



Prepared in cooperation with the National Park Service

Decision Support System for Evaluation of Gunnison River Flow Regimes With Respect To Resources of the Black Canyon of the Gunnison National Park

By Gregor T. Auble, Mark Wondzell, and Colin Talbert

Open-File Report 2009-1126

U.S. Department of the Interior
U.S. Geological Survey

Warner Point reach of Gunnison River(1994), Jonathan Friedman, USGS

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U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|--|----------|--|
| Length | | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| Area | | |
| acre | 4,047 | square meter (m ²) |
| acre | 0.004047 | square kilometer (km ²) |
| square foot (ft ²) | 929.0 | square centimeter (cm ²) |
| square foot (ft ²) | 0.09290 | square meter (m ²) |
| square inch (in ²) | 6.452 | square centimeter (cm ²) |
| square mile (mi ²) | 2.590 | square kilometer (km ²) |
| Volume | | |
| cubic foot (ft ³) | 28.32 | cubic decimeter (dm ³) |
| cubic foot (ft ³) | 0.02832 | cubic meter (m ³) |
| cubic yard (yd ³) | 0.7646 | cubic meter (m ³) |
| cubic mile (mi ³) | 4.168 | cubic kilometer (km ³) |
| acre-foot (acre-ft) | 1,233 | cubic meter (m ³) |
| Flow rate | | |
| foot per second (ft/s) | 0.3048 | meter per second (m/s) |
| cubic foot per second, cfs (ft ³ /s) | 0.02832 | cubic meter per second (m ³ /s) |
| Mass | | |
| ounce, avoirdupois (oz) | 28.35 | gram (g) |
| pound, avoirdupois (lb) | 0.4536 | kilogram (kg) |
| Pressure | | |
| pound-force per square inch (lbf/in ²) | 6.895 | kilopascal (kPa) |
| pound per square foot (lb/ft ²) | 0.04788 | kilopascal (kPa) |
| pound per square inch (lb/in ²) | 6.895 | kilopascal (kPa) |
| Density | | |
| pound per cubic foot (lb/ft ³) | 16.02 | kilogram per cubic meter (kg/m ³) |
| pound per cubic foot (lb/ft ³) | 0.01602 | gram per cubic centimeter (g/cm ³) |

SI to Inch/Pound

| Multiply | By | To obtain |
|--|-----------|---|
| Length | | |
| centimeter (cm) | 0.3937 | inch (in.) |
| millimeter (mm) | 0.03937 | inch (in.) |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| Area | | |
| square meter (m ²) | 0.0002471 | acre |
| square kilometer (km ²) | 247.1 | acre |
| square centimeter (cm ²) | 0.001076 | square foot (ft ²) |
| square meter (m ²) | 10.76 | square foot (ft ²) |
| square centimeter (cm ²) | 0.1550 | square inch (ft ²) |
| square kilometer (km ²) | 0.3861 | square mile (mi ²) |
| Volume | | |
| cubic decimeter (dm ³) | 0.03531 | cubic foot (ft ³) |
| cubic meter (m ³) | 35.31 | cubic foot (ft ³) |
| cubic meter (m ³) | 1.308 | cubic yard (yd ³) |
| cubic kilometer (km ³) | 0.2399 | cubic mile (mi ³) |
| cubic meter (m ³) | 0.0008107 | acre-foot (acre-ft) |
| Flow rate | | |
| meter per second (m/s) | 3.281 | foot per second (ft/s) |
| cubic meter per second (m ³ /s) | 35.31 | cubic foot per second, cfs (ft ³ /s) |
| Mass | | |
| gram (g) | 0.03527 | ounce, avoirdupois (oz) |
| kilogram (kg) | 2.205 | pound avoirdupois (lb) |
| Pressure | | |
| kilopascal (kPa) | 0.1450 | pound-force per inch (lbf/in) |
| kilopascal (kPa) | 20.88 | pound per square foot (lb/ft ²) |
| kilopascal (kPa) | 0.1450 | pound per square inch (lb/ft ²) |
| Density | | |
| kilogram per cubic meter (kg/m ³) | 0.06242 | pound per cubic foot (lb/ft ³) |
| gram per cubic centimeter (g/cm ³) | 62.4220 | pound per cubic foot (lb/ft ³) |

Decision Support System for Evaluation of Gunnison River Flow Regimes With Respect To Resources of the Black Canyon of the Gunnison National Park

By Gregor T. Auble,¹ Mark Wondzell,² and Colin Talbert³

Introduction

Purpose

This report describes a decision support system to inform evaluation of streamflow regimes of the Gunnison River with respect to resources of Black Canyon of the Gunnison National Park (BLCA). The increasing use of sophisticated reservoir operations models has cast many water-management decisions as choices amongst different operating rules or policies, each of which has associated likely sequences of streamflow. The resulting complexity of hydrologic data is combined with an increasing emphasis in riverine ecology on natural flow variability and the importance of multiple aspects of the flow regime, which drive evaluation of environmental effects beyond specification of a single minimum flow or optimum flow for a target organism.

The decision support system described here is intended to help fill the gap between large data sets of simulated flow alternatives and judgments about the relative desirability of those alternatives with respect to natural resources. The intent of this work is not to evaluate alternatives, but rather to provide a tool for informing the evaluation of alternatives. The basic approach is to array differences among alternative flow regimes by calculating values of indicator variables representing different valued characteristics or processes of the riverine ecosystem.

There are multiple types of uncertainty in the comparison of alternatives. The characterization of an alternative as one or more flow sequences may imperfectly represent the flow sequences that might be produced by the alternative. The scientific understanding and quantitative relations between flow and the physical and biological responses of riverine systems are complex and may be imperfectly represented by indicator variables or calculations. Indicator variables may incompletely capture the underlying natural resource concerns. There is also room for disagreement about the relative importance or weighting of multiple resource concerns. Thus, a decision support system requires a balancing between simplifying assumptions—necessary to achieve the benefits of reduced complexity—and oversimplification into a highly synthetic result that cannot be understood or decomposed into constituent variables and calculations. This decision support system addresses the balancing by producing a set of indicators grouped into several areas of natural resource concern. The indicators are explicit and replicable calculations that reflect conditions or

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processes within each area of concern. Alternatives are compared directly in terms of these indicators, each of which can be individually understood and challenged in terms of the assumptions involved in the calculations. Different users could make different decisions using this system as they might weight the importance of multiple indicators differently or value different aspects of the system. Thus, the goal of the decision support system is not to make a decision, but rather to reduce the complexity of information and focus attention on tradeoffs involved in the decision.

Study Area

Black Canyon of the Gunnison National Park is located along the Gunnison River in western Colorado (fig. 1). The Black Canyon of the Gunnison National Monument was established “for the preservation of the spectacular gorges and additional features of scenic, scientific, and educational interest” on March 2, 1933, by Presidential Proclamation No. 2033 (47 Stat. 2558) pursuant to the Antiquities Act of June 8, 1906 (16 U.S.C. 431). Boundary changes occurred in 1938, 1939, 1958, 1960, 1976, 1984, and 1999. In 1976, a portion of the park was designated as wilderness (90 Stat. 2692). In 1999, Black Canyon of the Gunnison National Monument was designated Black Canyon of the Gunnison National Park with the addition of nearly 10,000 acres of previously held BLM lands, including roughly 4 miles of the Gunnison Gorge and Gunnison River (113 Stat. 1126).

The Black Canyon is one of the steepest, narrowest canyons in the country. Elevations within the BLCA, which encompasses 12 miles of the 53-mile Black Canyon, exceed 8,000 feet, and canyon walls, which in places are only 1,300 feet apart, plunge 2,200 vertical feet to the river below. Access through the canyon is extremely difficult and arduous; rock piles, scree slopes, and boulders litter the canyon floor and make travel by foot or watercraft nearly impossible. Early explorers considered the canyon inaccessible.

Immediately upstream from BLCA are the three Curecanti Unit dams (Blue Mesa, Morrow Point, and Crystal, constructed in 1966, 1970, and 1976, respectively), known today as the Aspinnall Unit. These dams regulate flow through the Black Canyon, effectively attenuating spring peak flows and augmenting late summer low flows. Flows are further modified by diversion of water through the 6-mile-long Uncompahgre Valley Water Users Association Gunnison Tunnel. Completed in 1909 and used to irrigate lands in the neighboring Uncompahgre Valley, the Gunnison Tunnel carries a 1902 water right priority date and can divert as much as 1,300 cubic feet per second (ft³/s). Immediately downstream of BLCA is the Gunnison Gorge National Resource Conservation Area, administered by the Bureau of Land Management (BLM).

Stream discharge is measured immediately below the inlet (East Portal) of the Gunnison Tunnel (U.S. Geological Survey gage 0912800), at the upstream boundary of BLCA. Discharge records began in 1906; the highest recorded instantaneous peak discharge is 19,000 ft³/s, which occurred on June 15, 1921, and the lowest recorded daily mean flow is 0 ft³/s, which occurred seven times between 1911 and 2000.

Warner and Walker (1972) provide a detailed description of a U.S. Geological Survey topographic surveying expedition in the Black Canyon in 1934 that includes photographs illustrating the sparse vegetation of the canyon bottom. The geology of the Black Canyon is summarized in Hansen (1965), reprinted as Hansen (1987), with additional detail described in Hansen (1964) and Hansen and Peterman (1968). The hydrology of the Gunnison River and its modification by upstream reservoirs and diversions is summarized by Diaz and others (1996).

