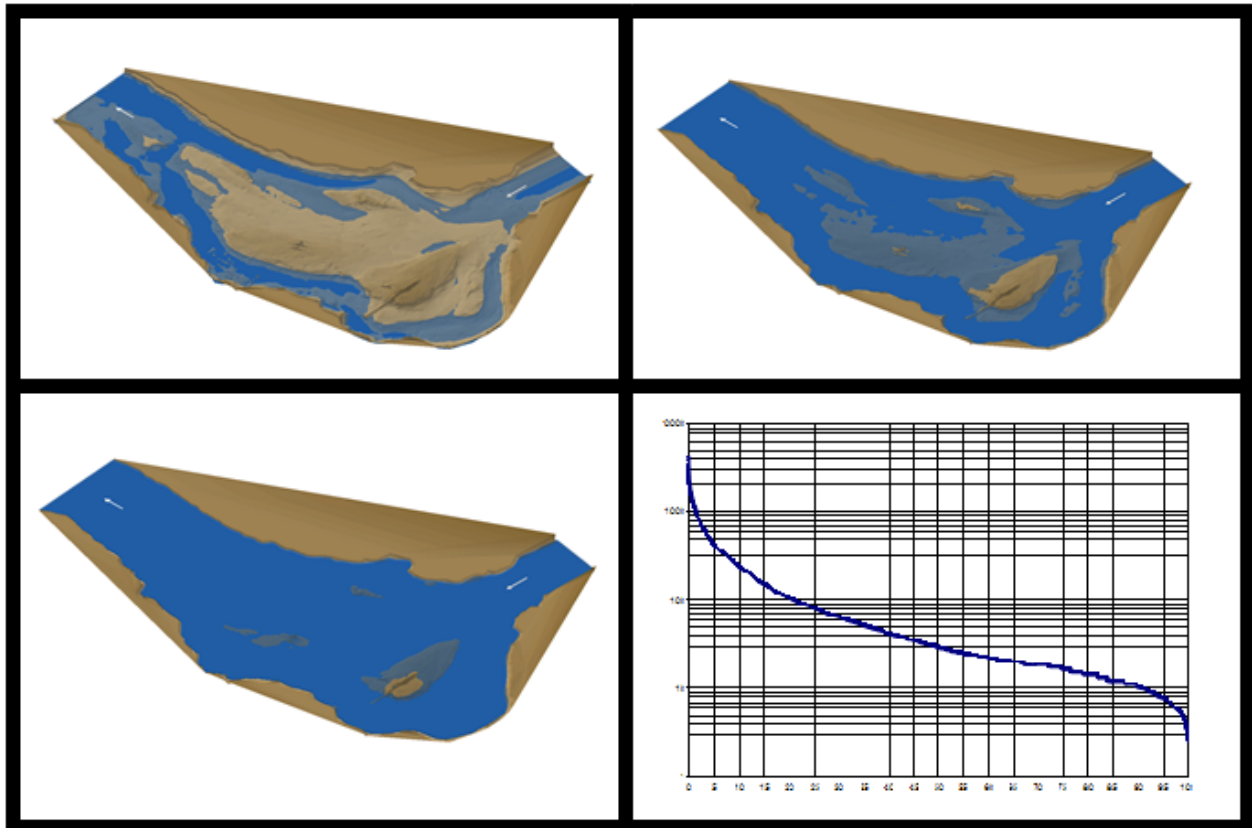# Standard Operating Procedure for
Flow Duration Analysis in California

CDFW-IFP-005

August 2013

California Department of Fish and Wildlife
Instream Flow Program
Sacramento, California

Standard Operating Procedure for

Flow Duration Analysis in California

CDFW-IFP-005

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Suggested Citation

CDFW, 2013, **Standard Operating Procedure for Flow Duration Analysis in California**. Department of Fish and Wildlife Instream Flow Program Standard Operating Procedure CDFW-IFP-005, 17 p.
Available at: http://www.dfw.ca.gov/water/instream_flow.html.

