FIGURE C-17
Annual Salinity, San Juan River near Bluff, UT

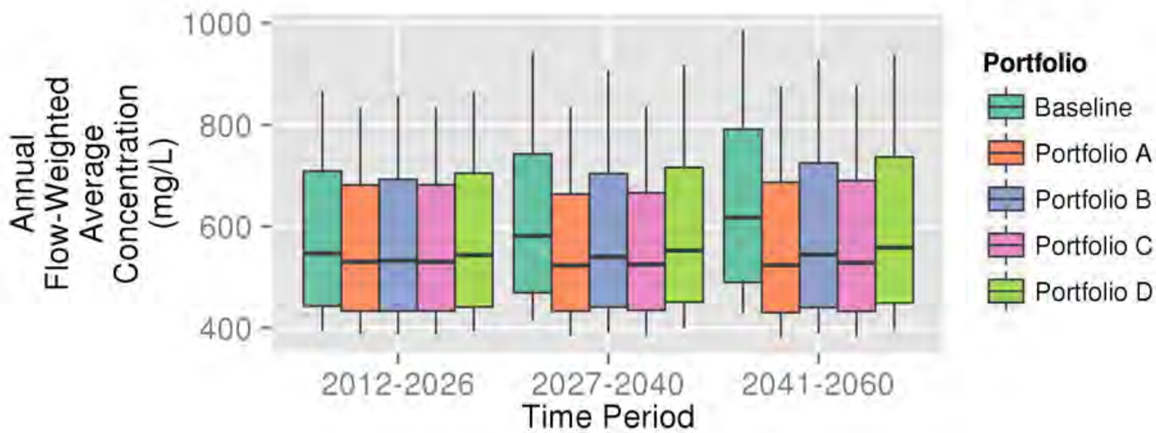



FIGURE C-18
Annual Salinity, Colorado River at Lees Ferry, AZ

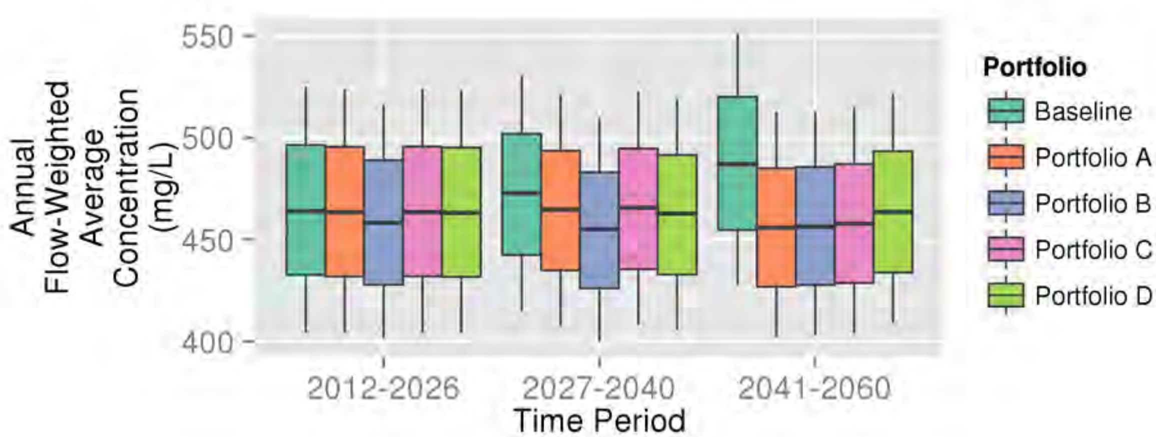



FIGURE C-19
Annual Salinity, Colorado River near Grand Canyon, AZ

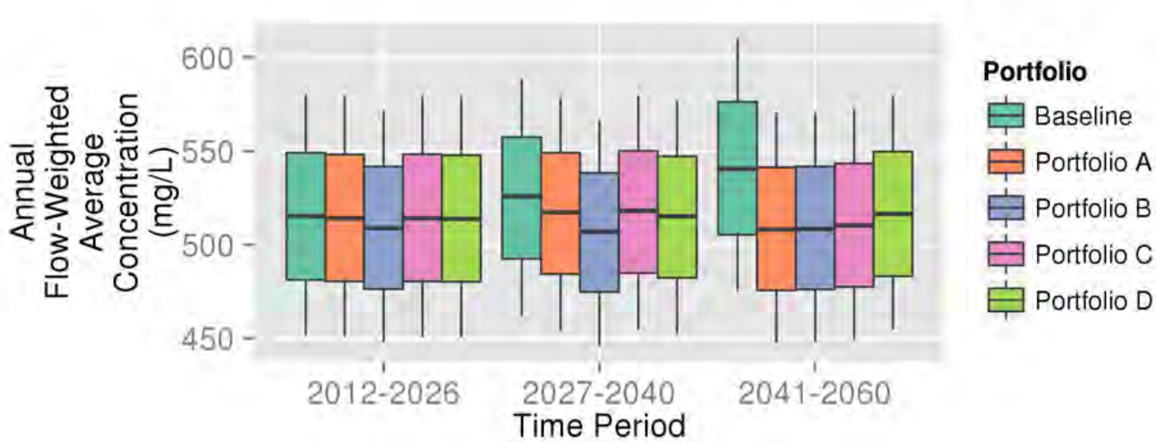
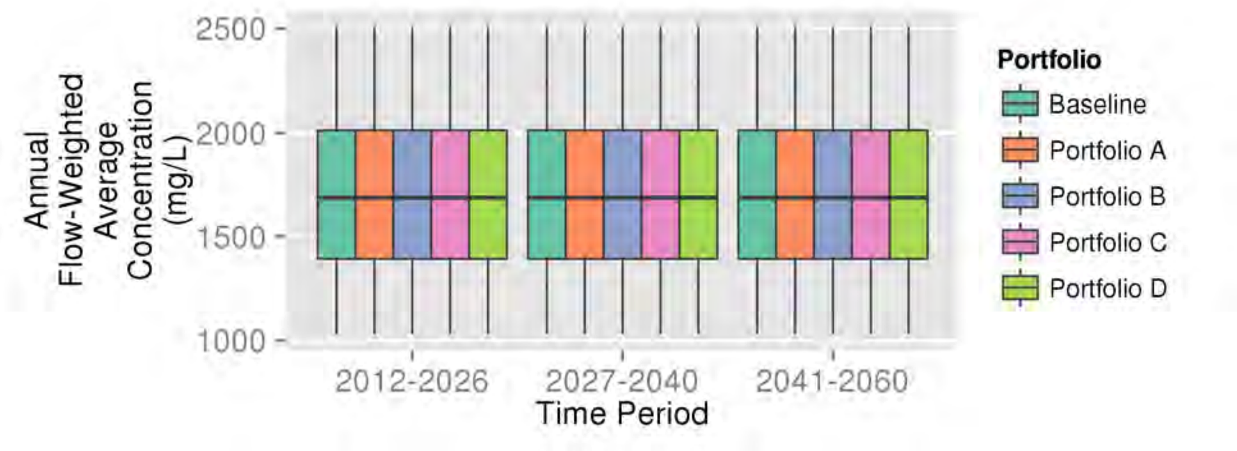


FIGURE C-20
Annual Salinity, Virgin River near Littlefield, AZ

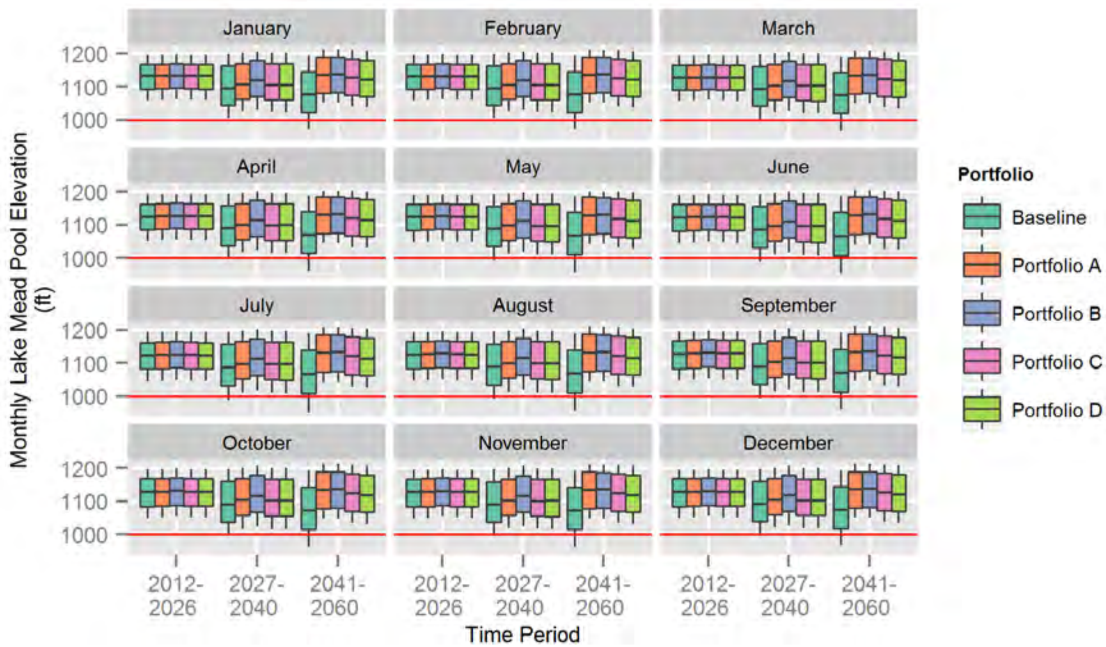



## 3.0 Metrics for the Sediment Transport Attribute of Interest

Reservoirs 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. These impacts can affect overall water quality.

These potential effects can be qualitatively assessed by examining the variability and magnitude of reservoir drawdown. In examining Lake Mead, pool elevation is shown to reduce over time under the Baseline, with very low elevations reached under the 10th percentile (figure C-21). Implementing each portfolio increases the expected elevation and dramatically improves the potential low elevations over time. These increased elevations imply that there could be less downcutting and subsequent sediment transport issues in the portfolios relative to the Baseline. By 2060, implementation of each portfolio results in a higher median elevation than that seen today. This increase implies that in the future, there could be less downcutting than is seen presently and therefore less impact due to sediment.

FIGURE C-21
Monthly Lake Mead Pool Elevation




## 4.0 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.

With decreasing storage volumes, water temperatures will generally trend closer to influent flow temperatures. This change reflects a rise in overall temperature from releases. Under some future climate scenarios, this effect will be combined with an increase in ambient temperatures. This change could result in reduced habitat for cold water fish species, such as trout, and an increase in invasive species predation.

These potential effects can be qualitatively assessed by examining the variability and magnitude of reservoir drawdown. In examining figure C-21, Lake Mead elevation is shown to reduce over time under the Baseline, with very low elevations reached under the 90th percentile. Implementing each portfolio increases the expected elevation and dramatically reduces the range in elevations over time compared to the Baseline. This change implies that water temperatures from reservoir releases could be cooler under the portfolios when compared to the Baseline. By 2060, implementation of each portfolio results in a greater median elevation than seen today, implying more storage and potentially cooler temperatures. However, under the downscaled GCM supply scenario, ambient temperature would likely increase, potentially diminishing any benefit from increased storage volume.

# 5.0 Other Water Quality Attribute of Interest

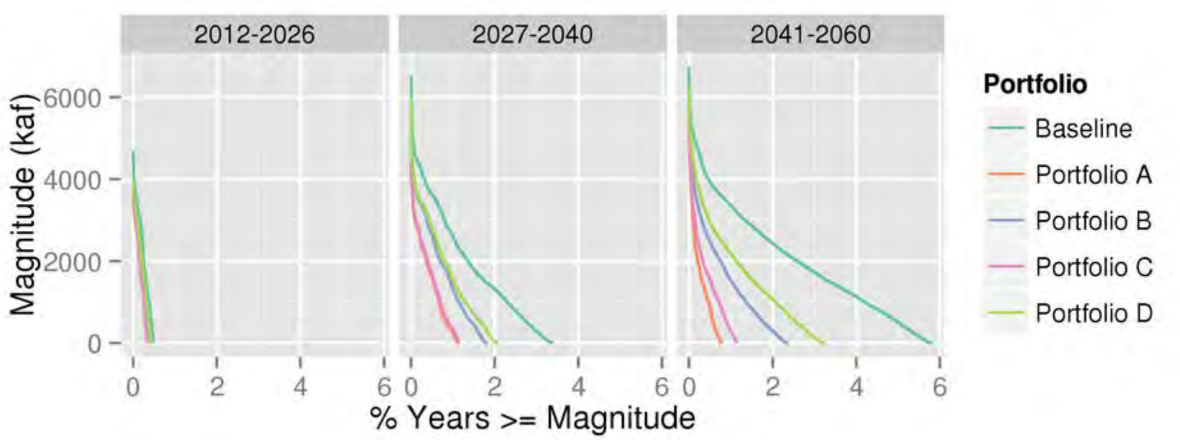
Numerous other water quality attributes are of interest to various stakeholders. Changing system conditions could potentially affect other water quality attributes such as selenium, dissolved oxygen, nutrients, algae, metals, perchlorate, and emerging contaminants.

As noted in the sediment transport section, lower reservoir volumes and level variability can result in greater dissolved oxygen demand, nutrient release, and subsequent algal growth. Increased temperatures due to either or both reduced reservoir levels and climate change can also exacerbate these issues due to a reduced capacity of warmer water to dissolve oxygen and higher potential algal growth rates. In addition, downcutting of reservoir deltas and sediment release could result in resuspension of deposited selenium and metals. Selenium, metals, perchlorate, and emerging contaminants could also have higher concentrations due to lower flows and less dilution.

These potential effects can be qualitatively assessed by examining the variability and magnitude of reservoir drawdown. In examining figure C-21, Lake Mead elevation is shown to reduce over time under the Baseline with very low elevations reached under the 10th percentile. Implementing each portfolio increases the expected elevation and dramatically improves elevations in the worst case supply scenarios. These improvements imply that there could be less downcutting and subsequent sediment transport issues and water temperature issues (e.g., dissolved oxygen demand, nutrient release, algal growth, and resuspension of metals).

Potential changes in concentration of selenium, metals, perchlorate, and emerging contaminates can be qualitatively assessed by examining changes in flow. Lee Ferry deficit can be used as a surrogate for flow at Lee Ferry. Figure C-22, shows Lee Ferry deficit under Baseline and the portfolios over time. In general, Lee Ferry deficit is shown to be more frequent and of greater magnitude over time under the Baseline. Implementing each portfolio increases the expected flow over time or rather reduces the frequency and magnitude of Lee Ferry deficit, although future flows with the portfolios implemented are still reduced when compared to current conditions. This result implies that less water would be available for dilution of selenium, metals, perchlorate, and emerging contaminants.

Figure C-22
Annual Lee Ferry Deficit



# 6.0 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 Municipal and Industrial (M&I) water use, such as reduced useful life of water-dependent appliances, increased use of water-softening chemicals, and increased purchase of bottled water. The necessary steps to run this economic model using all of the Study's results is beyond the scope of the Study. Therefore, the economic effects due to salinity levels were included as a qualitative metric. In addition, EPA has set voluntarily guidelines for salinity levels in drinking water supplies with a target of less than 500 mg/L, measured as total dissolved solids. Some water providers, notably the Metropolitan Water District of Southern California, blend Colorado River water with other water supplies that have lower salinity in an attempt to meet these guidelines. When salinity levels are elevated in the Colorado River, the ability of M&I water suppliers to meet their target blended salinity is diminished.

Potential socioeconomic impacts were evaluated qualitatively by examining CRSS results for changes in salinity. Figures C-1 to C-20, illustrate that salinity could increase at almost every monitoring point under the Baseline over time. In most cases, implementing each portfolio reduces future salinity compared to the Baseline. However, in most cases, future salinity levels are greater than current levels. Of particular interest is the salinity at Imperial Dam (figure C-20). It appears that the median salinity could increase by about 25 milligrams per liter over current conditions. This increase could result in negative socioeconomic consequences. However, the predicted values, even for the 10th percentile, are well below the numeric criteria of 879 milligrams per liter established for water quality at Imperial Dam.

Potential economic damages due to increased salinity could 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.

Appendix G4

# Attachment D
# Flood Control Metrics' Results

# Attachment D — Flood Control Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics,* were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for the quantitative metrics associated with the Flood Control resource category. The Flood Control resource attributes of interest are shown in table D-1.

Results are presented by portfolio with all scenario combinations grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(6) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

(7) Frequency and magnitude plots showing line plots relating the frequency of occurrence (typically the percentage of years) of an event compared to the magnitude of the event. These plots are also presented over time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

TABLE D-1
Flood Control Metrics

| Attribute of Interest | Resource Metric | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|---|
| Flood Control Releases and Reservoir Spills | Flood Control Release | 2.1 | Quantitative | Percent Exceedance | Lake Mead | D-1 |
| | Reservoir Spills | 2.2 | Quantitative | Percent Exceedance | Fontenelle | D-2 |
| | | | | | Flaming Gorge | D-3 |
| | | | | | Blue Mesa | D-4 |
| | | | | | Lake Powell | D-5 |
| | | | | | Lake Mead | D-6 |
| Critical River Stages Related to Flooding Risk | Flooding Risk | 3 | Quantitative | Monthly | Downstream of Aspinall Unit | D-7 |
| | | | | | Downstream of Navajo Dam | D-8 |
| | | | | | Downstream of confluence with Animas River | D-9 |
| | | | | | Downstream of Lake Mead | D-10 |

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

For Lake Mead, criteria are developed for flood control releases under agreement between the U.S. Army Corps of Engineers and the Bureau of Reclamation (Reclamation). These criteria are used to develop system space requirements from August through December and 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 above mean sea level) 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. 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. The primary objective of spill avoidance is to minimize the amount of water that does not pass through hydropower facilities.

The Colorado River Simulation System (CRSS) was used to quantify the frequency and magnitude of both flood control releases at Lake Mead and reservoir spills. The reservoir spill metrics were quantified at Fontenelle, Flaming Gorge, Blue Mesa, Lake Powell, and Lake Mead using the relative comparison quantification method.

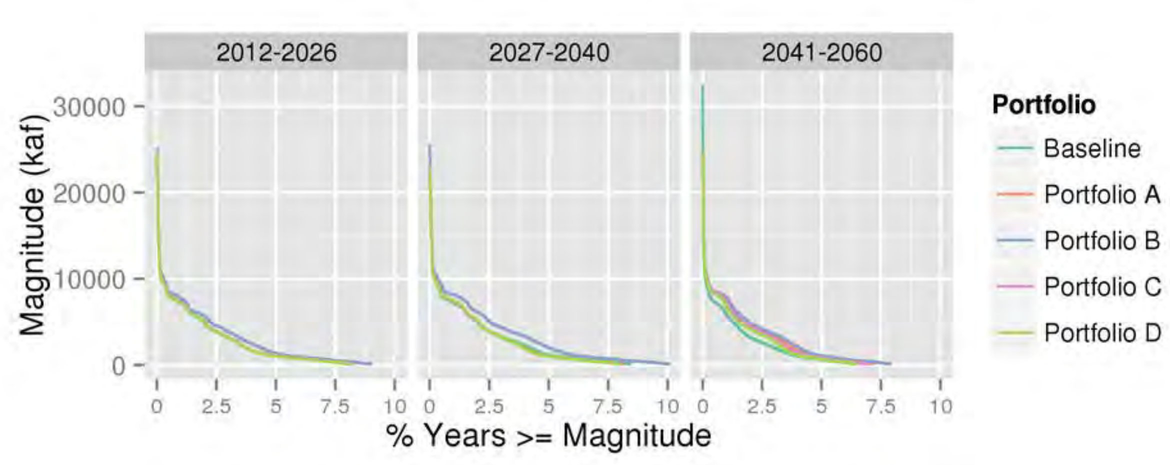
Figure D-1 shows the magnitude and frequency of flood control releases at Mead. Under the Baseline, these releases decrease marginally in both magnitude and frequency over time.

Implementation of each portfolio results in a slight increase in both magnitude and frequency of flood control releases compared to the Baseline.

Figures D-2 through D-6 show the magnitude and frequency of reservoir spills for Fontenelle, Flaming Gorge, Blue Mesa, Lake Powell, and Lake Mead, respectively. For Fontenelle and Flaming Gorge, there is little discernible difference over time in the Baseline and with the implementation of each portfolio. This consistency is likely due to minimal upstream demands and lack of augmentation in the Green River Basin. Blue Mesa, Lake Powell, and Lake Mead all show increases in magnitude and frequency of spills over time under the Baseline. This likely results from operating below hydropower capacity, such that continuing to release when hydropower generation capacity is reduced is counted as a spill in the same way that exceeding reservoir capacity is counted as a spill. Implementation of each portfolios results in a reduction in spills over time – likely due to demand reduction and augmentation that primarily reduce the likelihood of low elevations and subsequent low elevation spills.

## 2.1 Flood Control Releases from Lake Mead

FIGURE D-1
Lake Mead Flood Control Release Percent of Years Exceeding Magnitude



## 2.2 Reservoir Spills

FIGURE D-2
Fontenelle Spill Percent of Years Exceeding Magnitude

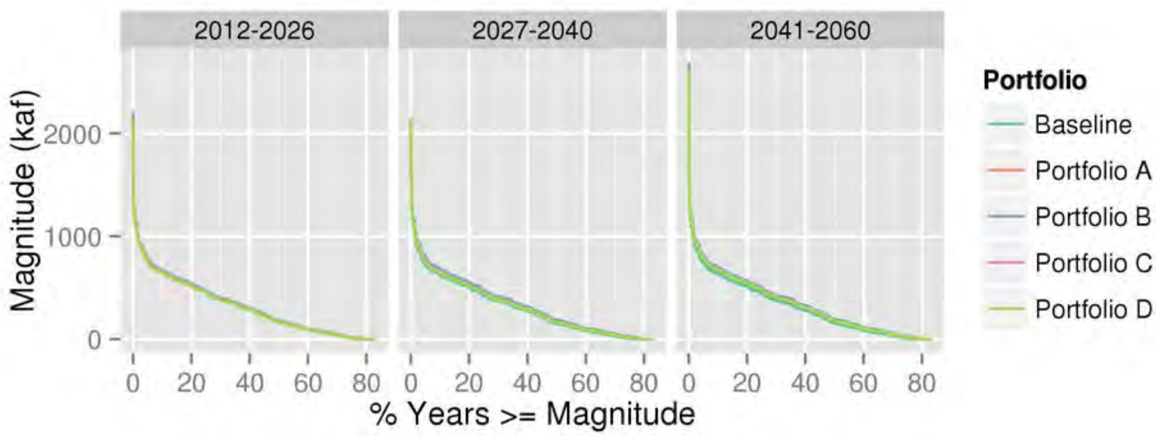



FIGURE D-3
Flaming Gorge Spill Percent of Years Exceeding Magnitude

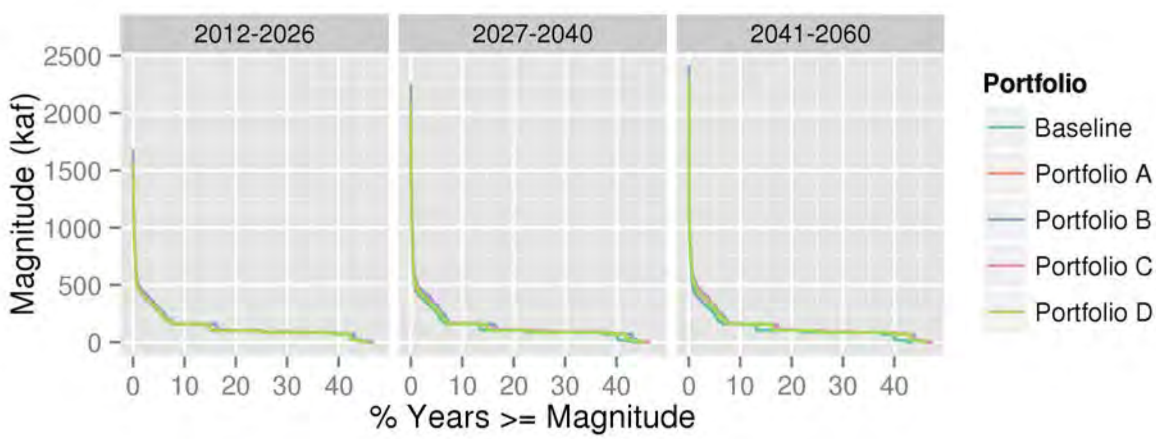



FIGURE D-4
Blue Mesa Spill Percent of Years Exceeding Magnitude

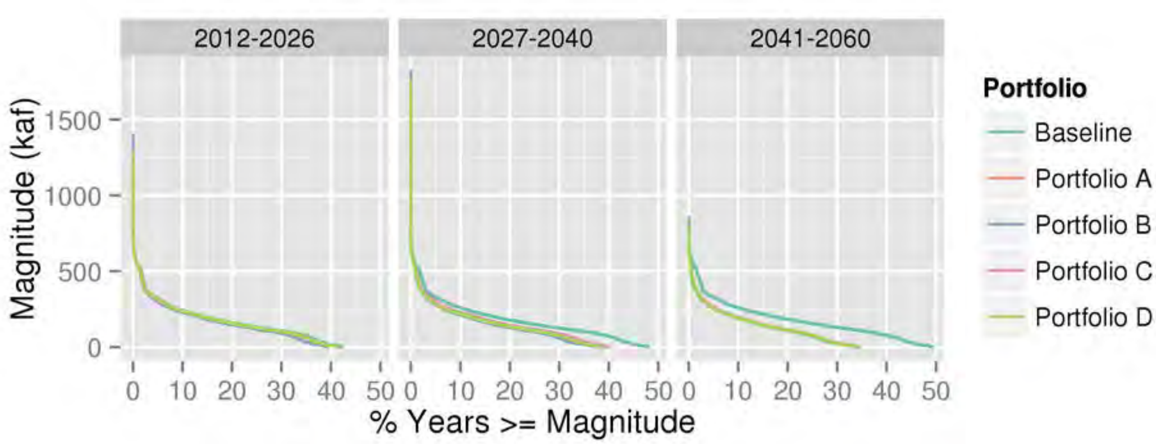


FIGURE D-5
Lake Powell Spill Percent of Years Exceeding Magnitude

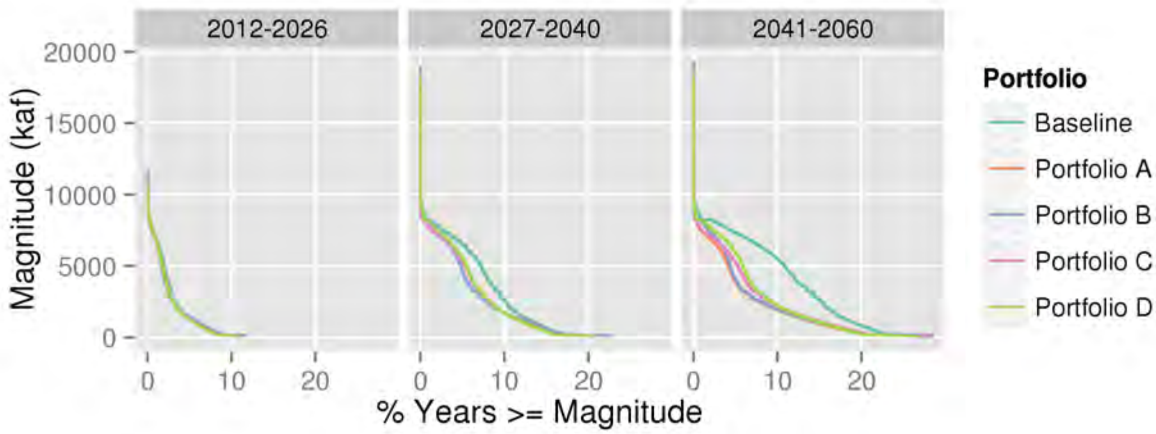
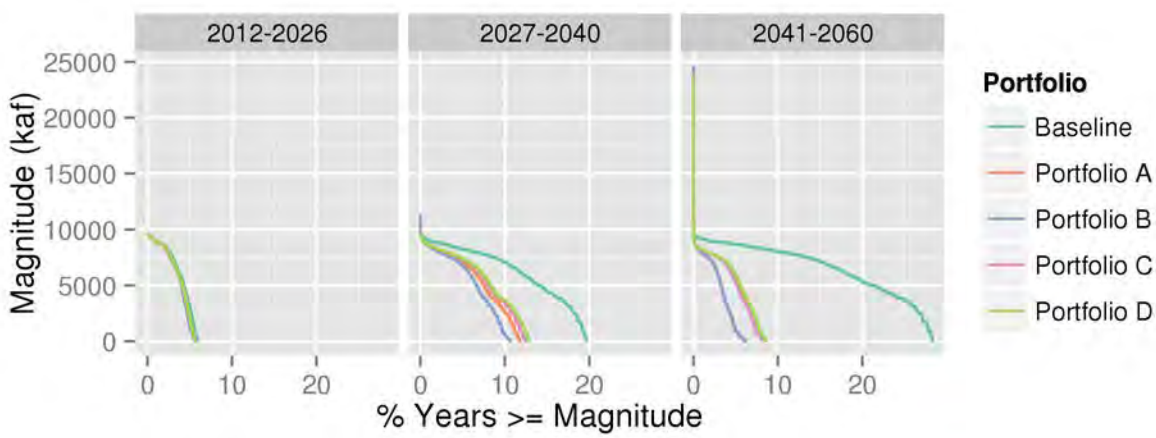



FIGURE D-6
Lake Mead Spill Percent of Years Exceeding Magnitude

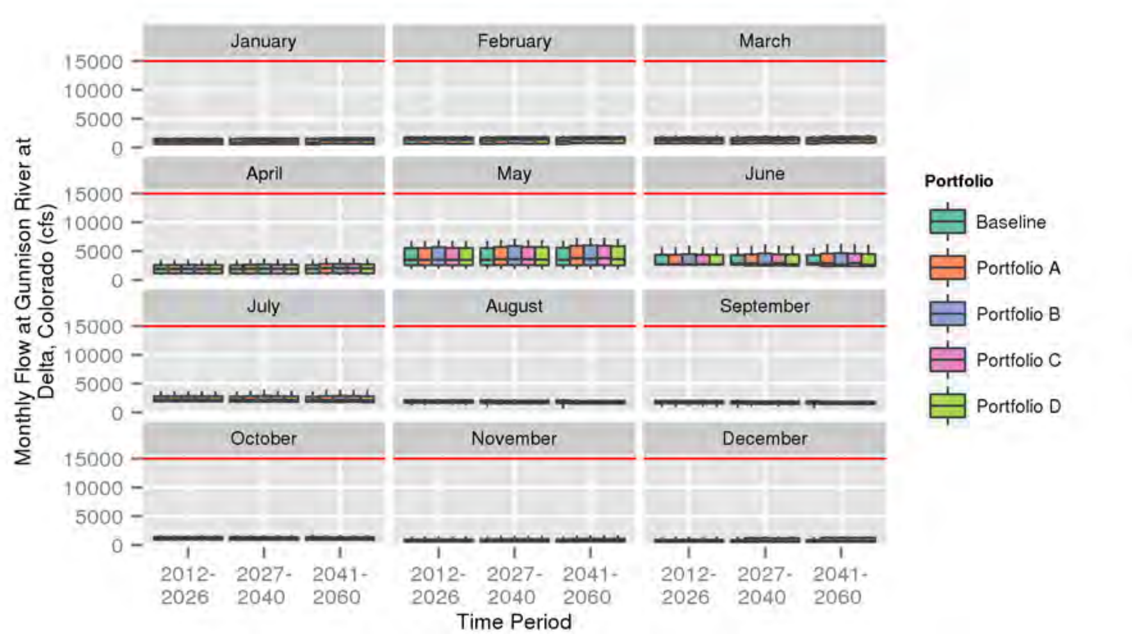



## 3.0 Metrics for the Critical River Stages Related to Flooding Risk Attribute of Interest

Empirical relationships between flow and flood risk (safe channel capacity) exist downstream of Navajo Dam, the Aspinall Unit, and Lake Mead. Reference safe channel capacity values include 15,000 cubic feet per second (cfs) for the Gunnison River at Delta, Colorado; 5,000 cfs for the San Juan River below Navajo Dam; 12,000 cfs for the San Juan near Farmington, NM; and 28,000 cfs for the Colorado River below Hoover Dam;. Additional analysis of CRSS output data was performed to estimate flooding potential. Navajo and Mead release in CRSS were used for the metrics below Navajo Dam, and below Hoover Dam. For the San Juan River near Farmington, NM, the flow was approximated as the releases from Navajo, plus the natural flow above Bluff, Utah minus Colorado's demands in the San Juan Basin. Additionally, a gage for the Gunnison River at Delta, Colorado does not exist in CRSS; however, a gage location in CRSS does exist for the Gunnison River near Grand Junction, Colorado. A linear model was used to estimate flow at Delta from flow at the Grand Junction gage[2]. The model is based on historical data and assumes the historical flow relationship between both sites will continue in the future. This may not be an appropriate assumption under all future supply/demand combinations. However, the approximation provides a view of possible flows at Delta commensurate with the relative comparison nature of the metrics.

Figures D-7 through D-10 present monthly flows for Gunnison River at Delta, Colorado; the San Juan River below Navajo Dam; the San Juan near Farmington, NM; and the Colorado River below Hoover Dam. In general, peak flows occur in May and June, with some significant peaks in July. Under the Baseline, flows decrease over time at all locations. Implementation of each portfolio results in increases in flow over time compared to the Baseline. Only maximum flows (exceeding the 90th percentile) on the San Juan River below Navajo Dam approach or exceed the safe channel capacity. These flows occur in May and June from the present period (2012 through 2026) to the 2041 through 2060 period for the Baseline and each of the portfolios.

FIGURE D-7
Monthly Flooding Risk Downstream of Aspinall Unit
*Safe Channel Capacity Reference Value is shown as Solid Red Line.*




2 The linear model used to relate Grand Junction flow to Delta flow in cubic feet per second (cfs) was: Delta Flow = .8306*Grand Junction Flow – 180.3 cfs. The $R^2$ value of the model fit to the historical data is 0.98.

FIGURE D-8
Monthly Flooding Risk Downstream of Navajo Dam
*Safe Channel Capacity Reference Value is shown as Solid Red Line.*

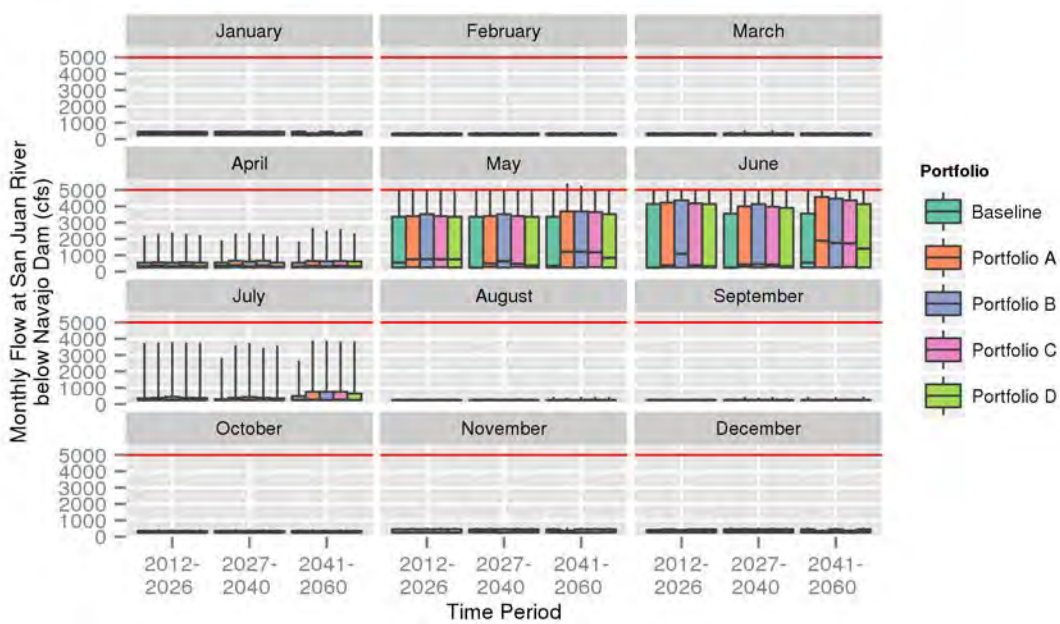



FIGURE D-9
Monthly San Juan Flooding Risk Downstream of confluence with Animas River
*Safe Channel Capacity Reference Value is shown as Solid Red Line.*

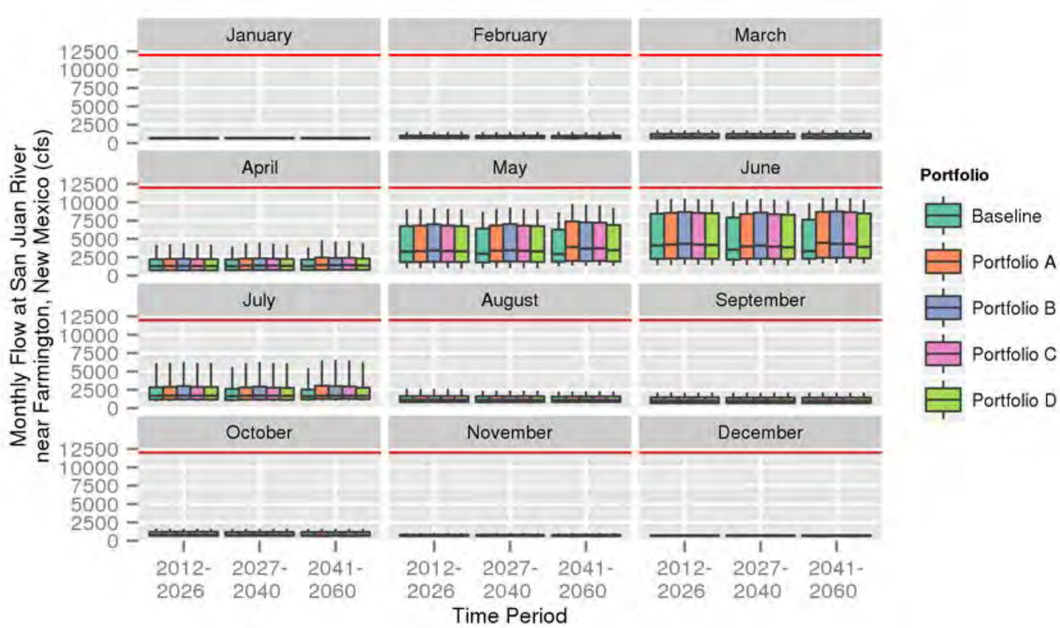


FIGURE D-10
Monthly Flooding Risk Downstream of Lake Mead
*Safe Channel Capacity Reference Value is shown as Solid Red Line.*

**Appendix G4**

# Attachment E
# Recreational Resources Metrics' Results

# Attachment E — Recreational Resources Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics*, were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for both the quantitative and qualitative metrics associated with the Recreational Resources category. The Recreational Resources attributes of interest are shown in table E-1.