Auble and others (1994) conducted plot-based vegetation sampling at the Warner Point reach in the Black Canyon and developed both a community classification and relations between

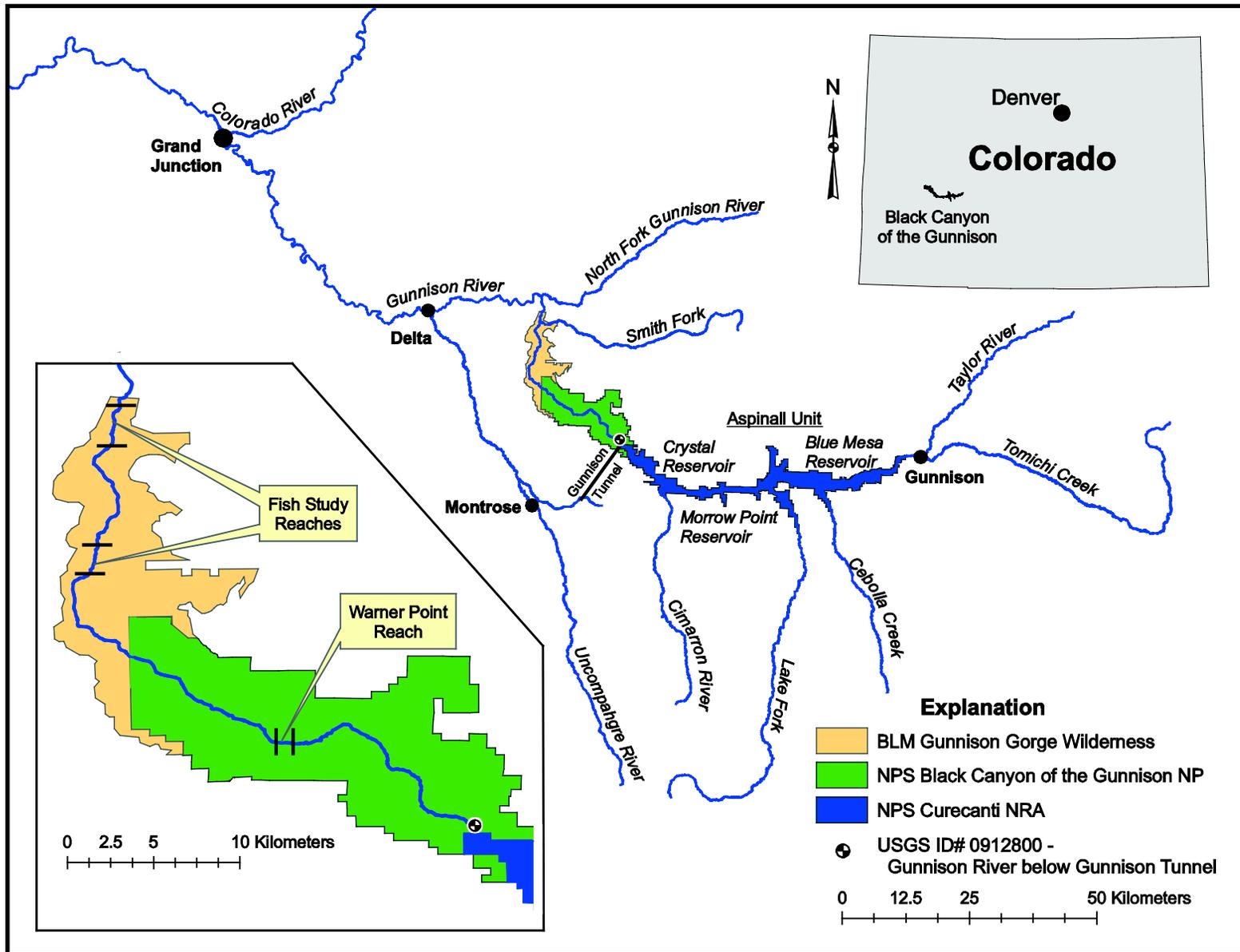


Figure 1. Location map.

hydrology and community distribution. Friedman and Auble (1999), also focusing on the Warner Point reach, quantified a model relating annual mortality of box elder to streamflow (shear stress and extended inundation).

Several investigators have examined sediment transport in the channel and bottom land of the Black Canyon. Chase (1992) estimated streamflow thresholds for gravel and cobble motion. Elliott and Hammack (1999, 2000) examined entrainment of riparian gravel and cobbles in the Warner Point reach and estimated streamflows required to mobilize geomorphic features. Liquori (1995) inventoried talus and debris-flow deposits in the BLCA bottom land and described both their delivery mechanisms and transport by the Gunnison River. Dubinski (2005) and Dubinski and Wohl (2007) estimated a historical sediment budget for the Gunnison River in BLCA and developed a model relating streamflow to channel mobilization for different sediment particle sizes throughout BLCA.

Nehring and Miller (1987), Nehring (1988), and Nehring and Anderson (1993) reported on extensive studies of brown and rainbow trout at two sites in the Gunnison Gorge downstream from BLCA. This work included quantification of physical habitat simulation models (PHABSIM, Bovee and Milhous, 1978; Bovee, 1982) combining hydraulic simulation and empirical suitability curves to estimate weighted usable area of suitable habitat for different species and life stages, and multiple years of fish census data that suggest fry habitat is most limiting for trout in this part of the Gunnison River. The endangered fish (Colorado pikeminnow, razorback sucker, and humpback chub) live in the Gunnison and Colorado Rivers downstream from BLCA. Concern about these species (McAda, 2003) has motivated a number of studies and analyses of downstream sections of the Gunnison River and is a consideration in water-management decisions upstream from BLCA that influence Gunnison River streamflow through BLCA (for example, operation of Aspinall Unit as described in Bureau of Reclamation, 2009).

Structure of Decision Support System

Basic Use

The system is implemented as a Microsoft Office EXCEL workbook, with embedded macros, entitled *BCG_DSS.xls*. It currently runs within either Microsoft Office EXCEL 2003 or 2007. The workbook, a set of input data files, and supporting descriptions can be downloaded from <http://www.fort.usgs.gov/Products/Software/>. Macros must be enabled when opening *BCG_DSS.xls*, which may require setting a general security level and perhaps enabling macros when opening the workbook. Immediately upon opening the workbook, a title window appears that is cleared by clicking **Ok**, which then activates a **Main Menu** window (fig. 2), which contains a **Display General Instructions** button for the first-time user.

Navigation among worksheets and the execution of the calculations for alternatives are performed through a user interface of clicking buttons and selecting from drop-down menus. The EXCEL toolbars and spreadsheet display structures remain visible and functional. They can be used as an alternative means of navigation among worksheets, as well as for EXCEL operations such as cut-and-paste, resizing, altering graph symbols, and data entry.

The basic steps to use the decision support system are listed below.

1. Specify inputs of alternative flow regimes to be evaluated (**Specify Inputs** button).
2. Execute the calculation of indicators associated with these regimes (red **Execute** button).
3. Examine the input data as it has been read into the decision support system (**Display Input Data** drop-down menu).

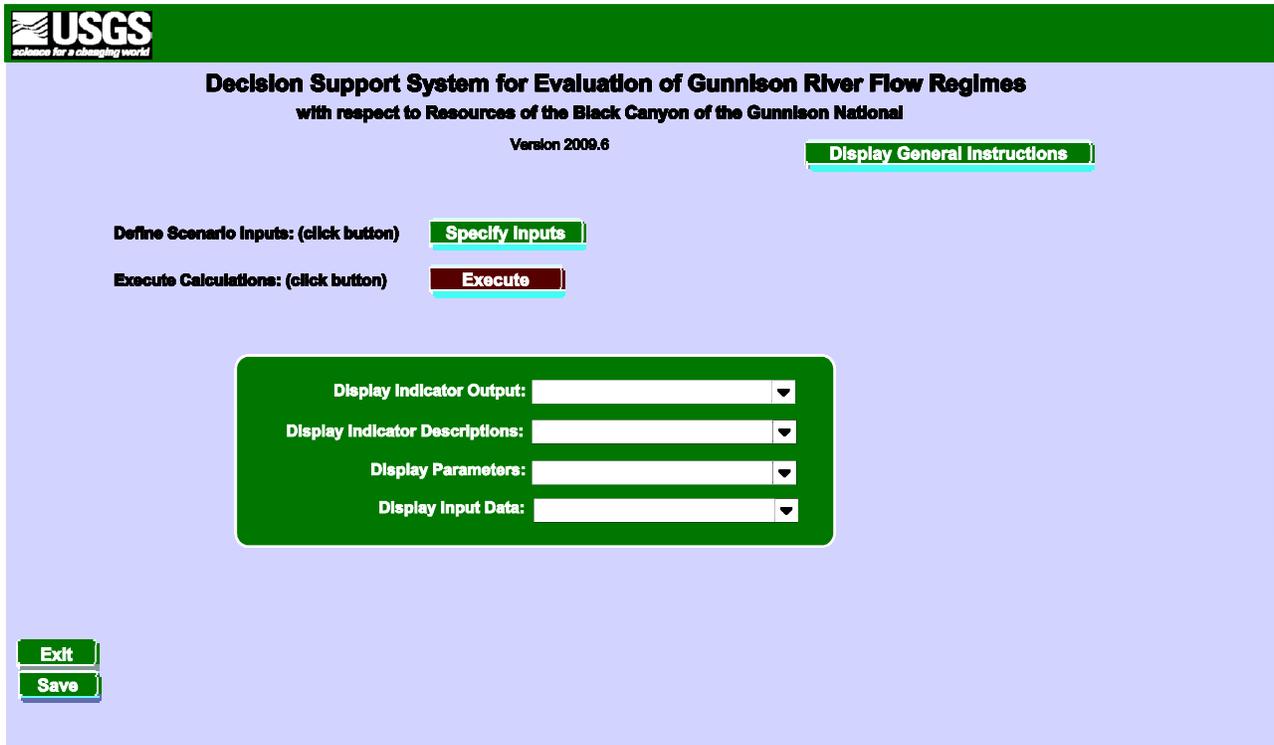


Figure 2. Screen capture depicting **Main Menu** at top level of navigation.

4. Display output as graphs (**Display Indicator Output** drop-down menu) and tables (**Tabular Output** button on graph pages).
5. View descriptions of the indicators (**Display Indicator Descriptions** drop-down menu).
6. View and potentially alter the parameters being used in the calculations (**Display Parameters** drop-down menu).

Some of the navigation among worksheets is contextual in the sense that the navigation options depend on the worksheet being displayed—tabular output for an indicator is accessed from the sheet displaying the graph of the respective indicator and display of parameters or descriptions default to the particular indicator being displayed when accessed from graph or tabular output sheets. The Main Menu sheet also contains buttons to Save and **Exit**. Both of these functions can also be performed as direct EXCEL commands.