Abbreviations and Acronyms

CDFW	California Department of Fish and Wildlife
IFP	Instream Flow Program
FDA	Flow Duration Analysis
SOP	Standard Operating Procedure
IFC	Instream Flow Council
USGS	United States Geological Survey

Introduction

This document serves as the California Department of Fish and Wildlife's (CDFW) Instream Flow Program (IFP) standard operating procedure (SOP) for performing a flow duration analysis (FDA). This procedure uses existing hydrologic data and may be used in conjunction with other IFP SOPs as necessary to meet project objectives. Instructions are provided for:

- Data set retrieval:
    - Determination of period and time unit
    - Obtaining historical hydrologic records for a stream
- Data analysis (using Excel 2010):
    - Data set organization
    - Exceedence probability calculation
    - Graph setup
- Interpretation of results

Note: This SOP assumes familiarity with several Excel 2010 spreadsheet features including using formulas, absolute cell references, copying formulas, filtering a table of data, using the auto-fill feature to generate numbers down a column, and basic graphing features. Some instructions for using these features are included, and more detail can be found in the software's electronic Help manual.

Scope of Application

This SOP provides procedural reference for CDFW staff conducting FDA to identify important flow characteristics and designing a representative sampling schedule for an instream flow study, when site conditions and research objectives indicate FDA is an appropriate methodology. It is also intended as an informational resource for staff from other state and federal agencies, nongovernmental organizations, private contractors and other organizations throughout California.

The CDFW Instream Flow Program encourages staff and contractors to contact us with any questions or for assistance with project planning. For more information, contact Diane Haas of the CDFW IFP at: Diane.Haas@Wildlife.ca.gov or (916) 445-8575.

What is a Flow Duration Analysis?

FDA is a method that was adopted by the U.S. Geological Survey (USGS) in 1920 and remains widely utilized today to assess flow data (USGS 1969; Annear et al. 2004). FDA is most commonly used by CDFW and other agencies for studying flow characteristics of a stream as a component of an instream flow study, and determining flow recommendations for fish and aquatic ecosystem health. Utilizing existing hydrologic data, this method provides data that describe the flow characteristics of a given stream. Many hydraulic habitat flow models require sampling at a representative range of flows (20-80%). FDA may be used to identify flows of interest in these instances.

The FDA procedure results in the development of a flow exceedence probability curve (Figure 1), which shows the percentage of time that the stream flow is likely to equal or exceed a flow value of interest. For example, between 1950 and 2010 the daily mean flow of the river in Figure 1 was at least 30 cfs for 50% of the time.

The flow exceedence probability curve is developed using existing hydrologic flow data from a specified time period of interest, and can be formatted to fit daily, weekly or monthly data. To create the curve, flow values for the time period of interest are first ranked by magnitude. Then, exceedence probability is calculated by determining the percentage of time that the stream flow is likely to equal or exceed a specified value. Exceedence probabilities are plotted against flow values, and the curve reflects average flow characteristics of a stream throughout the range of discharge.