Results are presented on a portfolio basis, in which all scenarios are grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed qualitatively or discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(8) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041 through 2060.

TABLE E-1
Recreational Metrics

| Attribute of Interest | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|
| Shoreline Public Use Facilities | 2 | Quantitative | Monthly | Flaming Gorge | E-1 |
| | | | | Blue Mesa | E-2 |
| | | | | Navajo | E-3 |
| | | | | Lake Powell | E-4 |
| | | | | Lake Mead | E-5 |
| River and Whitewater Boating | 3 | Quantitative | Monthly by Boating Flow Day Type | Colorado River at Glenwood Springs, CO | E-6 |
| | | | | Dolores River near Cisco, UT | E-7 |
| | | | | Colorado River near Cisco, UT | E-8 |
| | | | | Green River near Greendale, UT | E-9 |
| | | | | Yampa River near Maybell, CO | E-10 |
| | | | | Yampa River at Deerlodge Park, CO | E-11 |
| | | | | Green River at Jensen, UT | E-12 |
| | | | | San Juan River near Bluff, UT | E-13 |
| Other Recreational | 4 | Qualitative | NA | Basin-Wide | NA |
| Socioeconomic Impacts | 5 | Qualitative | NA | Basin-Wide | NA |

# 2.0 Metrics for the Shoreline Public Use Facilities Attribute of Interest

Figures E-1 through E-5 show box plots of pool elevation at the following reservoirs: Flaming Gorge, Blue Mesa, Navajo, Lake Powell, and Lake Mead. Additionally, reference values for Shoreline Public Use Facilities, as identified in *Technical Report D – System Reliability Metrics*, are provided for reference. These values represent the current minimum pool elevation for operation of major marinas and boat ramps. For Recreational Resources, it is beneficial to maintain pool elevations above these reference values. Flaming Gorge (figure E-1) infrequently falls below any reference elevation, across all time periods. Further, the impact of portfolios is minimal; reflecting the limited option yield above that reservoir. Under the Baseline, Blue Mesa pool elevation (figure E-2) spans the four reference elevations, particularly in the second (2027 through 2040) and third (2041 through 2060) periods. All portfolios show pool elevation improvements, by about 20 feet in the third time period; the lack of difference between portfolios is because most options impacting Blue Mesa are common to all portfolios. Baseline Navajo median pool elevations (figure E-3) are above all reference values for all months. However, in the second and third time periods, the 25th percentile begins to fall below the first reference elevation for several months. All portfolios bring the 25th percentile above that threshold, with *Portfolio A* showing the largest change in pool elevation relative to the Baseline. Similar results are seen for Lake Powell (figure E-4). Portfolios increased pool elevations enough that the 25th percentiles are generally near or above the first reference elevation, while over time the Baseline 25th percentile fell below several reference elevations. Figure E-5 shows results for Lake Mead. Across the three time periods, the Baseline median pool elevation falls from being about centered in the reference elevations to being below most. Portfolios show the greatest impact at Lake Mead; by the third time period, pool elevation improved relative to the Baseline by about 60 feet above mean sea level (msl), bringing median pool elevation generally higher than the first time period (2012 through 2026), particularly for *Portfolio A and B.*

FIGURE E-1
Monthly Flaming Gorge Reservoir Pool Elevation
*Shoreline Public Use Facilities Reference Elevations Show as Solid Red Lines.*

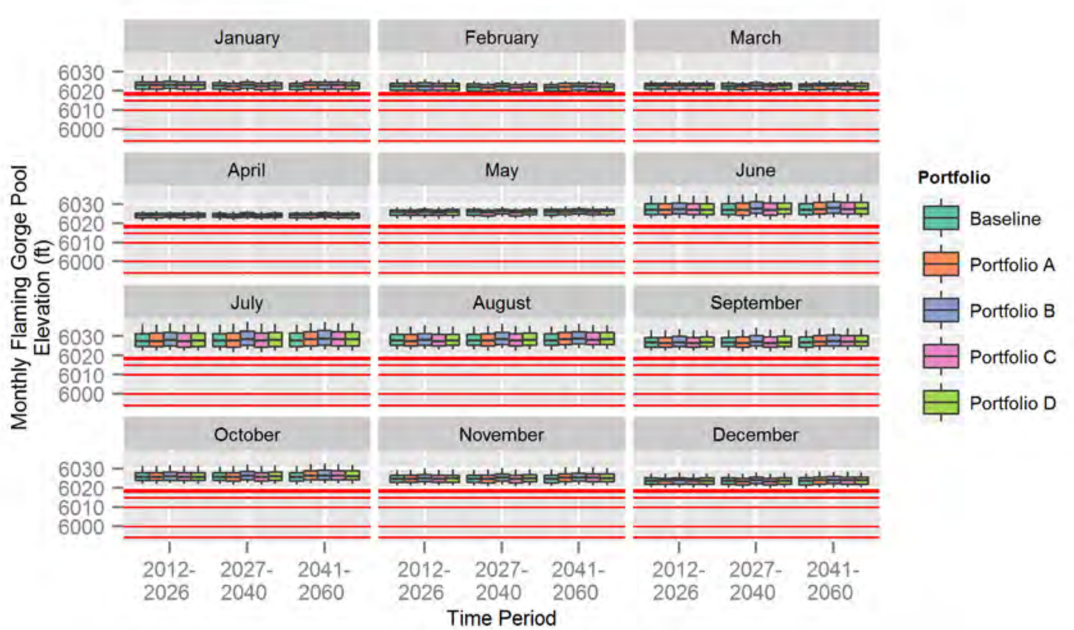


FIGURE E-2
Monthly Blue Mesa Reservoir Pool Elevation
*Shoreline Public Use Facilities Reference Elevations Show as Solid Red Lines.*

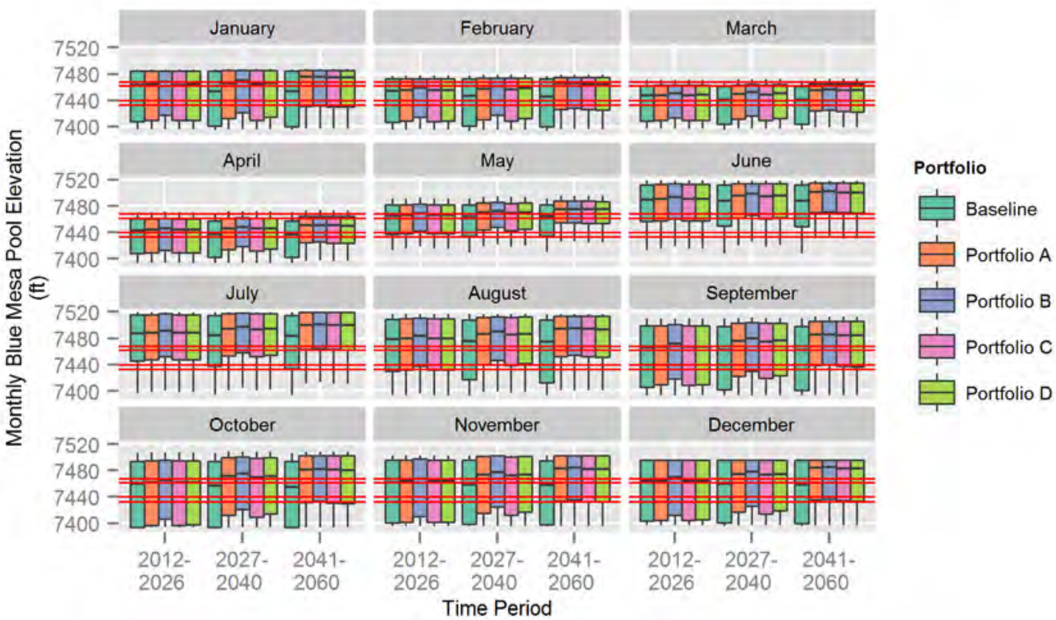



FIGURE E-3
Monthly Navajo Reservoir Pool Elevation
*Shoreline Public Use Facilities Reference Elevations Show as Solid Red Lines.*

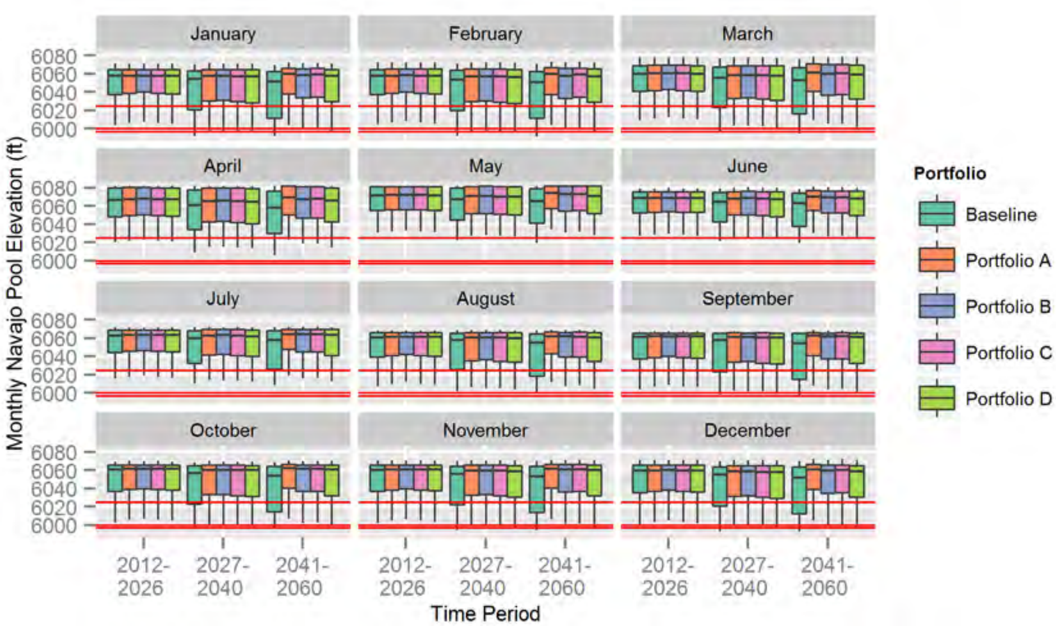


FIGURE E-4
Monthly Lake Powell Pool Elevation
*Shoreline Public Use Facilities Reference Elevations Show as Solid Red Lines.*

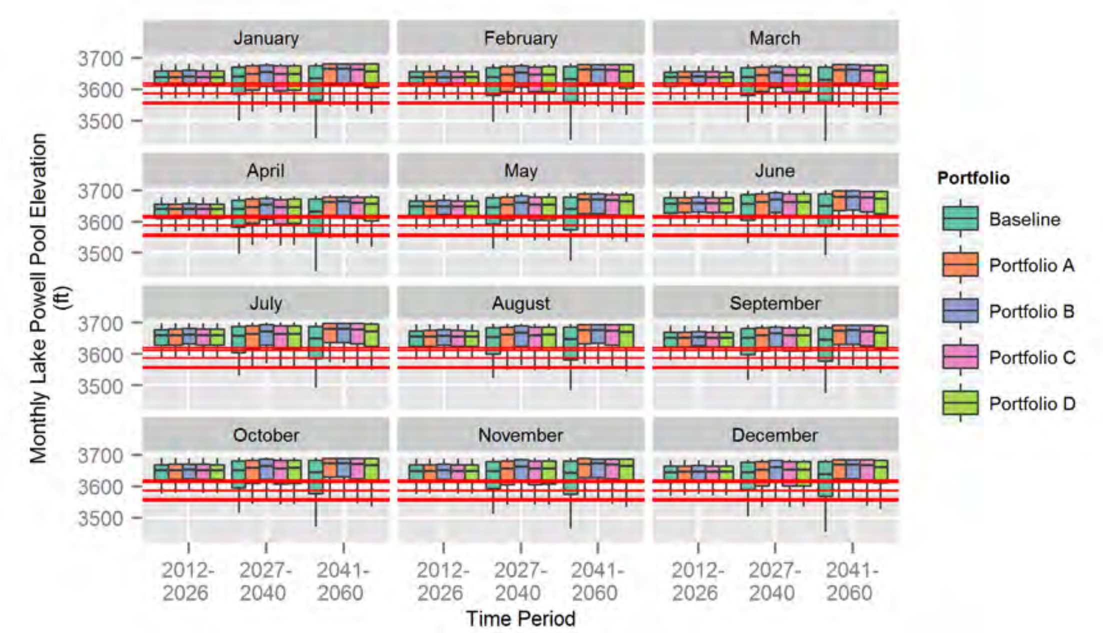
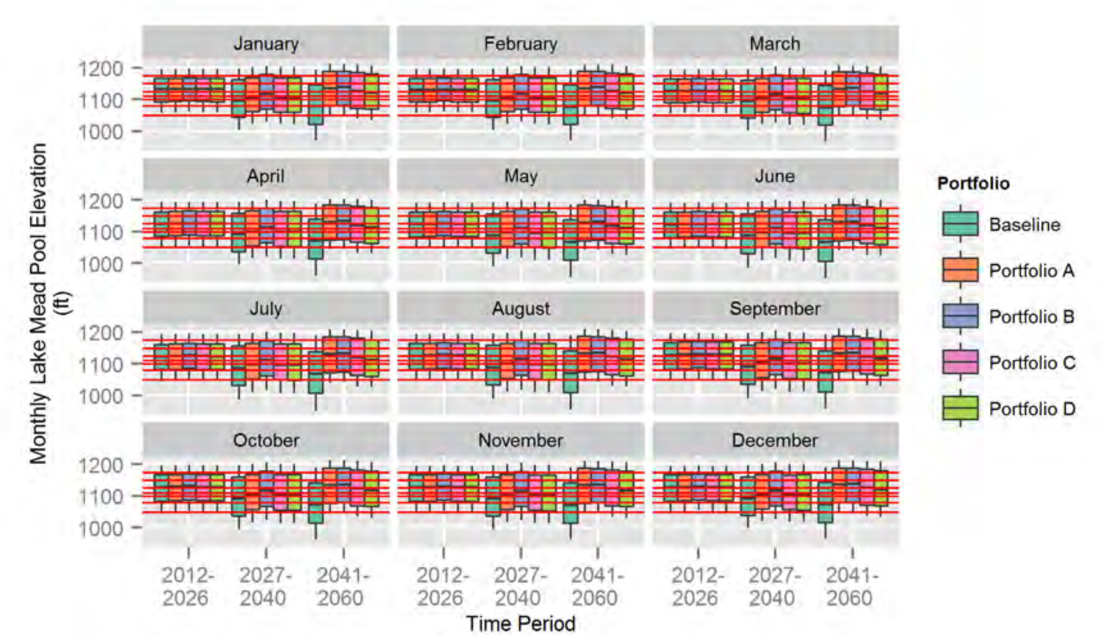



FIGURE E-5
Monthly Lake Mead Pool Elevation
*Shoreline Public Use Facilities Reference Elevations Show as Solid Red Lines.*



# 3.0 Metrics for the River and Whitewater Boating Attribute of Interest

Figures E-6 through E-13 show monthly river and whitewater metrics by boating flow day types: below acceptable, acceptable low, optimal, acceptable high, and above acceptable boating flow days. The boating flow days increase monotonically with flow; that is, acceptable high boating flow days will always be for higher flows than optimal boating flow days. These values reflect the flow aspect of river and whitewater boating quality. The process for computing flow day types is described in *Technical Report D – System Reliability Metrics.* Generally, under the Baseline, flows reduce over time and a shift is observed from one flow day type to another. For example, the month of June in figure E-8 shows a reduction in the number of acceptable high days and an increase in the number of optimal days. Locations that do not follow this trend are those directly impacted by reservoir releases (e.g., figure E-9, Green River near Greendale, UT) or those locations with limited upstream flow changes (e.g., figure E-10, Yampa River near Maybell, CO). These types of locations tend to be the least impacted by the implementation of portfolios (e.g., figure E-7, Dolores River near Cisco, UT). Locations with greater upstream option influence generally showed a shift toward higher flow day types with the implementation of portfolios. For example, in May of the third time period, the Colorado River at Glenwood Springs (figure E-6) shows a substantial shift from mostly below-acceptable boating flow days to acceptable-low boating flow days when portfolio results are compared with the Baseline. Similar shifts to more-acceptable and optimal boating flow days are evident for the San Juan River near Bluff, UT (figure E-13). This was most notable for *Portfolio A* and *Portfolio C*, which both route conserved water to a conceptual off-stream storage location above Powell as part of the banking option. It is noteworthy that across all locations, many of the below acceptable boating flow days occur during winter months that are generally less popular for river and whitewater boating. While some sites may show a slight shift over time toward more early season (March or April) acceptable or optimal boating flow days, most of these boating flow days still occur during the summer months, even in the third time period.

FIGURE E-6A
Monthly River and Whitewater Boating by Boating Flow Day Type, Colorado River at Glenwood Springs, CO

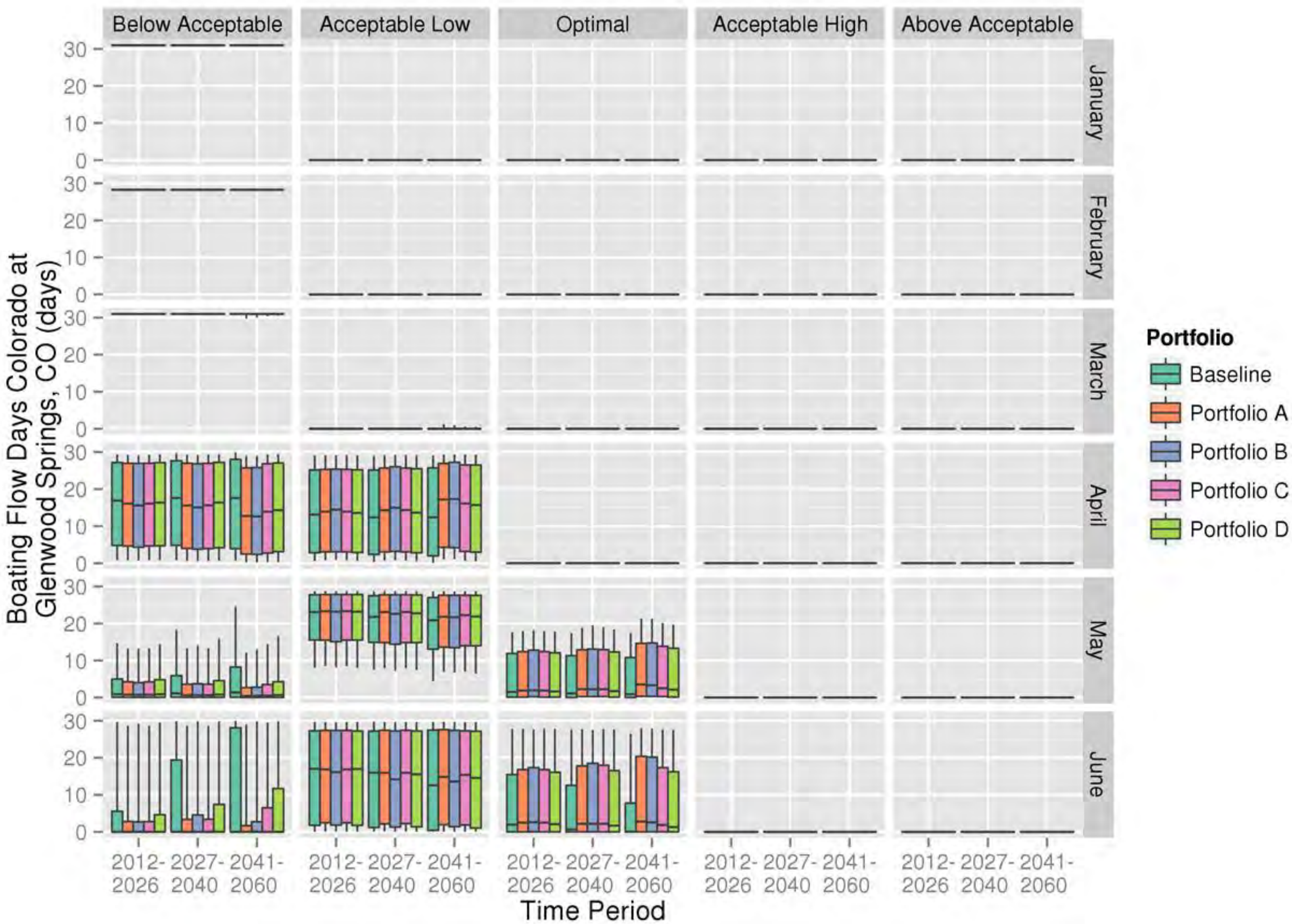


FIGURE E-6B
Monthly River and Whitewater Boating by Boating Flow Day Type, Colorado River at Glenwood Springs, CO

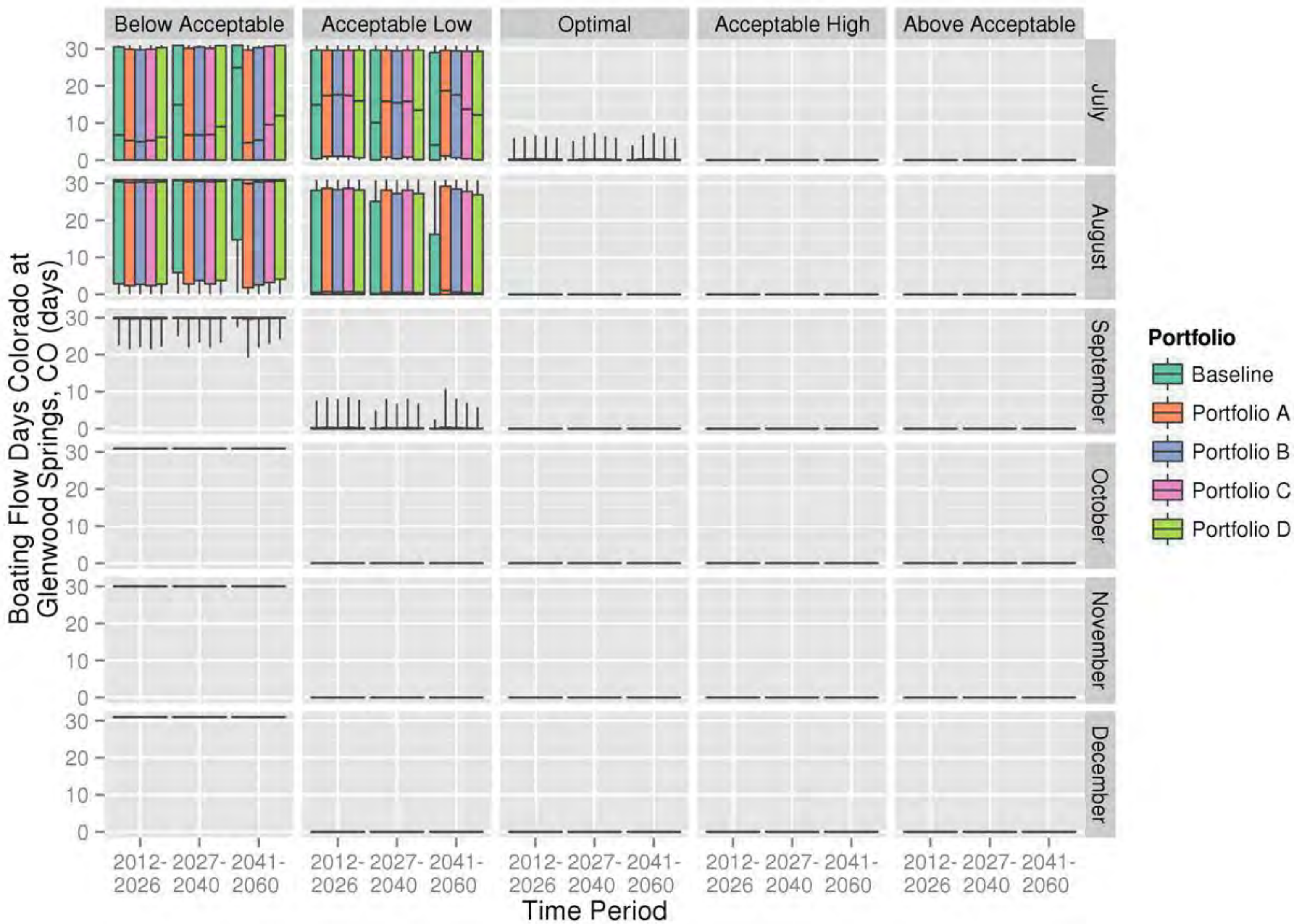


FIGURE E-7A
Monthly River and Whitewater Boating by Boating Flow Day Type, Dolores River near Cisco, UT

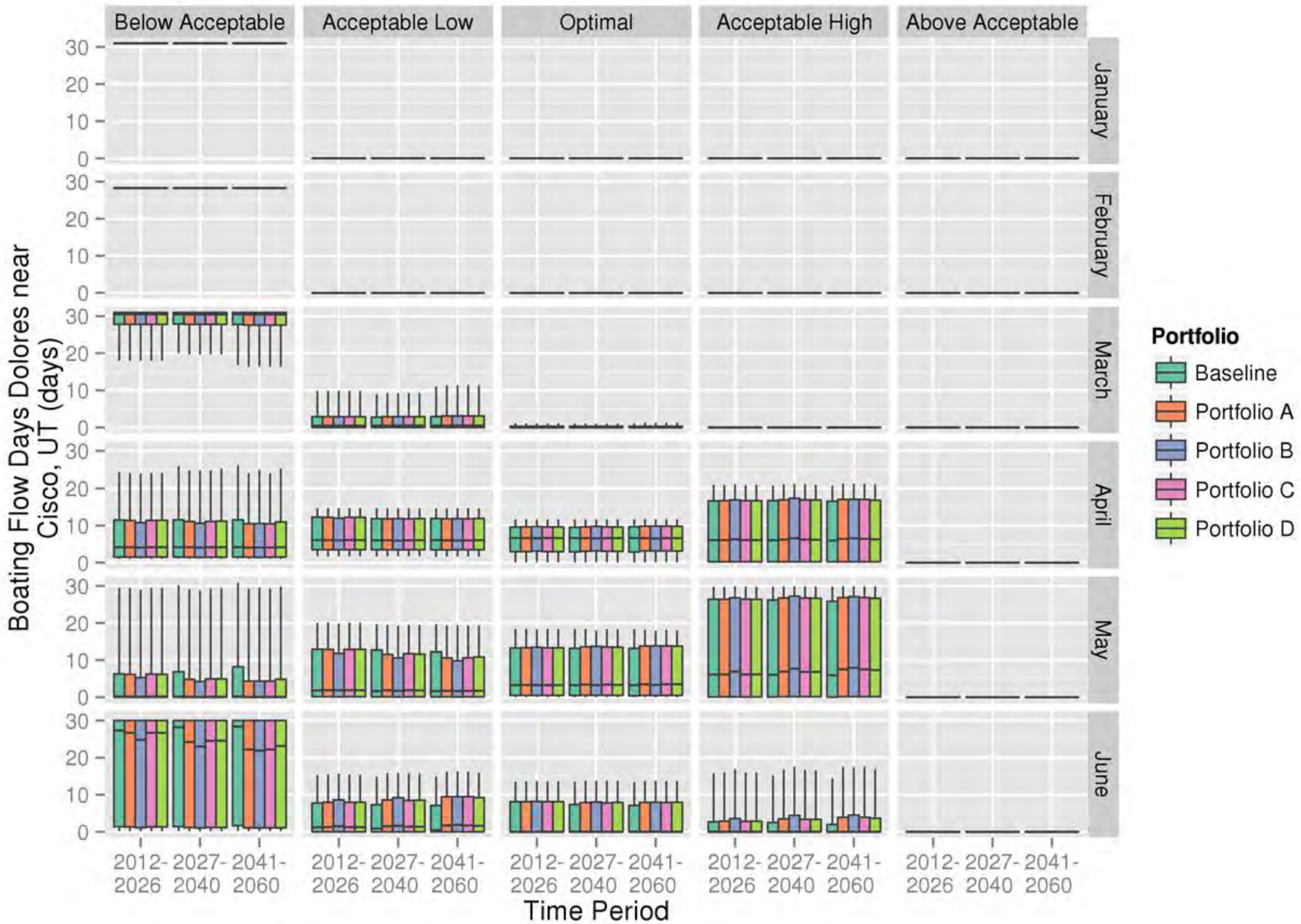


FIGURE E-7B
Monthly River and Whitewater Boating by Boating Flow Day Type, Dolores River near Cisco, UT

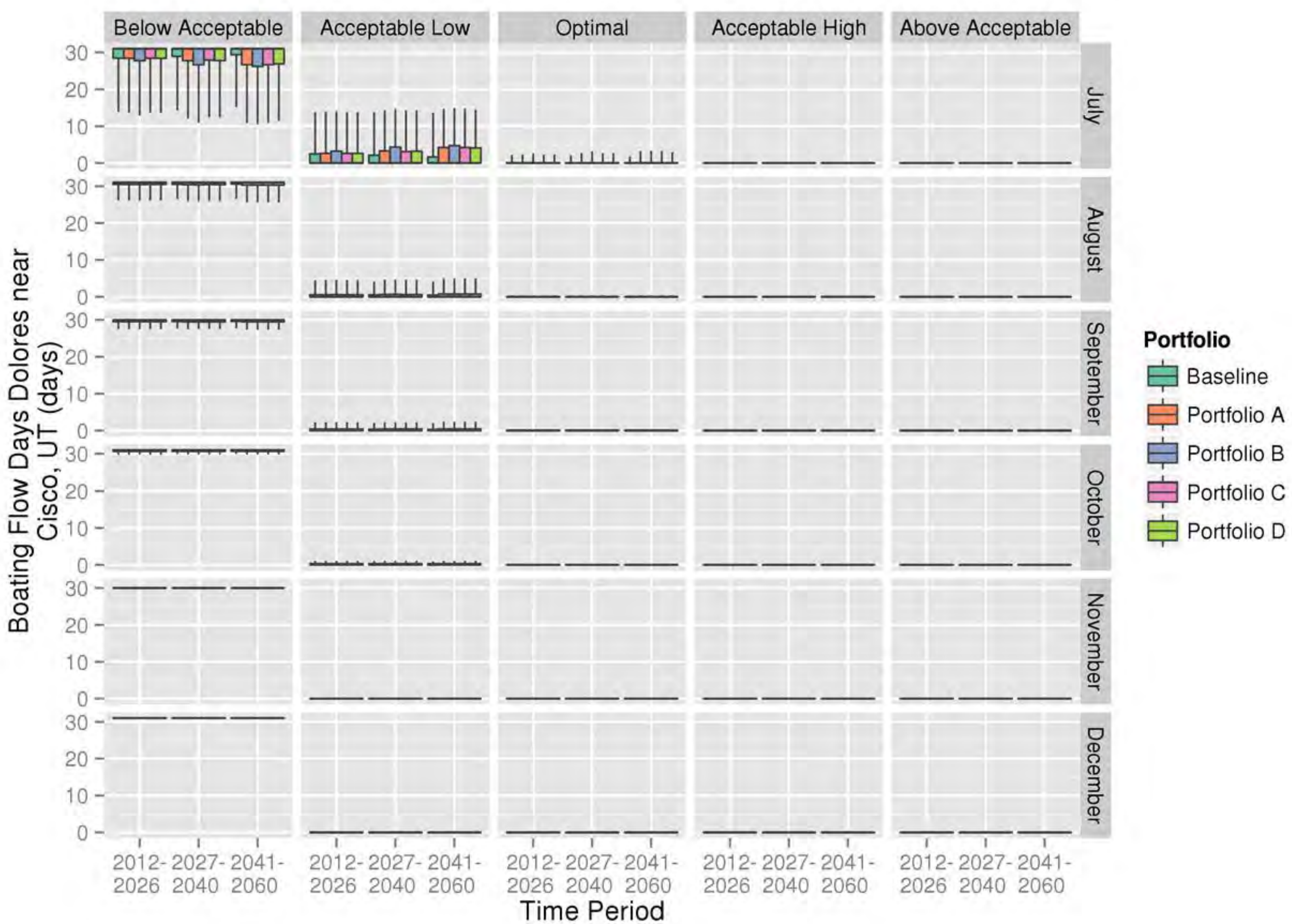


FIGURE E-8A
Monthly River and Whitewater Boating by Boating Flow Day Type, Colorado River near Cisco, UT

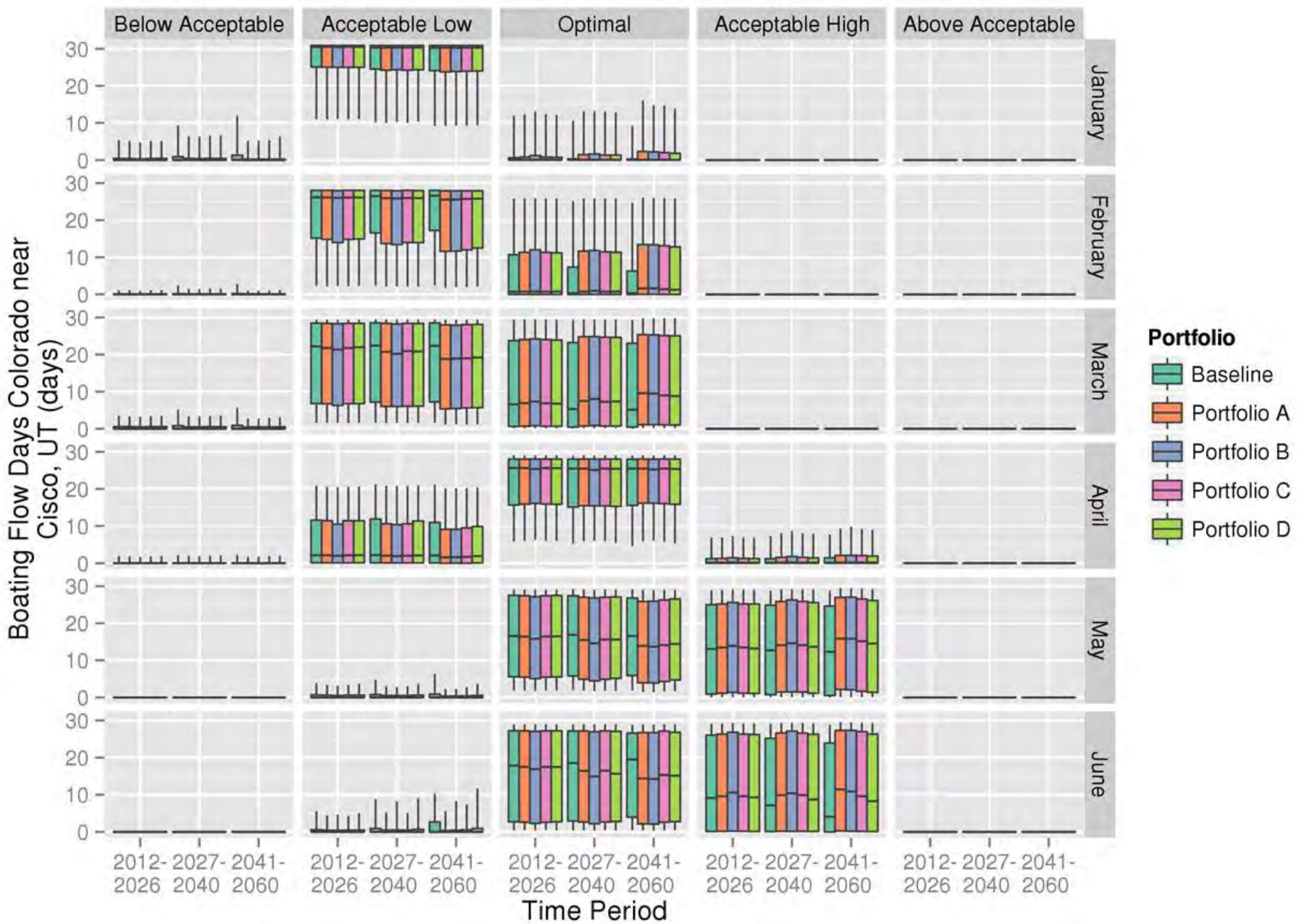


FIGURE E-8B
Monthly River and Whitewater Boating by Boating Flow Day Type, Colorado River near Cisco, UT