Input

The **Input Scenario Specification** worksheet (fig. 3) is where the user defines the input data associated with each scenario. Input data are provided as worksheets within EXCEL workbook files. The user defines the flow alternatives on the **Input Scenario Specification** worksheet by entering a scenario name and the location (full path name of file, worksheet, and columns) for the different types of input data. The **View Instructions** button on this worksheet displays basic instructions for input data. Example input data files are provided with the decision support system program in an *InputDataFiles* directory. There are two basic types of input data: daily hydrologic data and secondary data for National Park Service (NPS) water-right calculations. Only daily

[Main Menu](#)

[Display Formatting Instructions](#)

Daily Hydrologic Data

| Scenario Name | File Name (full path): | Sheet within workbook | Daily Date Column: | Flow Data (cfs) Column: |
|---------------|--|-----------------------|--------------------|-------------------------|
| H1934 | C:\BCG\inputDataFiles\Hgage_1934-1964.xls | Hgage_1934-1964 | c | d |
| Abt1934 | C:\BCG\inputDataFiles\HbvTun_1934-1964.xls | HbvTun_1934-1964 | a | b |
| RN1975 | C:\BCG\inputDataFiles\RcNat_1975-2005.xls | RcNat_1975-2005 | a | b |
| H1975 | C:\BCG\inputDataFiles\Hgage_1975-2005.xls | Hgage_1975-2005 | c | d |
| BRnoAc | C:\BCG\inputDataFiles\BRnoAction.xls | Run0 | a | c |
| BRaitA | C:\BCG\inputDataFiles\BRaitA.xls | Run0 | a | c |
| BRaitB | C:\BCG\inputDataFiles\BRaitB.xls | Run0 | a | c |
| BRaitC | C:\BCG\inputDataFiles\BRaitC.xls | Run0 | a | c |

Secondary Input Data for NPS Water Right Calculations

Unregulated April 1 - July 31 Blue Mesa Inflow (acre-feet)

leave blank if not available

| Scenario Name (auto-copied from above) | File Name (full path): | Sheet within workbook | Year Column: | May 1 Forecast (acre-feet) Column: | Actual Inflow (acre-feet) Column: |
|--|--------------------------------------|-----------------------|--------------|------------------------------------|-----------------------------------|
| H1934 | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| Abt1934 | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| RN1975 | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| H1975 | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| BRnoAc | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| BRaitA | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| BRaitB | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |
| BRaitC | C:\BCG\inputDataFiles\HBM_Inflow.xls | HBM_Inflow | a | b | c |

Daily Blue Mesa Live Storage (acre feet)

leave blank if not available

assumed to not affect drought provision calculation if missing for scenario or year

| Scenario Name (auto-copied from above) | File Name (full path): | Sheet within workbook | Daily Date Column: | Dec. 31 BM Live Storage (acre-feet) Column: |
|--|---|-----------------------|--------------------|---|
| H1934 | C:\BCG\inputDataFiles\HBM_Storage.xls | HBM_Storage | a | b |
| Abt1934 | C:\BCG\inputDataFiles\HBM_Storage.xls | HBM_Storage | a | b |
| RN1975 | C:\BCG\inputDataFiles\RcNat_1975-2005.xls | RcNat_1975-2005 | a | c |
| H1975 | C:\BCG\inputDataFiles\HBM_Storage.xls | HBM_Storage | a | b |
| BRnoAc | C:\BCG\inputDataFiles\BRnoAction.xls | Run0 | a | b |
| BRaitA | C:\BCG\inputDataFiles\BRaitA.xls | Run0 | a | b |
| BRaitB | C:\BCG\inputDataFiles\BRaitB.xls | Run0 | a | b |
| BRaitC | C:\BCG\inputDataFiles\BRaitC.xls | Run0 | a | b |

Figure 3. Screen capture depicting **Input Scenario Specification** where user defines location of input data for scenarios.

hydrologic data are required. However, evaluation of indicators of NPS water rights will be limited to the extent that secondary data required for these calculations are not provided.

In our testing of the system, errors in the specification or structure of the input data caused by far the most difficulty. We have tried to trap some common errors, but if things are not working, carefully check the input data specifications and contents of the data files themselves, comparing them to the example files provided. In general, input data files should start with data on the second line of the file below a first line containing column headings and should contain contiguous blocks of data without embedded empty cells or rows. Additional formatting details are provided below for the different types of input data.

Daily Hydrologic Input

The decision support system was developed to evaluate daily streamflow from a stream gage at the upstream boundary of the park (U.S. Geological Survey gage 0912800) and daily output (model slot Crystal_to_GunnisonTunnelOutflow) corresponding to this gage from the RIVERWARE model being used by the Bureau of Reclamation (Bureau of Reclamation, 2009). However, daily streamflow values could come from any source, including arbitrary sequences, as long as they are specified as daily values in an input data worksheet.

The decision support system is structured to compare as many as eight alternative flow regimes, where each alternative is represented by a daily sequence of at least 20 calendar years of streamflow occurring between 1901 and 2050. The daily flow record must start on a January 1 and end on a December 31 and be complete for all the calendar years included; missing values must be estimated by the user in the input data file. Daily streamflows are entered in cubic feet per second (ft³/s), abbreviated as cfs, formatted in EXCEL general or numeric format. Date values should be in EXCEL date or date-time format. Although there is no necessary correspondence between the calendar years of a flow alternative and actual historical years, any secondary data provided for NPS water-right calculations must appropriately correspond to the daily streamflow data for a given alternative. Furthermore, comparisons of specific yearly output across scenarios representing alternative water-management operations are potentially confusing if a specific year represents very different climatic conditions in the different flow alternatives (for example, 2020 is a Dry year in one flow alternative, whereas 2020 is a Wet year in a different flow alternative). This decision support system is not structured to directly analyze water-management options in terms of multiple, stochastically generated flow sequences.

Secondary Input

The National Park Service (NPS) water right for the instream flow of the Gunnison River in BLCA varies in relation to interannual variability in basin water supply (Colorado District Court Water Division 4, 2009). Secondary data on water supply is thus required in order to calculate some components of the NPS water right. If these data are not available for a particular flow alternative, all calculations will proceed and be displayed except some of the NPS water-right indicators.

Two kinds of secondary input are required. The first concerns unregulated annual April 1–July 31 inflow to Blue Mesa reservoir in acre-feet. This quantity well expresses interannual variability in water supply, is used in simulation and operation of the Aspinall Unit facilities, is subject to real-time forecasting using snowpack conditions, and is used in the formal specification of the NPS water right. Both actual and May 1 forecast values of unregulated April 1–July 31 inflow to Blue Mesa are required. The Forecast Inflow in the NPS water right (Colorado District Court Water Division 4, 2009) is defined as:

Forecasted Inflow means the May 1 forecast for the Gunnison River Basin, issued by the Colorado River Basin River Forecast Center or successor agency and used by the Bureau of Reclamation for forecasts, of the most probable (50 percent chance of exceedance) unregulated April 1 through July 31 inflow to Blue Mesa Reservoir.

Forecast and actual inflow should be generally available for simulations of Aspinall Unit operations (RIVERWARE model) as well as actual future years. Reconstruction of what the forecast would have been before forecasts were made or for periods for which input data for the forecasting algorithms are not available—including estimation of what the forecast would be for an

arbitrary daily flow sequence—are problematic. In the example input data directory *InputDataFiles*, we provide and describe estimates of actual and forecast Blue Mesa inflow that may be suitable for use with scenarios based on historical hydrologic patterns.

Both the May 1 forecast and actual values are required, as well as values for the two preceding years (in order to assess a longer-term drought condition). Annual values for forecast and actual April–July Blue Mesa inflow are entered as acre-feet in cells with EXCEL general or numeric formatting. Cells containing corresponding years should be in EXCEL general or numeric format.

The other type of secondary input data concerns the live storage in acre-feet in Blue Mesa Reservoir on December 31 of the previous year. This information is used only to suspend the application of a drought-provision reduction of the NPS Peak Flow right when low basin water supply is mitigated by the availability of substantial reservoir storage. The threshold value of Blue Mesa live storage volume is 550,000 acre-feet. If drought conditions exist, as determined from Blue Mesa inflow data, drought provisions in the NPS water right are not implemented if the reservoir storage on December 31 of the previous year exceeds 550,000 acre-feet. Thus, the effects of Blue Mesa Reservoir storage can be disabled by input values of storage less than 550,000 acre-feet, as would be appropriate when evaluating historical conditions before the dam was built.

The location of Blue Mesa live storage input data is entered on the **Input Scenario Specification** screen (fig. 3). Although only one value for a year (December 31) is needed, input is specified as a sequence of daily, rather than yearly, values to facilitate direct use of output from the Bureau of Reclamation RIVERWARE model (slot BlueMesaStorage). Live storage is provided in acre-feet (EXCEL general or numeric format) and date is provided in EXCEL date or date-time formatted cells. A complete input data set is not required. If no input file is identified for a flow alternative, then the effect of Blue Mesa storage is disabled by assuming values of less than 550,000 acre-feet. If the value for December 31 of a specific year is missing from the input data set, it is estimated as the January 1 value for the next year if that value is provided. If this estimation is not possible (January 1 of the next year is also missing), then a value of less than 550,000 acre-feet is assumed.

Execution and Output

The system is implemented as a VBA (Visual Basic for Applications) macro within a Microsoft Office EXCEL workbook in order to (1) utilize widely available software, (2) allow direct examination of the underlying code by multiple users, and (3) support convenient input of multiple sources of alternative flow regimes as workbook files. Invoking the VBA editor within EXCEL allows examination of all the VBA code and objects. Values of parameters, as well as fonts, graphics elements, cell formulas, named ranges, and VBA code, can be modified by the user, although some of the cells are initially protected to limit inadvertent changes. A button control in the **WorkbookLookups** worksheet containing program parameters can be used to turn this protection off to allow editing of all cells.

The code performs some limited error trapping such as checking that file paths are valid and that input data are complete. However, we have not explored all possible situations that might produce errors, and the program should be viewed as a working tool to be improved by the user if necessary. Serious errors may send the workbook into a Debug mode within VBA from which the application can either be terminated or the source of the error can be further investigated by the user. The most likely sources of execution errors are problems with the specification or contents of input data files. Some execution errors may stem from having other workbooks open within the same instance of EXCEL running the decision support system. Thus, it is desirable to open EXCEL

in a second instance to concurrently examine other workbooks. Refer to the site <http://www.fort.usgs.gov/Products/Software/> to communicate suspected program bugs and to check for revised versions of the code.

No special interfaces have been developed for saving or printing output. EXCEL output menu controls and cut-and-paste operations can be used to export desired graphs or tables from *BCG_DSS.xls* to other locations.

Both the decision support system and this document use mixed units, which reflects a compromise between a scientific preference for metric or S.I. units and the desirability of limiting unit conversions both from the original results of the studies used to define relationships and by the user in preparing input data and interpreting results in the context of water-management decisions. Tables of conversion factors are provided at the beginning of this document.