Annual Flow Exceedence Probability Curve
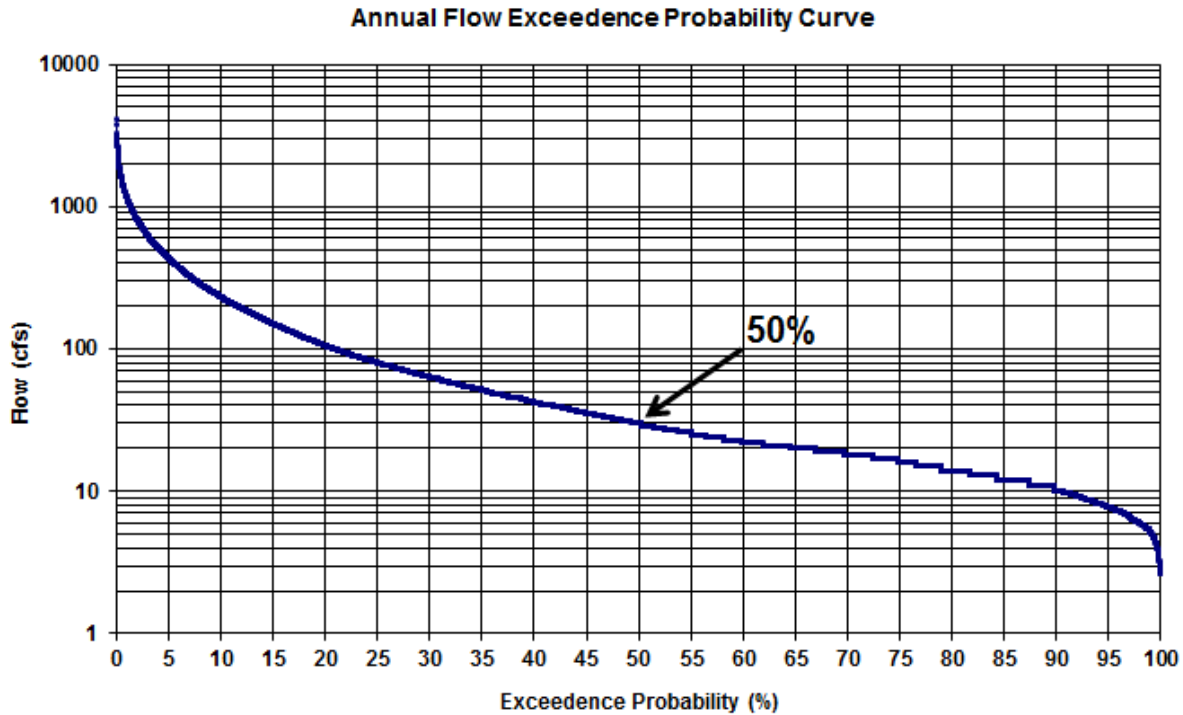
Figure 1. Example of a flow exceedence probability curve.

Method Overview

FDA is performed by first obtaining a chronological record, typically 30 years or more, of flow data for a given stream recorded by a fixed gaging station (USGS 1969). The FDA is more robust when longer periods of hydrologic data records can be used. First, flows are sorted by magnitude and assigned rank numbers, then the exceedence probability for each flow is calculated, and finally the calculated exceedence probabilities are plotted against flow values to create a flow exceedence probability curve.

Section 1: Considerations for Obtaining Flow Data

Before beginning FDA, obtain flow measurements data from a flow gage for a given stream and time frame. Online resources, such as the United States Geological Survey's National Water Information System (http://waterdata.usgs.gov), and the California Department of Water Resources' California Data Exchange Center (http://cdec.water.ca.gov) provide public flow data for many streams across the United States. CDFW recommends obtaining and using at least 30 years of records (USGS 1969). When fewer than 30 years of data are available, the reliability and accuracy of the curve is compromised; in this case, reference *Flow-Duration Curves* (USGS 1969) for procedures on how to adjust short-term data to represent long-term data.

The unit of time of flow data (i.e. hourly, daily, weekly, monthly or annually) can greatly affect the utility of the flow exceedence probability curve (USGS 1969). It is important to select a unit of time that meets project objectives and best utilizes available data. Any missing or excluded data should be clearly noted throughout data processing and graphing.

Section 2: Procedures for Compiling Annual Flow Data

After locating the relevant data for creating the flow exceedence probability curve, the annual flow data for the period of record are entered into a Microsoft Excel © (Excel) spreadsheet as follows:

Step 1. Transfer or input the gage flow measurement data into Excel. Create five columns (date, flow measurement, month, year, and water year and organize the data accordingly (Figure 2). This will allow data to be sorted by month later in Section 4.