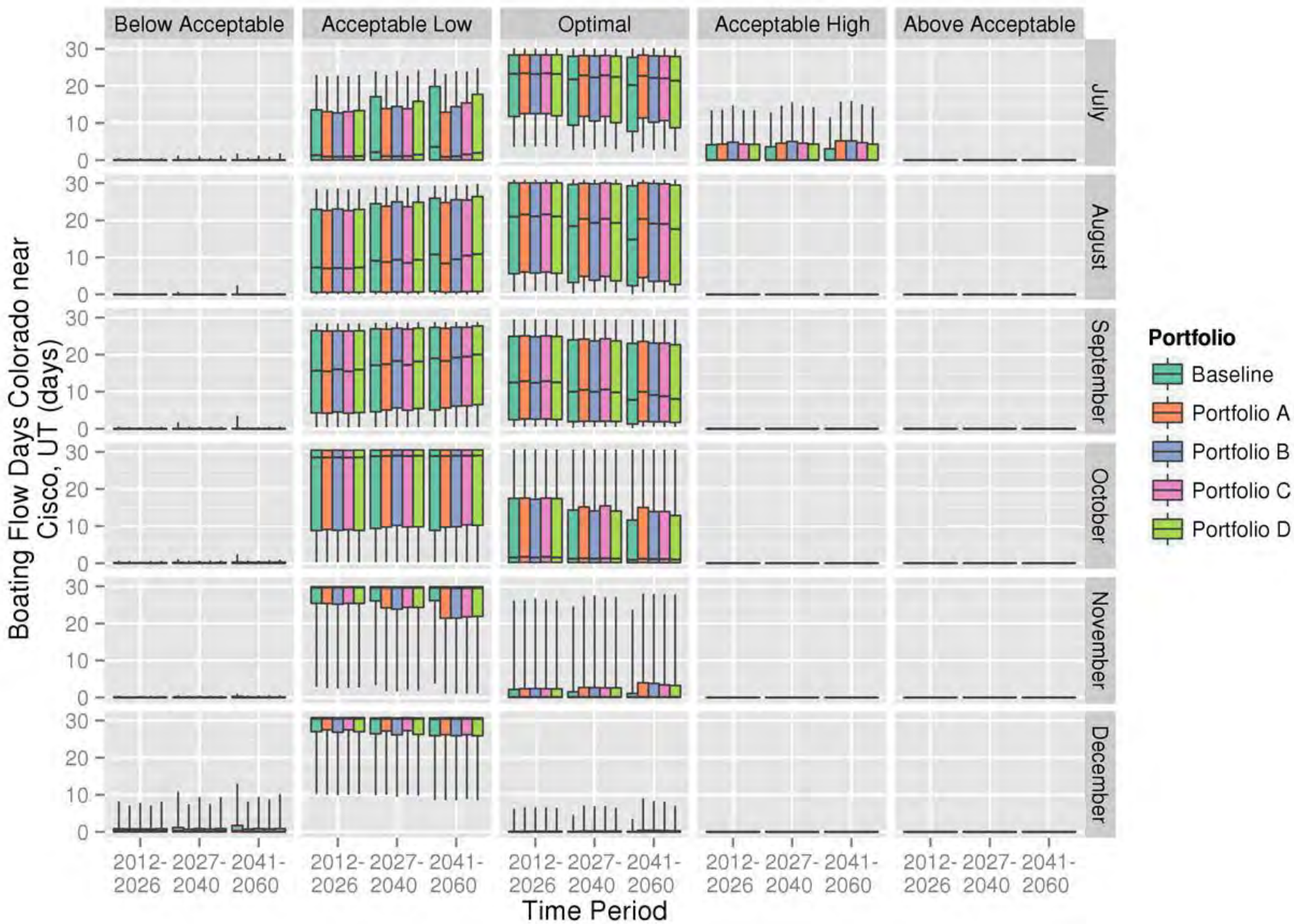


FIGURE E-9A
Monthly River and Whitewater Boating by Boating Flow Day Type, Green River near Greendale, UT

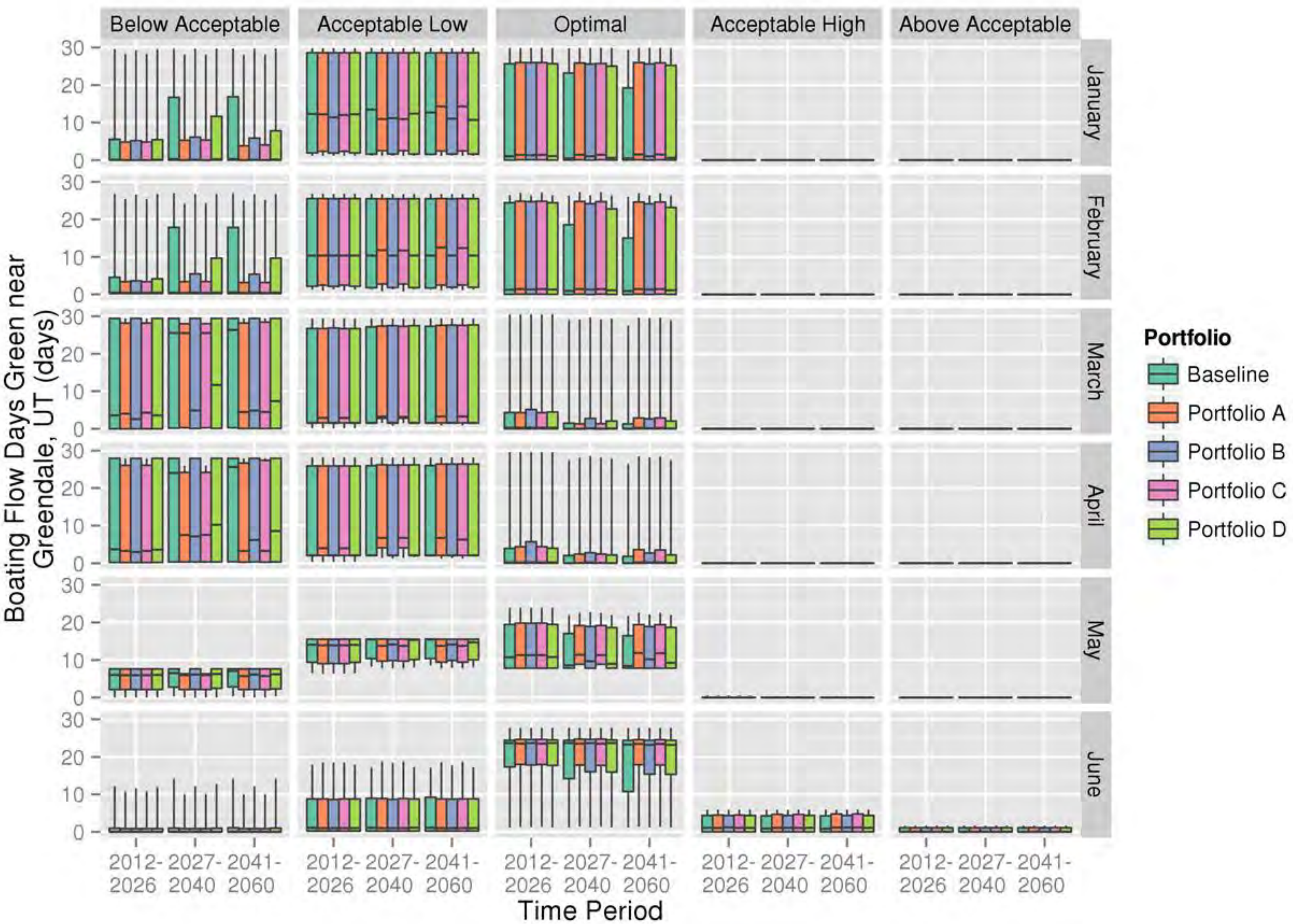


FIGURE E-9B
Monthly River and Whitewater Boating by Boating Flow Day Type, Green River near Greendale, UT

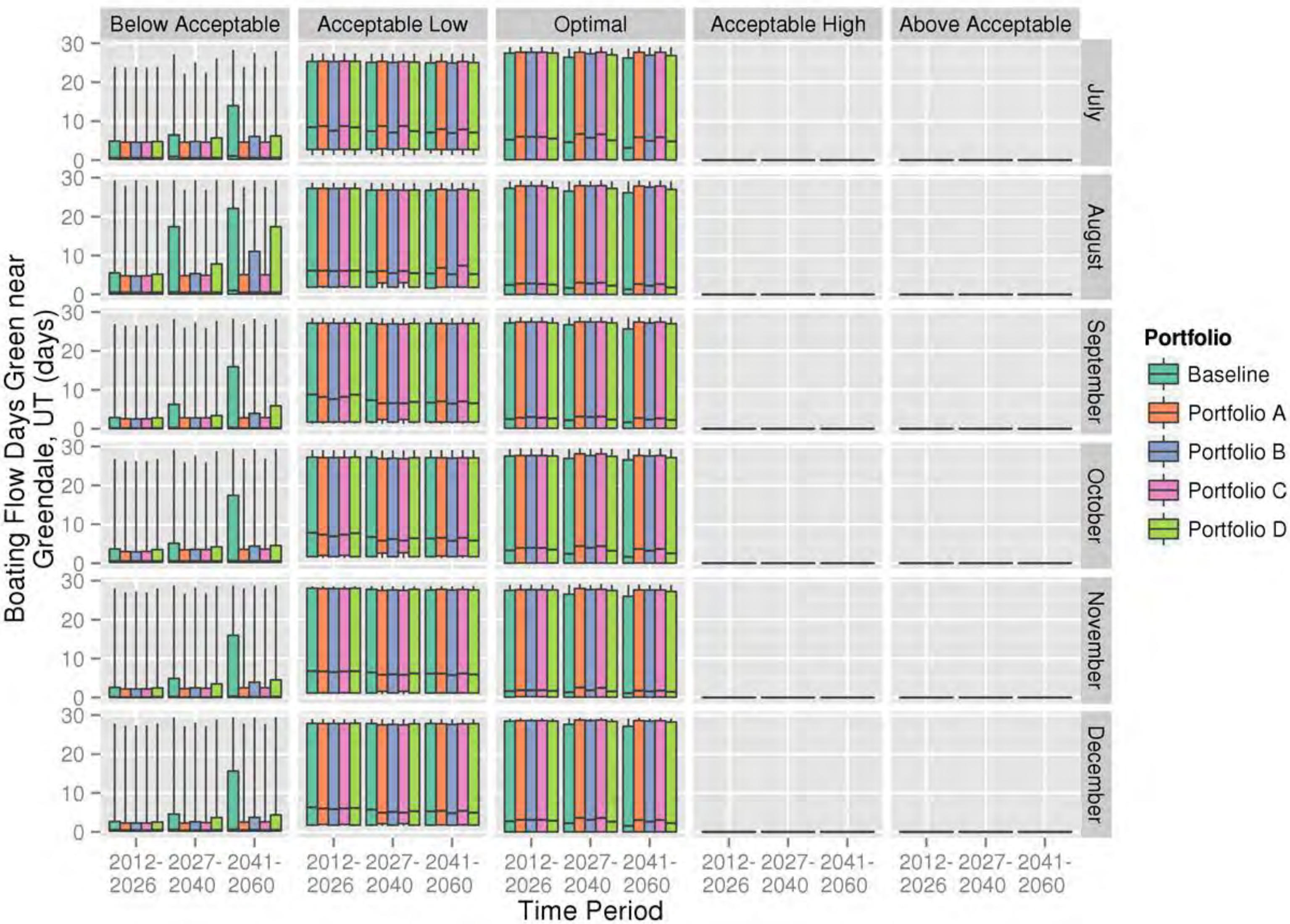


FIGURE E-10A
Monthly River and Whitewater Boating by Boating Flow Day Type, Yampa River near Maybell, CO

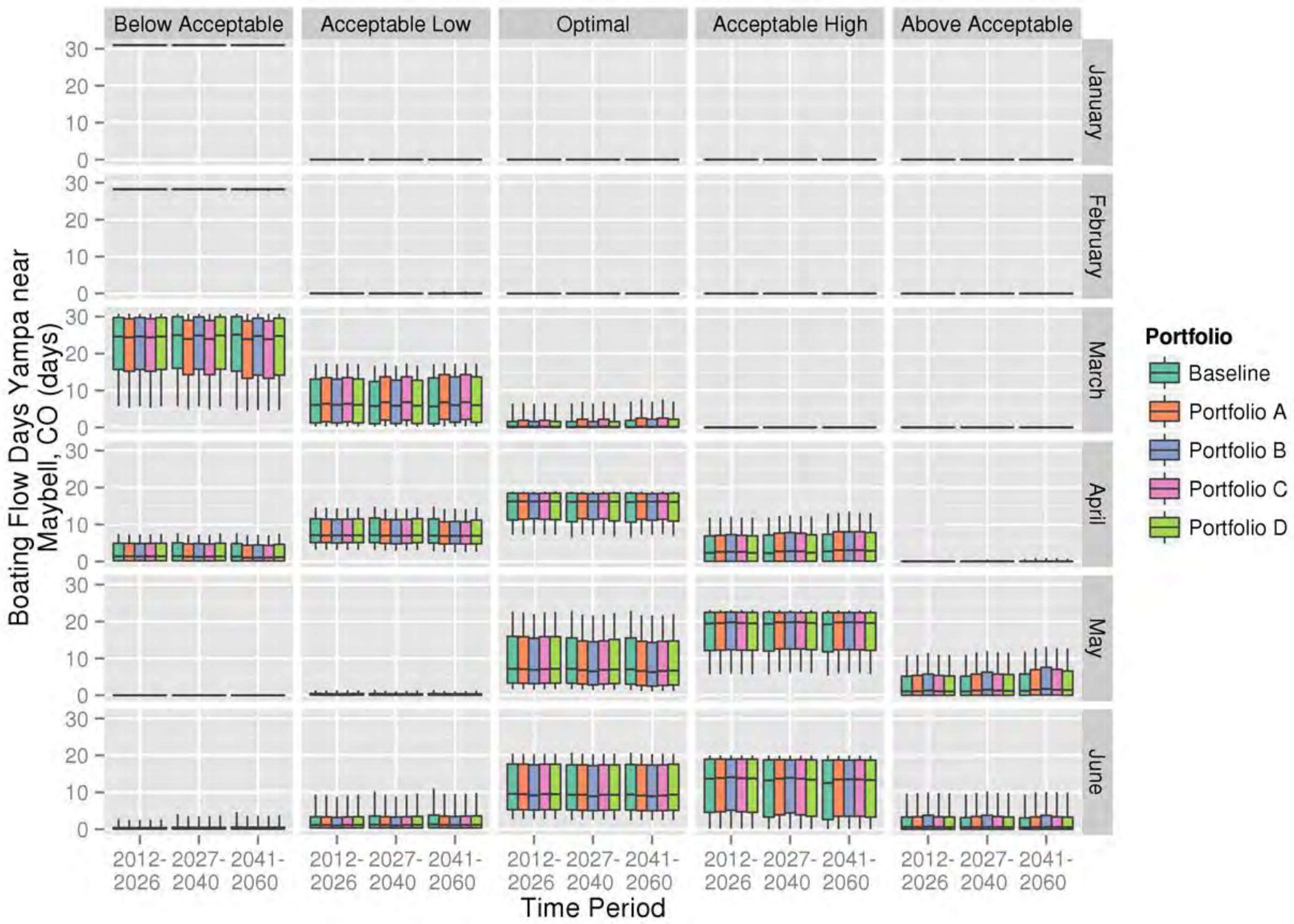


FIGURE E-10B
Monthly River and Whitewater Boating by Boating Flow Day Type, Yampa River near Maybell, CO

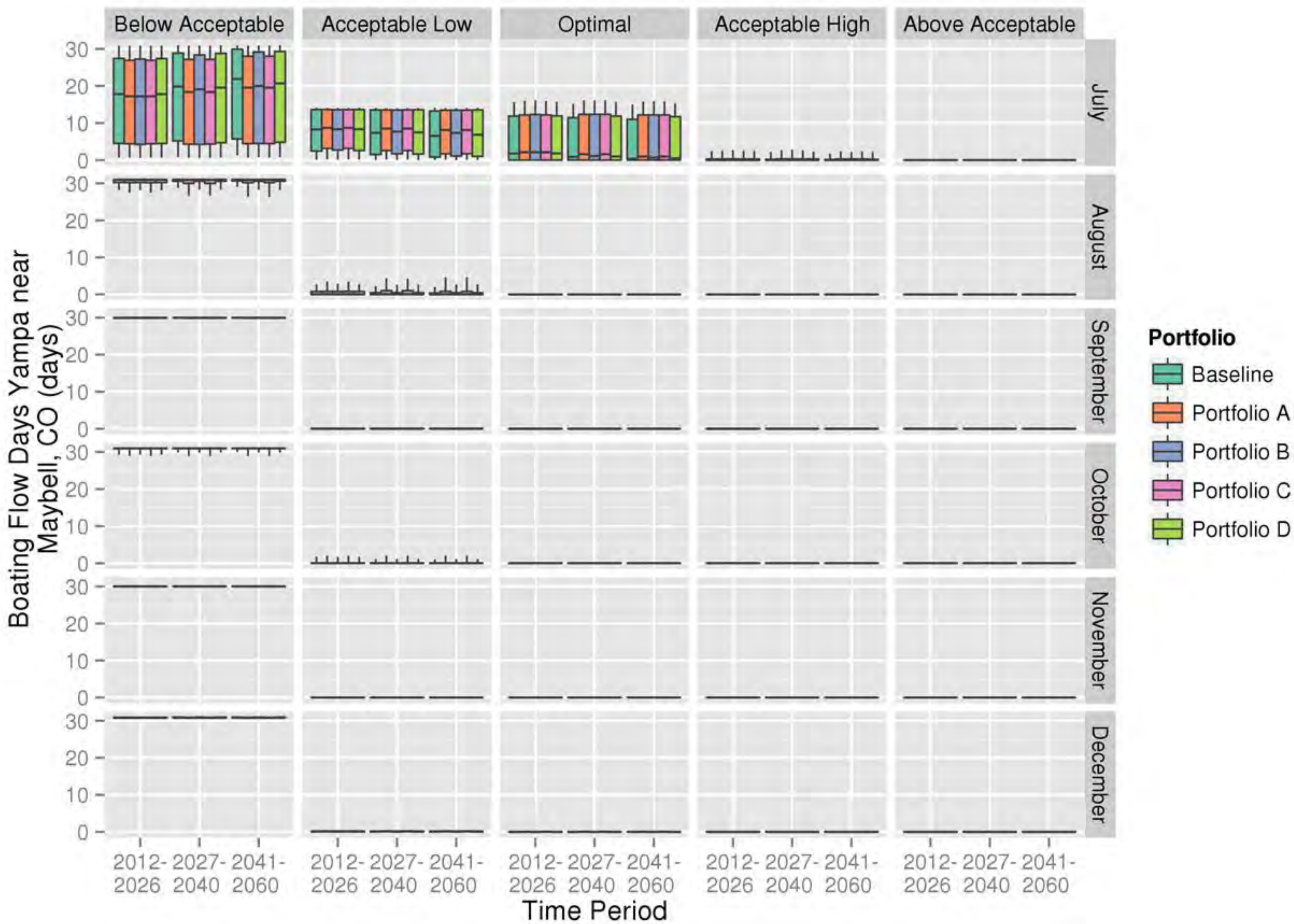


FIGURE E-11A
Monthly River and Whitewater Boating by Boating Flow Day Type, Yampa River at Deerlodge Park, CO

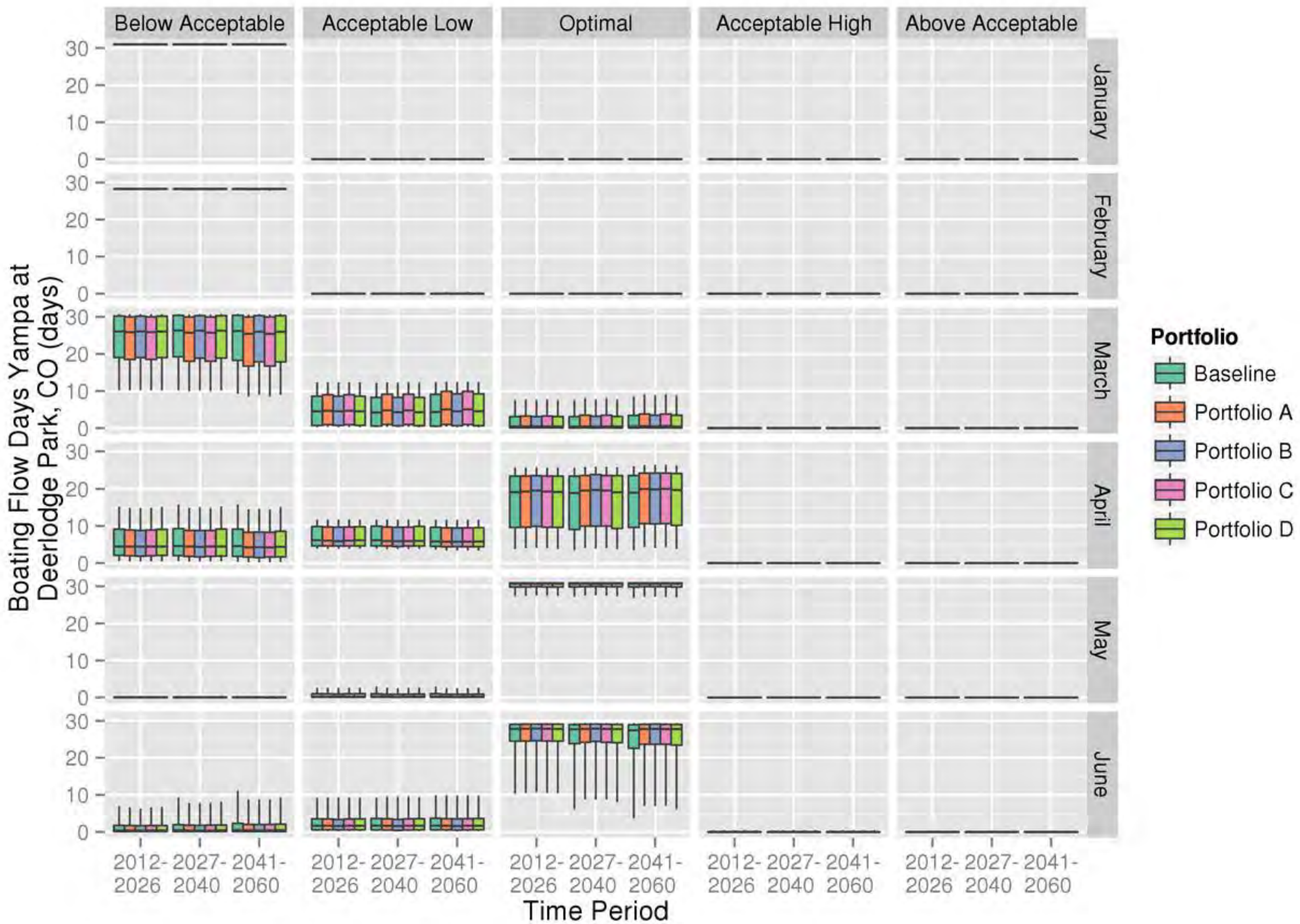


FIGURE E-11B
Monthly River and Whitewater Boating by Boating Flow Day Type, Yampa River at Deerlodge Park, CO

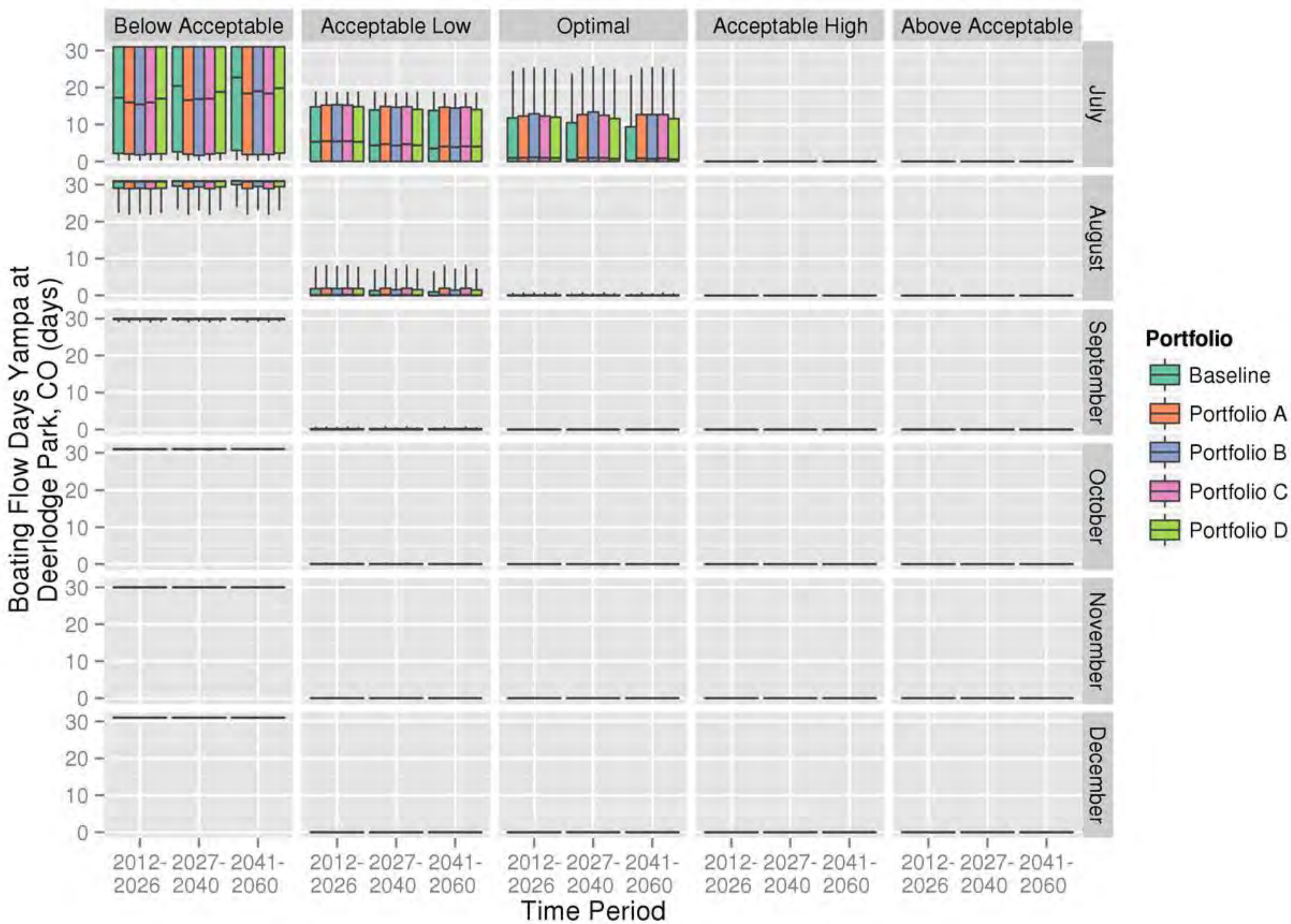


FIGURE E-12A
Monthly River and Whitewater Boating by Boating Flow Day Type, Green River at Jensen, UT

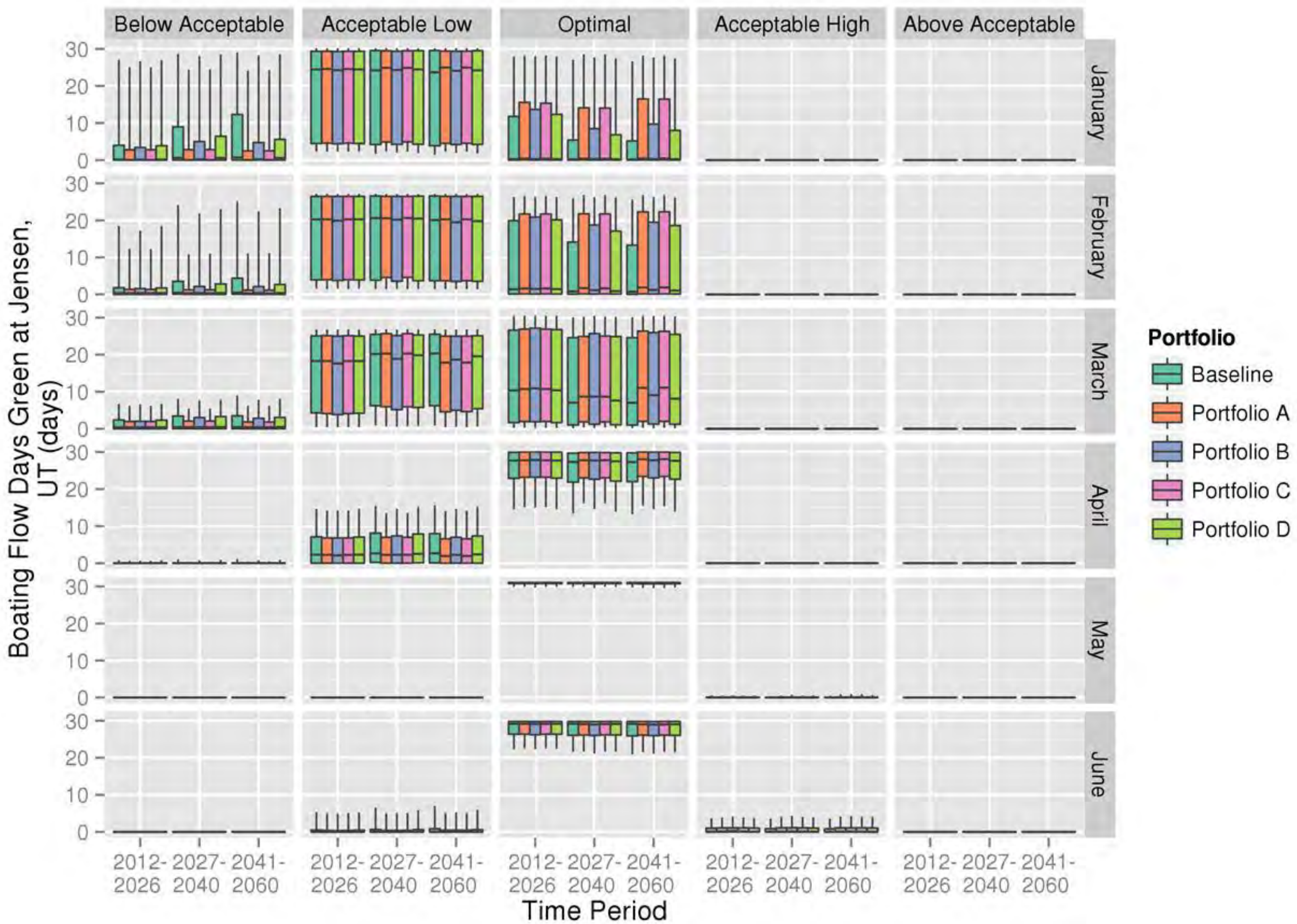


FIGURE E-12B
Monthly River and Whitewater Boating by Boating Flow Day Type, Green River at Jensen, UT

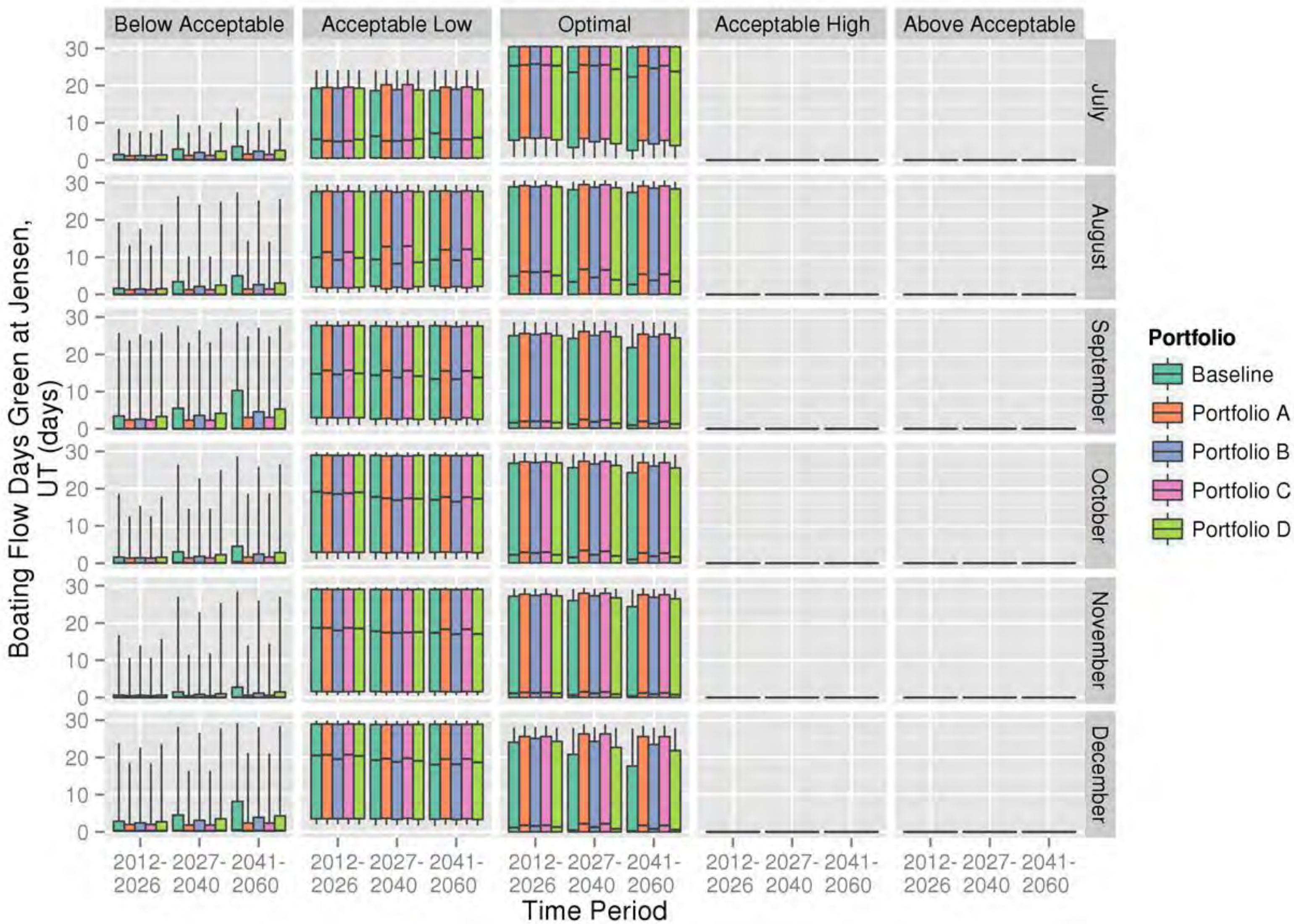


FIGURE E-13A
Monthly River and Whitewater Boating by Boating Flow Day Type, San Juan River near Bluff, UT

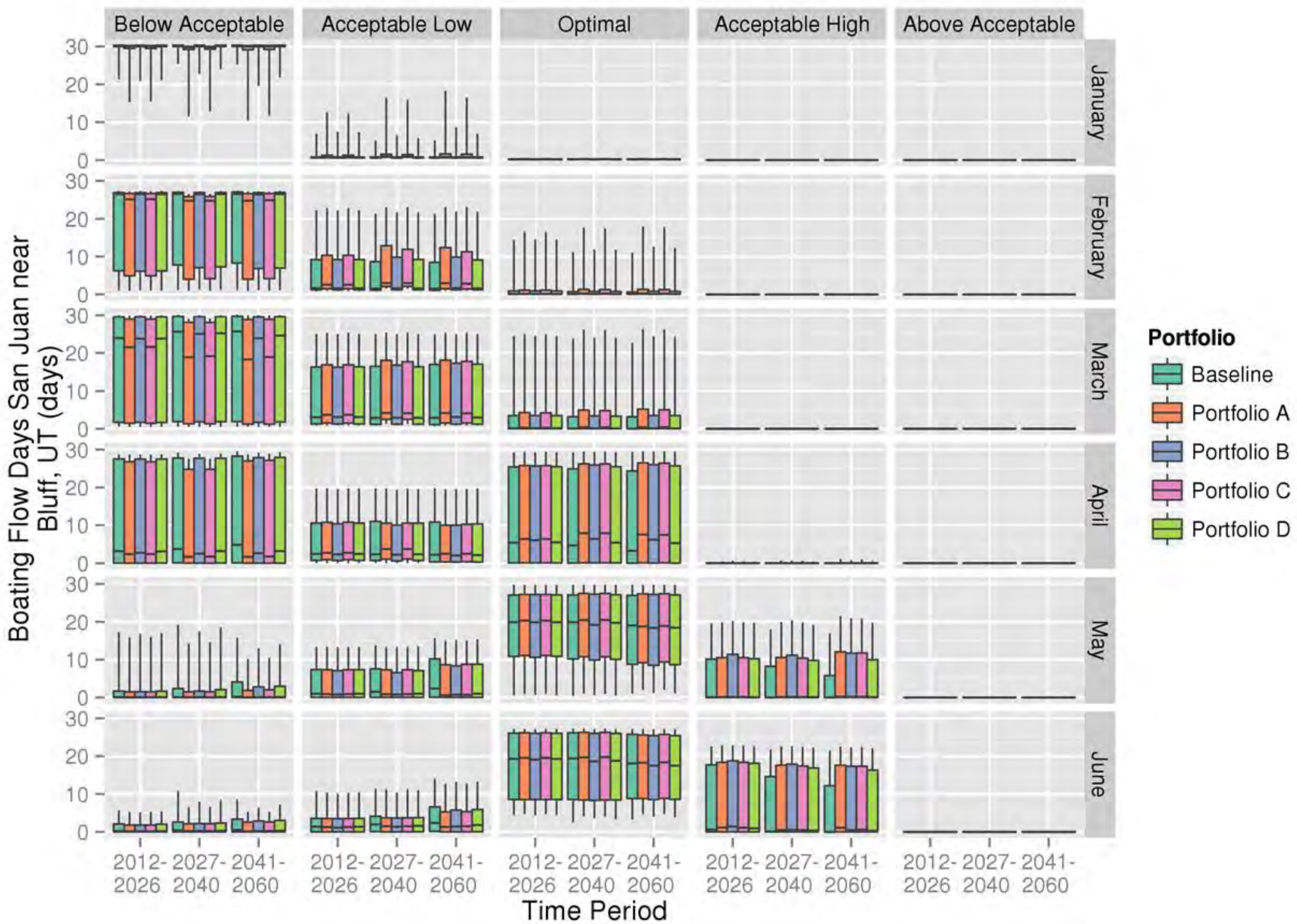
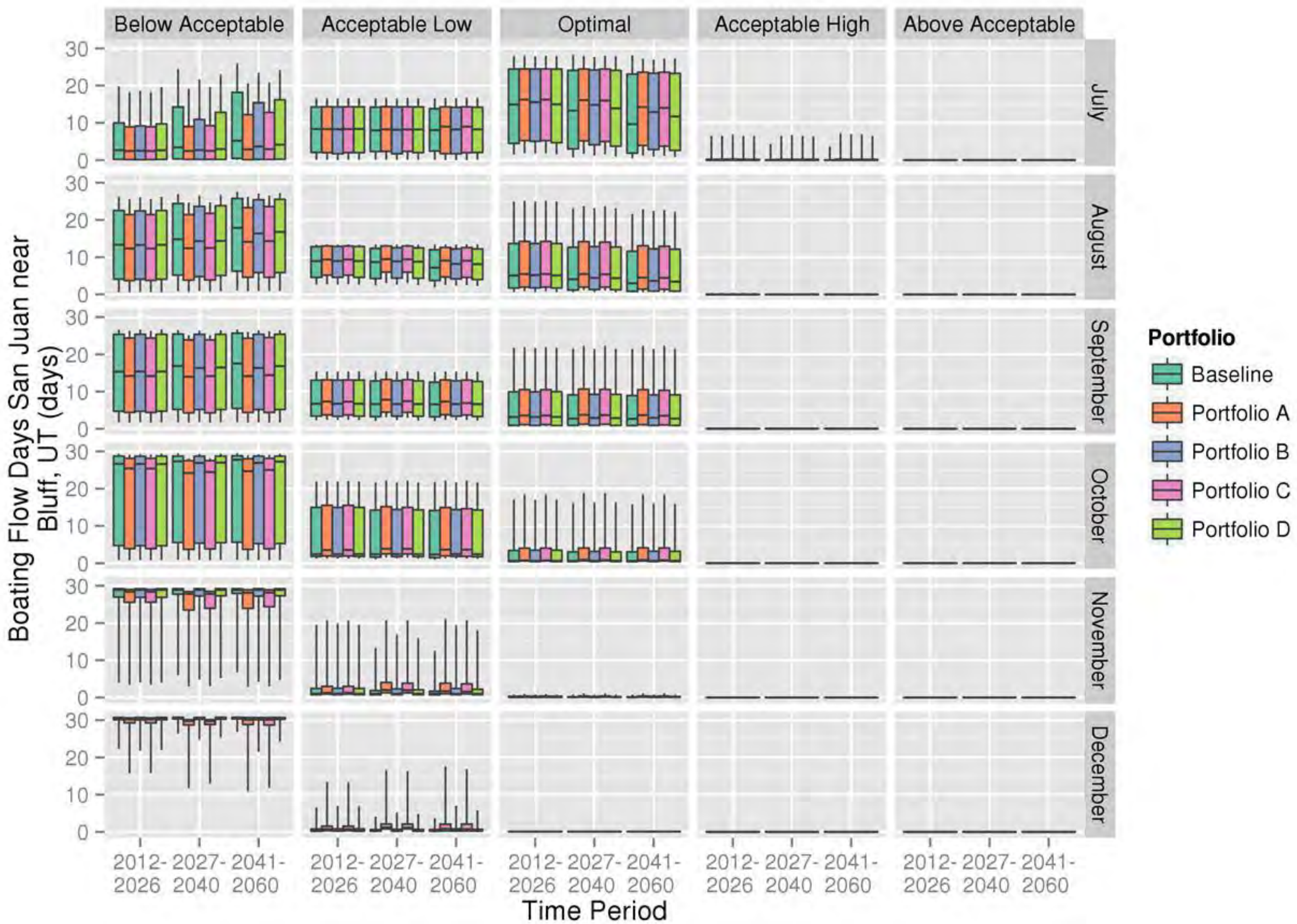


FIGURE E-13B
Monthly River and Whitewater Boating by Boating Flow Day Type, San Juan River near Bluff, UT



# 4.0 Other Recreational Attributes of Interest

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

As reservoirs are significantly drawn down, sediment can be re-suspended and may result in the release of nutrients, possibly enhancing algal blooms. Riverine sediment transport, therefore, can have implications for the quality of recreation experience. In addition, sediment transport can affect beach formation and maintenance. Significant and/or frequent drawdown can lead to erosion, loss of beaches, and subsequent negative effects on recreation. These potential effects were qualitatively assessed by examining the variability and magnitude of reservoir drawdown. In figure E-5, Lake Mead elevation is shown to be lower in general and exhibit a broad range of elevations under the Baseline. Further, sedimentation, coupled with lower reservoir levels can reduce recreation opportunities by limiting access to certain areas or by creating operational challenges to boat ramps and marinas.