Selecting the red **Execute** button from the **Main Menu** invokes the main processing VBA macro, which controls the processing of input data and updating of worksheets. A status box tracks execution. When calculations are completed, an **Input Data Summary** sheet is displayed providing summary information about each flow alternative (fig. 4). The user then navigates to the **Main Menu** to examine output in more detail.

Several types of graphs are used to display output. These can generally be manipulated using standard EXCEL commands to rescale axes, move labels, and change symbols, line widths, and colors. Pie charts are used to depict plant community composition (fig. 5). Many of the indicators are graphed using box plots portraying distributions of values associated with each flow alternative (fig. 6). These box plots depict the range of indicator values (most often a collection of annual values) as the tops and bottoms of a whisker line, the 10th and 90th percentiles as the tops and bottoms of the box, and the median value as a line within the box. Thus, they are slightly different from a common form of box plots where the tops and bottoms of the box depict the percentiles and the whiskers are some function of the inter-quartile range. Percentiles are calculated with EXCEL conventions for interpolation.

| | H1934 | AB71934 | RN1975 | H1975 | BTnoAc | BRa1A | BRa1B | BRa1C |
|--|--------|---------|--------|--------|--------|--------|--------|--------|
| Number of Years of Record | 31 | 31 | 31 | 31 | 31 | 31 | 31 | 31 |
| First Year of Record | 1934 | 1934 | 1975 | 1975 | 1975 | 1975 | 1975 | 1975 |
| Last Year of Record | 1964 | 1964 | 2005 | 2005 | 2005 | 2005 | 2005 | 2005 |
| Blue Mesa Unregulated Inflow Data Provided | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Overall Minimum Daily Discharge (cfs) | 0 | 109 | 21 | 65 | 298 | 298 | 298 | 298 |
| Overall Mean Daily Discharge (cfs) | 1,134 | 1,567 | 1,627 | 1,154 | 1,095 | 1,095 | 1,095 | 1,095 |
| Overall Maximum Daily Discharge (cfs) | 16,300 | 16,700 | 19,329 | 10,600 | 12,156 | 11,750 | 11,871 | 12,560 |

Figure 4. Screen capture depicting **Input Data Summary** displaying summary characteristics of flow scenarios as read into the decision support system.

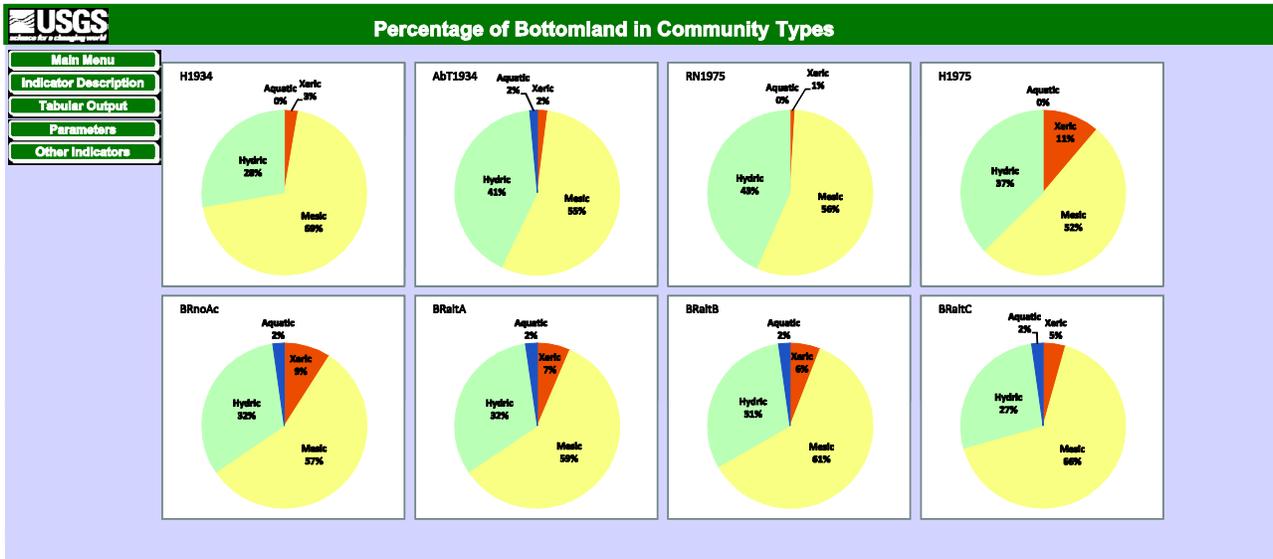


Figure 5. Screen capture depicting Display Indicator Output for Plant Communities indicator.

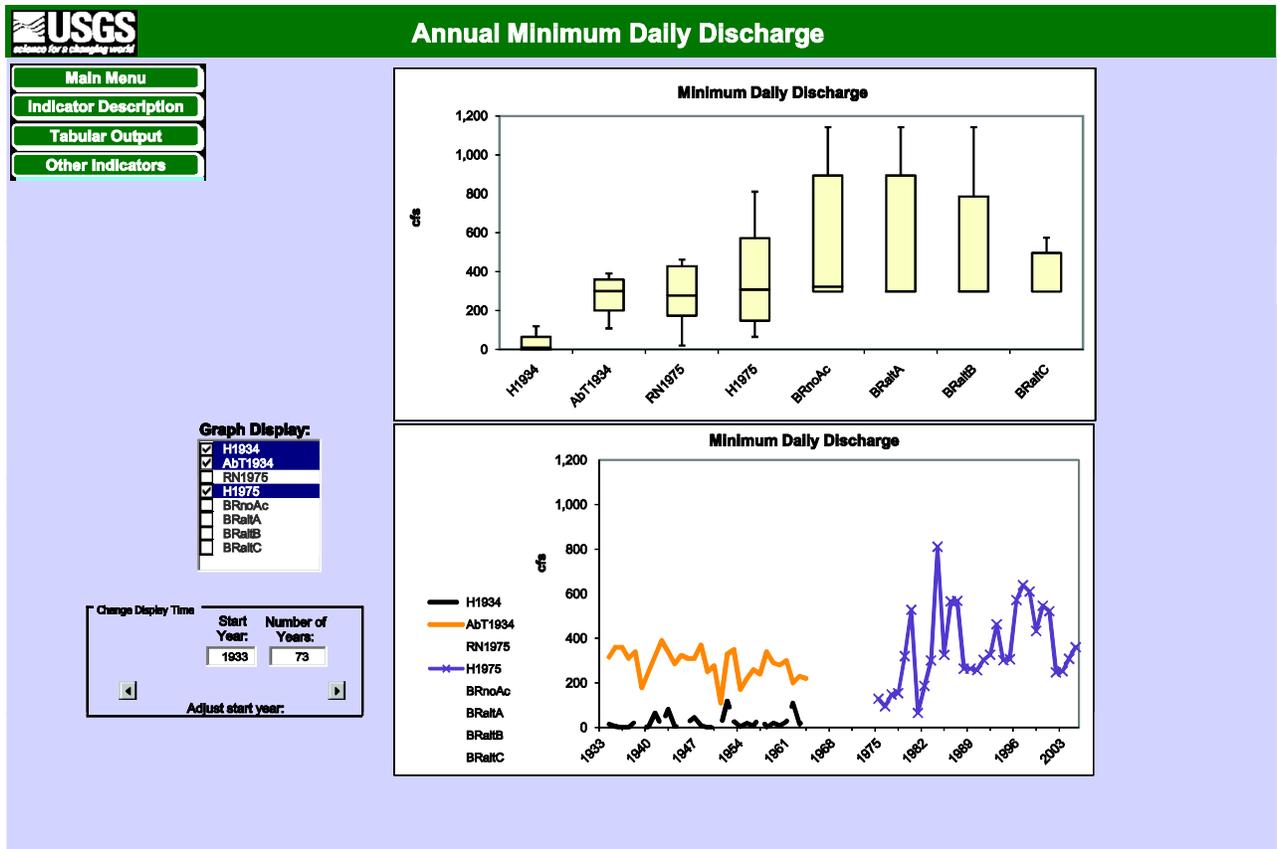


Figure 6. Screen capture depicting Display Indicator Output for Annual Minimum Daily Discharge indicator.

Some indicators are also portrayed with alternative-selectable, time-series plots. These have two forms. In the form used in figure 6, multiple alternatives can be selected for overlay on the same time-series graph, and the time axis can be rescaled to focus on either long or short intervals with adjustable starting times. The other form of time-series graph compares values of the NPS water right to observed flow values over time for a single, selectable flow alternative (fig. 7). Figure 7 also illustrates the final type of summary graph in which alternatives are compared with bar charts of the percentage of years in which a condition is satisfied. Tabular output of each indicator is also available from the **Tabular Output** button on the respective graph sheets.

Indicator Variables

Box Elder Clearing

Photographs and reports from visits indicate that there was little riparian vegetation on the canyon bottom in many areas of the Black Canyon of the Gunnison prior to flow regulation (Warner and Walker, 1972). Currently, many bottom-land surfaces are vegetated with a combination of herbaceous and woody plant species. Friedman and Auble (1999) developed a box elder clearing model for the Warner Point reach of the Gunnison River (fig. 1). Their model relates