	A	B	C	D	E
1	Date	Flow (cfs)	Month	Year	WY
2	3/10/1995	4150	3	1995	1995
3	12/23/1955	4120	12	1955	1956
4	1/31/1963	3830	1	1963	1963
5	2/3/1998	3770	2	1998	1998
6	4/3/1958	3260	4	1958	1958
7	12/6/1966	3260	12	1966	1967
8	2/1/1963	3250	2	1963	1963
9	1/1/1997	3160	1	1997	1997
10	1/15/1952	3060	1	1952	1952
11	1/16/1978	3040	1	1978	1978
12	2/14/2000	2990	2	2000	2000
21909	11/9/1990	2.8	11	1990	1991
21910	11/10/1990	2.8	11	1990	1991
21911	8/16/1977	2.7	8	1977	1977
21912	9/7/1990	2.7	9	1990	1990
21913	8/23/1977	2.6	8	1977	1977
21914	9/9/1990	2.6	9	1990	1990
21915	10/29/1990	2.6	10	1990	1991
21916	11/5/1990	2.6	11	1990	1991

Figure 2. Example of initial organization of mean daily discharge data.

Step 2. Compute the total number of days in the period of record (Fig 3)**.**

21910	11/10/1990	2.8	11	1990	1991
21911	8/16/1977	2.7	8	1977	1977
21912	9/7/1990	2.7	9	1990	1990
21913	8/23/1977	2.6	8	1977	1977
21914	9/9/1990	2.6	9	1990	1990
21915	10/29/1990	2.6	10	1990	1991
21916	11/5/1990	2.6	11	1990	1991
21917			TOTAL DAYS:		21,915

Figure 3. Example of calculation of total days covered in the period of record using mean daily discharge data.

Step 3. Sort the data according to magnitude, and assign ranks. Highlight all of the data (excluding column headers) and select the "sort" command to rank data by flow (cfs), from largest to smallest. Create a new column and assign each discharge value a rank (M), starting with 1 for the largest daily discharge value. Use the Excel auto-fill feature to generate a list of rank numbers down to the last discharge row (Figure 4).

	A	B	C	D	E	F
1	Date	Flow (cfs)	Month	Year	WY	Rank (M)
2	3/10/1995	4150	3	1995	1995	1
3	12/23/1955	4120	12	1955	1956	2
4	1/31/1963	3830	1	1963	1963	3
5	2/3/1998	3770	2	1998	1998	4
6	4/3/1958	3260	4	1958	1958	5
7	12/6/1966	3260	12	1966	1967	6
8	2/1/1963	3250	2	1963	1963	7
9	1/1/1997	3160	1	1997	1997	8
21908	10/30/1990	2.8	10	1990	1991	21907
21909	11/9/1990	2.8	11	1990	1991	21908
21910	11/10/1990	2.8	11	1990	1991	21909
21911	8/16/1977	2.7	8	1977	1977	21910
21912	9/7/1990	2.7	9	1990	1990	21911
21913	8/23/1977	2.6	8	1977	1977	21912
21914	9/9/1990	2.6	9	1990	1990	21913
21915	10/29/1990	2.6	10	1990	1991	21914
21916	11/5/1990	2.6	11	1990	1991	21915
21917			TOTAL DAYS:	21,915		

Figure 4. Example of sorting and ranking in Excel using mean daily discharge data.

Step 4. Compute e*xceedence probability* (P) for flow in each line of data by using the formula provided below. Create a new column and input the formula in the first cell (Figure 5). Make sure to select the appropriate cells called for by the formula (M = rank #, n = total days calculated) and use "$" symbols to lock the formulas' reference (absolute reference) to the total days cell. Apply the formula to all flows and calculate all the exceedence probabilities by copying the formula down the column to the last ranked discharge row. (You can copy the formula by hovering the mouse over the lower right corner of the formula's cell until a black cross-hair appears, then drag down the column.)

$$P = [\, M / (n + 1) \,] \times 100\%$$

P = the probability that a given flow will be equaled or exceeded (% of time)

M = assigned rank number

n = the total number of days for period of record

The Excel formula, as shown in Figure 5 is =(F3/(E21917+1))*100.