Implementing portfolios increases the expected elevations and reduces the range in elevations over time. These improvements imply that there could be less downcutting and subsequent sediment transport issues in the portfolios relative to the Baseline. By 2060, implementation of each portfolio results in a higher median elevation than that of today. This increase implies that in the future, there could be less downcutting than at present and therefore less impact due to sediment.

# 5.0 Metrics for the Socioeconomic Impacts Attribute of Interest

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

CRSS simulations indicate that both reservoir levels and flow could be reduced under the Baseline. Figures E-1 through E-5 show portfolio implementation generally increases reservoir levels, and figures E-6 through E-13 suggest higher flows over time when compared to the Baseline. However, a portfolio is unlikely to exactly maintain historical reservoir levels or flow. Timing, magnitude, and location of portfolio options create uncertainty with regard to the socioeconomic impacts. In general, as reservoir levels decrease below the level for shoreline public use facilities, opportunities for visitation also decrease. However, sizeable fluctuations in pool elevation can be as important as an absolute decrease with regard to the maintenance and operation of shoreline public use facilities. As such, a reduction in the range of reservoir levels or flow could help to mitigate socioeconomic impacts associated with overall magnitude reductions.

Appendix G4

# Attachment F

# Ecological Resource Metrics' Results

# Attachment F — Ecological Resource Metrics' Results

## 1.0 Introduction

System reliability metrics (metrics), defined in *Technical Report D – System Reliability Metrics,* were developed to assess the performance of Colorado River Basin (Basin) resources with and without the implementation of options and strategies. Metrics were developed for six resource categories (Water Deliveries, Electrical Power Resources, Water Quality, Flood Control, Recreational Resources, and Ecological Resources) and for numerous attributes of interest within each category.

This attachment presents summary results for the quantitative metrics associated with Ecological Resources. The Ecological Resource attributes of interest are shown in table F-1.

Results are presented by portfolio with all scenario combinations grouped together. In accordance with the scenario planning approach employed in the Colorado River Basin Water Supply and Demand Study (Study), all scenarios are plausible and results are presented to reflect the distribution of outcomes associated with the various scenarios considered. All scenarios have been resampled such that each scenario contributes equally to the distribution. Results are intended to be used to make relative comparisons. They are not intended to specify absolute values.

Information for each attribute of interest and subsequent metrics is discussed and presented as quantitative information in figures that reflect key outcomes. Where applicable, figures display reference values from *Technical Report D – System Reliability Metrics*. Figures include:

(9) Box and whisker type plots that show the median, 25th and 75th percentiles and include "whiskers" representing the 10th and 90th percentiles. The statistical data for a given "box" represent the metric over all combined supply and demand scenarios, unless otherwise noted. The boxes are presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041through 2060.

(10) Bar charts are used to display the percent of years that met a desired target or the percent of years that are within a given category. The bars are also presented for the Baseline as well as each portfolio for time periods representing 2012 through 2026, 2027 through 2040, and 2041through 2060.

TABLE F-1
Ecological Resource Metrics

| Attribute of Interest | Resource Metric | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|---|
| Flows to Support Threatened and Endangered Species | Flows to Support Threatened and Endangered Species | 2 | Quantitative | Monthly | Yampa River near Maybell, CO | F-1 |
| | | | | | Glen Canyon Dam | F-2 |
| | | | | Year Type Frequency and Flow by Year Type | Colorado River near Cameo, CO | F-3 and F-4 |
| | | | | | Gunnison River near Grand Junction, CO | F-5 and F-6 |
| | | | | | Colorado River near the Colorado-Utah Stateline | F-7 and F-8 |
| | | | | | Green River near Greendale, UT | F-9 and F-10 |
| | | | | | Green River at Green River, UT | F-11 and F-12 |
| | | | | | Duchesne River near Randlett, UT | F-13 and F-14 |
| | | | | Year Type Frequency and Percent of Years Meeting Target | Green River at Jensen, UT | F-9 and F-15 |
| | | | | Monthly and Annual | San Juan River near Bluff, UT | F-16 through F-20 |
| | | | | Annual | Hoover Dam to Davis Dam | F-21 |
| | | | | | Davis Dam to Parker Dam | F-22 |
| | | | | | Parker Dam to Imperial Dam | F-23 |
| Aquatic and Riparian Habitat | Instream Flow Rights | 3.1 | Quantitative | Monthly | Taylor River near Taylor Park, CO | F-24 |
| | | | | | Gunnison River below Crystal Reservoir, CO | F-25 |
| | Cottonwood Recruitment Metric | 3.2 | Quantitative | Annual | Dolores River near Cisco, UT | F-26 |
| | | | | | San Juan River near Archuleta, NM | F-27 |
| | | | | | Green River below Fontenelle Reservoir, WY | F-28 |
| | | | | | Green River near Green River, WY | F-29 |
| | | | | | San Rafael near Green River, UT | F-30 |
| | | | | | Colorado River near Cisco, UT | F-31 |

TABLE F-1
Ecological Resource Metrics

| Attribute of Interest | Resource Metric | Section | Quantitative or Qualitative | Plot Type | Location | Figure Number |
|---|---|---|---|---|---|---|
| Aquatic and Riparian Habitat | Flow-Dependent Ecological Systems | 3.3 | Quantitative | Year Type Frequency and Flow by Year Type | Yampa River near Maybell, CO | F-32 and F-33 |
| | | | | | Little Snake River near Lily, CO | F-34 and F-35 |
| | | | | | Yampa River at Deerlodge Park, CO | F-36 and F-37 |
| | | | | | White River near Watson, UT | F-38 and F-39 |
| Wildlife Refuges and Fish Hatcheries | Wildlife Refuges and Fish Hatcheries | 4 | Quantitative | Flow by Year Type | Browns Park National Wildlife Refuge | F-40 |
| | | | | | Seedskadee National Wildlife Refuge | F-41 |
| | | | | | Ouray National Wildlife Refuge | F-42 |
| | | | | Annual | Havasu National Wildlife Refuge | Table F-2 |
| | | | | | Cibola National Wildlife Refuge | |
| | | | | | Imperial National Wildlife Refuge | |
| | | | | | Willow Beach Fish Hatchery | |

# 2.0 Metrics for the Flows to Support Threatened and Endangered Species Attribute of Interest

The Upper Colorado River Endangered Fish Recovery Program and San Juan River Basin Recovery Implementation Program (Recovery Programs) are designed to help recover several fish species listed as endangered under the federal Endangered Species Act (the Colorado pike minnow, the razorback sucker, the bonytail, and the humpback chub) while allowing water development to continue in the Upper Colorado and San Juan River Basins. Flow recommendations[3] are defined as part of the Recovery Programs; therefore, flows are used as metrics for these fish species, and the Recovery Programs' recommendations provide the reference values. Providing flows is only one part of the recovery efforts, which include activities such as habitat development, non-native fish control, and monitoring and research. Therefore, the relative difference in achieving these flow recommendations across various scenarios should not be viewed as the sole means to recover the species. Many of the Recovery Program flow recommendations are for average daily flow rates, whereas the Colorado River Simulation System (CRSS) operates at the monthly time step. Recent research and development efforts resulted in the ability to evaluate daily flow targets below Navajo and Flaming Gorge Reservoirs (see *Technical Report D – System Reliability Metrics, Appendix D3 – Threatened and*

[3] 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.

*Endangered Species Metrics*). For other locations, monthly volumetric targets were developed based on the Recovery Program's flow recommendations. Assumptions (e.g., hydrologic period of record chosen for year type determination) were made to develop those approximations that in some cases resulted in flows different than those specified in the reference documents and those 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.

In addition to metrics based on Recovery Program flow recommendations, metrics also exist for Glen Canyon Dam and on the Colorado River below Hoover Dam. The metric at Glen Canyon Dam represents the minimum allowable release specified by the 1996 Glen Canyon Dam Record of Decision (Bureau of Reclamation [Reclamation], 1996). The metrics below Hoover Dam represent the permitted changes in point diversions in three reaches specified by the Lower Colorado River Multi-Species Conservation Program (Reclamation, 2004).

The metrics for flows to support threatened and endangered species are separated into two main groups: those with single flow targets for all months (e.g. minimum base flows) and those with targets that vary by month and/or hydrologic year type. Figures F-1 and F-2 present results for the Yampa River near Maybell, Colorado, and the releases from Glen Canyon Dam, which both have minimum flow targets as reference values.

Of those locations with flow targets that vary by month and/or hydrologic year type, most contain two figure types: (1) a year type frequency figure and (2) a figure showing flow volumes by month and hydrologic year type. With the exception of the Gunnison River near Grand Junction, Colorado, and the Green River near Greendale and Jensen, Utah, the year type frequency figures were developed as follows:

1. Using annual volumes at the specific gage from the control run (see appendix G3), percentiles that separate year types were computed (e.g., the 20th percentile separates the "dry" years from "below average" years on at the Colorado River near Cameo, Colorado).
2. Using the annual volumes from the modeled scenarios, each year was binned in its respective year type classification, as separated by the thresholds computed in step 1.
3. The frequency that each year type occurred in each time period was computed.

For the Gunnison River near Grand Junction, Colorado, the *Final Gunnison River Programmatic Biological Opinion* (U.S. Fish and Wildlife Service [USFWS], 2009) indicates that year types are determined by the April through July forecasted inflow into Blue Mesa Reservoir. Therefore, step 1 above was skipped, and step 2 was modified to use the April through July volume and the thresholds defined in USFWS (2009) to bin the year types[4]. Similarly, the year types for the Green River near Greendale, Utah, and the Green River near Jensen, Utah (Jensen), are determined by the April through July unregulated inflow into Flaming Gorge Reservoir. All year type frequency figures include reference values indicating the expected frequency of each year type as defined by the respective flow recommendations.

At these locations, a complementary figure displays the flow (or flow volume) at each location for each year type and month. As explained in *Technical Report D – System Reliability Metrics*,

[4] The Aspinall Unit within CRSS is not operated to reflect the *Record of Decision for the Aspinall Unit Operations Final Environmental Impact Statement* (Reclamation, 2012); therefore, model results were not expected to reflect Record of Decision operations.

the spring months (typically April though July) are aggregated together. For each time period and month, for each scenario, the flows representing the different year type percentiles were grouped together, e.g., the driest 10 percent of Januaries in 2012 though 2026 or the 30th through 70th percentiles of April though July of 2041 through 2060. Then, each year type was grouped together for all scenarios before the statistics were computed for the box plot. These figures help show the flow variability between and within year types in comparison to the reference values.

The final metrics that are presented for flows to support threatened and endangered species are those for Jensen and the San Juan River near Bluff, Utah (Bluff). Although these locations are largely analogous to those previously described, the daily flow recommendations are able to be directly compared using CRSS by disaggregating monthly volumes to plausible daily flow patterns instead of having to aggregate daily recommendations to monthly volumes – see *Technical Report D – System Reliability Metrics* for more information. The ability to directly compare disaggregated flows to recommendations changes the way the results can be viewed. For the daily flow targets and durations at Jensen, figure F-15 indicates the percent of years that were able to meet each flow target. The flow targets for Bluff include a minimum frequency and a maximum interval between occurrences that each flow target should meet and not exceed, respectively. Each flow target at Bluff includes a figure for the frequency of meeting the target, and a figure presenting the years since the flow target was last met (years since last occurrence). For the years since last occurrence, the historical gage record at Bluff was analyzed to determine the last occurrence, rather than starting the count from zero in 2012 (the first modeled year). This helps to more accurately present the years since the last occurrence for the first time period (2012 through 2026). Finally, Bluff also includes a minimum base flow target that is presented identically to like metrics as previously described.

Several overarching results are observed at most locations for flows to support threatened and endangered species metrics. To begin, the flow is generally higher in all portfolios than in the Baseline, particularly at the 75th and 90th percentiles. At locations separated by hydrologic year type, this trend is more apparent in the wetter year types. Typically, *Portfolios A* and *C* increase the flow more than *Portfolios B* and *D*; figure F-1 exemplifies this observation, which is due to the inclusion of an Upper Basin bank and the routing of conserved water to a conceptual off-stream storage location above Lake Powell. At most locations for which the year type frequency is shown, in the Baseline, there is an increase in the frequency of dryer year types and a decrease in the number of wetter year types through time. Again, all portfolios help stabilize or reduce the frequency of dry year types through time and stabilize or increase the frequency of wet year types, compared to the Baseline. In some cases (e.g., figure F-5), an increase in the frequency of wet year types through time within a single portfolio is achieved.

For Jensen (figure F-15), the frequency that each of the flow targets is met decreases through time under the Baseline. With the implementation of portfolios, the frequency that the flow targets are met increases not only as compared to the Baseline, but through time as well.

The average monthly flows at Bluff (figure F-16) follow the same trends in monthly flows discussed previously. In figures F-17 through F-20, the frequency that flow targets are met and the number of years between occurrences are shown for four different flow-duration targets. In all cases, portfolios perform better than the Baseline (i.e., increase the frequency of meeting the flow targets, and decrease the number of years between occurrences). For these metrics, the performance across portfolios is similar, with the exception those shown in figure F-18b, which indicates slightly better performance in the third period (2041 through 2060) in *Portfolio A*, and figure F-17a, which indicates slightly worse performance in that period by *Portfolio D*.

Figures F-21 through F-23 show the annual flow reductions in three reaches below Lake Mead. In all three reaches, the same general trend exists; the Baseline only exceeds the maximum allowable flow reduction at the 90th percentile in the third period, and the portfolios all decrease the flow reductions, compared to the Baseline. There is some variability across portfolios, with *Portfolio B* typically performing better and *Portfolio D* not performing as well.

FIGURE F-1
Monthly Flow, Yampa River near Maybell, CO
*Red Lines Indicate the Minimum Reference Value of 120 cubic feet per second (cfs)*

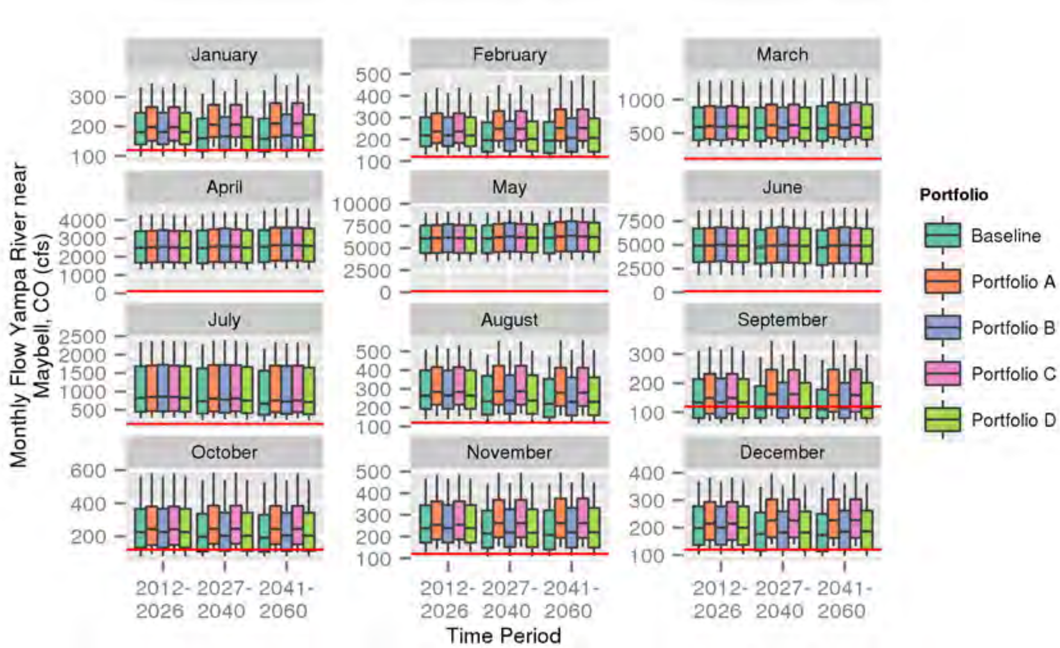


FIGURE F-2
Monthly Release from Glen Canyon Dam
*Red Lines Indicate the Minimum Base Flow Reference Value of 6,438 cfs*

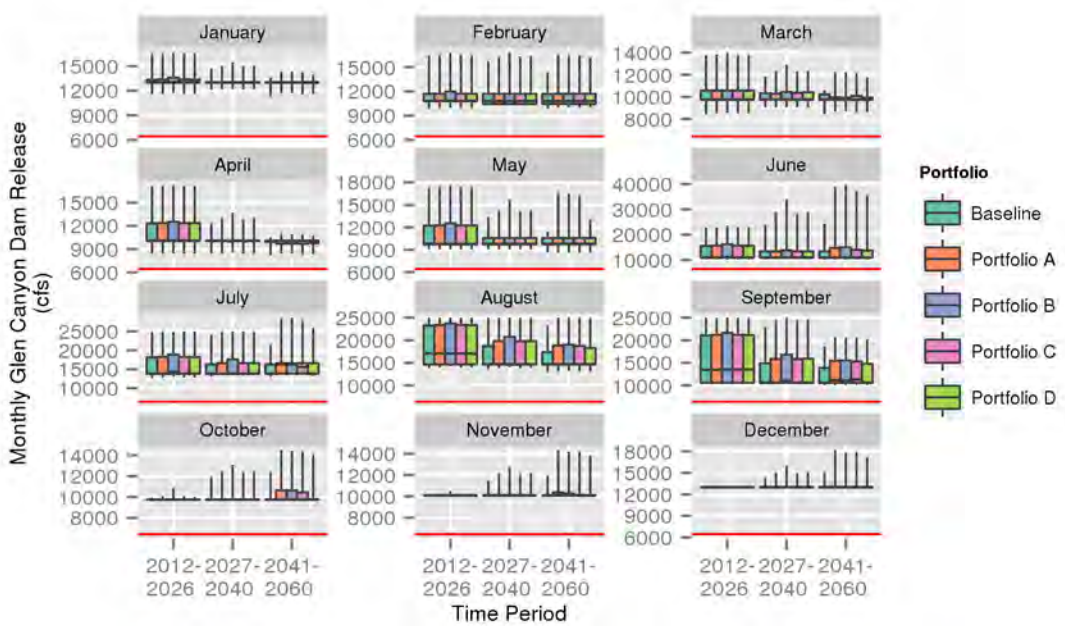



FIGURE F-3
Year Type Frequency, Colorado River near Cameo, CO
*Red Lines Indicate Frequency Reference Values*

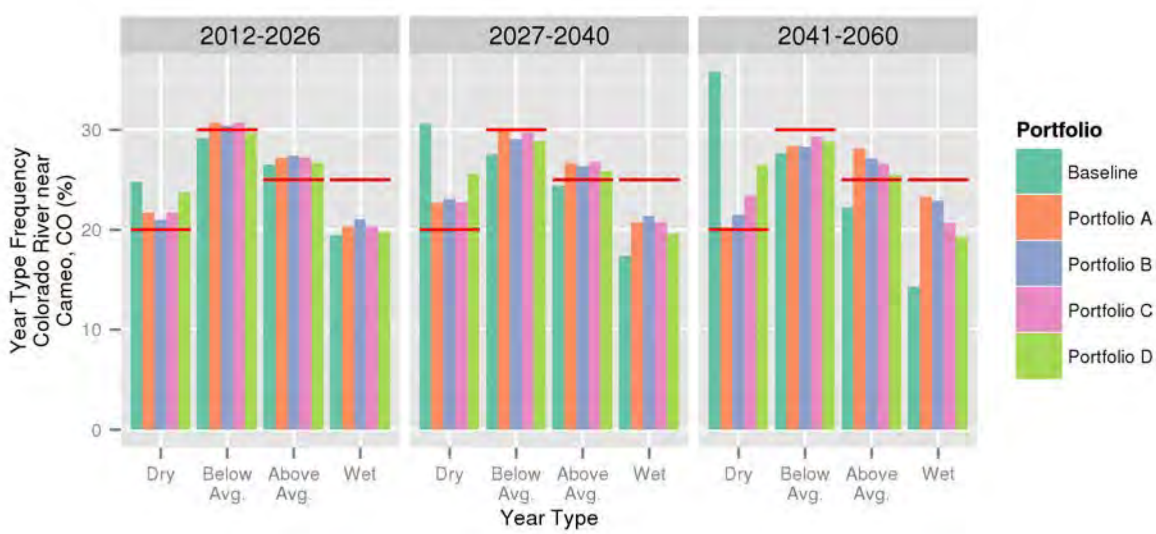


FIGURE F-4A
Flow Volume by Year Type, Colorado River near Cameo, CO
*Red Lines Indicate the Average Monthly Flow Recommendations as Reference Values*

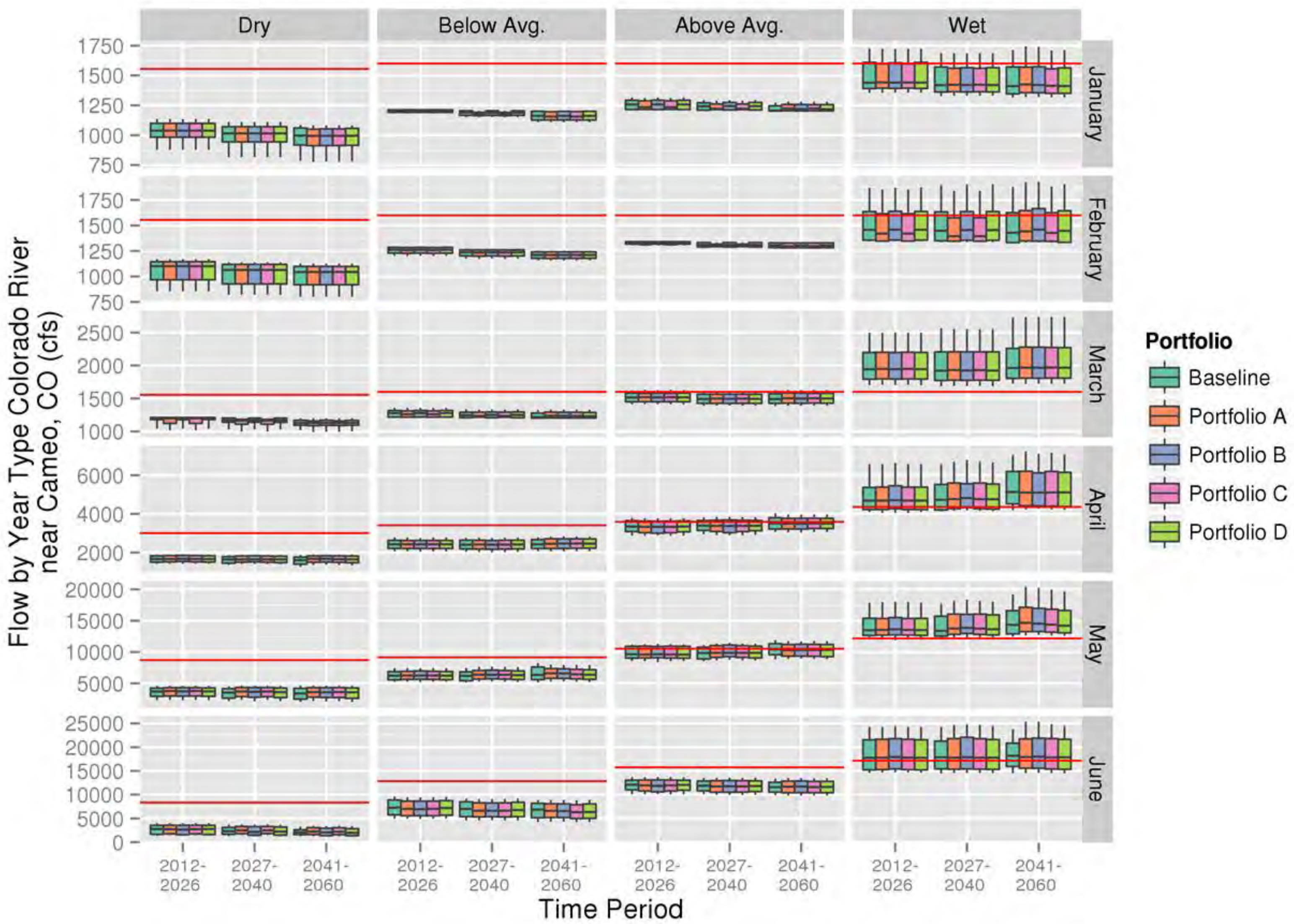


FIGURE F-4B
Flow Volume by Year Type, Colorado River near Cameo, CO
*Red Lines Indicate the Average Monthly Flow Recommendations as Reference Values*

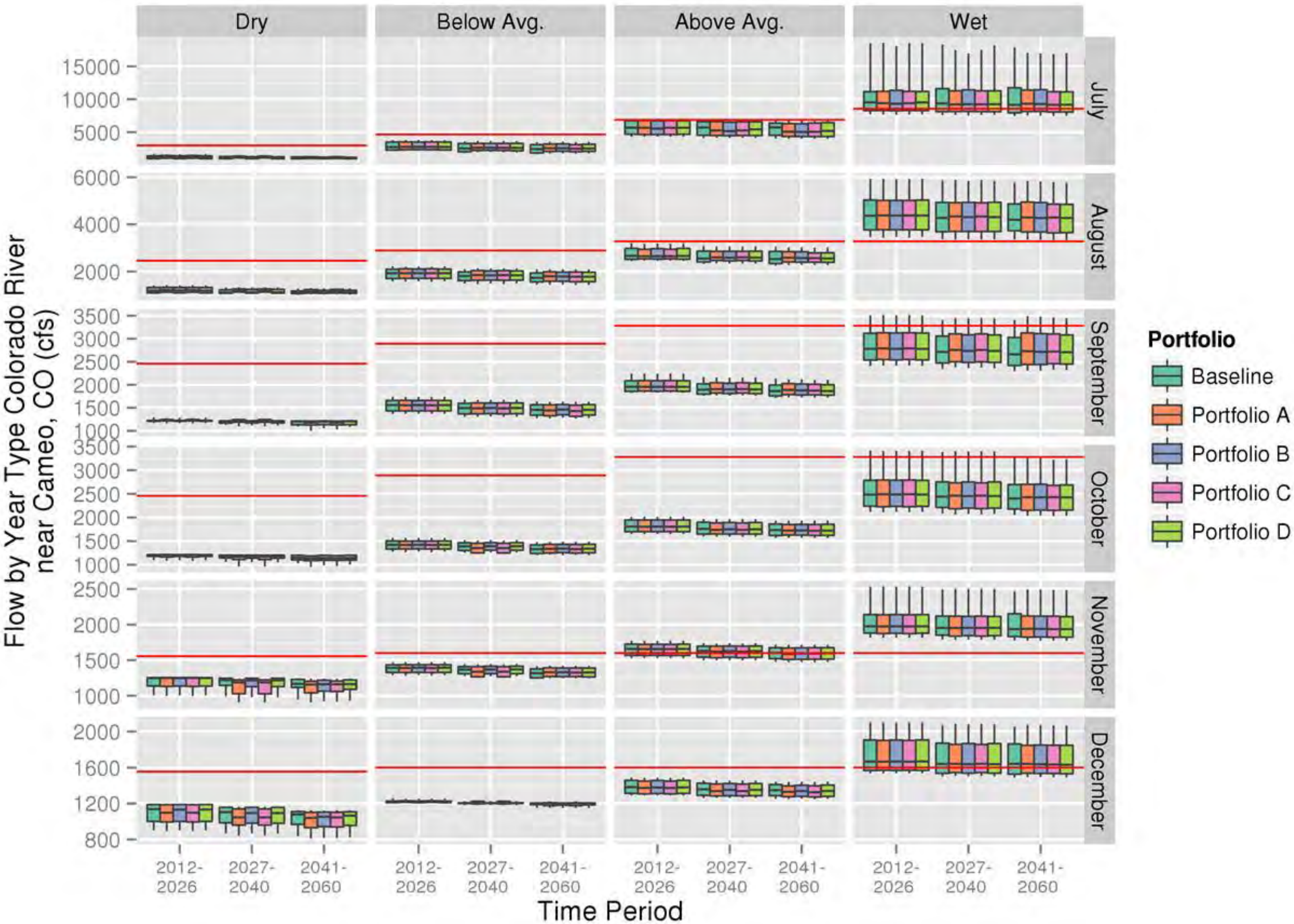


FIGURE F-5
Year Type Frequency, Gunnison River near Grand Junction, CO
*Red Lines Indicate Frequency Reference Values*

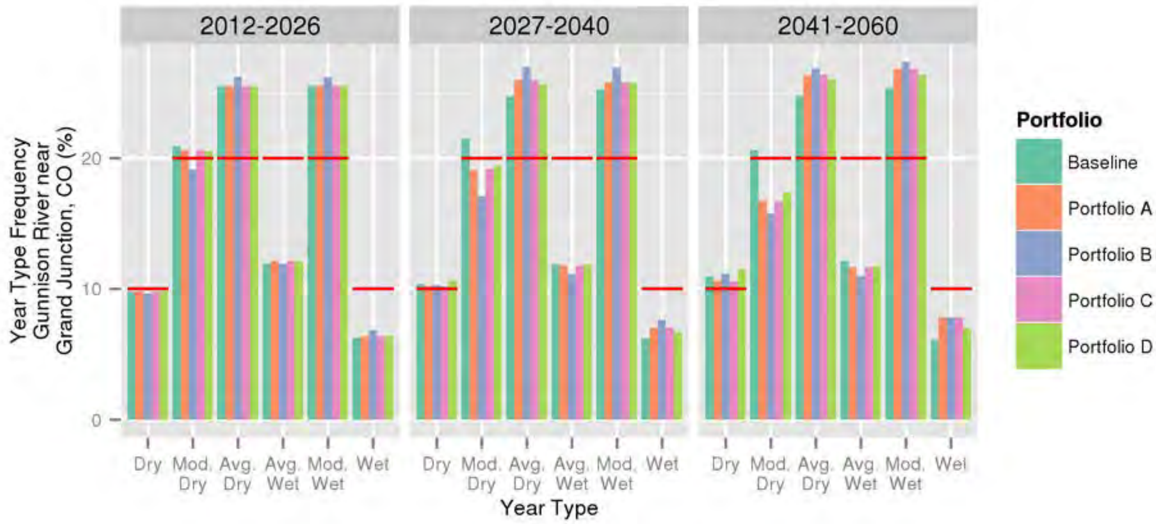


FIGURE F-6A
Flow Volume by Year Type, Gunnison River near Grand Junction, CO
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

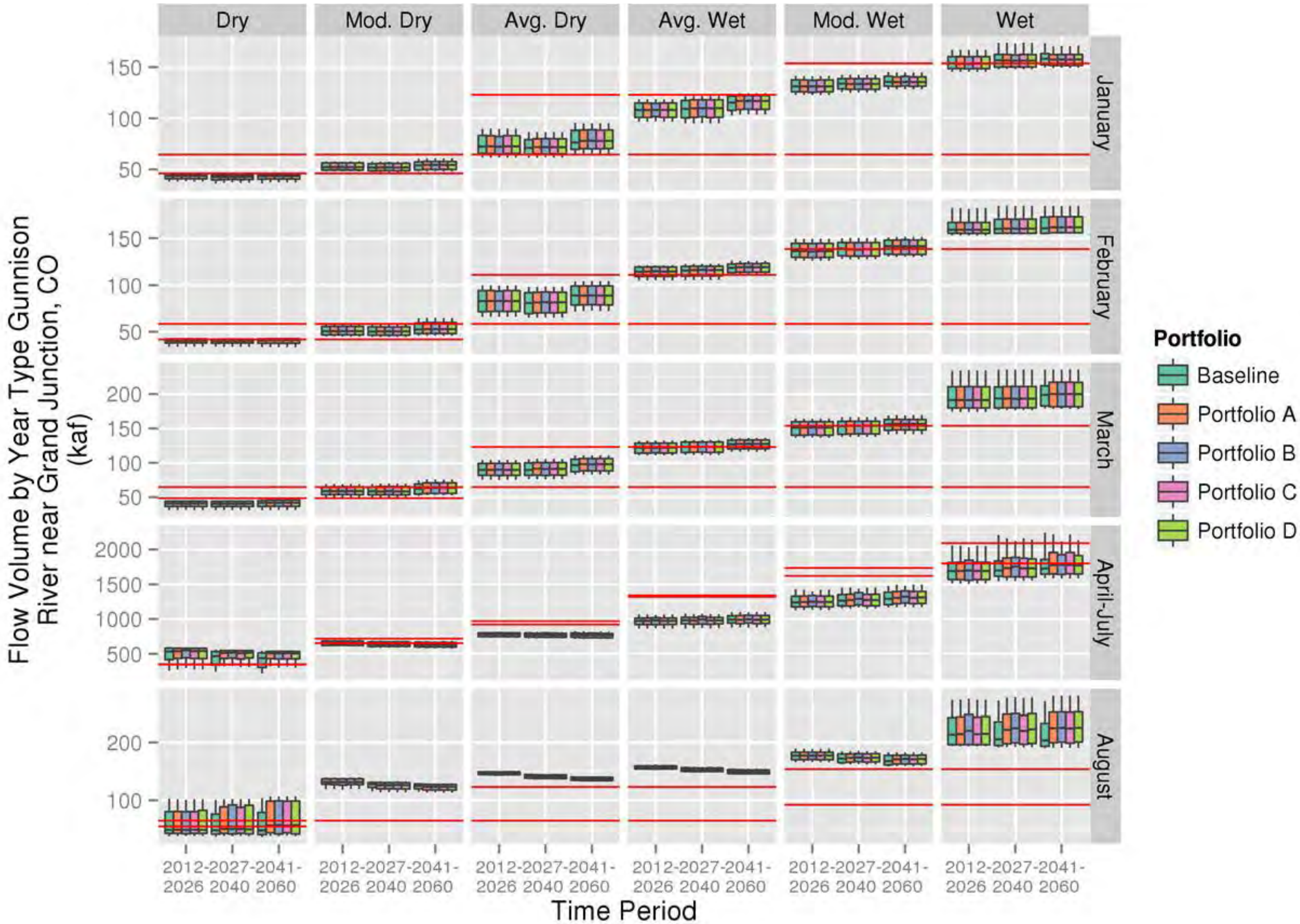


FIGURE F-6B
Flow Volume by Year Type, Gunnison River near Grand Junction, CO
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