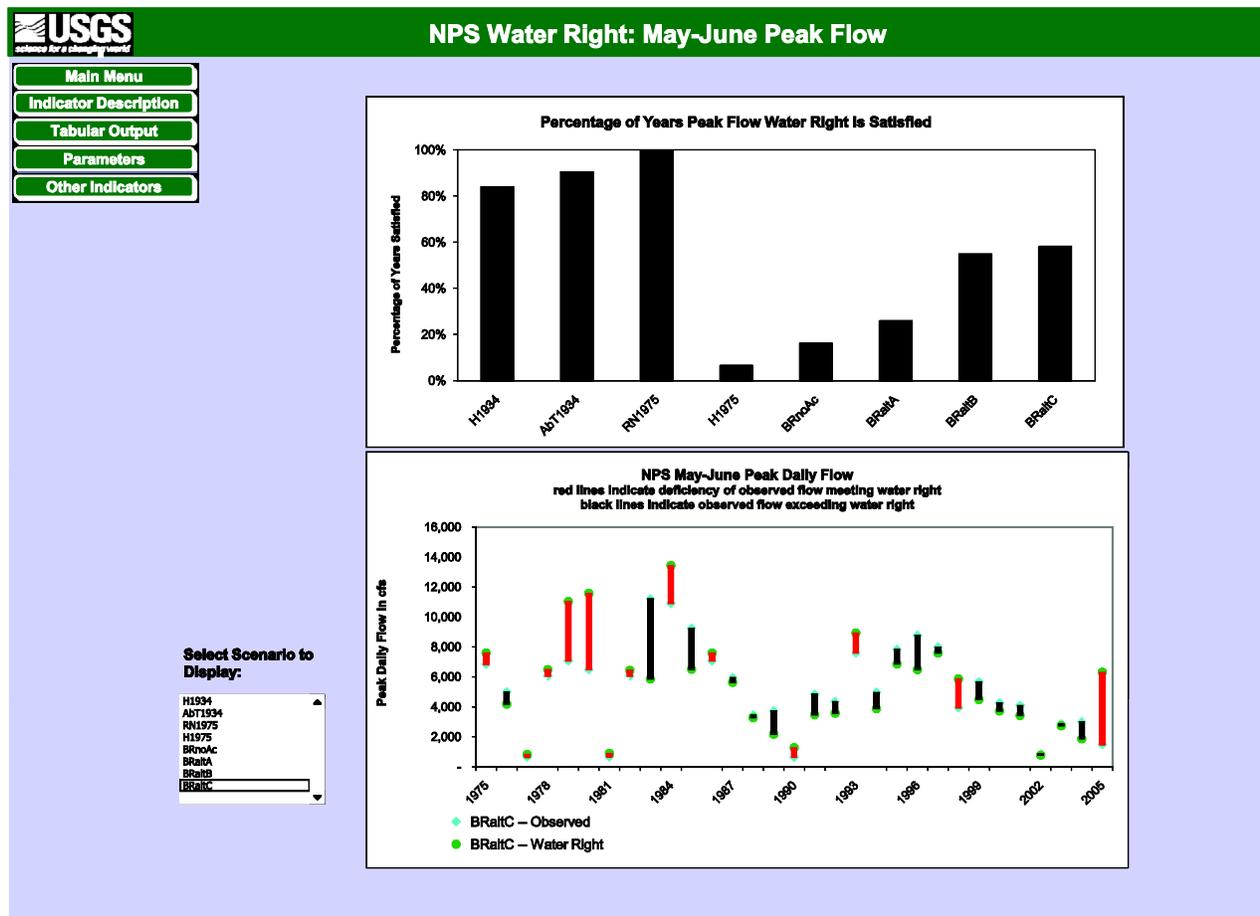


Figure 7. Screen capture depicting **Display Indicator Output** for **NPS Water Right: May-June Peak Flow** indicator.

streamflow to an annual fraction of the bottom land cleared. A step-backwater hydraulic model relates discharge to water-surface elevations, which are then used to estimate inundation durations and shear stresses at plots. Estimates of sediment particle sizes at plots are used to estimate critical shear stress at plots. Friedman and Auble (1999) proposed a two-part clearing function: a plot was cleared in a year if the shear stress exceeded the critical shear stress for mobilizing sediment at that plot, and a plot was cleared if it was inundated for more than 85 days in the growing season. They quantified this relation by (a) aging existing trees and retrospectively estimating the worst conditions those trees had survived and by (b) directly observing mortality over a year with extended inundation.

Work of Friedman and Auble (1999) is applied here to estimate two indicators: **Percentage of Bottomland Cleared** and **Percentage of Bottomland Cleared by Scour**. Parameter tables of the bottom-land plots used by Friedman and Auble define the inundating discharge (discharge required to inundate the plot) and the discharge producing greater than critical shear stress at the plot.

Shear stress, or the force per unit area applied by the water at the boundary surface, is calculated at the plot level as

$$\tau = \rho gRS \quad (1)$$

where τ is shear stress, ρ is the density of water, g is the acceleration of gravity, R is the hydraulic radius (assumed to be approximated by water depth over a plot), and S is the energy gradient at the cross section. Critical shear stress necessary to mobilize sediment is related to the sediment particle size through Shields equation (1936) as

$$\tau_{cr} = \tau_{cr}^* g (\rho_s - \rho) d_{50} \quad (2)$$

where τ_{cr} is critical shear stress, τ_{cr}^* is critical dimensionless shear stress, g is the acceleration of gravity, ρ_s is the density of sediment, ρ is the density of water, and d_{50} is the diameter of the 50th percentile or median particle. Particle sizes were assigned to plots based on pebble count measurements on all distinct fluvial surfaces at the Warner Point reach, and a value of 0.031 was used for τ_{cr}^* following Andrews' (1984) work on gravel-bed rivers in Colorado.

Values of discharge at which critical shear stress is exceeded were not estimated for discharges above 20,000 ft³/s, and the relation is assumed to reach a plateau above this discharge. Percentages of the bottom land are then calculated as percentages of these plots. Note that the total **Percentage of Bottomland Cleared** does not simply separate into **Percentage of Bottomland Cleared by Scour** (presented as an indicator) and a percentage cleared by inundation (not presented) because some plots can be cleared by both scour and inundation in a given year. Following Friedman and Auble (1999), (a) the bottom land is limited to plots above the 300-ft³/s flow line, (b) the relationships are quantified for the Warner Point reach, (c) shear stress uses the depth of water over the plot-specific ground surface, and (d) dimensionless critical shear stress is assumed to be 0.031 for the plot-based estimated D_{50} particle size. Here, we substitute maximum daily discharge for the peak instantaneous discharge used by Friedman and Auble (1999). For both indicators, box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) depict distributions of annual values associated with alternative flow regimes.

Plant Communities

Auble and others (1994) developed a riparian vegetation community model for the bottom land at the Warner Point reach (fig. 1) based on a direct gradient relation between community occurrence and long-term inundation duration. They based community definitions on a TWINSPLAN classification of species occurrences at randomly selected plots; they used a step-

backwater hydraulic model to estimate the inundating discharge of each plot and a 17-year flow history to calculate inundation duration for each plot. The distribution of communities in different classes of inundation duration (fig. 8) was then used to predict distribution across the plots under alternative flow regimes that would result in different inundation durations for the plots.

The indicator **Percentage of Bottomland in Community Types** estimates the percentage of bottom land in the four community types of (a) Aquatic, (b) Hydric, (c) Mesic, and (d) Xeric following Auble and others (1994) with respect to (a) definitions of communities; (b) a calibration table relating inundation duration to the probability of being in a given community; and (c) the set of plots of different inundating discharges in the Warner Point reach representing the bottom land above the 300-ft³/s flow line. Here we substitute a daily flow duration curve for the full period of input record specified for a flow alternative for the 17-year interval used by Auble and others (1994) in order to produce a single result for percentages of the bottom land in different riparian vegetation community types for each flow alternative. These distributions are depicted in a pie chart for each flow alternative (fig. 5).

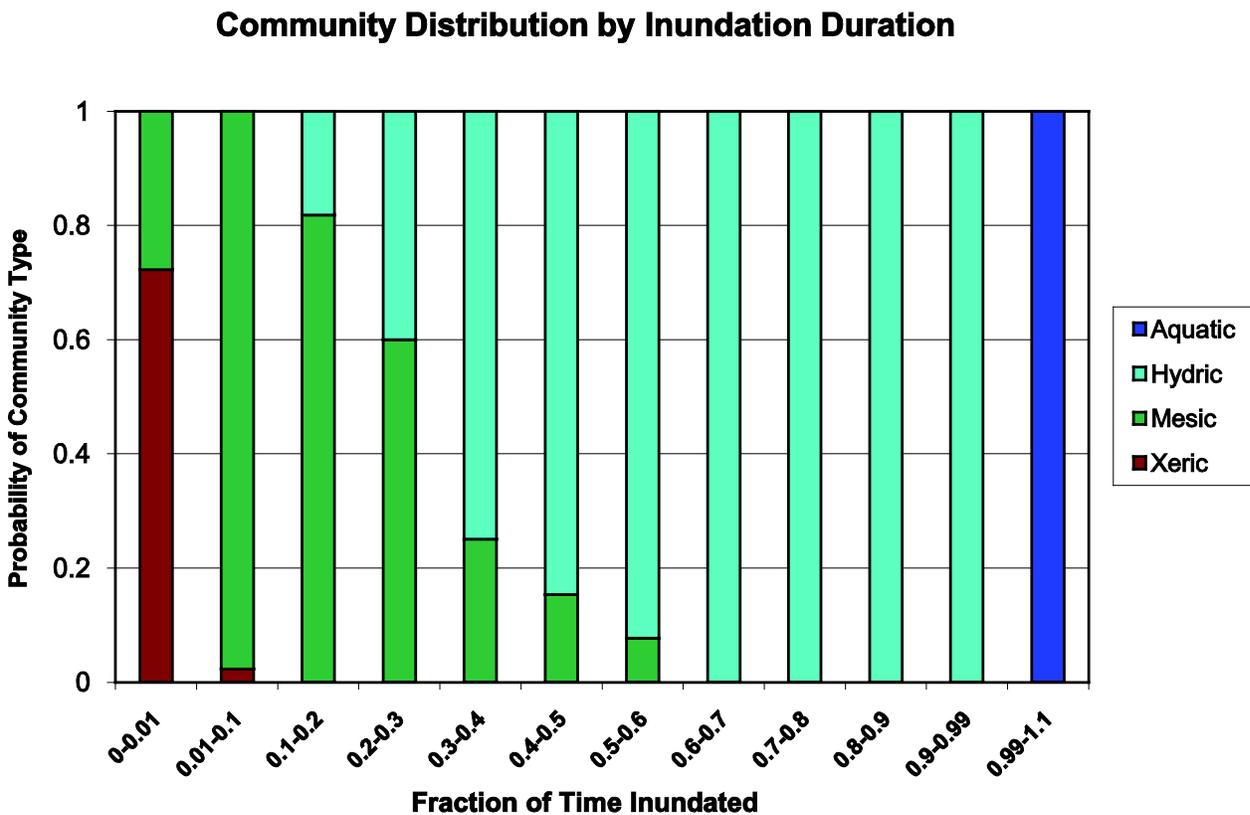


Figure 8. Screen capture depicting **Display Parameters** for relation between community distribution and inundation duration from Auble and others (1995). This relation is used in the calculation of the **Plant Communities** indicator.