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	A	B	C	D	E	F	G
							fx =(F2/(E21917+1))*100

	A	B	C	D	E	F	G
1	Date	Flow (cfs)	Month	Year	WY	Rank (M)	Exceedence Probability % (P)
2	3/10/1995	4150	3	1995	1995	1	0.00
3	12/23/1955	4120	12	1955	1956	2	0.01
4	1/31/1963	3830	1	1963	1963	3	0.01
5	2/3/1998	3770	2	1998	1998	4	0.02
6	4/3/1958	3260	4	1958	1958	5	0.02
7	12/6/1966	3260	12	1966	1967	6	0.03
8	2/1/1963	3250	2	1963	1963	7	0.03
9	1/1/1997	3160	1	1997	1997	8	0.04
10	1/15/1952	3060	1	1952	1952	9	0.04
21909	11/9/1990	2.8	11	1990	1991	21908	99.96
21910	11/10/1990	2.8	11	1990	1991	21909	99.97
21911	8/16/1977	2.7	8	1977	1977	21910	99.97
21912	9/7/1990	2.7	9	1990	1990	21911	99.98
21913	8/23/1977	2.6	8	1977	1977	21912	99.98
21914	9/9/1990	2.6	9	1990	1990	21913	99.99
21915	10/29/1990	2.6	10	1990	1991	21914	99.99
21916	11/5/1990	2.6	11	1990	1991	21915	100.00
21917			TOTAL DAYS:	21,915			

Figure 5. Example of display showing the calculation for exceedence probabilities using mean daily discharge data.

Section 3: Creating the Annual Flow Exceedence Graph

After exceedence probabilities have been calculated, the data may be used to create flow exceedence probability curves. Curves that utilize exceedence probabilities from the entire dataset are called annual flow exceedence graphs. Exceedence probabilities may also be selected by month to determine monthly flow exceedence probability curves, discussed in Section 4.

Step 1. Plot the exceedence probability values calculated in Section 2 against associated flows. In Excel 2010, highlight the data to be graphed (in the Figure 5 example, columns G and B), then select the "scatter plot" graph option. Place exceedence probability values on the x-axis and flows on the y-axis.

Step 2. Change the chart scaling to logarithmic. In Excel 2010, this is done by right clicking the y-axis, selecting "format axis", selecting the "scale" tab, and then checking the "logarithmic" box.