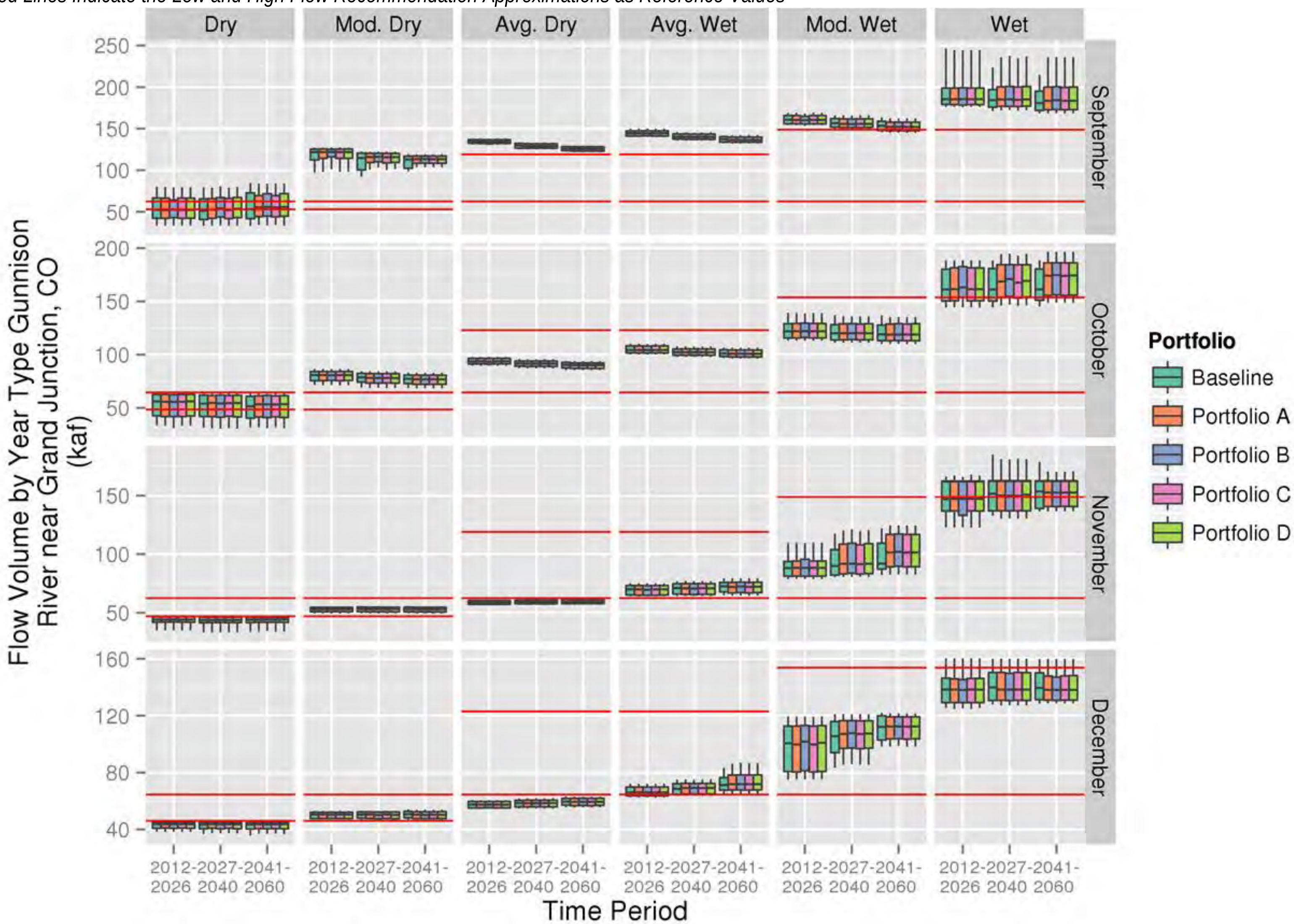


FIGURE F-7
Year Type Frequency, Colorado River near Colorado-Utah State Line
*Red Lines Indicate Frequency Reference Values*

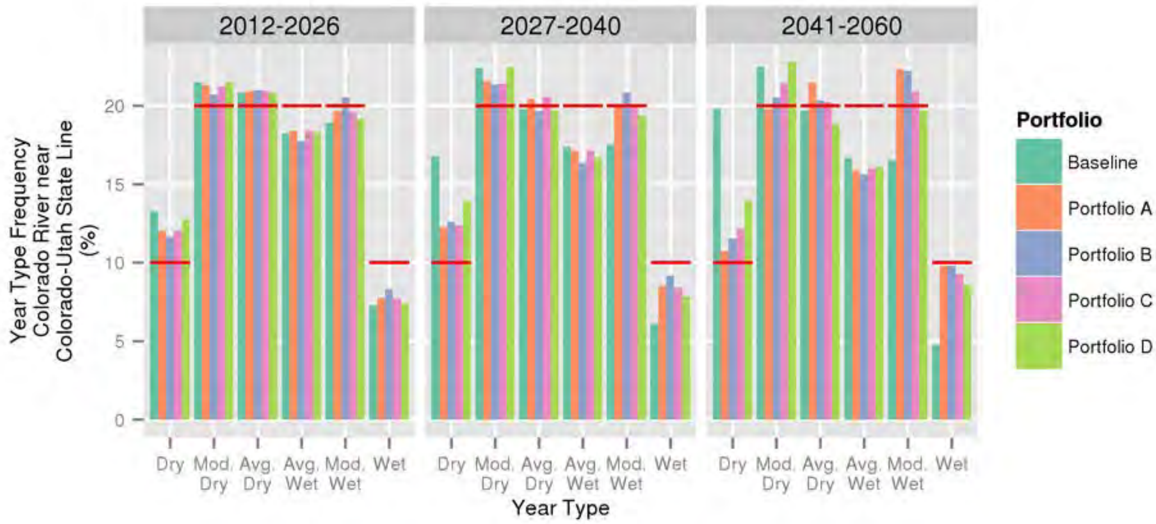


FIGURE F-8A
Flow Volume by Year Type, Colorado River near Colorado-Utah State Line
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

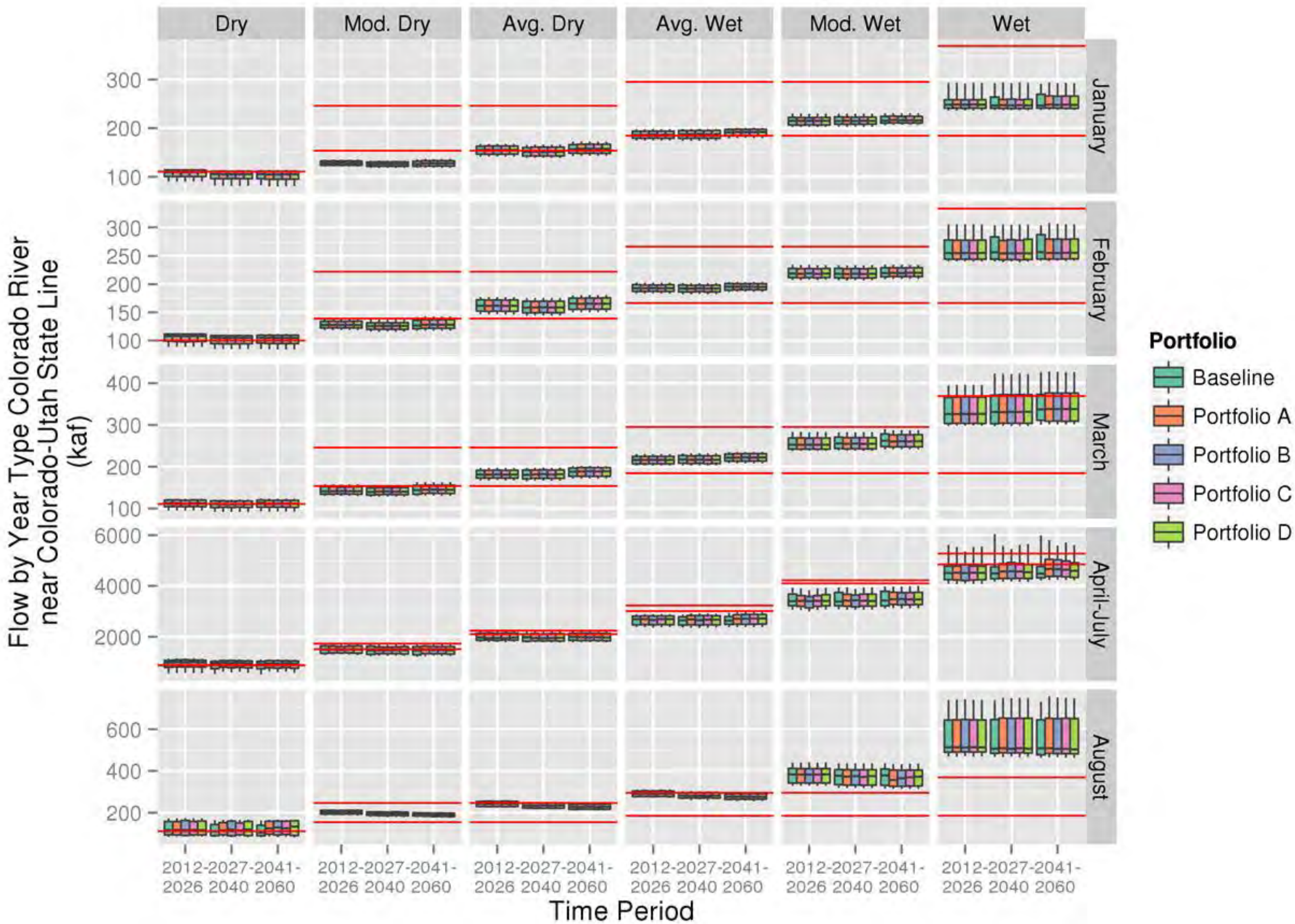


FIGURE F-8B
Flow Volume by Year Type, Colorado River near Colorado-Utah State Line
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

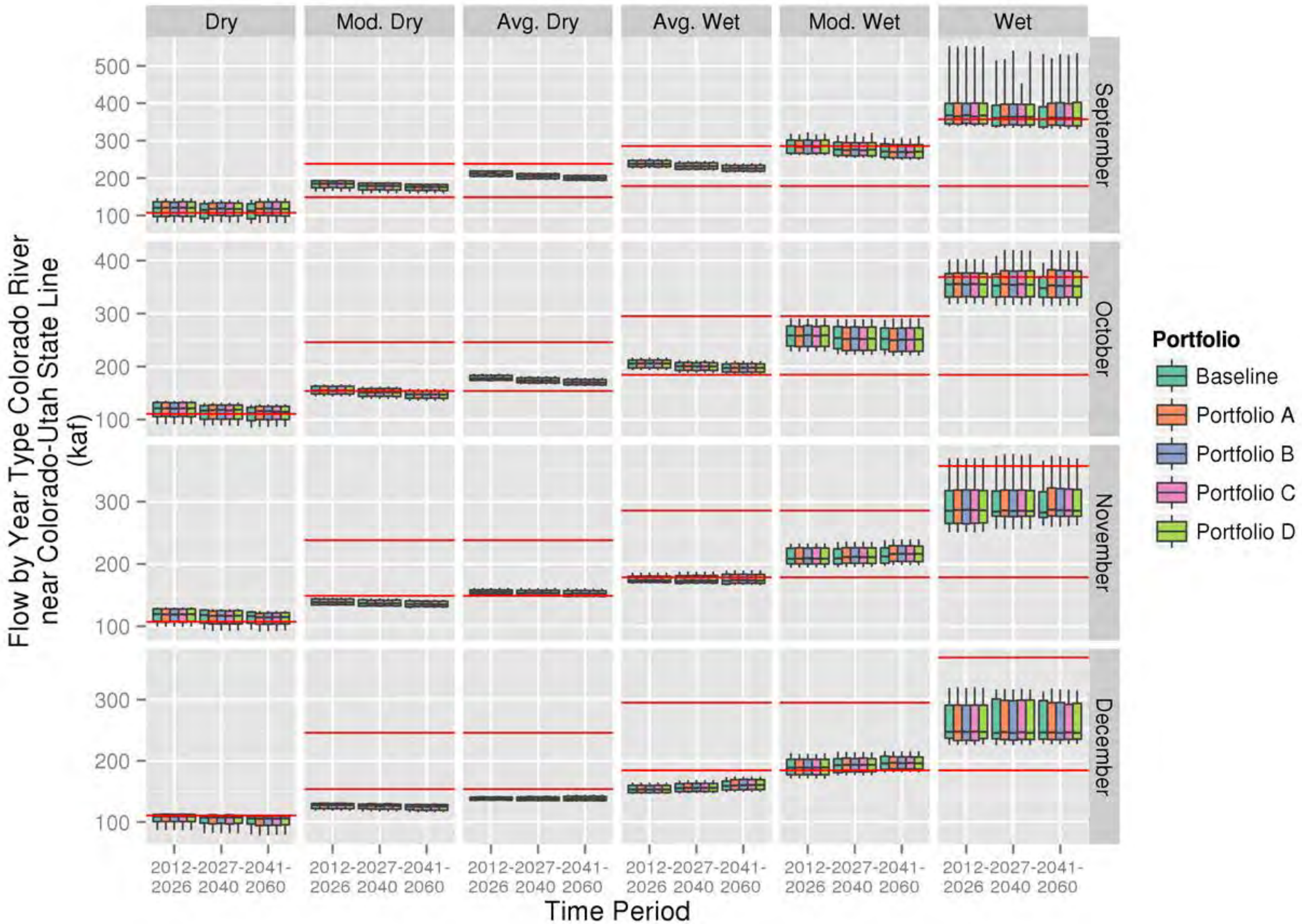


FIGURE F-9
Year Type Frequency, Green River near Greendale and Jensen, UT
*Red Lines Indicate Frequency Reference Values*

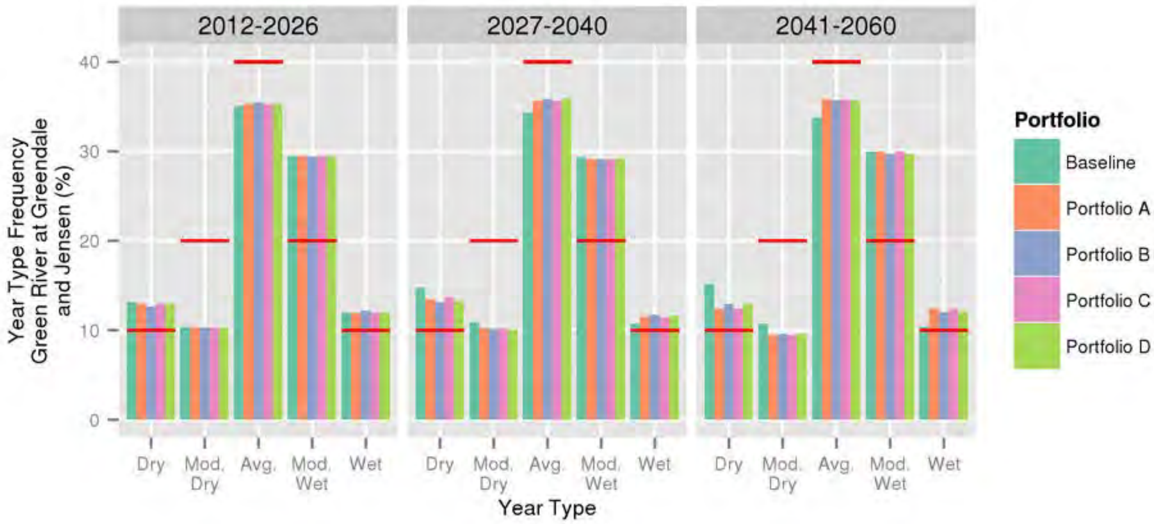


FIGURE F-10A
Flow by Year Type, Green River near Greendale, UT
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

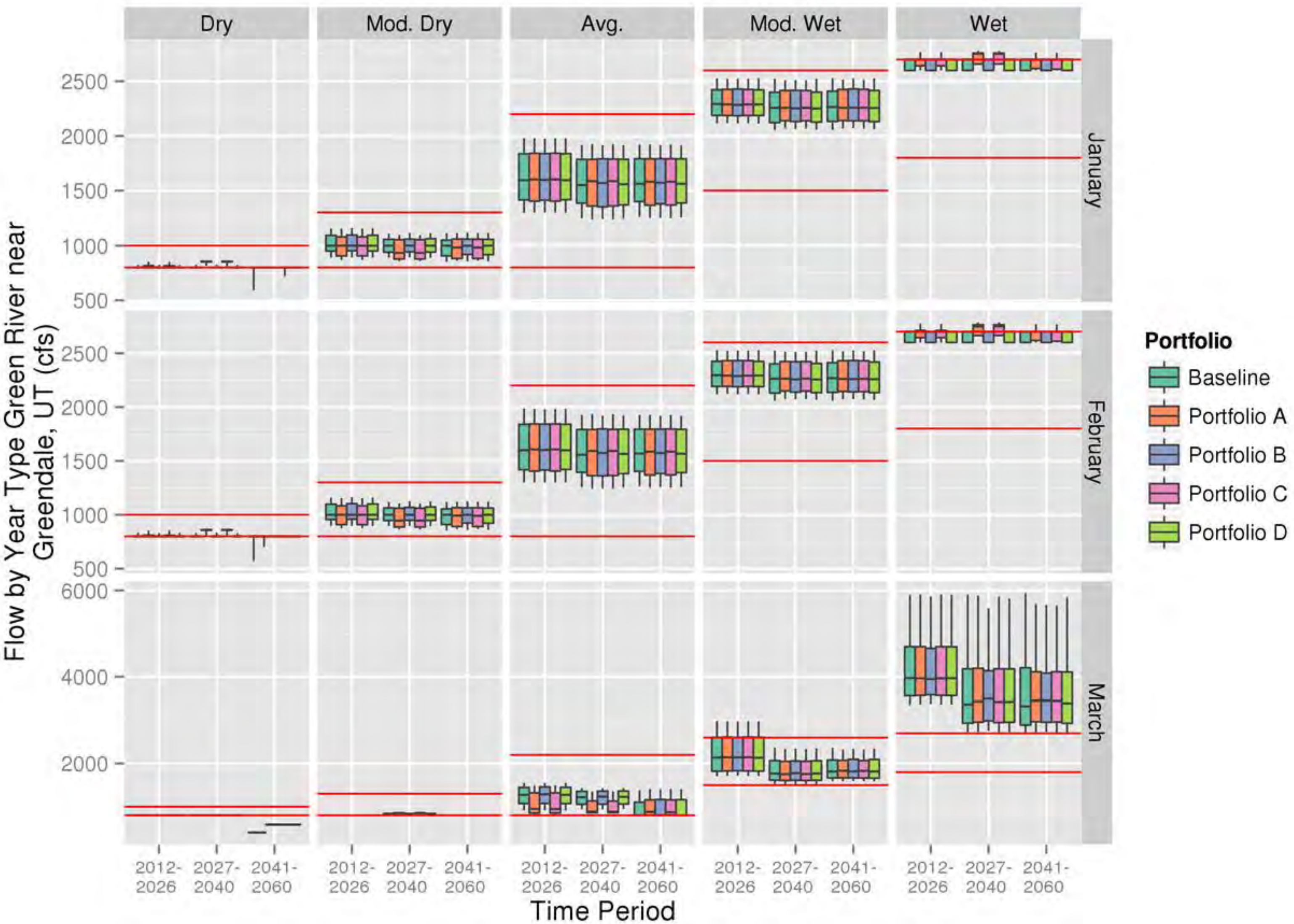


FIGURE F-10B
Flow by Year Type, Green River near Greendale, UT
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

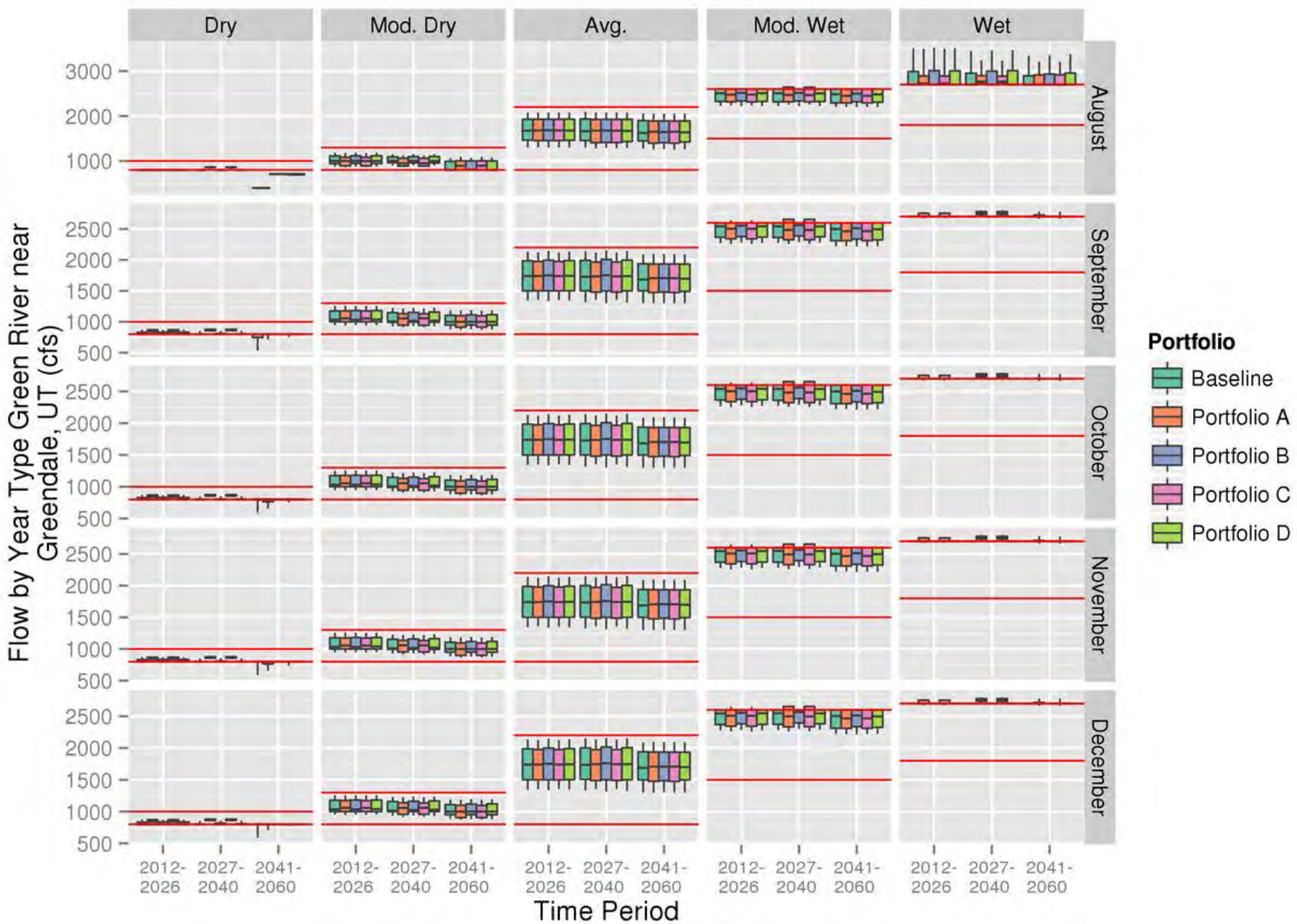


FIGURE F-11
Year Type Frequency, Green River at Green River, UT
*Red Lines Indicate Frequency Reference Values*

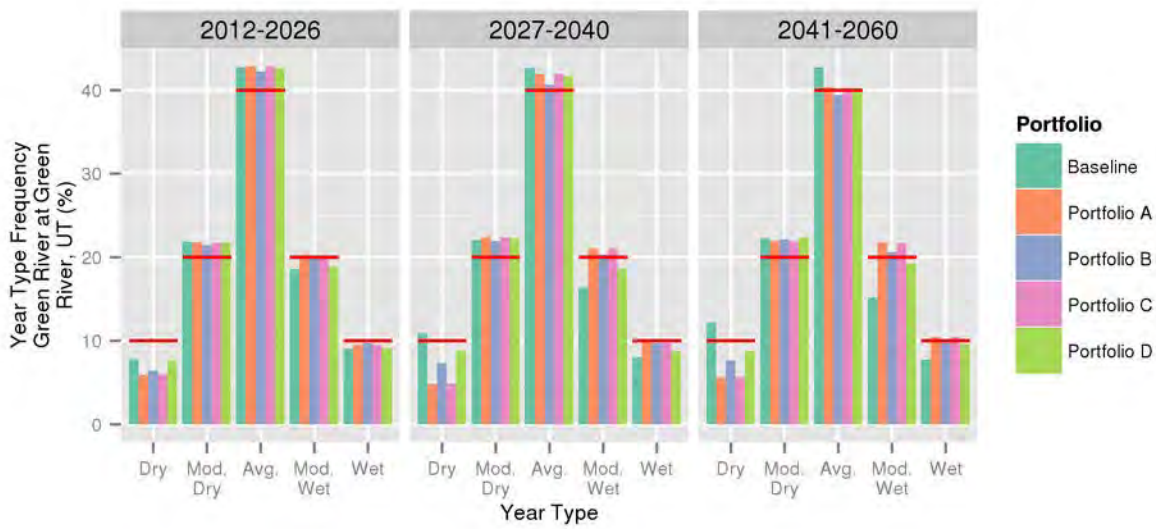


FIGURE F-12A
Flow Volume by Year Type, Green River at Green River, UT
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

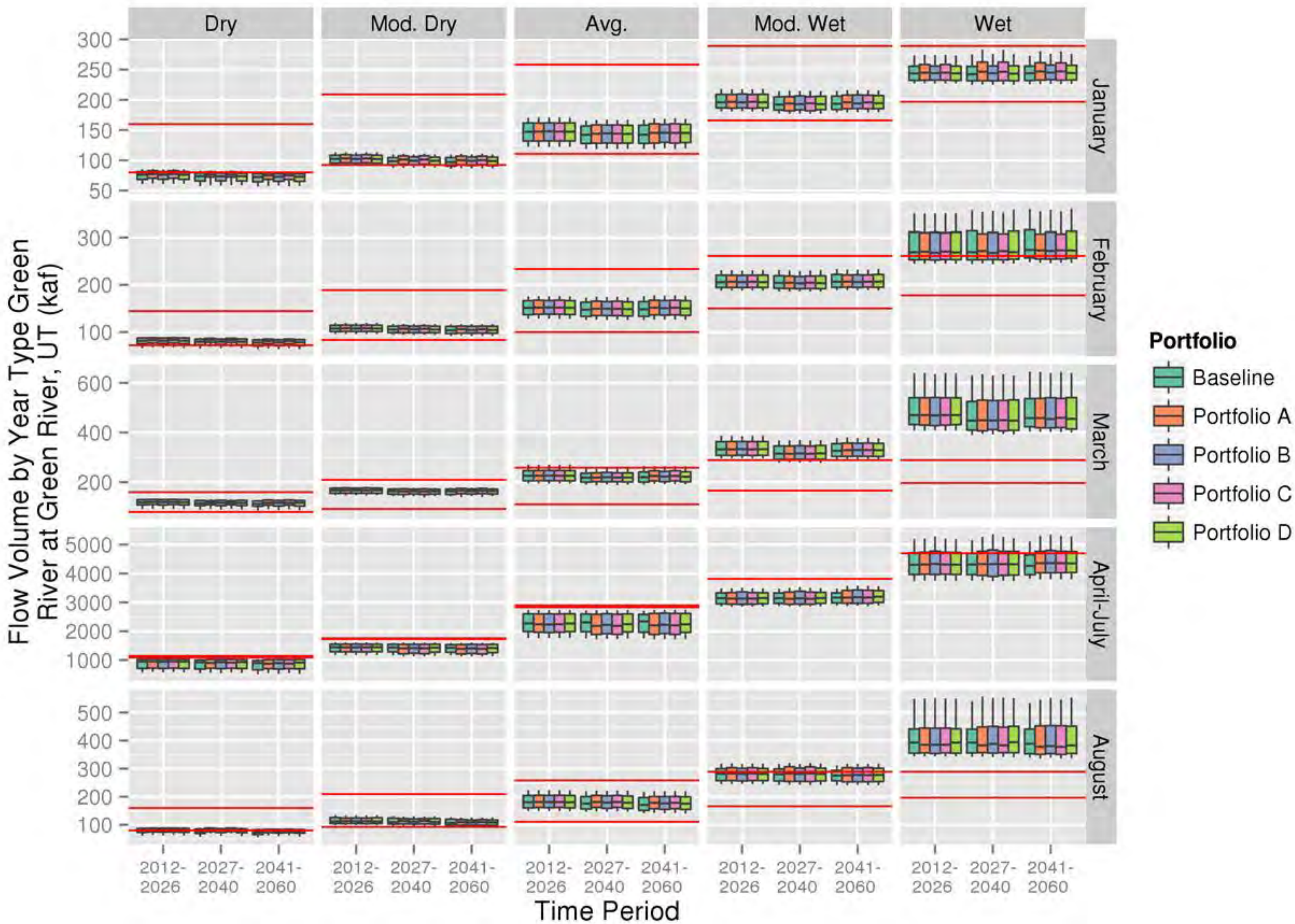


FIGURE F-12B
Flow Volume by Year Type, Green River at Green River, UT
*Red Lines Indicate the Low and High Flow Recommendation Approximations as Reference Values*

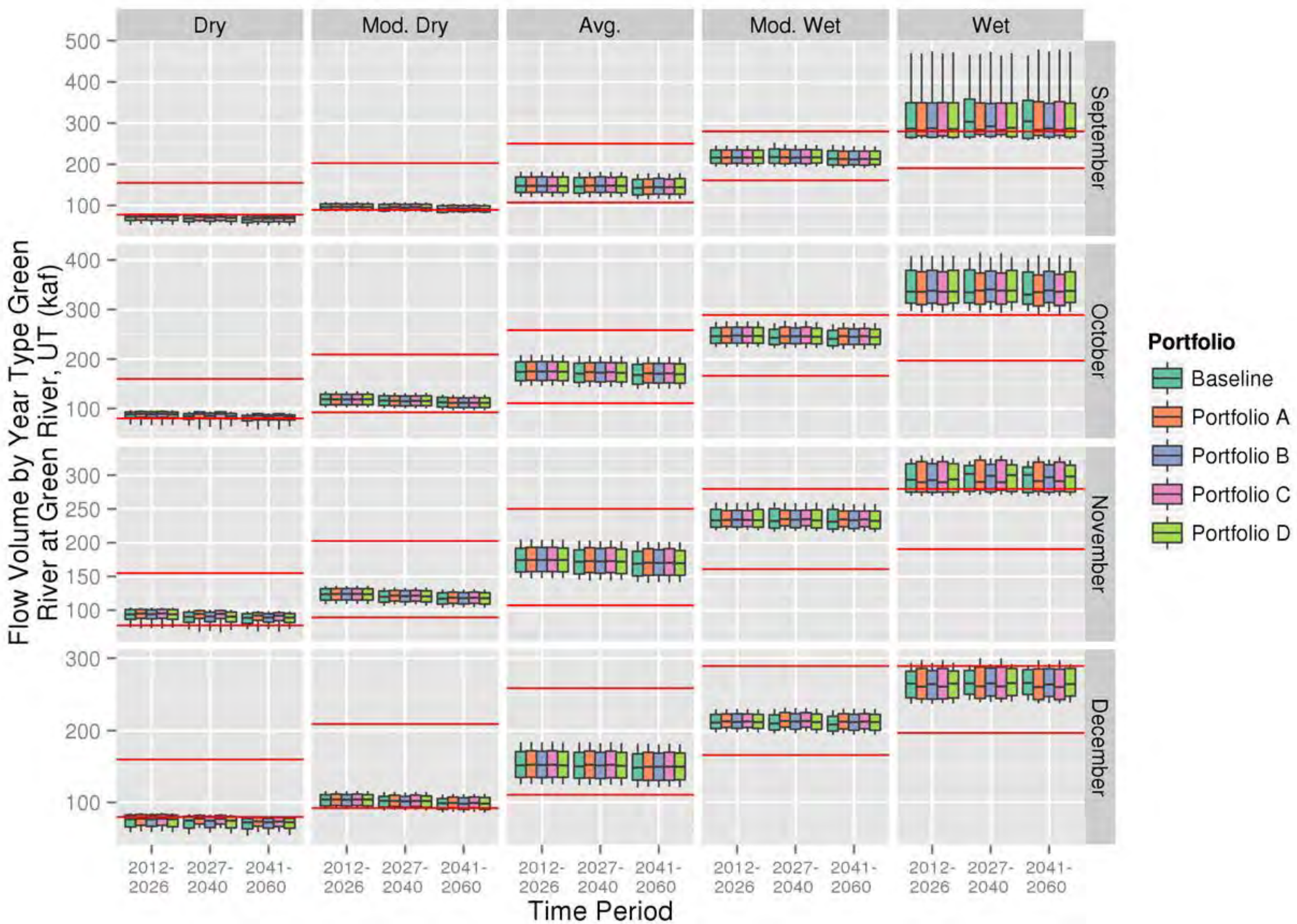


FIGURE F-13
Year Type Frequency, Duchesne River near Randlett, UT
*Red Lines Indicate Frequency Reference Values*

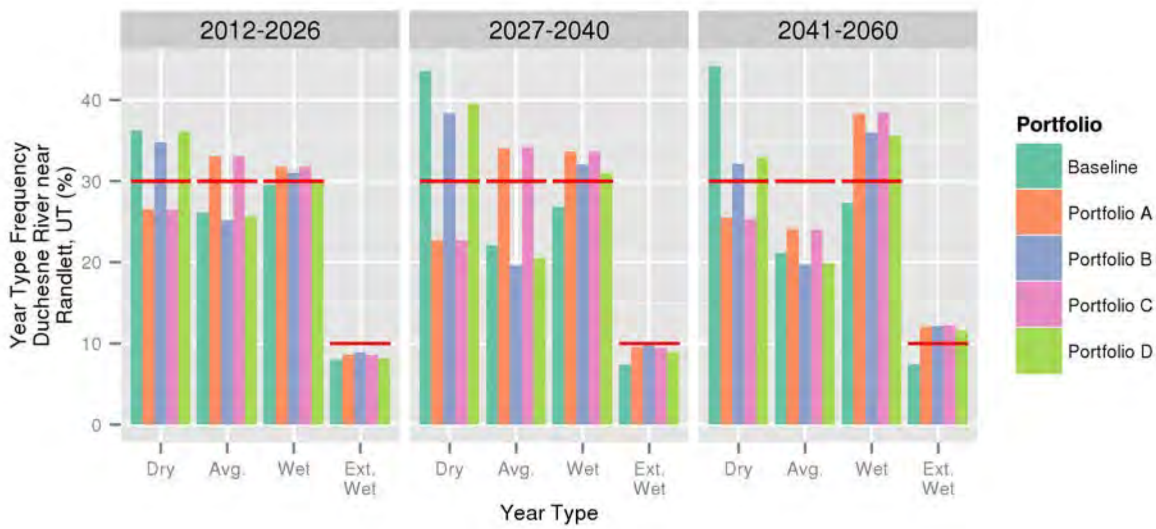


FIGURE F-14A
Flow Volume by Year Type, Duchesne River near Randlett, UT
*Red Lines Indicate the Flow Recommendation Approximations as Reference Values*

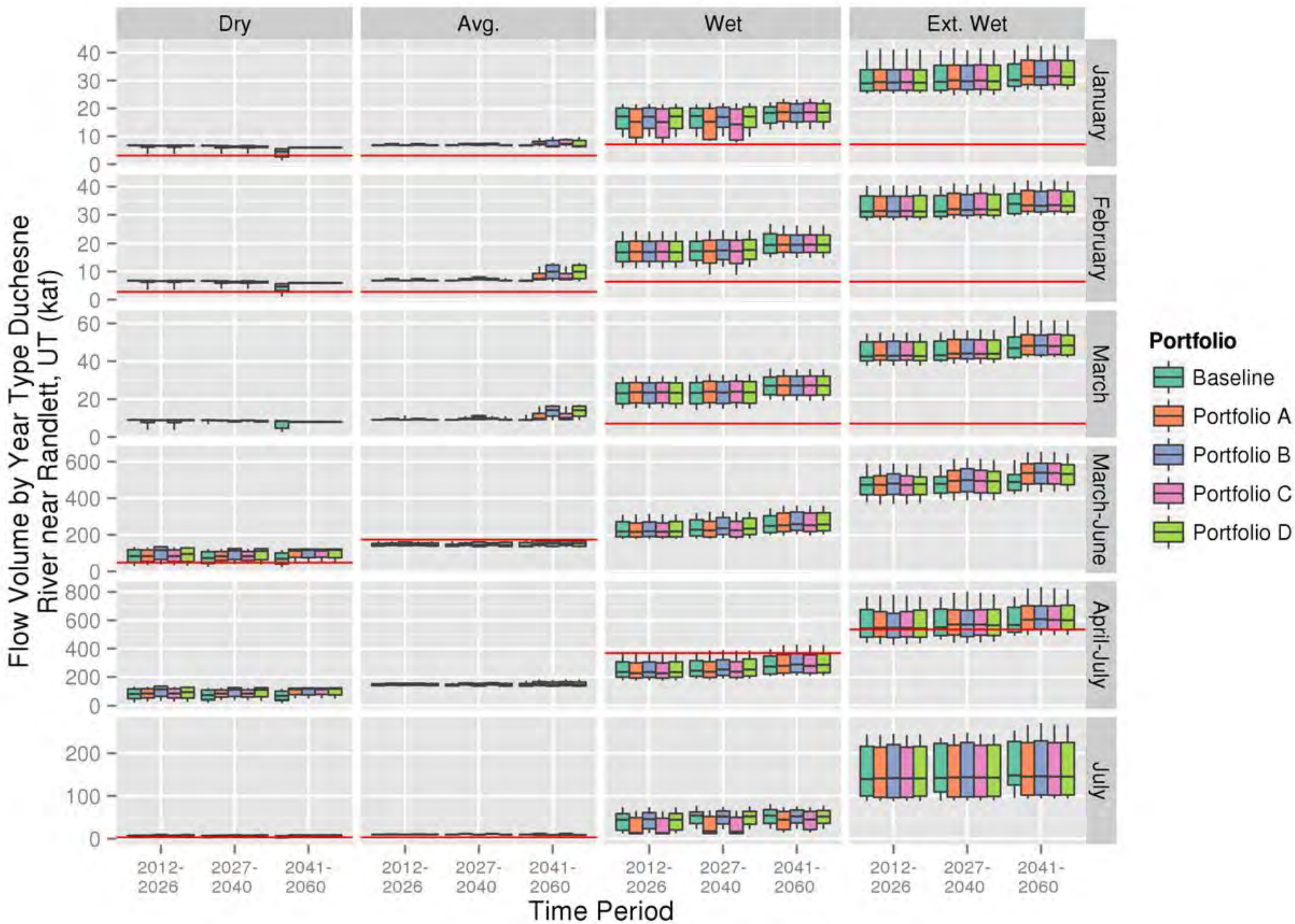


FIGURE F-14B
Flow Volume by Year Type, Duchesne River near Randlett, UT
*Red Lines Indicate the Flow Recommendation Approximations as Reference Values*