Trout Fry Habitat

Estimates of suitable fry habitat (**Rainbow Trout Fry Habitat** and **Brown Trout Fry Habitat**) are calculated by applying published relations between discharge and weighted useable habitat area to average daily flow within critical time intervals for each year (June 15 through July 15 for rainbow trout fry and May 1 through June 15 for brown trout fry). These relations are depicted in figures 9 and 10. They were derived from tables of mean monthly discharge and associated weighted useable areas in Nehring and Miller (1987) and Nehring (1988) based on work at two sites in the Gunnison Gorge downstream from the Park (fig. 1). The published relations are used with extrapolation assuming no change in weighted useable area with discharge below the low end of the curves and no change in weighted useable area with discharge at the high end of the curves. Original calculations were based on hydraulic models and species preferences for depth, velocity, and substrate conditions derived from a combination of literature and site-based fish observations.

Both indicators are presented as box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) depicting the distributions of annual values of weighted useable area. Other indicators relevant to fish habitat include **Annual Minimum Daily Discharge** and **Ramp Rate**.

Sediment Mobilization

Sediment dynamics and the consequent bottom-land disturbance regimes and maintenance of channel form are complex functions of sediment sources, the composition and particle-size distribution of bottom-land sediment, existing channel geometry and gradient, the magnitude and duration of streamflows with different capabilities of dislodging and transporting sediment of different sizes, and the stabilizing effects of vegetation. Several of the general hydrologic indicators calculated by the decision support system are thus relevant to sediment dynamics, including

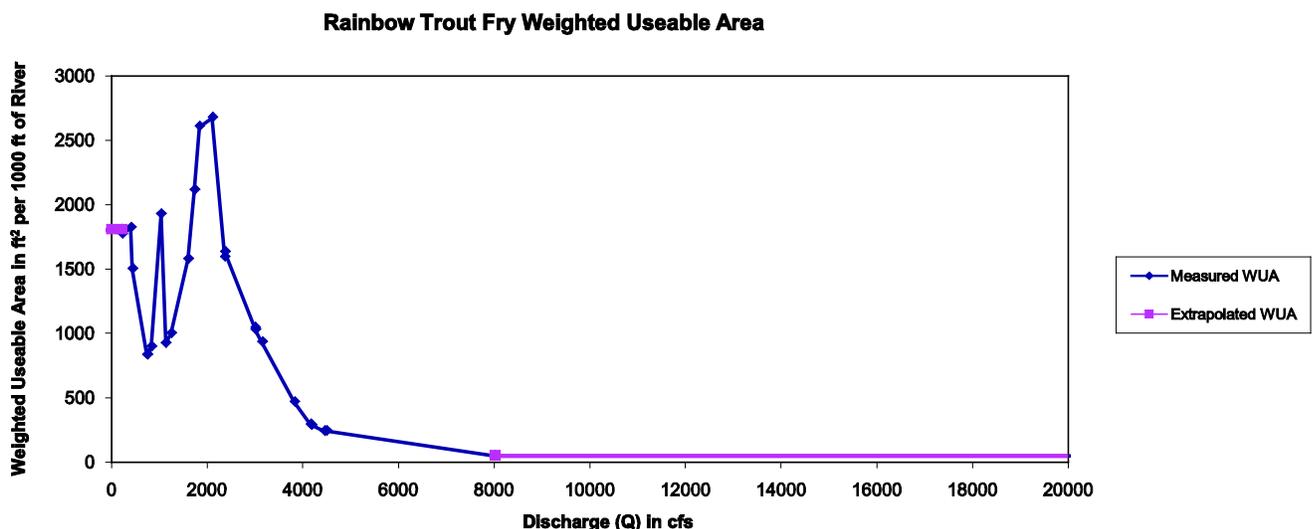


Figure 9. Screen capture depicting **Display Parameters** for rainbow trout fry habitat as a function of discharge. Relation is based on values reported in Nehring and Miller (1987) and Nehring (1988). It is used in the fish habitat indicator **Rainbow Trout Fry Habitat**.

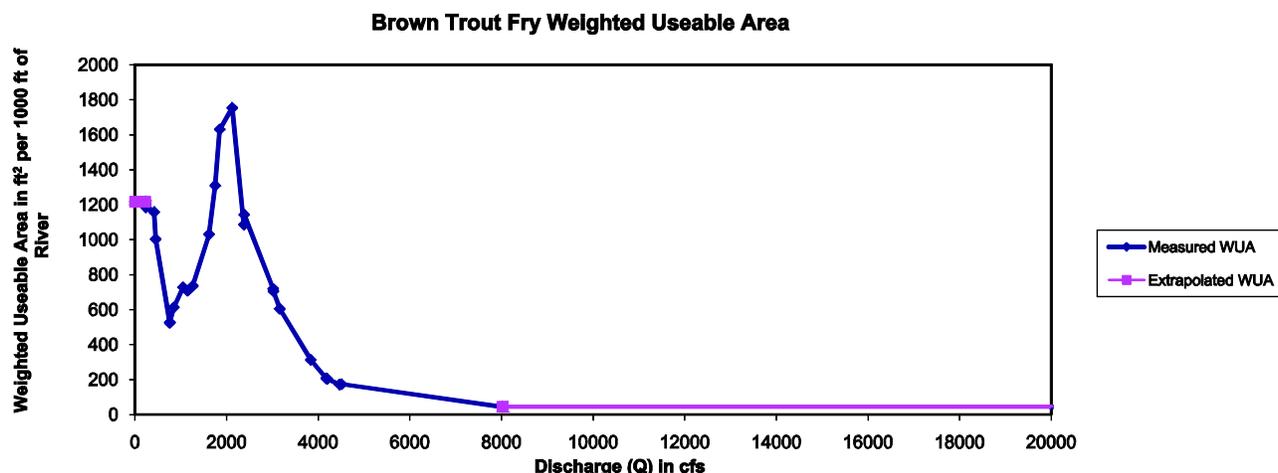


Figure 10. Screen capture depicting **Display Parameters** for brown trout fry habitat as a function of discharge. Relation is based on values reported in Nehring and Miller (1987) and Nehring (1988). It is used in the fish habitat indicator **Brown Trout Fry Habitat**.

Annual Mean Daily Discharge (Mean Daily Q), **Annual Maximum Daily Discharge** (Max Daily Q), and **14-Day Maximum Daily Discharge** (14-Day Max Q).

In addition, we calculate a set of indicators estimating annual sediment mobilization. Three indicators are based on Dubinski’s (2005) model for fraction of the river’s length having mobilization of three different sediment-size classes.

Dubinski (2005) and Dubinski and Wohl (2007) developed models of the fractions of the river in the park that are mobilized for the D_{16} , D_{50} , and D_{84} particle sizes by using generalized hydraulic models and particle-size compositions partitioned across the length of river. Dubinski (2005) used Komar’s (1987) equation for critical shear stress

$$\tau_{cr,i} = \tau_{cr}^* g (\rho_s - \rho) d_{50}^{0.6} d_i^{0.4} \quad (3)$$

where $\tau_{cr,i}$ is critical shear stress for the i th diameter particle size, τ_{cr}^* is critical dimensionless shear stress, g is the acceleration of gravity, ρ_s is the density of sediment, ρ is the density of water, and d_{50} is the diameter of the 50th percentile or median particle, and d_i is the diameter of the i th particle size for which critical shear stress is being estimated. This (Komar’s equation 3 above) reduces to the Shields equation (equation 1 above) used by Friedman and Auble (1999) for the median, d_{50} , particle size. Dubinski (2005) conducted sensitivity analyses of variation in both dimensionless critical shear stress and the roughness parameter of Manning’s n used in his hydraulic model and judged values of 0.045 for dimensionless critical shear stress and 0.05 for Manning’s n to be the most appropriate single values for application to all park reaches. We used these results of Dubinski (2005) to derive summary relationships (fig. 11) for fraction of the river length mobilized for each size fraction as a function of the maximum daily discharge of the year. Dubinski’s (2005) hydraulic simulations were conducted between 300 and 10,000 ft^3/s . We developed simple extrapolations of these relationships using a logit-transform regression (in which fraction mobilized is asymptotically bounded by 0 and 1.0) to estimate several points between 10,000 and 20,000 ft^3/s (fig. 11). We then constructed a linear interpolation of fractions of river length assuming 0.0 mobilized at 0 ft^3/s discharge, using points reported by Dubinski (2005) between 300 and 10,000 ft^3/s , and the regression-estimated points between 10,000 and 20,000 ft^3/s . The relationship was

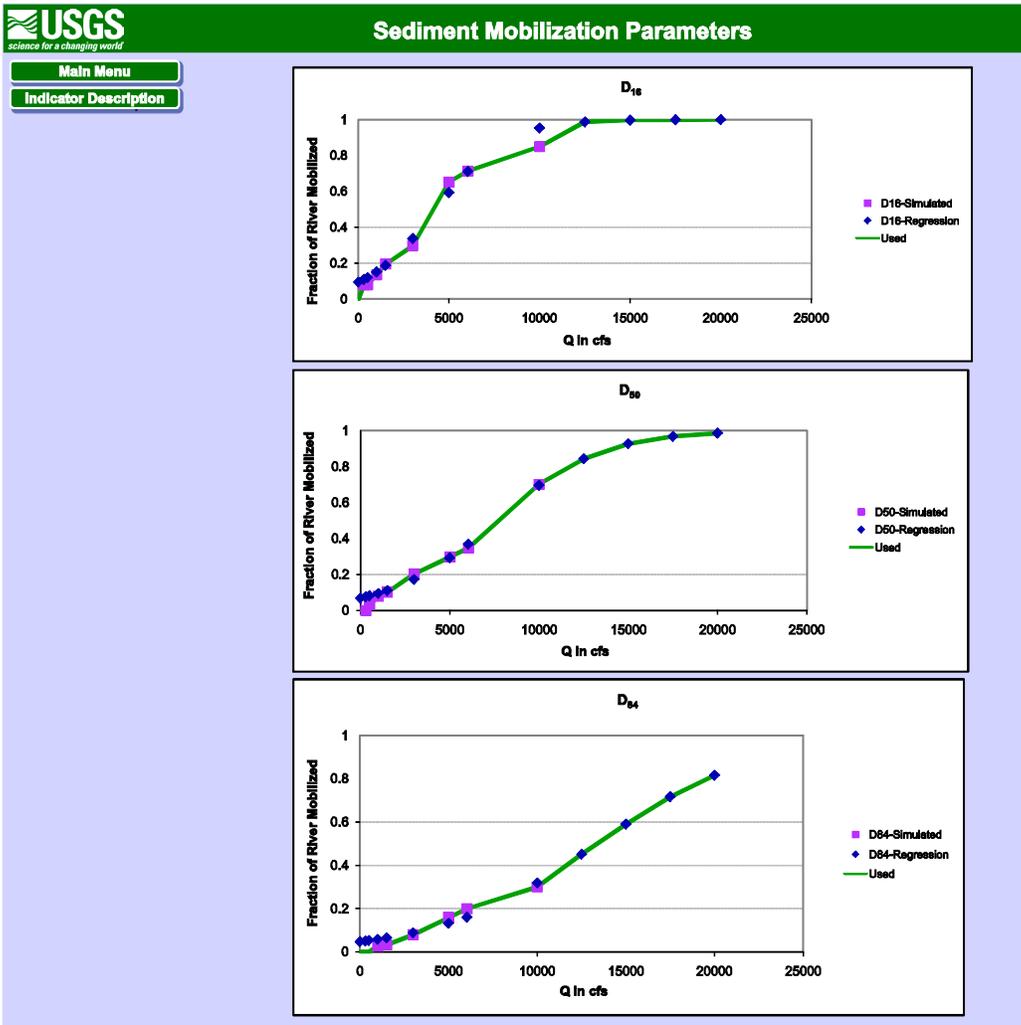


Figure 11. Screen capture depicting **Display Parameters** for annual percentages of river length mobilized for three reference particle sizes. Relations are derived from Dubinski (2005) with extrapolation beyond range of simulated discharges as indicated in the figure. These relations are used in the sediment mobilization indicators **Annual Percentage of River Length Mobilized- D_{16}** , **Annual Percentage of River Length Mobilized- D_{50}** , and **Annual Percentage of River Length Mobilized- D_{84}** .