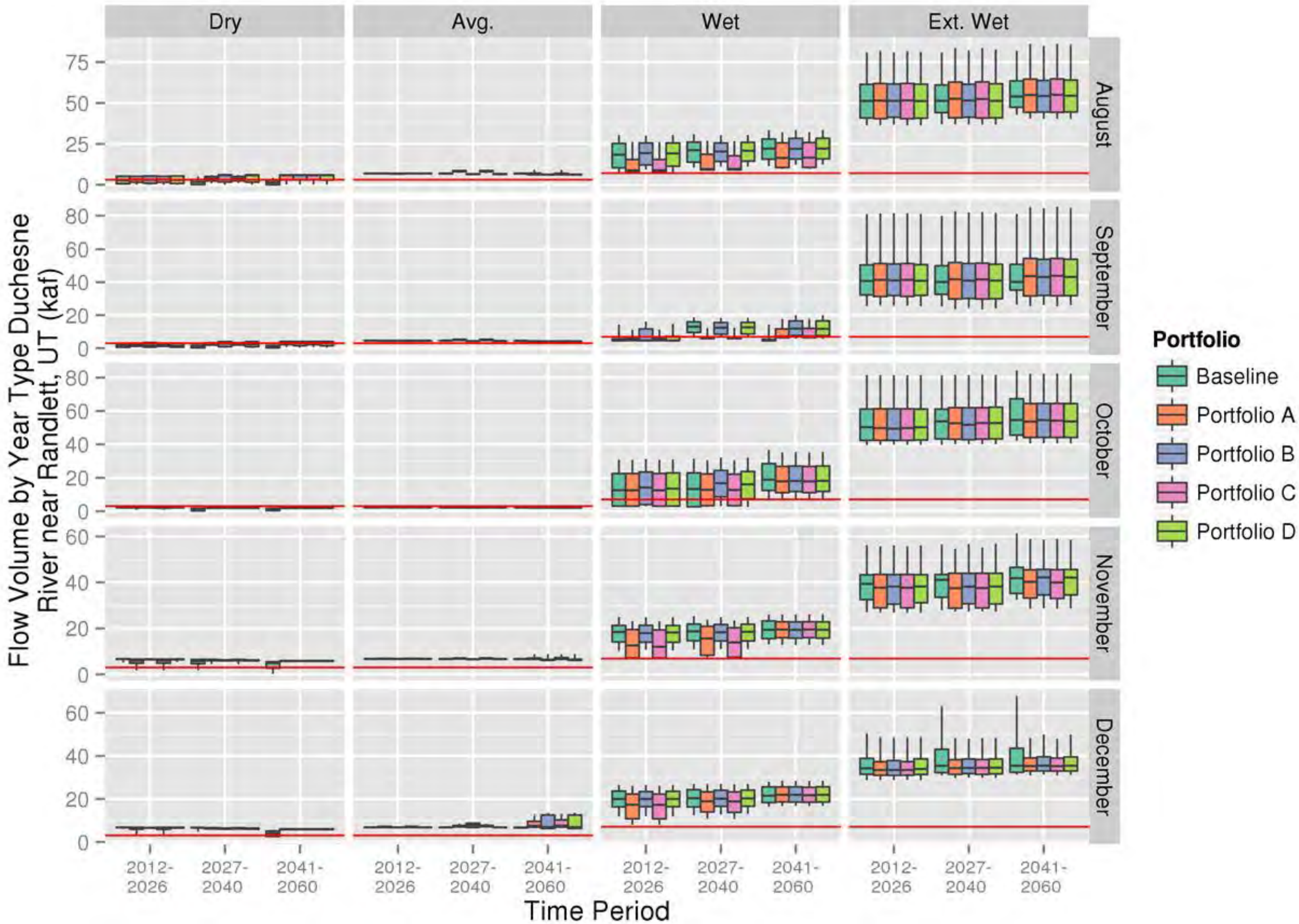


FIGURE F-15
Percent of Years Meeting Green River near Jensen, UT, Flow Targets
*(a) Represents Dry Year Type Target; (b) Represents Moderately Dry Year Type Target; (c) Represents Target for All Moderately Wet Year Types and 1 in 4 Average Years; (d) and (e) Represent Two Wet Year Type Targets; Red Lines Indicate Reference Values*

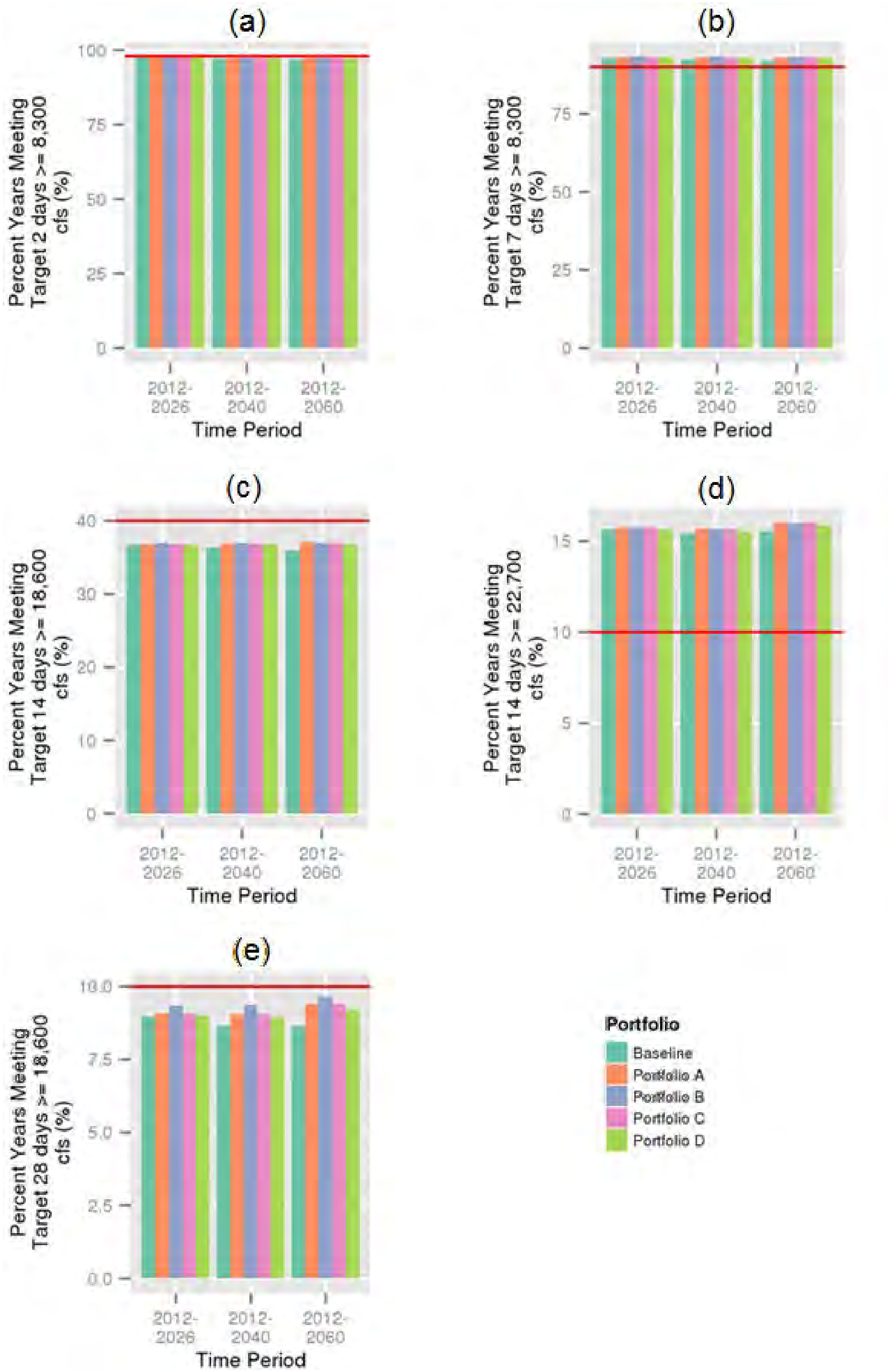


FIGURE F-16
Monthly Flow, San Juan River near Bluff, UT
*Red Lines Indicate the Minimum Reference Value of 500 cfs*

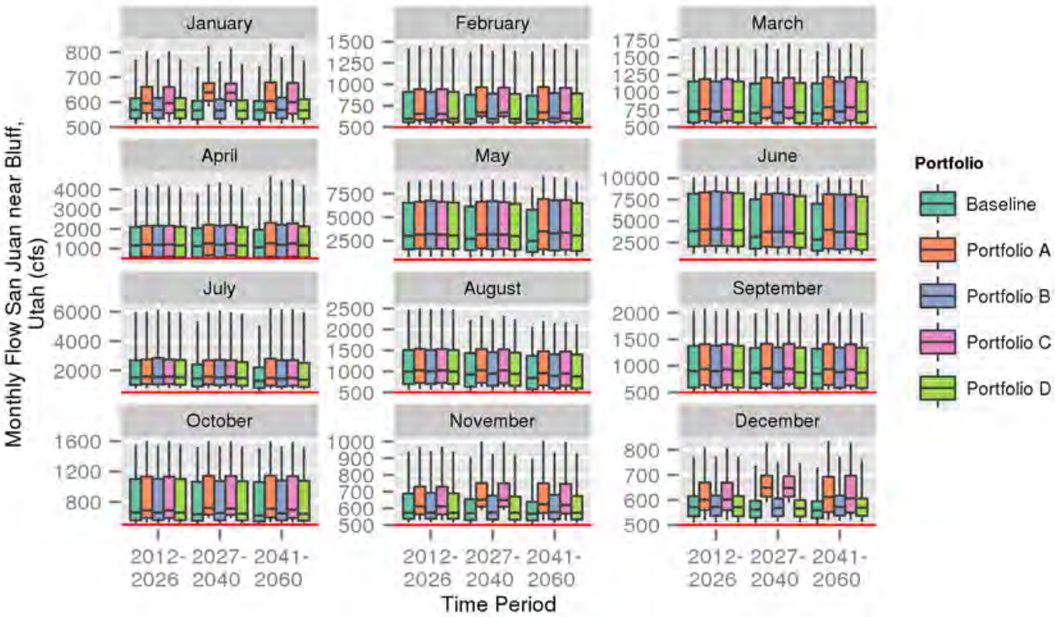


FIGURE F-17
San Juan River near Bluff, UT, 10 days >= 2,500 cfs
*(a) Percent of Years Meeting Target Flow and (b) Years since Last Occurrence of Target Flow-Duration; Red Lines Indicate (a) Minimum Frequency and (b) Maximum Interval Between Occurrences*

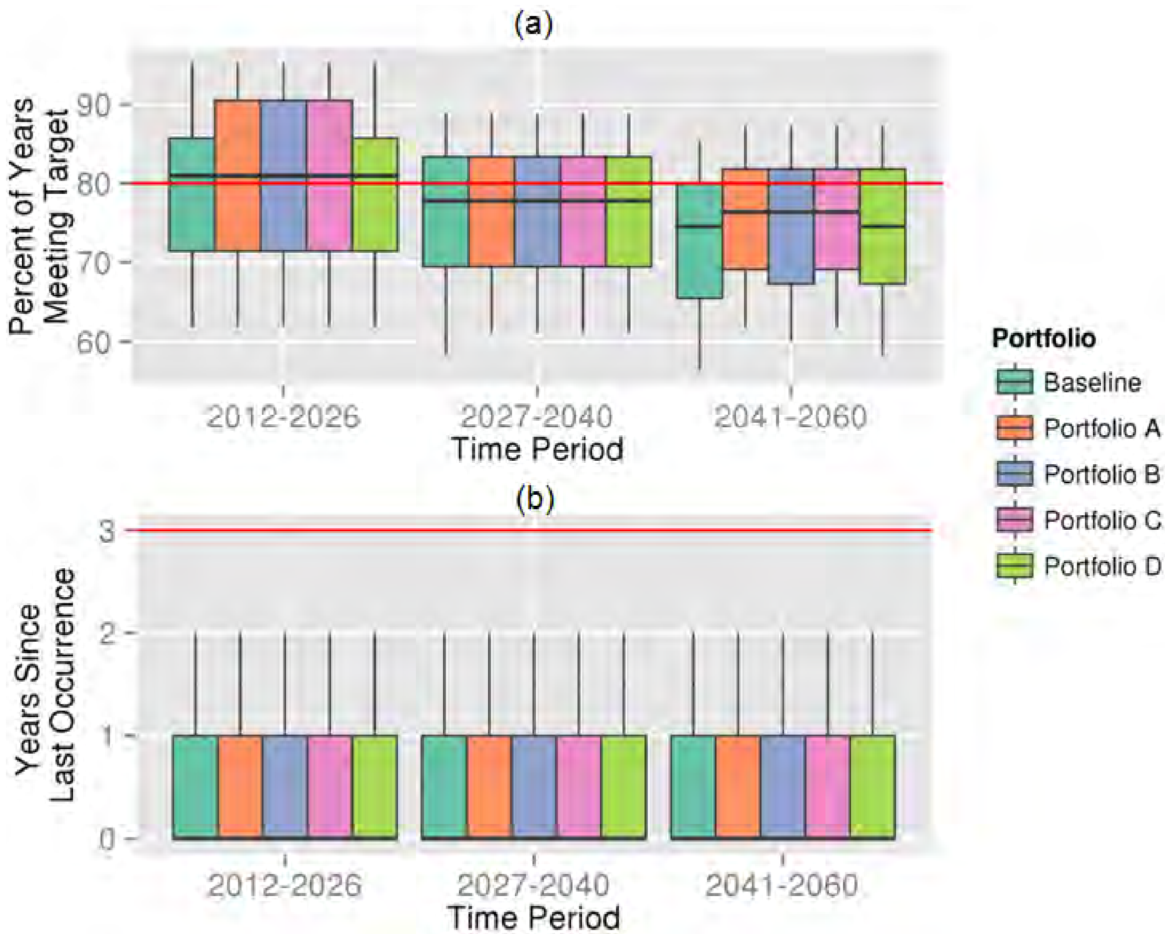


FIGURE F-18
San Juan River near Bluff, UT, 21 days >= 5,000 cfs
*(a) Percent of Years Meeting Target Flow and (b) Years since Last Occurrence of Target Flow-Duration; Red Lines Indicate (a) Minimum Frequency and (b) Maximum Interval Between Occurrences*

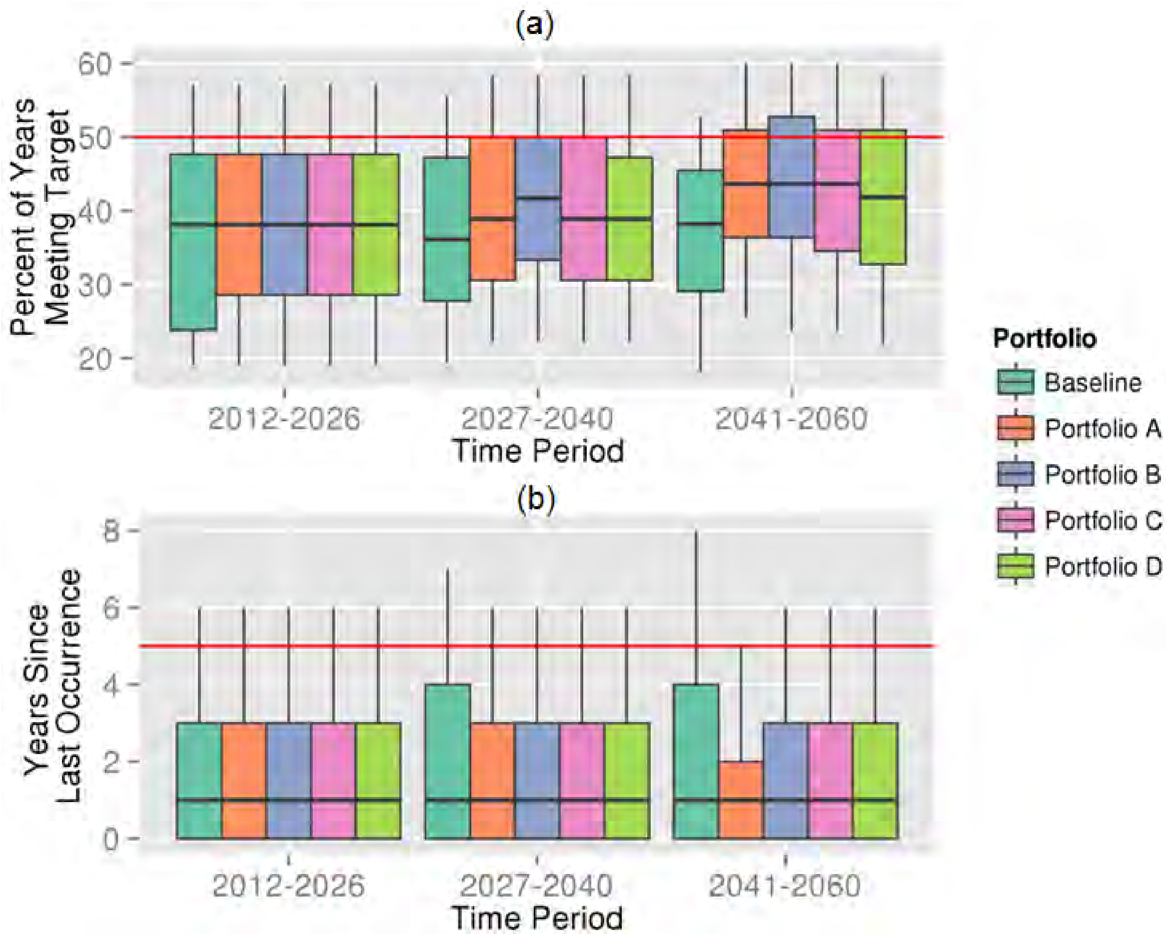


FIGURE F-19
San Juan River near Bluff, UT, 10 days >= 8,000 cfs
*(a) Percent of Years Meeting Target Flow and (b) Years since Last Occurrence of Target Flow-Duration; Red Lines Indicate (a) Minimum Frequency and (b)Maximum Interval Between Occurrences*

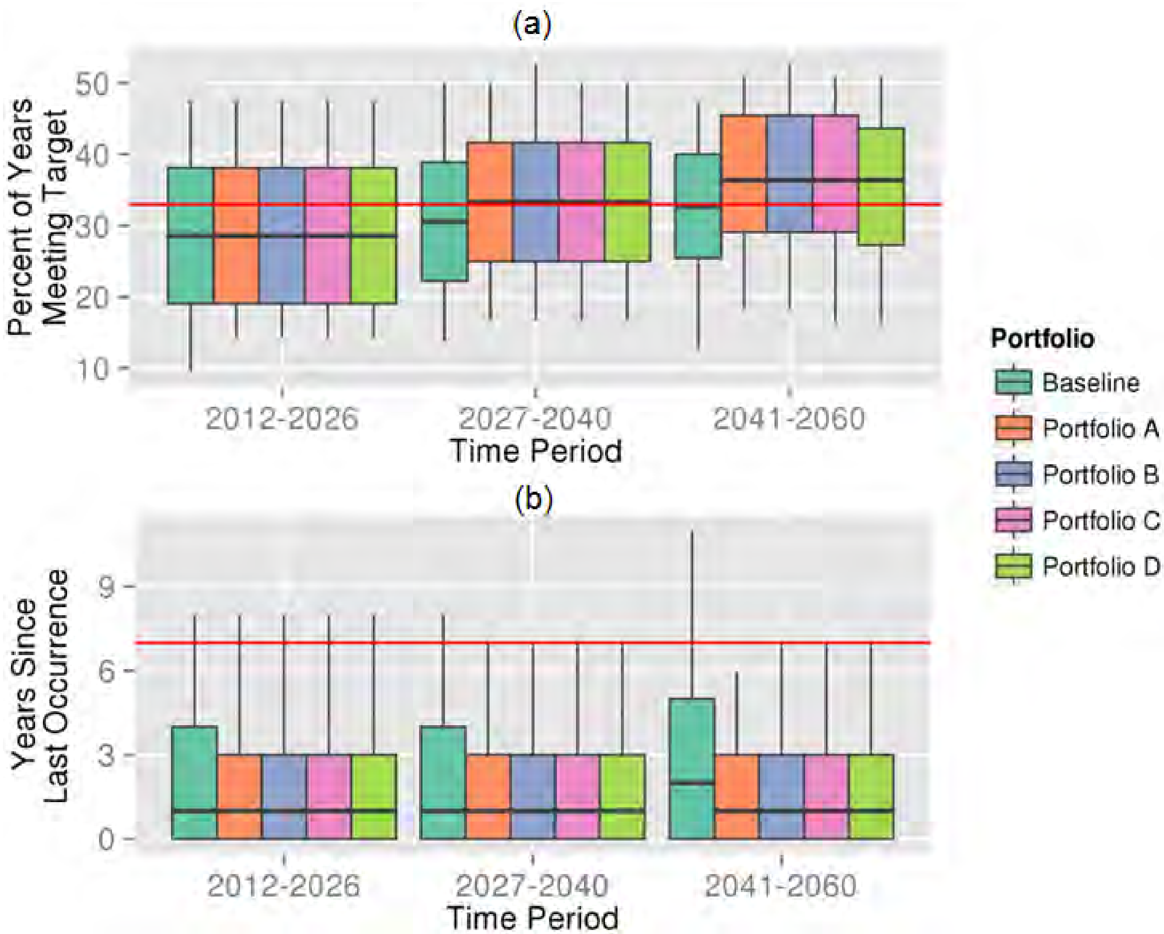


FIGURE F-20
San Juan River near Bluff, UT, 10 days >= 10,000 cfs
*(a) Percent of Years Meeting Target Flow and (b)Years since Last Occurrence of Target Flow-Duration; Red Lines Indicate (a) Minimum Frequency and (b) Maximum Interval Between Occurrences*

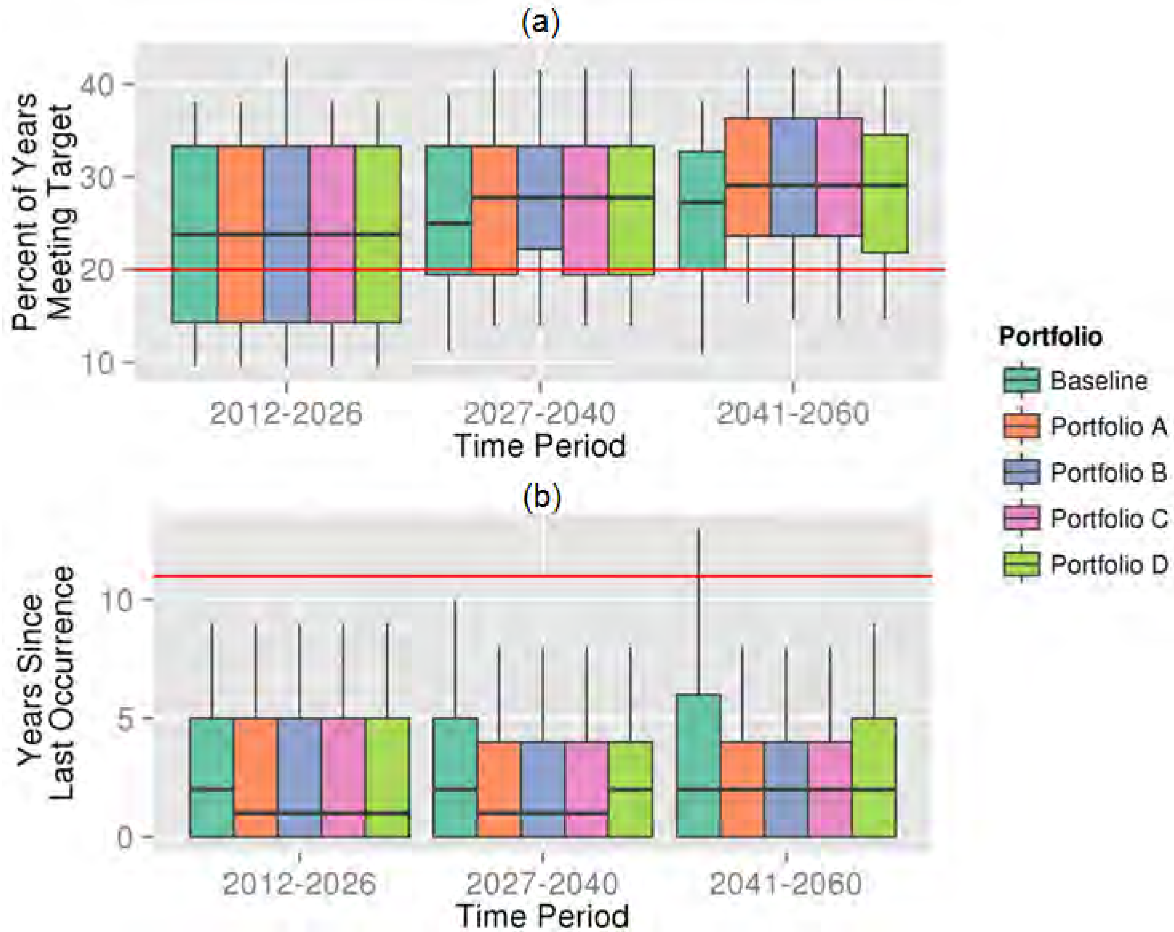


FIGURE F-21
Annual Flow Reductions, Hoover Dam to Davis Dam
*Red Line Indicates Maximum Allowable Flow Reduction*

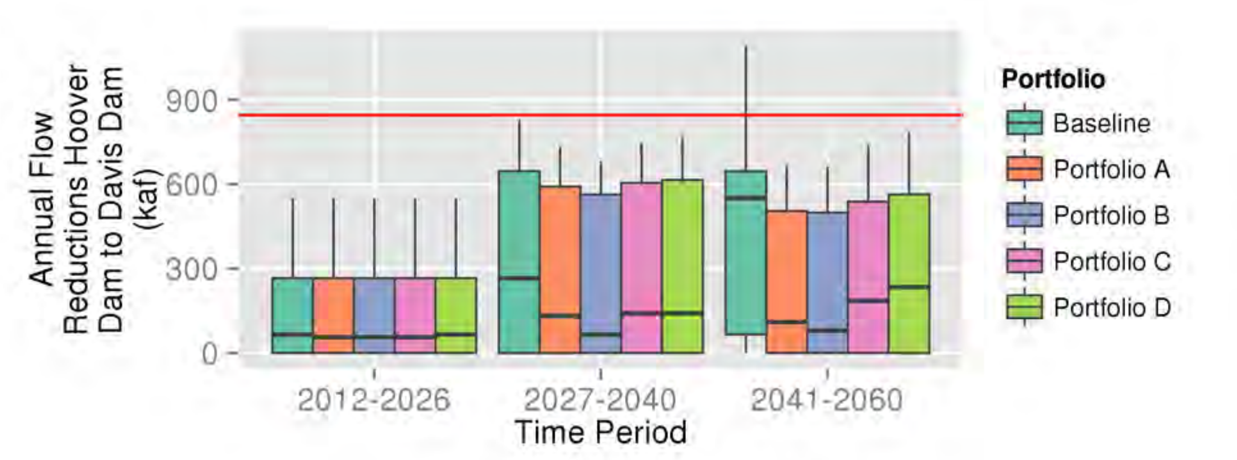



FIGURE F-22
Annual Flow Reductions, Davis Dam to Parker Dam
*Red Line Indicates Maximum Allowable Flow Reduction*

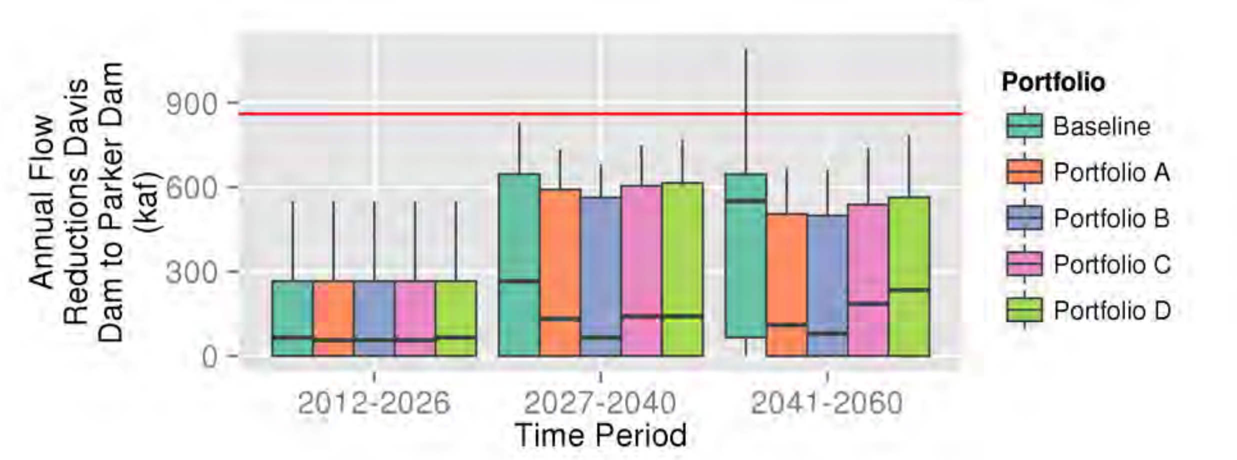
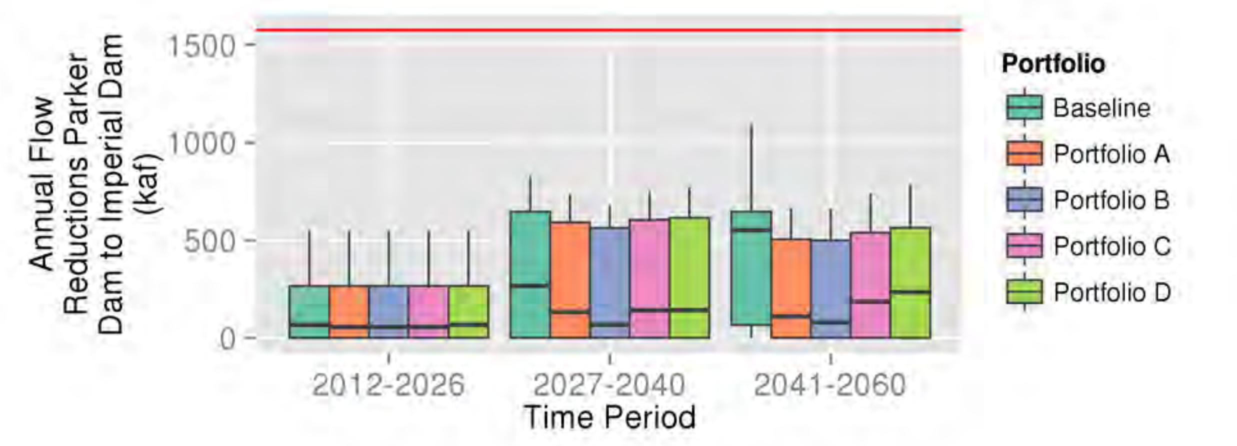


FIGURE F-23
Annual Flow Reductions, Parker to Imperial Dam
*Red Line Indicates Maximum Allowable Flow Reduction*




# 3.0 Metrics for the Aquatic and Riparian Habitat Attribute of Interest

## 3.1 Instream Flow Rights

The Colorado Water Conservation Board has secured many instream flow rights[5] to benefit the aquatic and riparian habitat across Colorado. Figures F-24 and F-25 present the results for the locations that instream flow rights coincide with gage locations in CRSS. Monthly flow at these two locations is presented along with reference values for the instream flow rights.

Figure F-24 indicates that flow on the Taylor River near Taylor Park, Colorado, is generally increased by portfolios, compared to the Baseline. The portfolios also reduce variability (e.g., the inner quartile range is reduced), compared to the Baseline. Figure F-25 indicates that portfolios tend to increase flows on the Gunnison River below Crystal Reservoir, compared to the Baseline. However, the variability remains largely the same, owing to the regulated nature of the Gunnison River below the Aspinall Unit.

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

FIGURE F-24
Monthly Flow Taylor River near Taylor Park, CO
*Red Lines Indicate Instream Flow Rights*

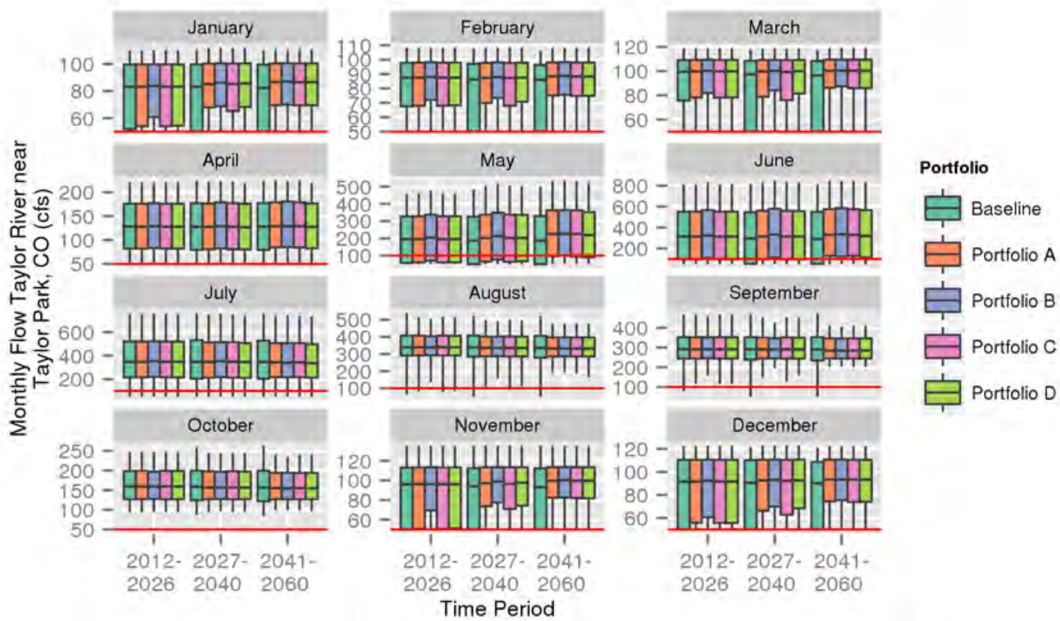
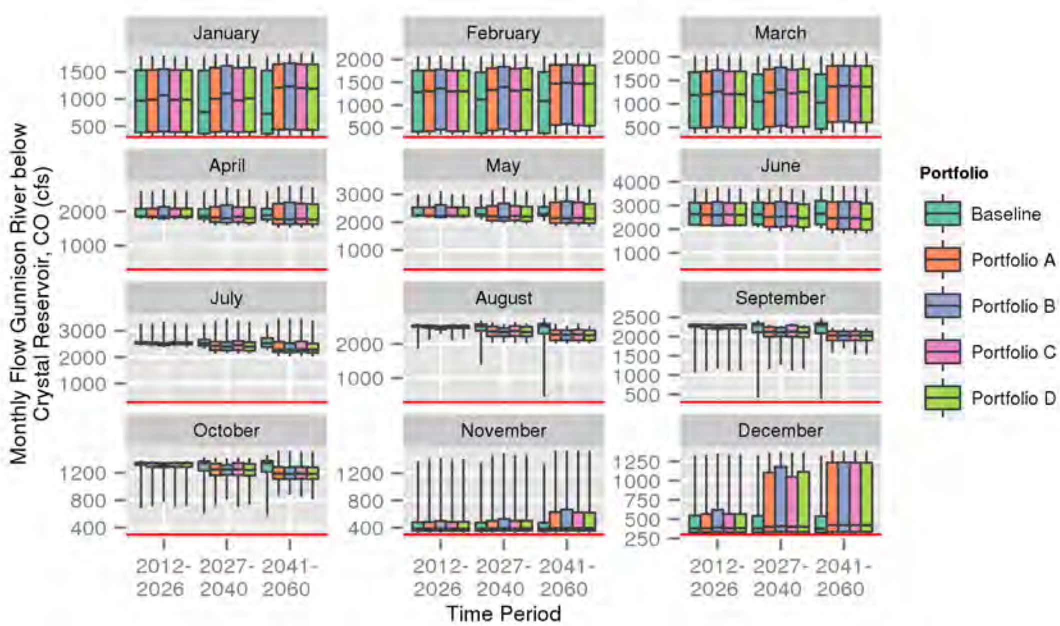



FIGURE F-25
Monthly Flow Gunnison River below Crystal Reservoir
*Red Lines Indicate Instream Flow Rights*



## 3.2 Cottonwood Recruitment

The cottonwood recruitment metric, developed in coordination with the FWS and The Nature Conservancy, 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. The metric uses monthly approximations to estimate physical processes that lead to positive conditions for cottonwood recruitment events. *Technical Report D – System Reliability Metrics* includes additional description of the metric and the steps for computing when positive conditions exist. Figures F-26 through F-31 present a count of the years since positive recruitment conditions occurred. To remove the effects of initial conditions (i.e., starting the count at 0 in 2012), the historical gage records at the six locations were analyzed using the same methodology employed in CRSS to determine the last year that positive conditions existed. This led to counts greater than the 49-year modeling horizon (e.g., figure F-30).

The Baseline trends vary across the different locations, with sites such as the San Juan River near Archuleta, New Mexico (figure F-27), changing very little through time and sites such as the Green River near Fontenelle, Wyoming (figure F-28), experiencing longer runs with no positive conditions occurring in later time periods. However, in most cases, portfolios reduce the number of years between positive conditions for recruitment occurring, compared to the Baseline. Generally, *Portfolio B* tends to perform better than other portfolios, though the Green River near Green River, Wyoming (figure F-29), is a noticeable exception.

FIGURE F-26
Years since Positive Conditions Occurred, Dolores River near Cisco, UT
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*

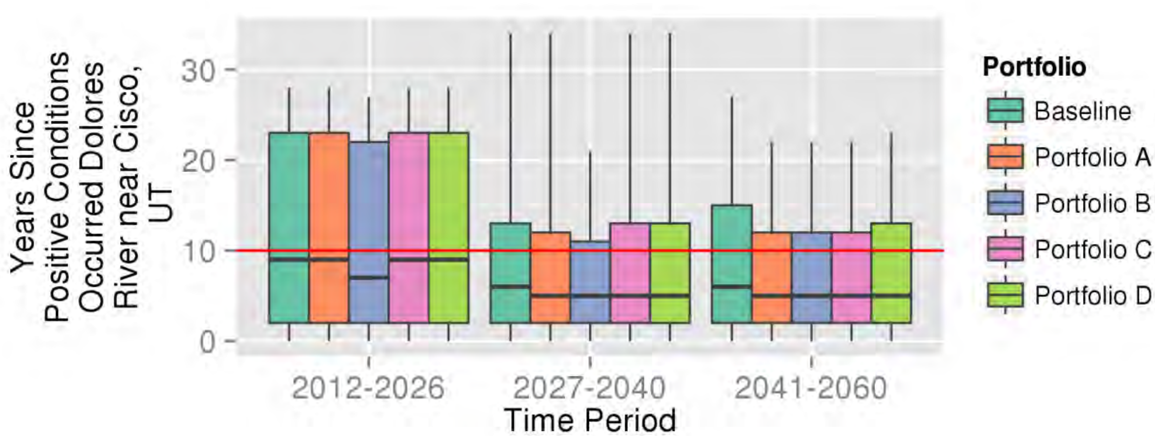


FIGURE F-27
Years since Positive Conditions Occurred, San Juan River near Archuleta, NM
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*

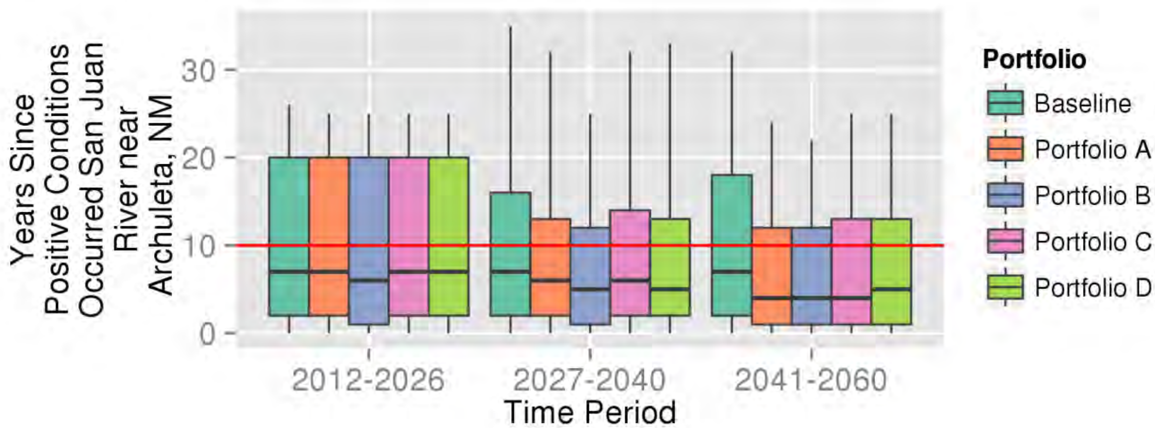



FIGURE F-28
Years since Positive Conditions Occurred, Green River Below Fontenelle, WY
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*

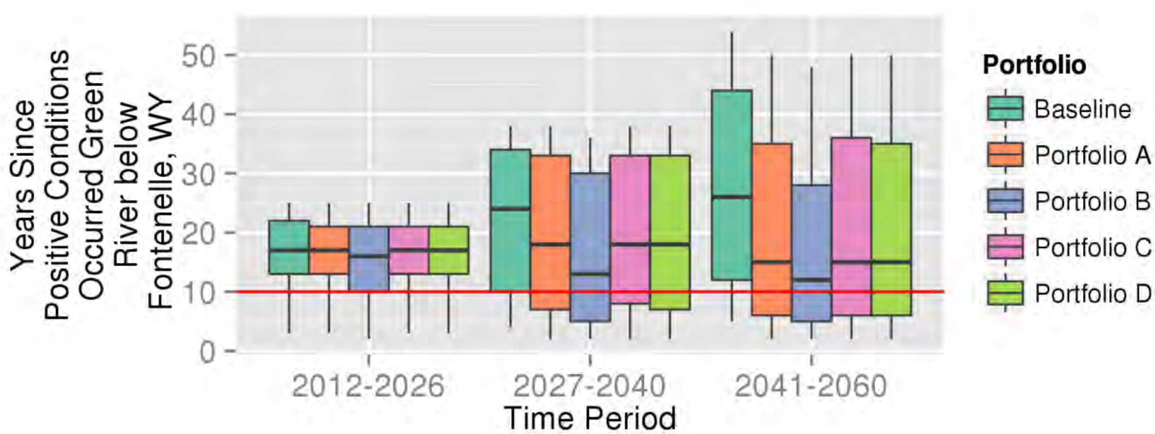


FIGURE F-29
Years since Positive Conditions Occurred, Green River near Green River, WY
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*

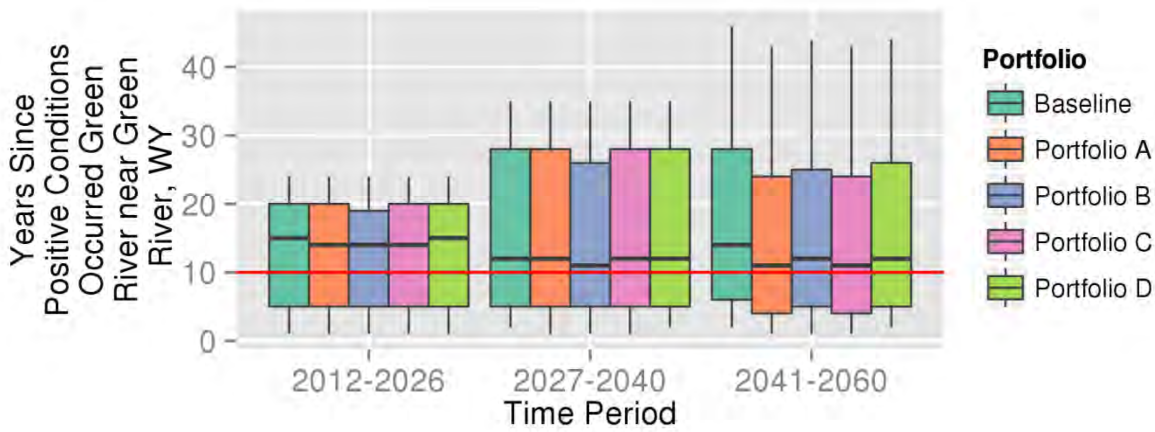



FIGURE F-30
Years since Positive Conditions Occurred, San Rafael River near Green River, UT
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*

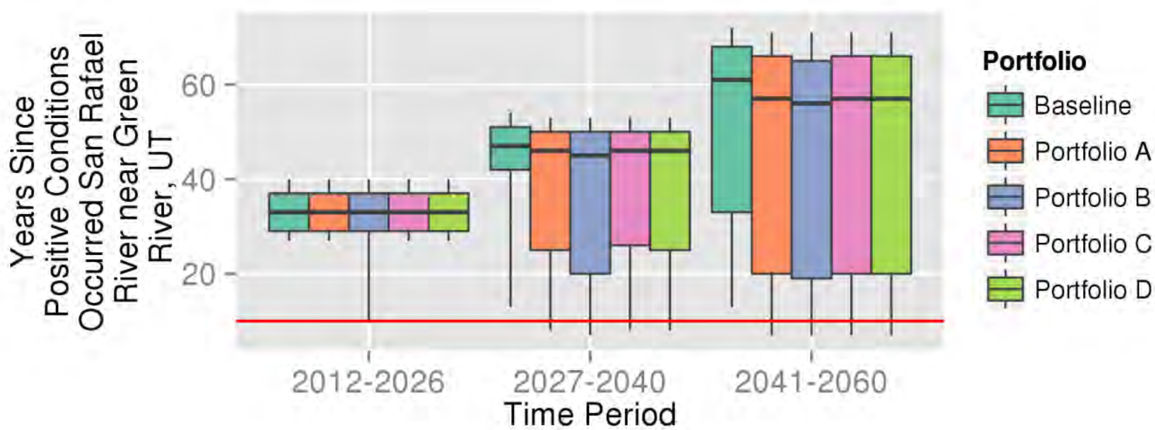
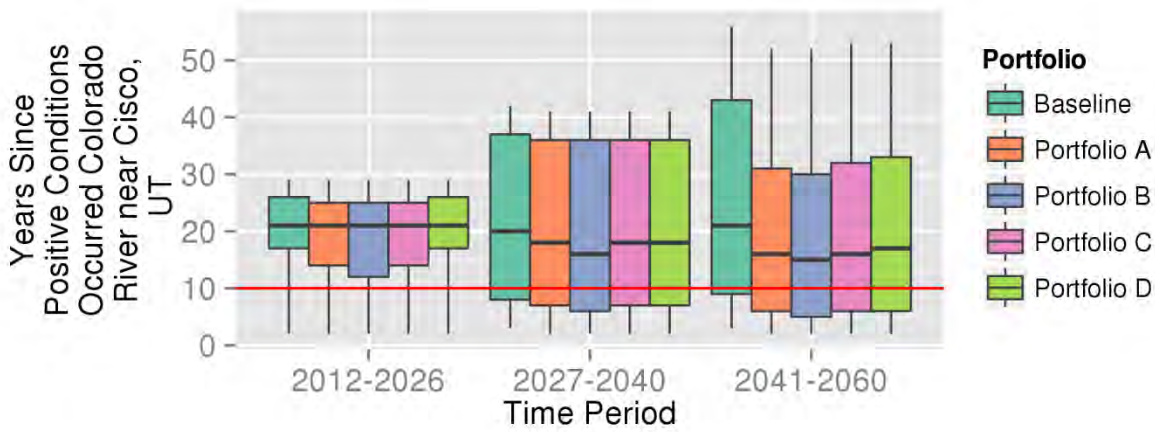


FIGURE F-31
Years since Positive Conditions Occurred, Colorado River near Cisco, UT
*Red Line Indicates Estimated Condition that Positive Conditions for Recruitment Should Exist Once Every 10 Years*




### 3.3 Flow-dependent Ecological Systems

Metrics were developed, in coordination with FWS and the Nature Conservancy, 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. 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 and temperature) that are not considered in the estimated flow-based conditions. Secondly, these flow conditions must be aggregated to a monthly time step to meet those of CRSS. Additionally, the methodology used to develop these flow conditions depends on assumptions behind the hydrologic year-typing. Acknowledging these limitations, figures F-32 through F-39 present the year type frequency and the flow by year type for four locations: the Yampa River near Maybell, Colorado; the Little Snake River near Lily, Colorado; the Yampa River at Deerlodge Park, Colorado; and the White River near Watson, Utah. The year type frequency figures were developed as follows:

1. Using annual volumes at the specific gage from the control run, the percentiles that separate year types were computed (e.g., the 20th percentile separates the "dry" years from "below average" years at the Colorado River near Cameo, Colorado).
2. Using the annual volumes from the modeled scenarios, each year was binned in its respective year type classification, as separated by the thresholds computed in step 1.
3. Last, the frequency that each year type occurred in each time period was computed.

For each time period and month, for each scenario, the flows representing the different year type percentiles were grouped together (e.g., the driest 10 percent of Januaries from 2012 to 2026 or the 30th through 70th percentiles of Aprils through Julys from 2041 to 2060). Then, each year type for all scenarios was grouped together before computing the statistics for the box plots.

Regarding year type frequency (figures F-32, F-34, F-36, and F-38), the same general trends are observed at all four locations. Under the Baseline, the frequency of dry years increases through time, and the frequency of wet years decreases through time. However, portfolios generally increase the frequency of moderately wet and wet year types and decrease the number of moderately dry and dry year types, both through time and compared to the Baseline. Typically, the frequency of moderately wet and wet year types is highest in *Portfolios A* and *C*. This is likely attributable to the banking mechanism that is in place in these portfolios and includes the routing of conserved water to a conceptual off-stream storage location above Lake Powell. When the conserved water is routed downstream, the flow in the reach increases, therefore classifying the year as a wetter year type than would be the case without conservation and routing.

Figures F-33, F-35, F-37, and F-39 present the flow by year type at the four locations. For locations in the Yampa Basin (figures F-33 through F-37), portfolios tend to benefit the flows in most year types. For the White River near Watson, UT (figure F-39), there is little variability between portfolios and the Baseline, or across portfolios. This is attributed to the relatively small demands that exist and the lack of any large options or strategies being implemented in the White River Basin.

FIGURE F-32
Year Type Frequency, Yampa River near Maybell, CO
*Red Lines Indicate Frequency Reference Values*

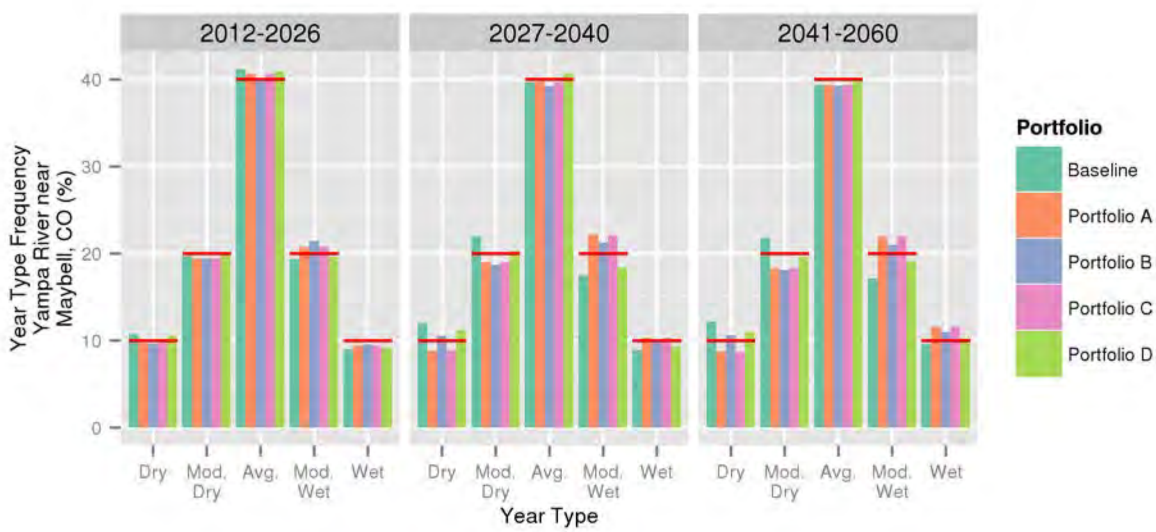


FIGURE F-33A
Flow Volume by Year Type, Yampa River near Maybell, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values; kaf = thousand acre-feet*

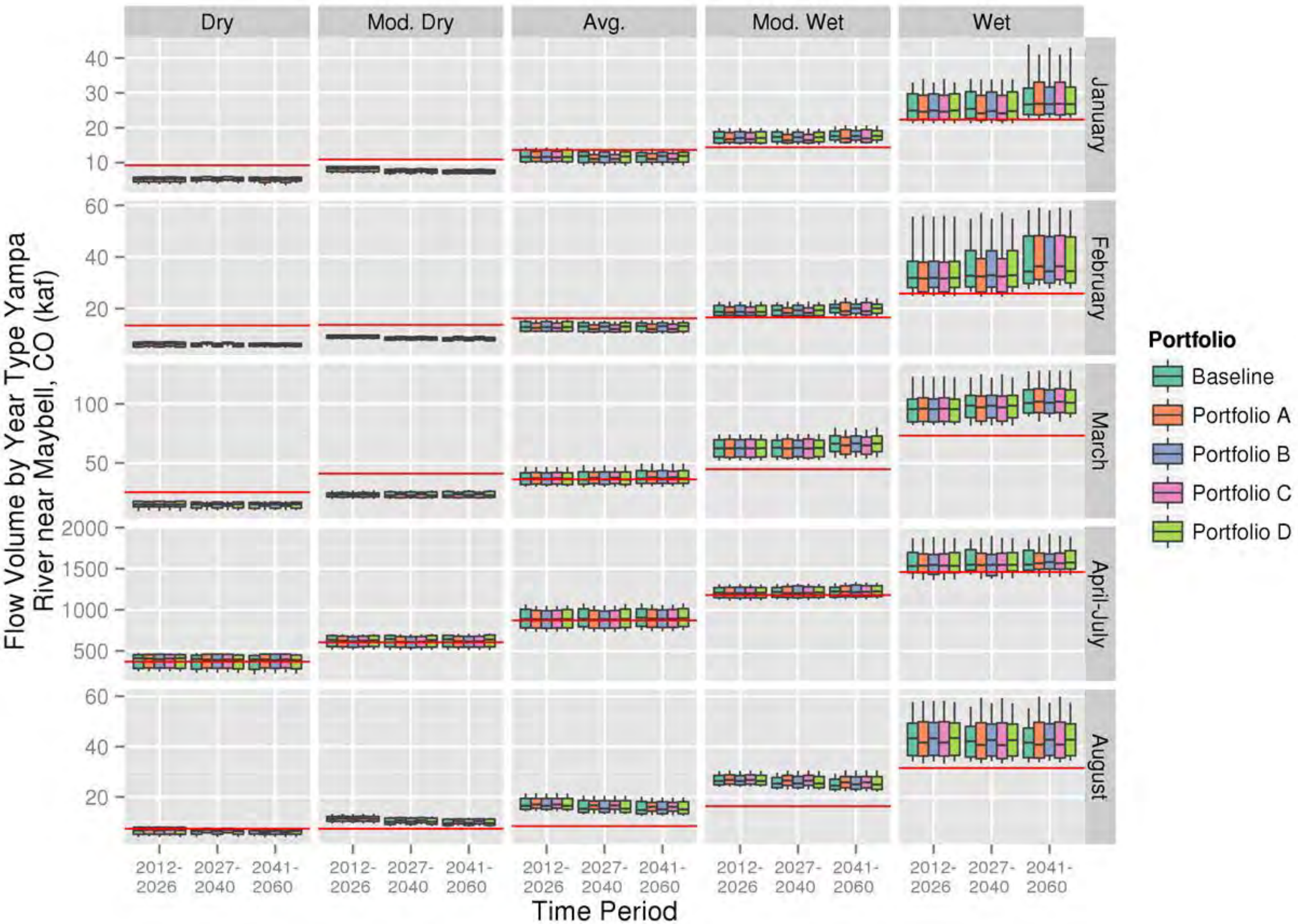


FIGURE F-33B
Flow Volume by Year Type, Yampa River near Maybell, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

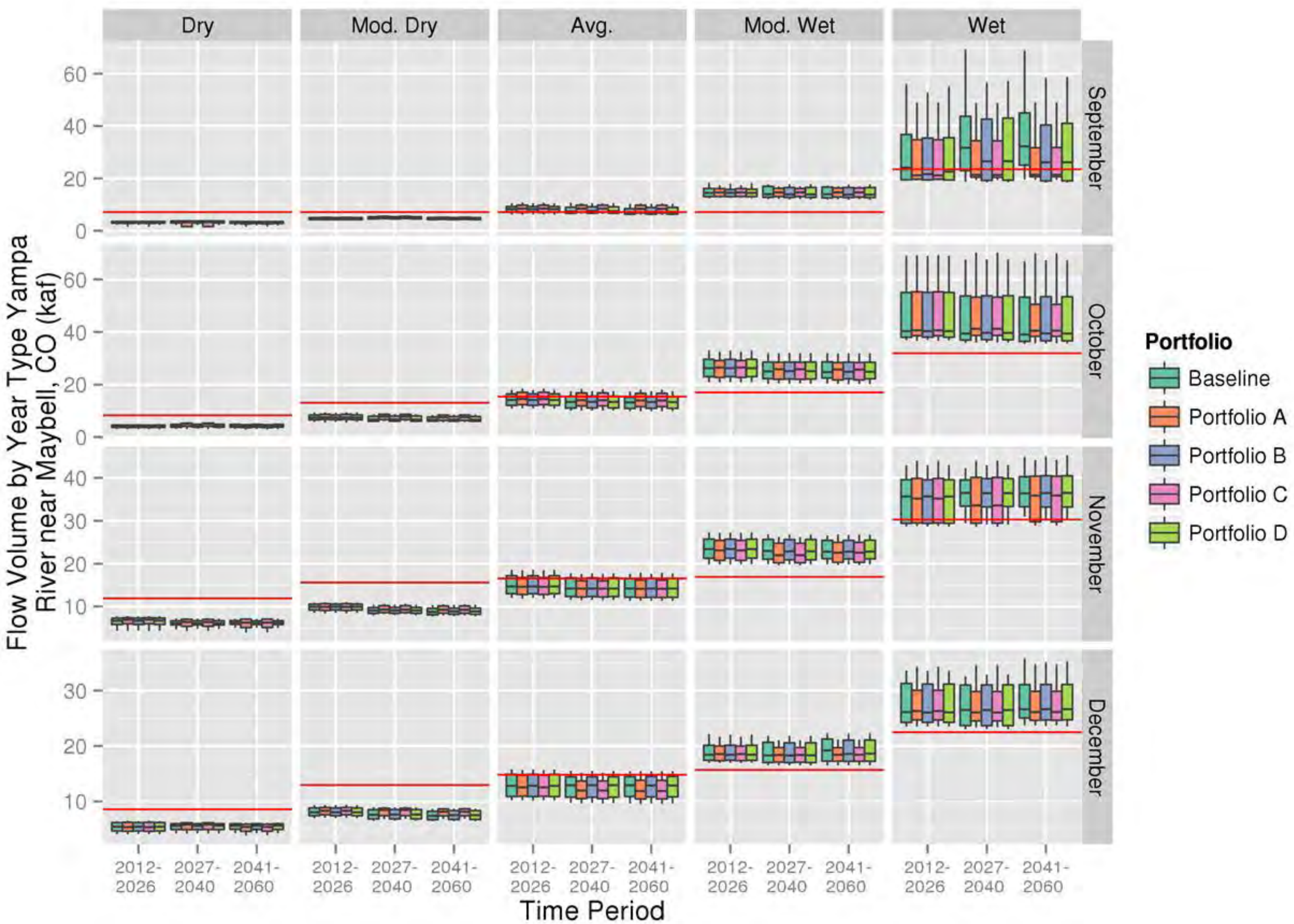


FIGURE F-34
Year Type Frequency, Little Snake River near Lily, CO
*Red Lines Indicate Frequency Reference Values*

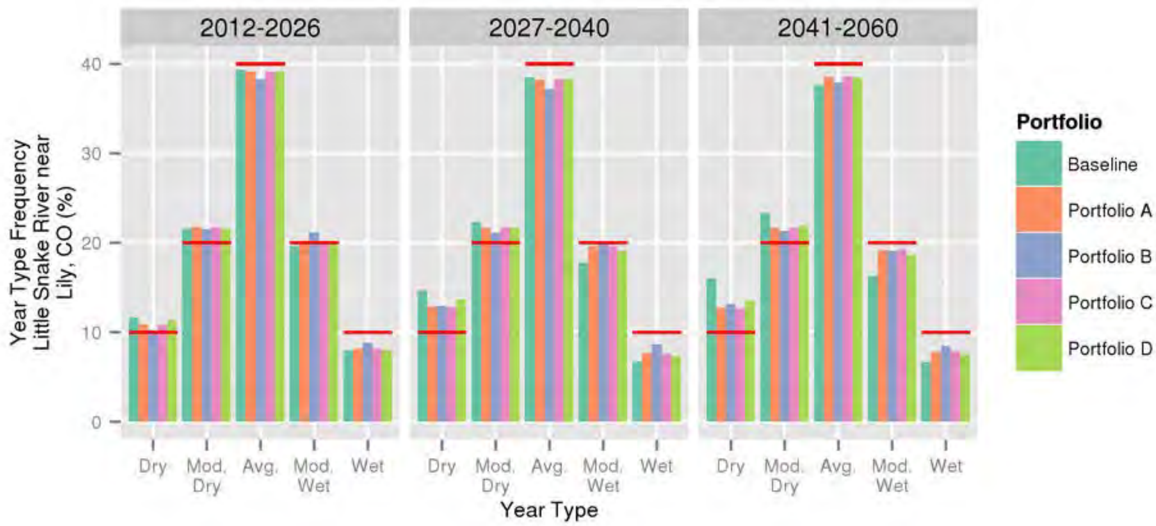


FIGURE F-35A
Flow Volume by Year Type, Little Snake River near Lily, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

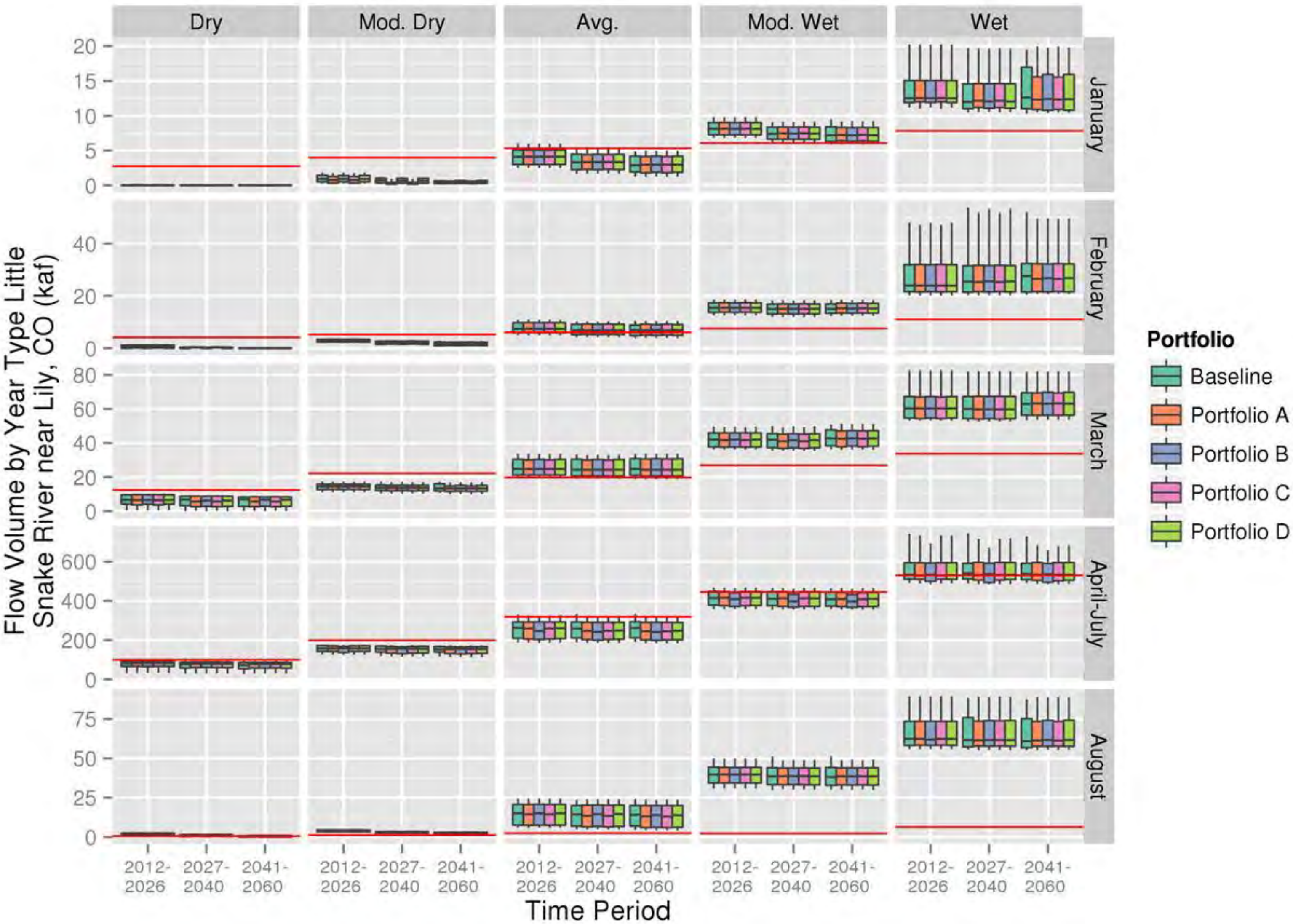


FIGURE F-35B
Flow Volume by Year Type, Little Snake River near Lily, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

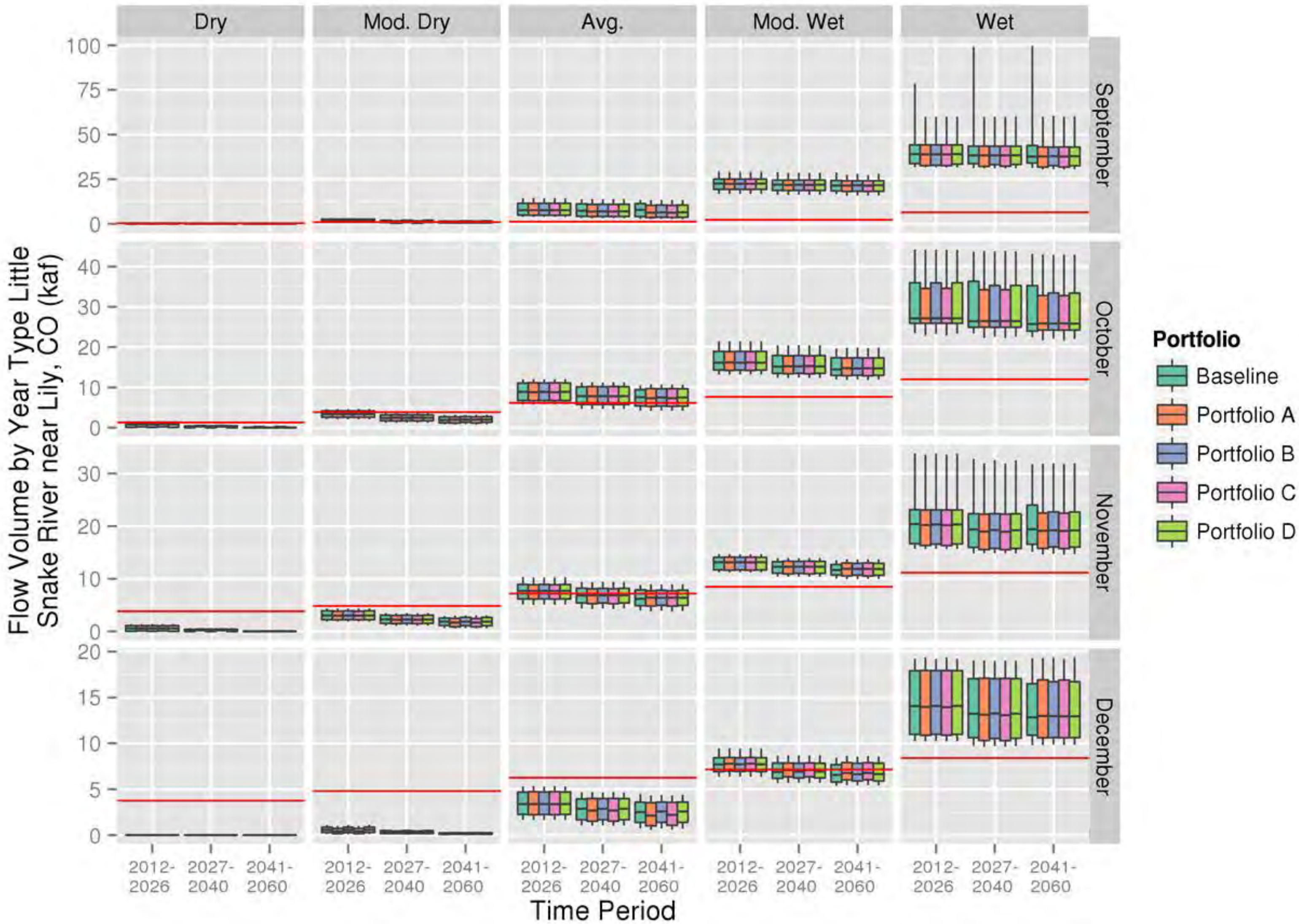


FIGURE F-36
Year Type Frequency, Yampa River at Deerlodge Park, CO
*Red Lines Indicate Frequency Reference Values*

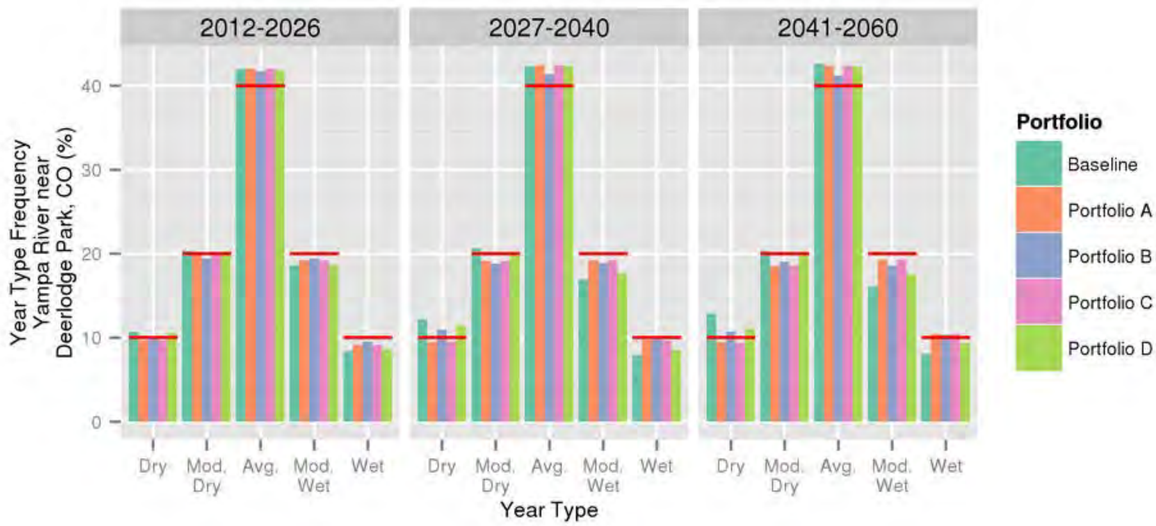


FIGURE F-37A
Flow Volume by Year Type, Yampa River at Deerlodge Park, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

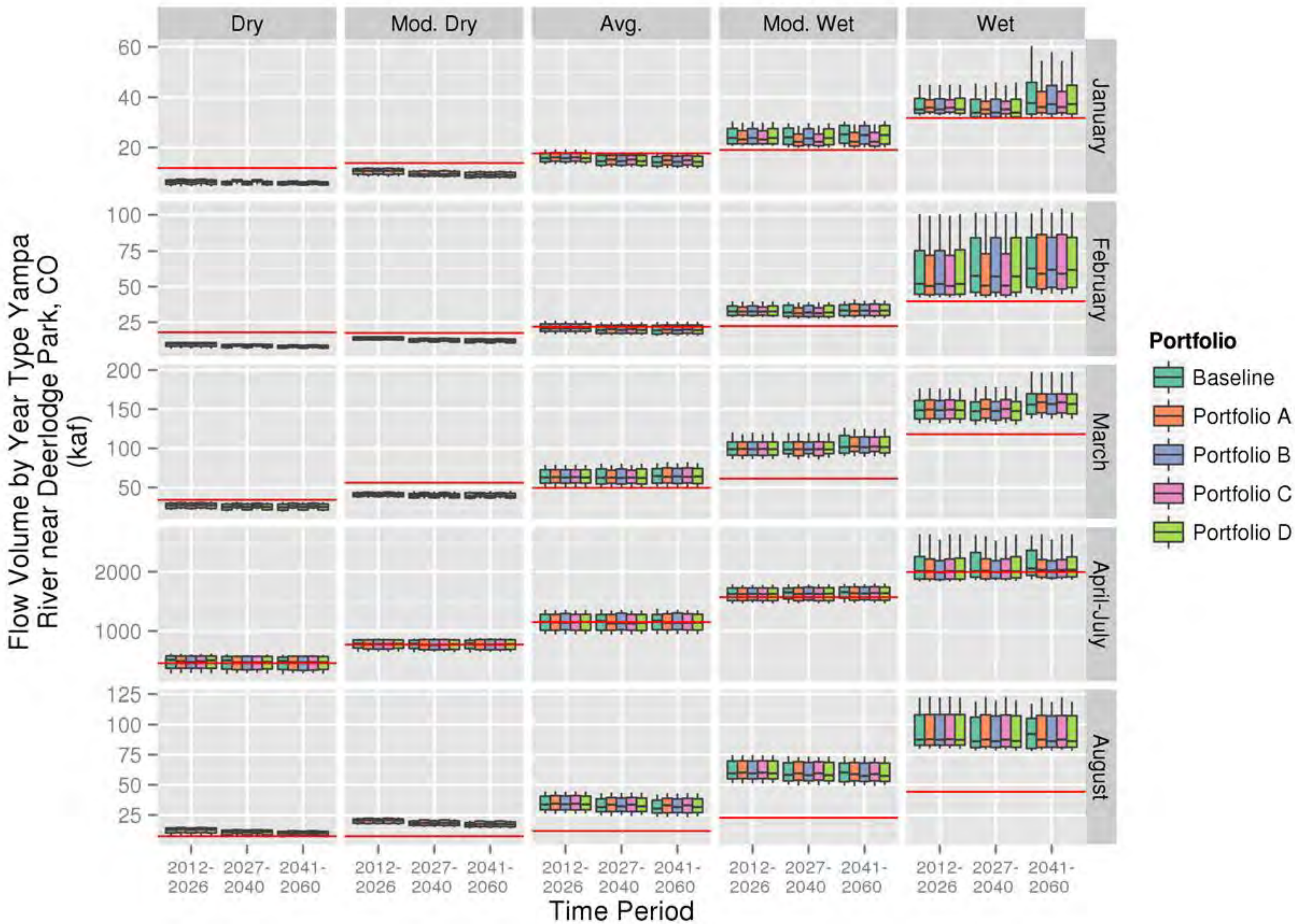


FIGURE F-37B
Flow Volume by Year Type, Yampa River at Deerlodge Park, CO
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