assumed to plateau above 20,000 ft^3/s . Thus, the overall relationship is most reliable between 300 and 10,000 ft^3/s , is considerably less reliable between 10,000 and 20,000 ft^3/s , and is bounded at a maximum value above 20,000 ft^3/s .

Alternative flow regimes are compared by box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of the annual percentages of river length mobilized for each of the three sediment particle sizes—**Annual Percentage of River Length Mobilized- D_{16}** , **Annual Percentage of River Length Mobilized- D_{50}** , and **Annual Percentage of River Length Mobilized- D_{84}** .

The box elder clearing indicator, **Percentage of Bottomland Cleared by Scour**, estimates sediment mobilization for the D_{50} size class at the Warner Point reach based on more site-specific hydraulic models and sediment particle-size determinations as described in Friedman and Auble (1999). Friedman and Auble's (1999) model produces somewhat lower values for mobilization of the D_{50} size class than Dubinski's (2005). The differences are produced by a combination of reasons, including (a) the nature of the hydraulic models and extrapolation beyond calibrated discharges, (b) Friedman and Auble's (1994) partitioning of shear stress and particle size across the bottom land to estimate percentage of bottom land mobilized as opposed to Dubinski's (2005) use of generalized conditions at reaches to estimate percentage of river length with mobilization, and (c) different assumed values for dimensionless critical shear stress

National Park Service Water Right

Overview

The National Park Service (NPS) Federal reserved water right (Colorado District Court Water Division 4, 2009) is a direct flow right "expressed in cubic feet per second ("c.f.s.") as measured at the Gunnison River below Gunnison Tunnel gage (No. 09128000)." This water right has three basic components: Minimum Flow, May-June Peak Flow, and Shoulder Flow. The specific values of the right in a given year involve some relatively complex calculations referencing previous and forecast hydrologic conditions expressed as unregulated inflow and referencing reservoir storage levels on December 31 of the previous year. For each flow alternative, we attempt a calculation of each element of the right in each year and then compare actual observed flows to the right. Details of these calculations are described under the individual indicators corresponding to the respective elements of the water right.

In general, specific flow values of the right depend on a secondary data set of annual forecast and actual inflow unregulated April 1 through July 31 inflow to Blue Mesa Reservoir. From Colorado District Court Water Division 4 (2009), "Forecasted Inflow" means the "May 1 forecast for the Gunnison River Basin issued by the Colorado Basin River Forecast Center or successor agency, and used by the Bureau of Reclamation for forecasts, of the most probable (50 percent chance of exceedance) unregulated April 1 through July 31 inflow to Blue Mesa Reservoir." This inflow is further used to define year categories as:

Dry Year: *A year in which the Forecasted Inflow is less than 381,000 acre-feet.*

Moderately Dry Year: *A year in which the Forecasted Inflow is greater than or equal to 381,000 acre-feet but less than 561,000 acre-feet.*

Average Dry Year: *A year in which the Forecasted Inflow is greater than or equal to 561,000 acre-feet but less than 709,000 acre-feet.*

Average Wet Year: *A year in which the Forecasted Inflow is greater than or equal to 709,000 acre-feet but less than 871,000 acre-feet.*

Moderately Wet Year: *A year in which the Forecasted Inflow is greater than or equal to 871,000 acre-feet but less than 1,123,000 acre-feet.*

Wet Year: *A year in which the Forecasted Inflow is greater than or equal to 1,123,000 acre-feet.*

Calculations of the specific values of the Peak and Shoulder Flows are based on the value of Forecast Inflow in a year, with the parameters of that calculation varying according to the year type. For both Peak and Shoulder Flows, the water-right values may be further modified under a "Drought Recovery Provision." This provision is invoked "In any year classified as Average Dry or Moderately Dry, which (1) follows a Dry year or two consecutive years classified as Dry and/or

Moderately Dry Years, and (2) in which in the prior year Blue Mesa Reservoir live storage content was at or below 550,000 acre-feet on December 31....” We use forecast inflow in the current year and actual inflow of preceding years in this calculation. The drought recovery modification for Shoulder Flows is formulated as a lower-bound threshold of 300 ft³/s. The drought recovery modification for Peak Flows is formulated as a multiplicative reduction factor applied to the unadjusted Peak Flow (Colorado District Court Water Division 4, 2009). This reduction factor is calculated as:

$$\frac{[(\text{Actual Apr. through July BM inflow in previous year})+(\text{May 1 Forecast for Apr. through July BM inflow in current year})]}{[(\text{Max. possible April through July BM Inflow in the previous year category})+(\text{Max. possible Apr. through July BM inflow in current year category})]} \quad (4)$$

where “Max. possible Apr. through July BM inflow” has the following values for the possible year classes of:

- Dry Year: 381,000 acre-feet
- Moderately Dry Year: 561,000 acre-feet
- Average Dry Year: 709,000 acre-feet.

Complete calculation of the NPS water right thus requires information on Forecast Inflow in the current year, previous and current years’ Actual Inflow (unregulated April 1 through July 31 inflow to Blue Mesa Reservoir), and furthermore the previous year’s (December 31) live storage in Blue Mesa Reservoir. This considerably expands the input data required to evaluate whether the water right is met beyond a simple flow record at the gage site and thus restricts the applicability of these indicators to flow alternatives for which appropriate and consistent additional data are available.

Actual and estimated historical values are available for forecast and actual April–July unregulated inflow. These values are provided as an input data file (in *InputDataFiles* directory) and can be used for flow alternatives in which the years of the flow alternative appropriately match the years of the historical record. Users beware that (1) these inflow values have to be consistent with the hydrology described in the gage flow for the alternative (you cannot fairly evaluate changes in streamflow data for a given year without considering whether those changes are consistent with the inflow data being used for that year); and (2) the inflow values required are not easily obtainable from measured or published streamflow because the required data (a) refers to unregulated rather than actual measured inflows and (b) involves forecasted values using additional secondary data sets.

The legal specification of the NPS water right (Colorado District Court Water Division 4, 2009) also identifies an unquantified flood protection provision as follows.

In order to minimize downstream flooding: (1) the United States shall continue to operate the Aspinall Unit to give the highest priority to flood control, subject to the need to release water in order to maintain the safety and integrity of the Aspinall Unit structures; and (2) this decree shall not be exercised to supersede flood control operations. This provision is intended to protect human health and safety and prevent the loss of property located along the Gunnison River downstream from the Park, including particularly, but without limitation, property in and the inhabitants of Delta County.

We calculate the NPS water right without any modification for how it might be reduced by the flood protection provision.

Minimum Flow

The **Minimum Flow** element of the NPS water right is fixed at 300 ft³/s for all days of all years. We calculate the observed minimum daily flow for each year and compare alternatives with two graphs. The first graph portrays the percentage of years in which the right was satisfied (percentage of years in which minimum flow was greater than or equal to 300 ft³/s). The second graph is an alternative-selectable, time-series plot that compares annual values of the water right and the actual minimum flow.

Other box plots and time-series plots of actual minimum flows are provided under the Hydrologic Indicators section as **Annual Minimum Daily Discharge**.

May–June Peak Flow

The observed **May–June Peak Flow** is calculated for each year as the maximum daily discharge over the interval May 1 through June 30. Calculation of the Peak Flow (May–June) element of the NPS water right is a multistep process. Peak Flow here refers to maximum daily discharge rather than instantaneous peak (Colorado District Court Water Division 4, 2009). First, an unadjusted Peak Flow right for each year is calculated as follows using Forecast Input (of unregulated Blue Mesa inflow as described in the NPS Water Right Overview section) for the respective year.

If Forecasted Inflow is 372,000 acre-feet or less, the Peak Flow shall be 482.95 c.f.s. plus 1.44 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s.

If the Forecasted Inflow is more than 372,000 acre-feet but not more than 715,000 acre-feet, the Peak Flow shall be 15.24 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s., minus 4,651.66 c.f.s.

If the Forecasted Inflow is more than 715,000 acre-feet but not more than 925,000 acre-feet, the Peak Flow shall be 5,449.13 c.f.s. plus 1.15 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s.

If the Forecasted Inflow is more than 925,000 acre-feet but not more than 1,001,000 acre-feet, the Peak Flow shall be 14.57 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s., minus 6975.28 c.f.s.

If the Forecasted Inflow is more than 1,001,000 acre-feet but not more than 1,050,000 acre-feet, the Peak Flow shall be 70.40 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s., minus 62886.00 c.f.s.

If the Forecasted Inflow is more than 1,050,000 acre-feet, the Peak Flow shall be 10.68 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s., minus 180.00 c.f.s.

This formula for unadjusted peak flow is presented graphically in figure 12.

The unadjusted Peak Flow is then subject to possible drought provision reduction. Drought provision is applied if the current year is classified as Average Dry or Moderately Dry and (1) follows a Dry year or two consecutive years classified as Dry or Moderately Dry Years, and (2) in which in the prior year Blue Mesa Reservoir live storage content was at or below 550,000 acre-feet on December 31, according to definitions of year class presented in the NPS Water Right Overview section. If the drought provision is in effect, the unadjusted Peak Flow value is reduced by multiplying the unadjusted value by the fraction defined in equation (4) of the NPS Water Rights Overview section. The observed May–June peak flow is calculated for each year as the maximum daily discharge in the interval May 1 through June 30.