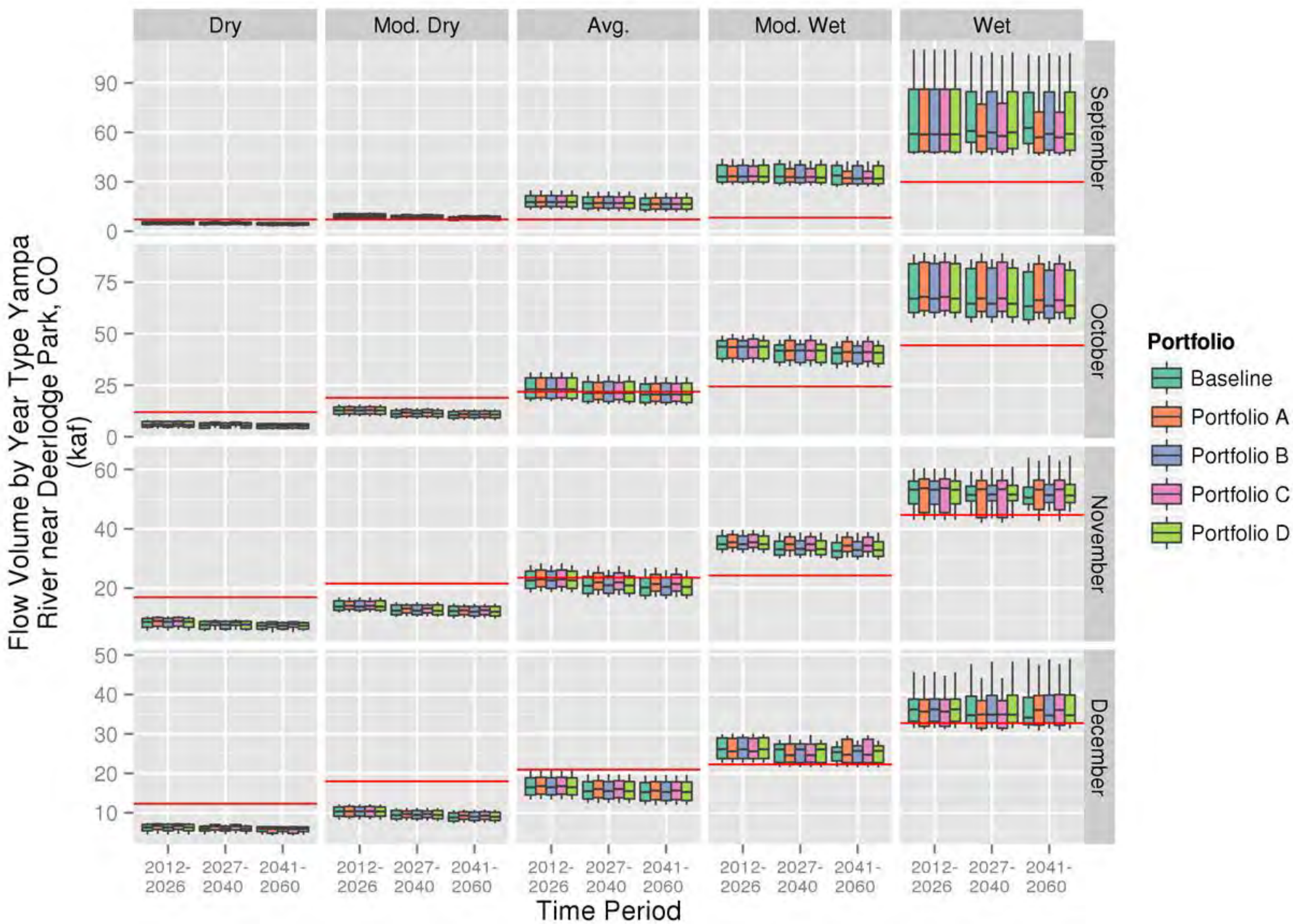


FIGURE F-38
Year Type Frequency, White River near Watson, UT
*Red Lines Indicate Frequency Reference Values*

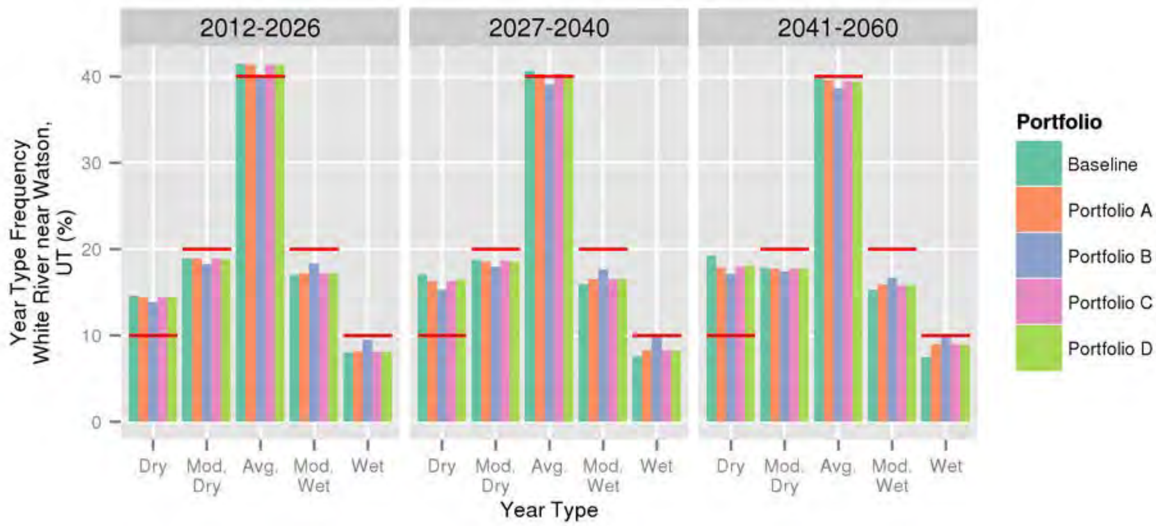


FIGURE F-39A
Flow Volume by Year Type, White River near Watson, UT
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*

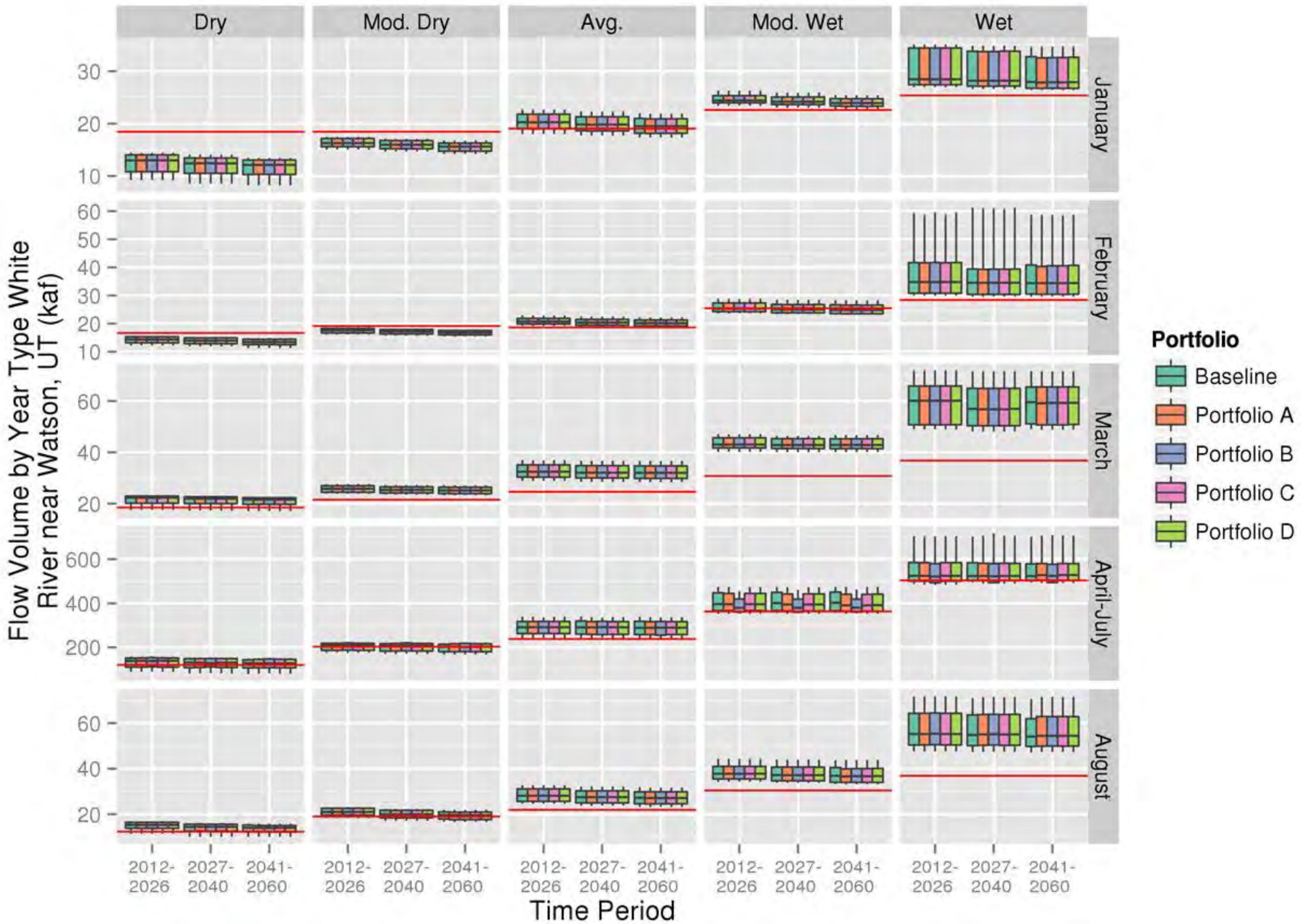
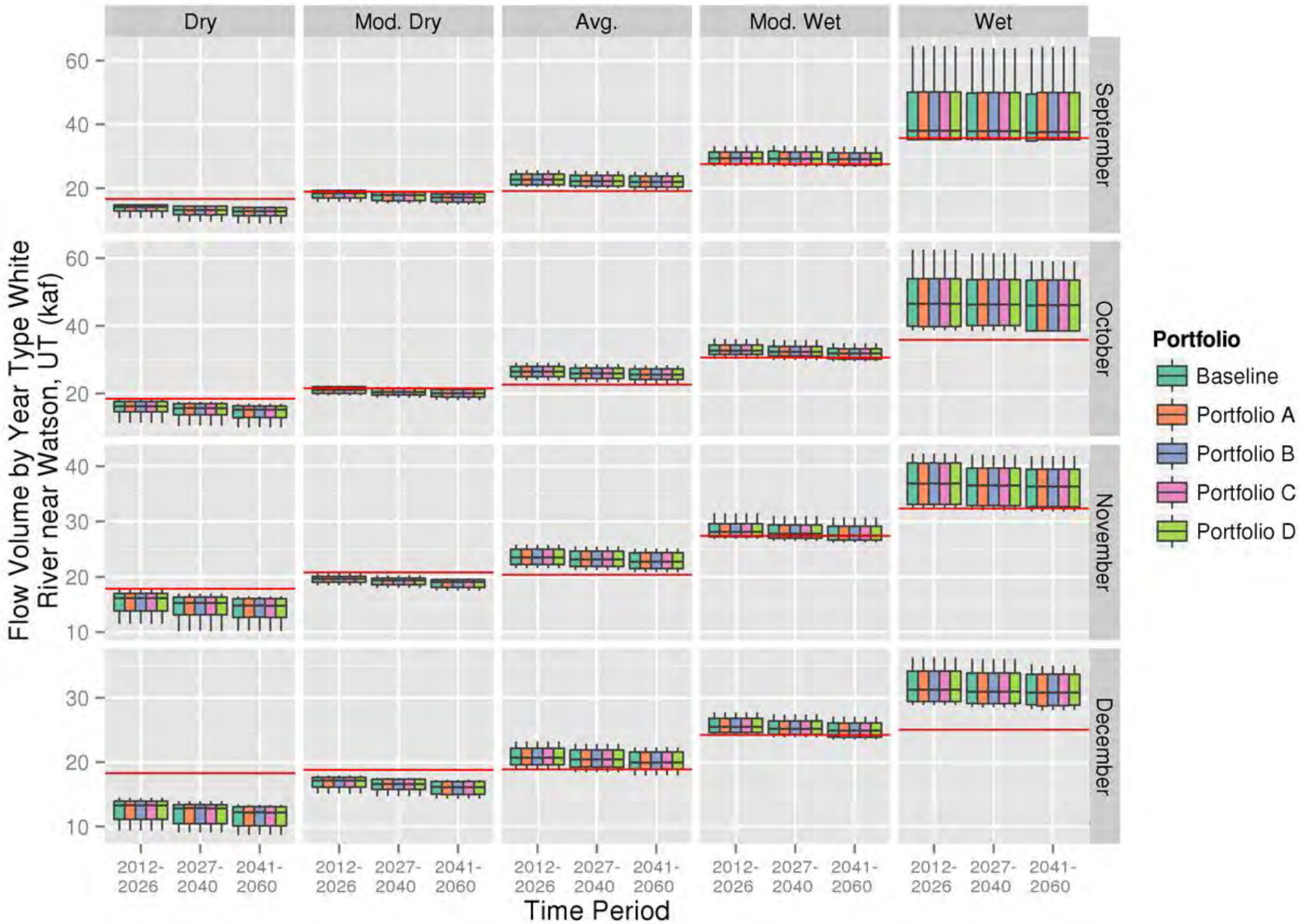


FIGURE F-39B
Flow Volume by Year Type, White River near Watson, UT
*Red Lines Indicate the Estimated Target Flow Conditions as Reference Values*



# 4.0 Metrics for Wildlife Refuges and Fish Hatcheries Attribute of Interest

Metrics and their reference values were developed, in coordination with FWS, for wildlife refuges and fish hatcheries in the Basin that have water rights. 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. In the Lower Basin, reference values are based on the wildlife refuges' entitlements and historical use, and vary by water demand scenario.

Figures F-40 through F-42 present the monthly flow for the reaches where the three Upper Basin wildlife refuges exist (Browns Park, Seedskadee, and Ouray National Wildlife Refuges [NWRs]). Although the reference values appear to be zero because of the scale of the figures, they are, in fact, not zero (see *Technical Report D – System Reliability Metrics*). At all three locations, the flow is more than sufficient to meet the reference values, and the portfolios tend to increase the flow in the reaches.

The reference values for the three Lower Basin NWRs and the fish hatchery are the requested depletions and diversions quantified in the Study. These demands vary by demand scenario (see *Technical Report C – Water Demand Assessment*). Displaying results for comparison with the appropriate reference value would require a scenario-by-scenario presentation. Instead, for these metrics, table F-2 presents the percentage of years that do not meet the NWR and fish hatchery demands. Although there are some extreme instances under the Baseline in which the demands are not fully met, the demands are met in all years under all portfolios.

FIGURE F-40A
Flow by Year Type, Browns Park National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values; kafm = thousand acre-feet per month*

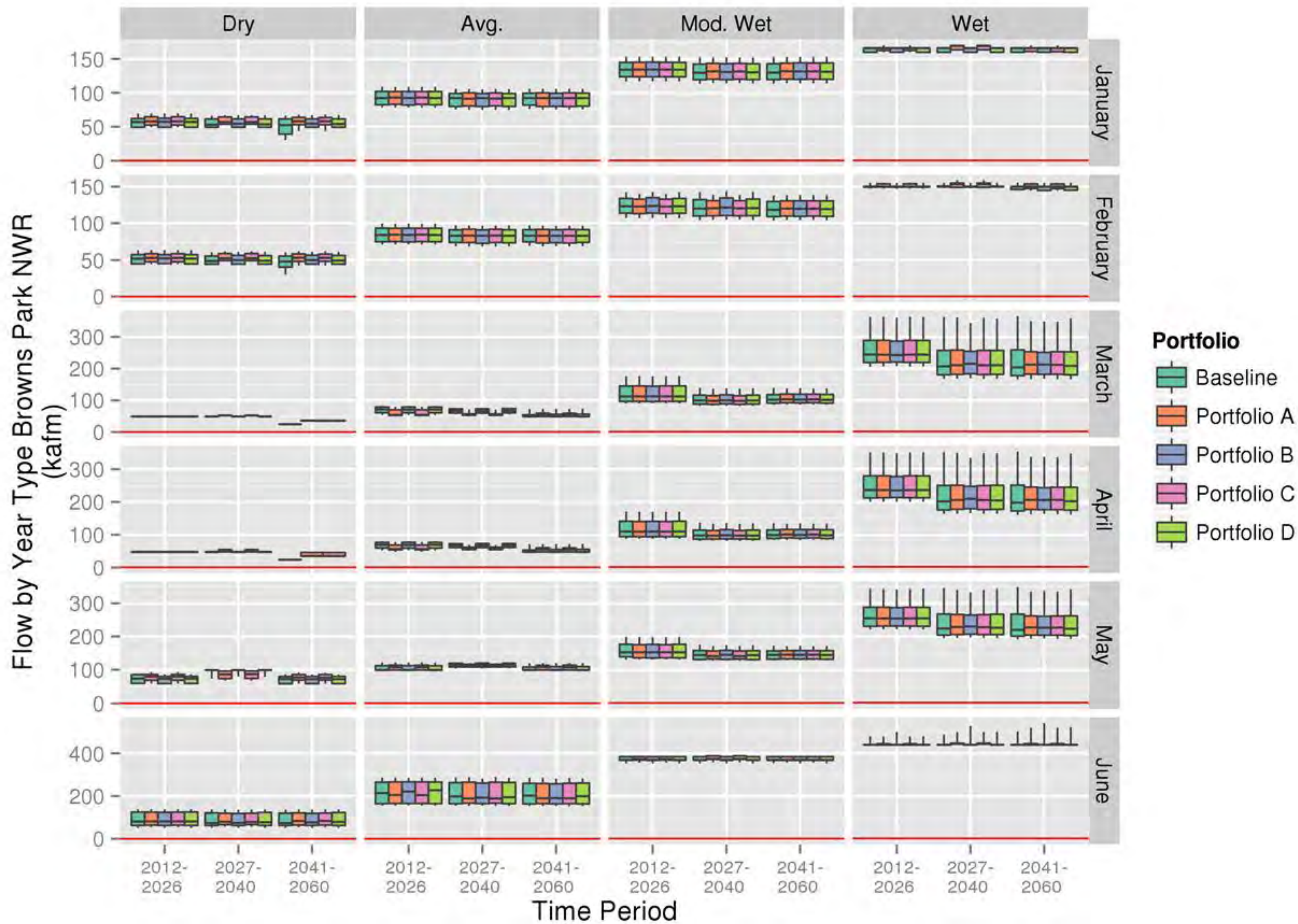


FIGURE F-40B
Flow by Year Type, Browns Park National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values*

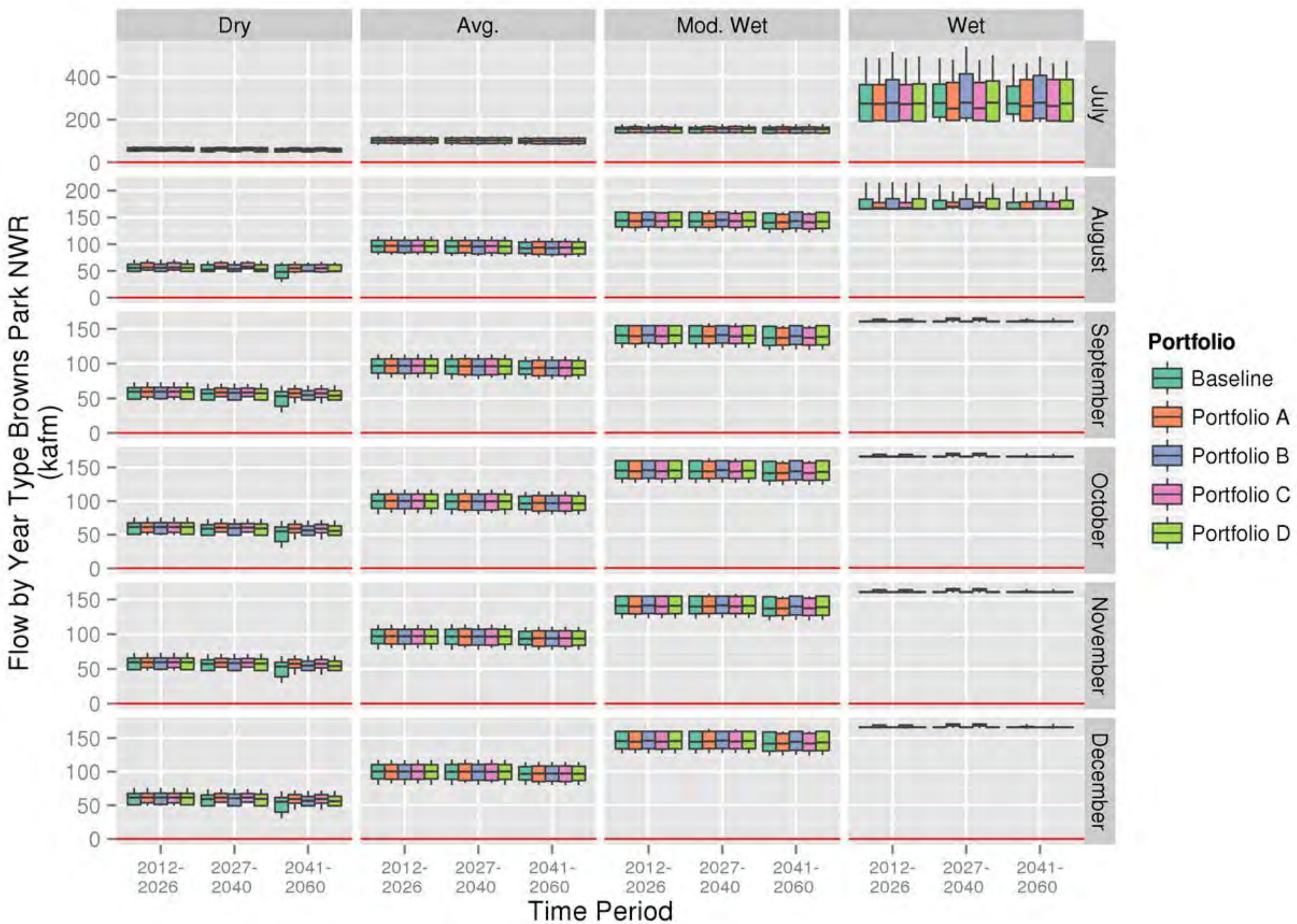


FIGURE F-41A
Flow by Year Type, Seedskadee National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values*

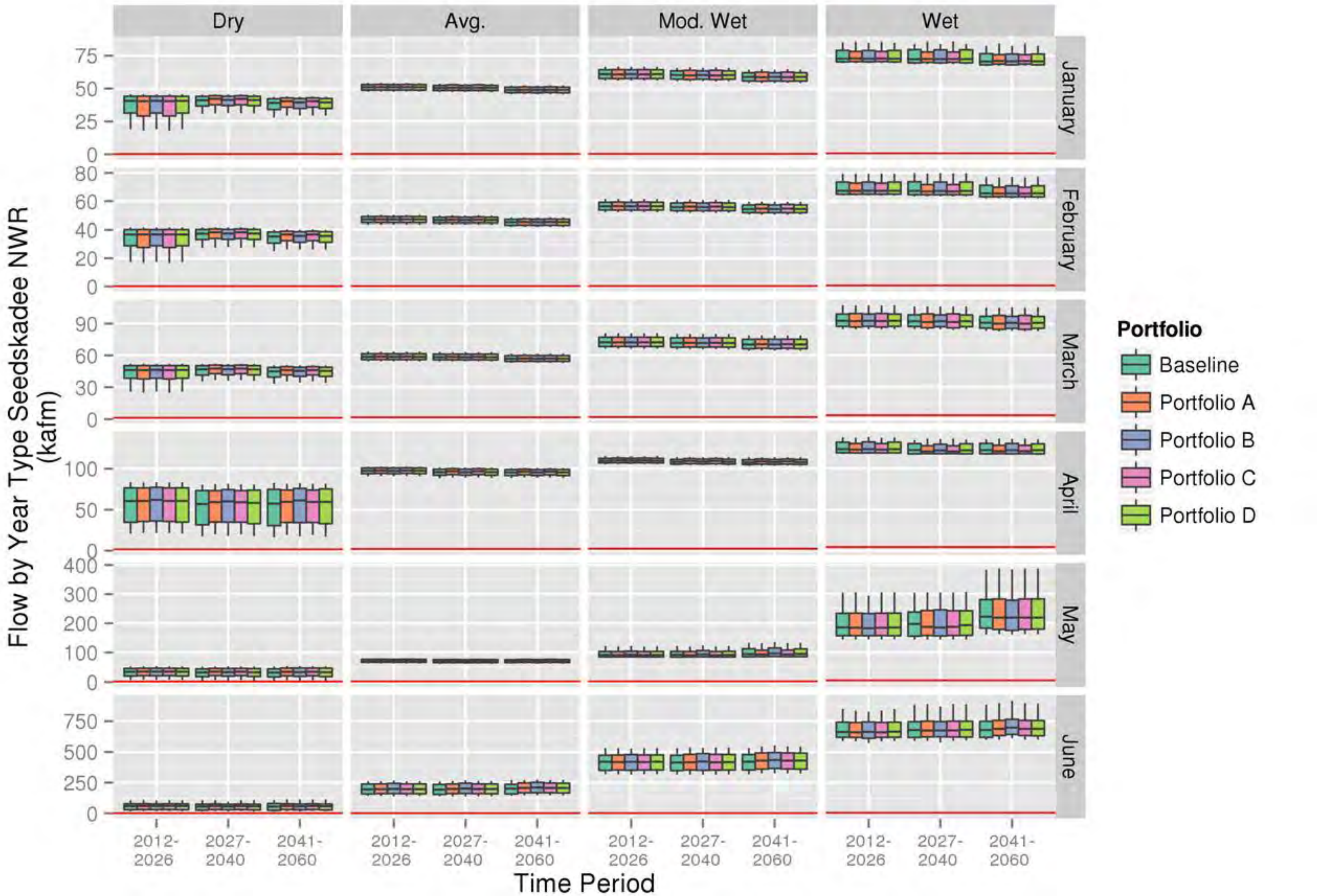


FIGURE F-41B
Flow by Year Type, Seedskadee National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values*

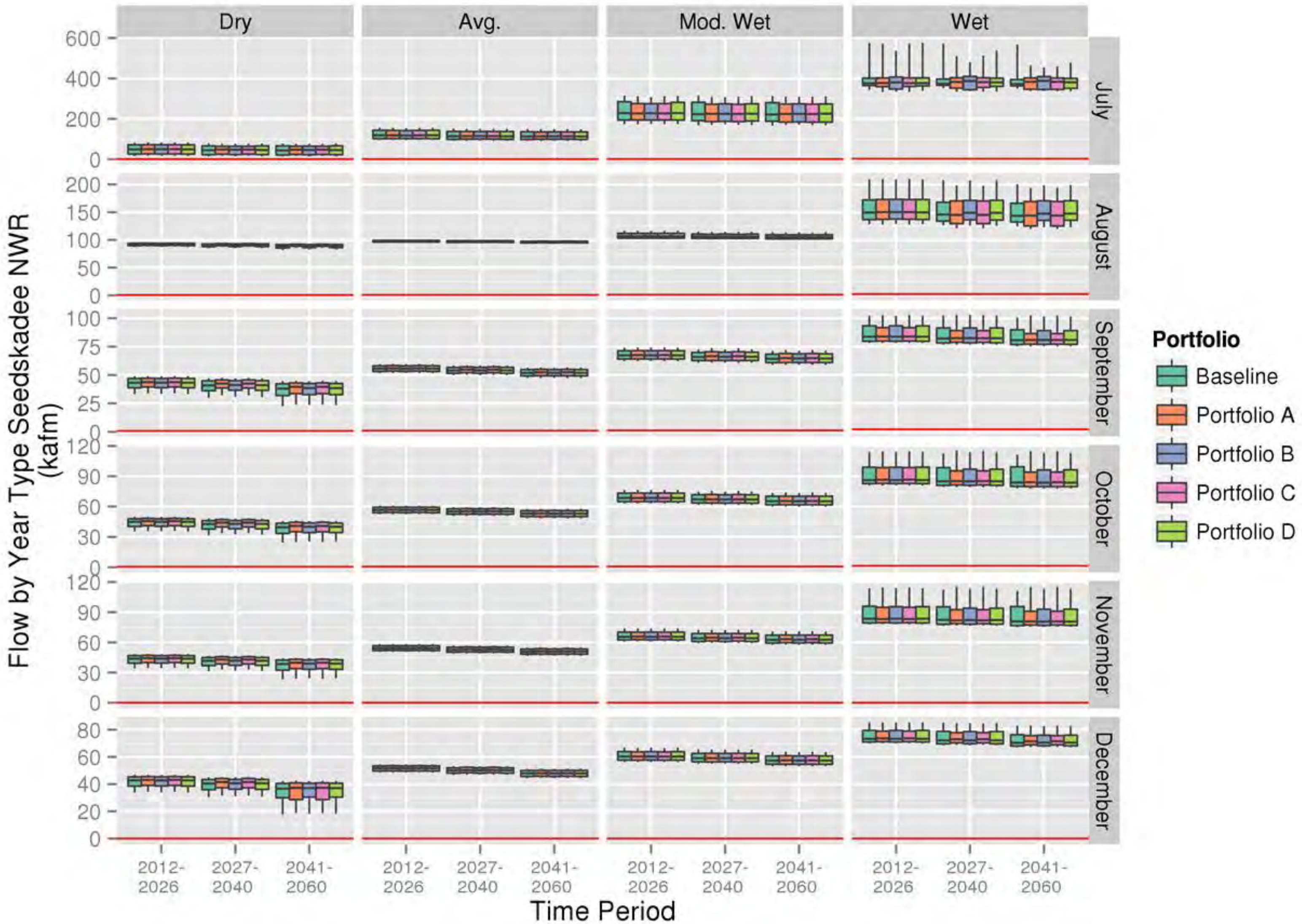


FIGURE F-42A
Flow by Year Type, Ouray National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values*

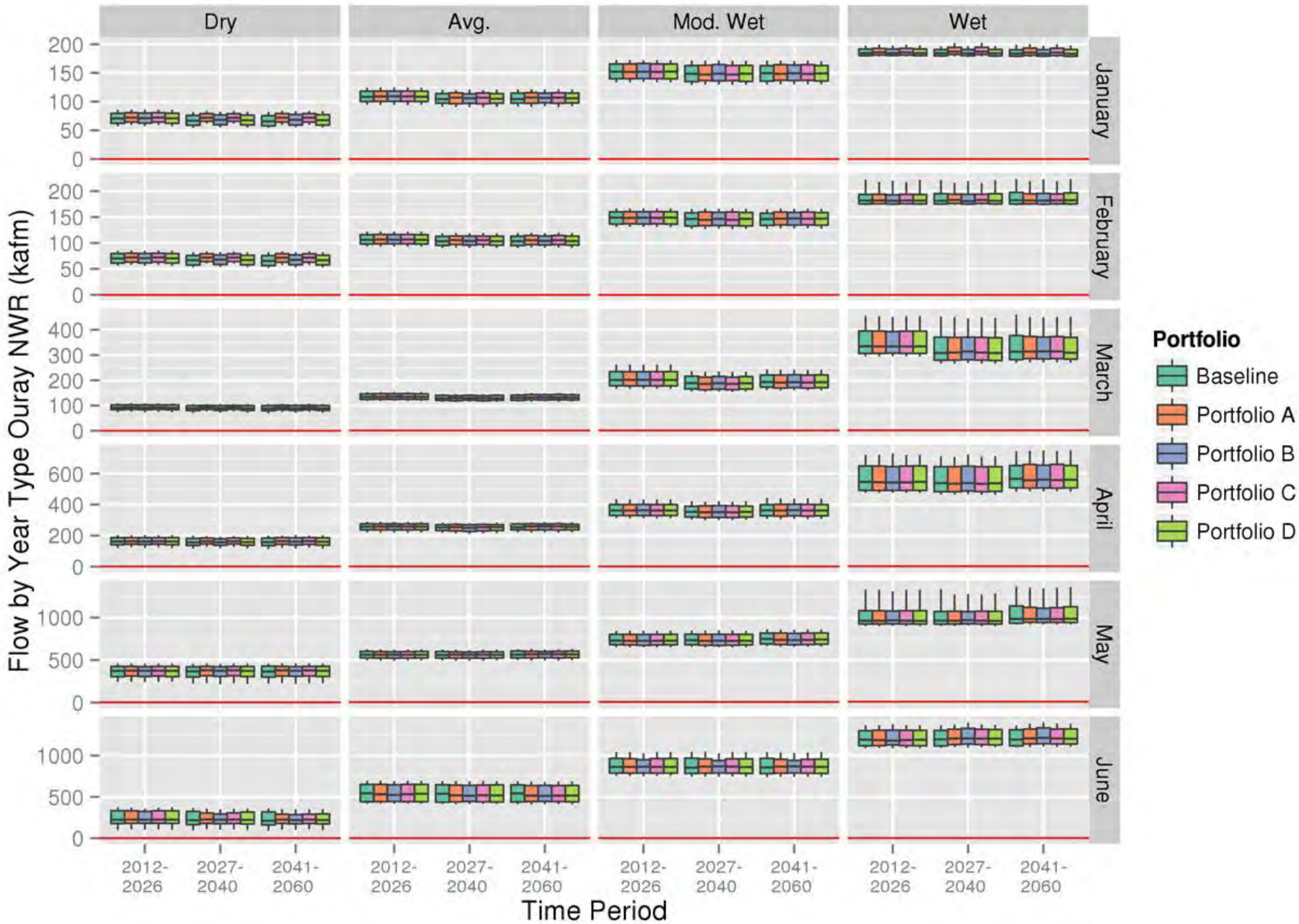


FIGURE F-42B
Flow by Year Type, Ouray National Wildlife Refuge
*Red Lines Indicate the Estimated Conditions as Reference Values*

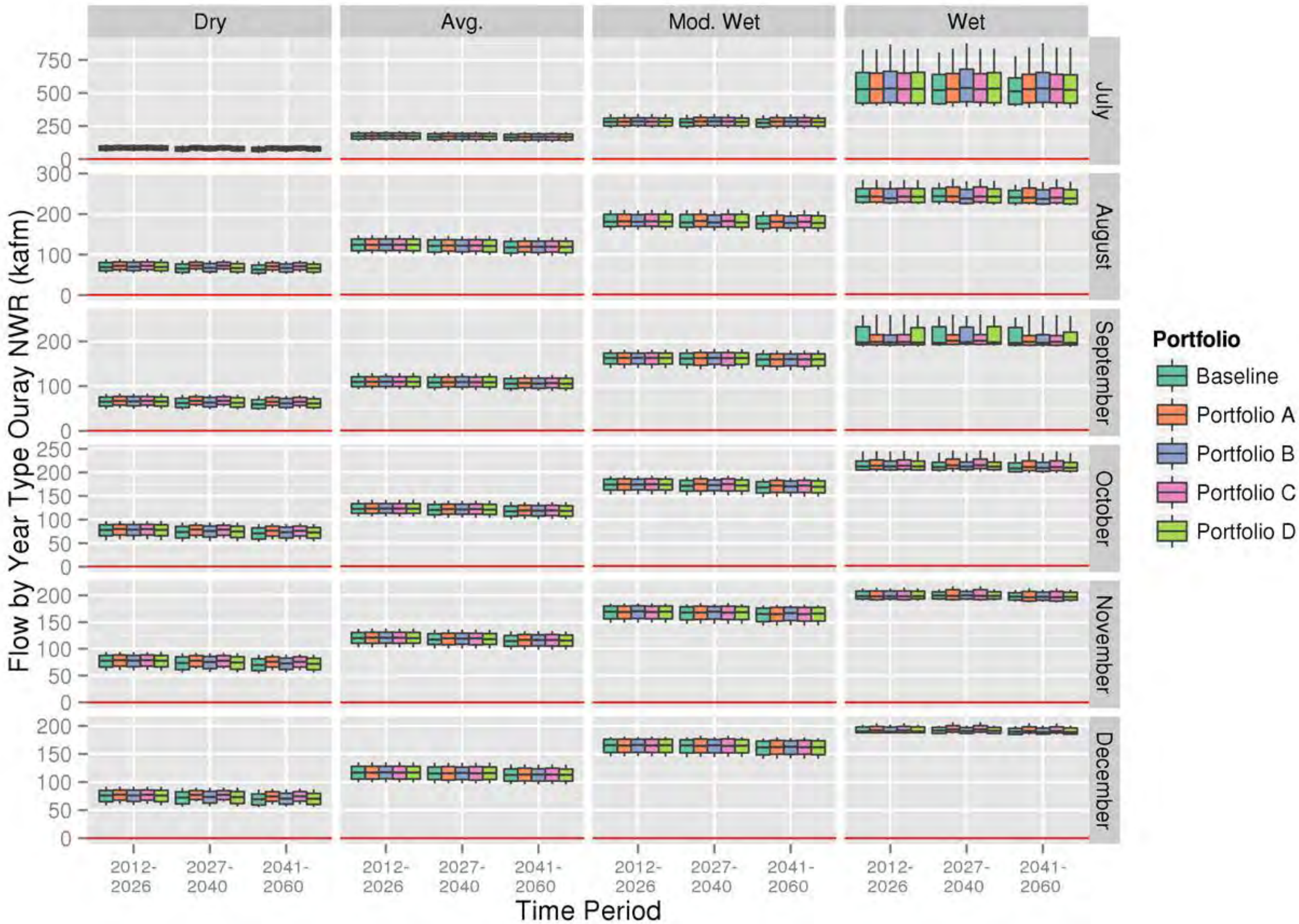


TABLE F-2
Lower Basin National Wildlife Refuges and Fish Hatcheries Percent of Years Not Meeting Requested Depletions and Diversions

| | Baseline | Portfolio A | Portfolio B | Portfolio C | Portfolio D |
|---|---|---|---|---|---|
| Havasu NWR | 0 | 0 | 0 | 0 | 0 |
| Cibola NWR | < 1% | 0 | 0 | 0 | 0 |
| Imperial NWR | < 1% | 0 | 0 | 0 | 0 |
| Willow Beach Fish Hatchery | 0 | 0 | 0 | 0 | 0 |

# 5.0 References

Bureau of Reclamation (Reclamation). 1996. *Record of Decision Operation of Glen Canyon Dam Final Environmental Impact Statement*. October.

Bureau of Reclamation (Reclamation). 2004. *Lower Colorado River Multi-Species Conservation Program. Volume I: Programmatic Environmental Impact Statement/Environmental Impact Report*. Final. December.

Bureau of Reclamation (Reclamation). 2012. *Record of Decision for the Aspinall Unit Operations, Final Environmental Impact Statement.*

U.S. Fish and Wildlife Service (FWS). 2009. *Final Gunnison River Basin Programmatic Biological Opinion*.