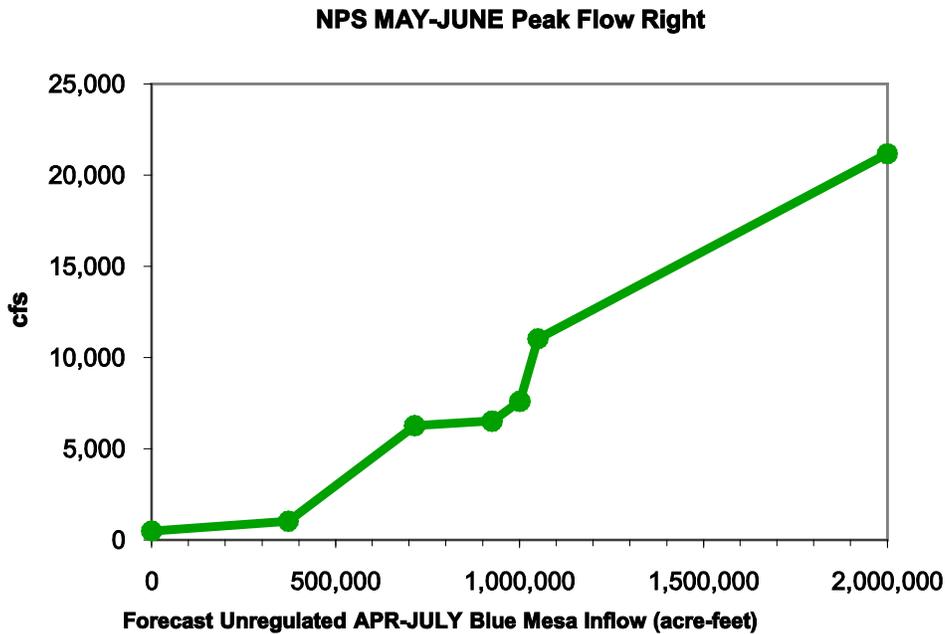


Figure 12. Screen capture depicting **Display Parameters** for NPS Peak Flow water right as a function of Forecast unregulated April–July Blue Mesa inflow. Water right is fully specified in (Colorado District Court Water Division 4, 2009). Right displayed here is unadjusted for drought year provisions.

If the required data on Blue Mesa Inflow are not provided for one or more years of a flow alternative, no calculation of the Peak Flow right is made for that year and no overall calculation of the percentage of years the right was satisfied is attempted. Missing data for December 31 values of storage in Blue Mesa Reservoir are treated more generously. First we substitute the January 1 value (if that is provided) for a missing value for December 31 of the previous year. Second, we ignore the effect of Blue Mesa Reservoir storage if no actual or estimated December 31 value is available by assuming that Blue Mesa Reservoir storage has no effect on whether the drought provision is or is not in effect. This facilitates the evaluation of alternatives that do not have Blue Mesa Reservoir (for example, before its construction). The effect of Blue Mesa Reservoir can also be disabled by providing input values for Blue Mesa Reservoir storage of less than 550,000 acre-feet on December 31.

Alternatives are compared with two graphs (fig. 7). The first graph portrays the percentage of years in which the right was satisfied. The second graph is an alternative-selectable, time-series plot that compares annual values of the Peak Flow (May–June) element of the NPS water right and actual values of **May–June Peak Flow**. Other box plots and time-series plots of **Actual Maximum Daily Discharge** over all days of the year (as opposed to those restricted to May–June) are provided as a hydrologic indicator.

Shoulder Flow

Shoulder Flow refers to the minimum daily flow that occurs in the restricted interval of May 1 through July 25 (Colorado District Court Water Division 4, 2009). The observed shoulder flow in a year is the minimum daily flow over this interval. The shoulder flow water right for each

year is calculated using Forecast Inflow for the current year and a determination of whether the drought recovery provision is in effect as described in National Park Service Water Rights Overview section herein. Treatment of missing data required to calculate the shoulder flow right is the same as described here for the peak flow right. Shoulder flow right in a year is calculated as follows (Colorado District Court Water Division 4, 2009).

If the Forecasted Inflow is 561,000 acre-feet or less, or the drought recovery provisions of are applicable, the flow for the period shall be 300 c.f.s.

If the Forecasted Inflow is more than 561,000 acre-feet but not more than 690,000 acre-feet, the flow for the period shall be 2.692 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s, minus 1207.69 c.f.s.

If the Forecasted Inflow is more than 690,000 acre-feet but not more than 1,000,000 acre-feet, the flow for the period shall be 1.129 times the Forecasted Inflow number divided by 1,000, expressed as c.f.s, minus 129 c.f.s.

If the Forecasted Inflow is more than 1,000,000 acre-feet, the flow for the period shall be 1000 c.f.s

This formula is presented graphically in figure 13. Alternatives are compared with two graphs. The first graph portrays the percentage of years that the right was satisfied. The second graph is an alternative-selectable, time-series plot that compares the annual values of Shoulder Flow water right and the actual value of **Shoulder Flow** (minimum daily flow in interval May 1–July 25).

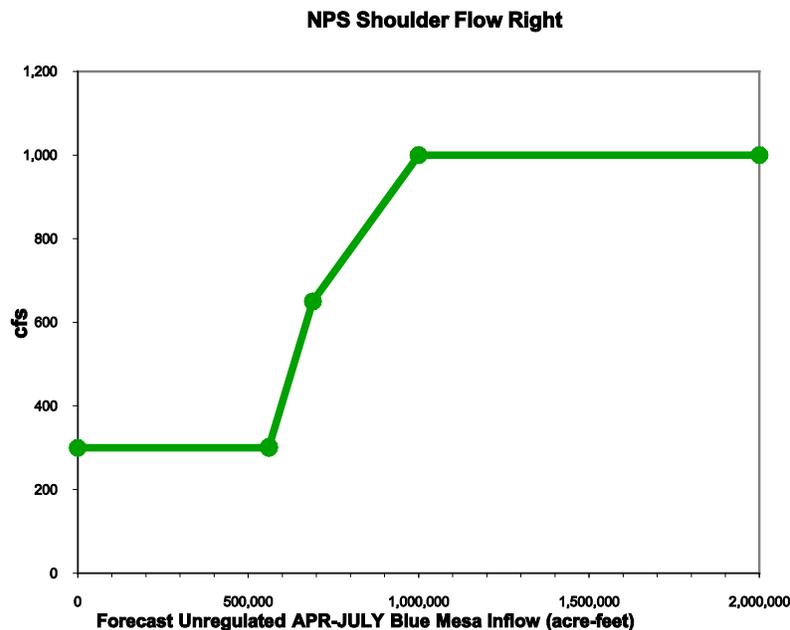


Figure 13. Screen capture depicting **Display Parameters** for NPS Shoulder Flow water right as a function of Forecast unregulated April–July Blue Mesa inflow. Water right is fully specified in (Colorado District Court Water Division 4, 2009). Right displayed here is unadjusted for drought year provisions.

Hydrologic Indicators

Annual Minimum Daily Discharge

Annual Minimum Daily Discharge (Min Daily Q) is the minimum value of daily discharge for each year. This is portrayed as both box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of annual values in each flow alternative and as a time-series graph for selectable flow alternatives (fig. 6). This indicator (**Annual Minimum Daily Discharge**) is equivalent to the **Minimum Flow** component of the National Park Service (NPS) Water Right.

Annual Mean Daily Discharge

Annual Mean Daily Discharge (Mean Daily Q) is the mean value of daily discharge for each year. This is portrayed both as box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of annual values in each flow regime and as a time-series graph for selectable flow alternatives.

Annual Maximum Daily Discharge

Annual Maximum Daily Discharge (Max Daily Q) is the maximum value of daily discharge for each year. This is portrayed both as box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of annual values in each flow regime and as a time-series graph for selectable flow alternatives.

Annual 14-Day Maximum Daily Discharge

Annual 14-Day Maximum Daily Discharge (14-Day Max Daily Q) is the highest daily discharge that is equaled or exceeded for 14 consecutive days in a given year. Flow alternatives are compared as box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of values of maximum 14-day discharge for years within each flow regime and as a time-series graph for selectable flow alternatives.

Ramp Rate

Many aquatic organisms, including fish at multiple life stages, are sensitive to rapid changes in flow often referred to as ramping rates. **Ramp Rate** is evaluated in terms of how often specified thresholds of change are exceeded. It is calculated as the percentage of days in each year where the change in discharge exceeds these threshold values. For this calculation, threshold values can be defined for up to three separate flow ranges and are specified as thresholds of maximum absolute change in flow from one day to the next. Ranges and thresholds are disabled by setting table entries to extreme values or by leaving parameter table entries blank.

Flow alternatives are compared with box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of percentage of days exceeding thresholds within each year.

Flow Constancy

Flow Constancy (Daily Flow Constancy) is a measure of the percentage of days in the flow record when the flow remains essentially constant from one day to the next. It is calculated by first taking the \log_{10} of each daily flow and then converting these \log_{10} values to discrete increments of 0.004321 (increments of approximately 1 percent of untransformed flow). The indicator is then calculated as the percentage of days in the overall flow record for which the discretized daily flow

does not change from that of the previous day. Flow alternatives are compared with box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of the distribution of annual values.

Note that the source of the daily flow record should be considered when comparing values of **Flow Constancy**. Flow regimes themselves may differ in flow constancy—for example, a stable, spring-fed stream compared to a snowmelt hydrograph compared to a heavily managed flow regime dominated by a small number of desirable flows. Discretization may also be introduced in the measurement and reporting of flow data or in the way a flow simulation model treats short-term variation.

Coefficient of Variation of Monthly Discharge within Years

Coefficient of Variation of Monthly Discharge within Years (CV of Monthly Q within Years) is the coefficient of variation of mean monthly flows around the grand mean monthly flow of the year in which they occur. For each year, 12 monthly mean flows are calculated as the means of daily flow in the respective months. A coefficient of variation is then calculated for the dispersion of these monthly mean flows around the grand mean of months within that year. Thus, the number of values for each flow alternative is equal to the number of years of record for that regime. Flow alternatives are compared with box plots (line at median, box at 10th and 90th percentiles, whiskers to range of data) of these annual values of coefficient of variation.

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