Step 3. Title and label the graph. In the graph title, name the source and time period of data and note any excluded data. The title should display the name of the stream(s) being analyzed, the time interval used (i.e. average daily flows), the period represented (i.e. Oct. 1, 1950 - Sept 30, 2010), and the name of the gaging station that recorded the data. Axes should be labeled with units. The graph should look similar to Figure 6:
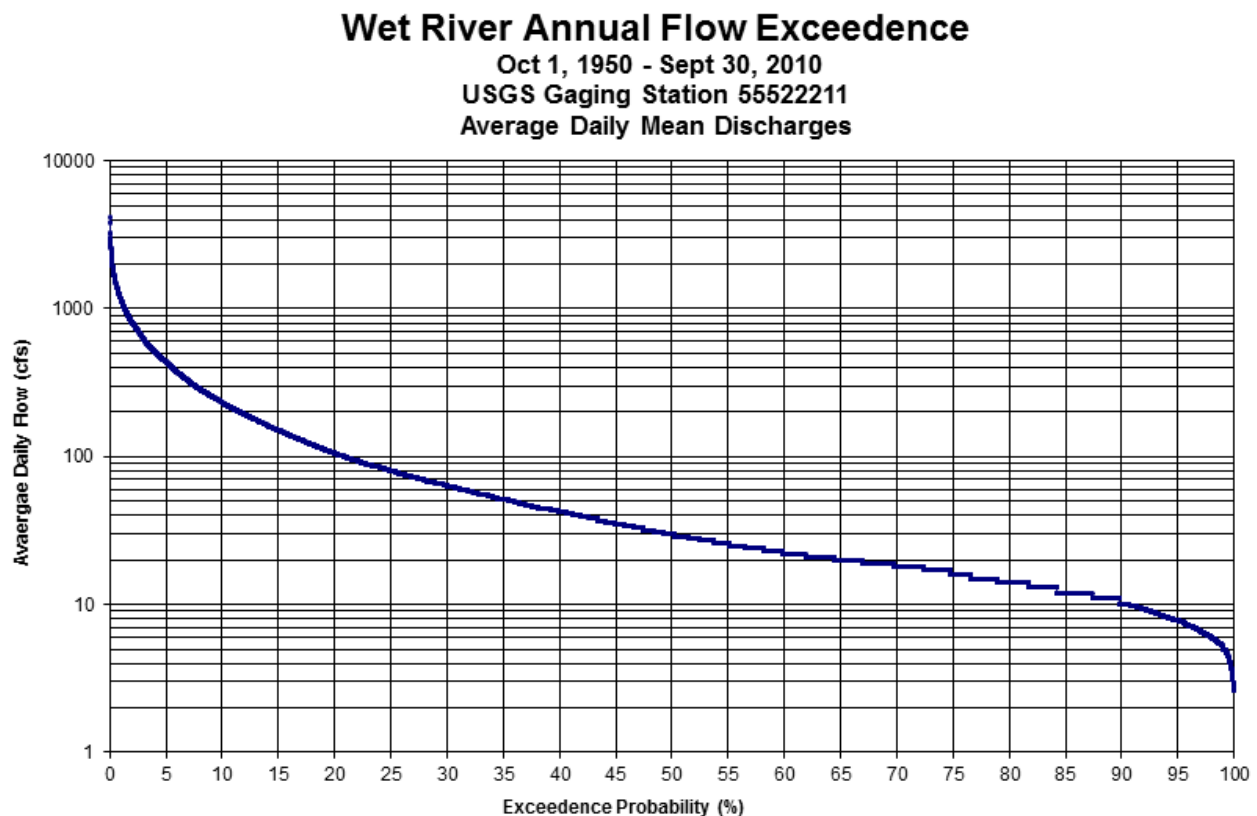

Figure 6. Example of flow exceedence probability curve displaying graph labels.

Section 4: Creating a Monthly Flow Exceedence Graph

Depending on project objectives and available data, separate curves can be generated to represent each month of the year. For the purpose of this example, the procedures for only one month (January) will be demonstrated.

Step 1. Select the flows from the month(s) of interest throughout the time period to develop a curve. First, filter flow data for the month of interest. The "filter" feature in Excel 2010 can be used to filter data for only the month of interest. In the example of January, a filter was applied using the following steps:

a. Highlight all data and column labels

b. Click the "data" tab, move the mouse over "filter" and select "auto filter"

c. In the months column label, click the drop-down arrow and select "1" in the filter for January (see Figure 7)

	A	B	C	D	E	F	G
1	Date	Flow (cfs)	Month	Year	WY	Rank (M)	Exceedence Probability % (P)
2	3/10/1995	4150	3	1995	1995	1	0.00
3	12/23/1955	4120	12	1955	1956	2	0.01
4	1/31/1963	3830	1	1963	1963	3	0.01
5	2/3/1998	3770	2	1998	1998	4	0.02
6	4/3/1958	3260	4	1958	1958	5	0.02
7	12/6/1966	3260	12	1966	1967	6	0.03
8	2/1/1963	3250	2	1963	1963	7	0.03
9	1/1/1997	3160	1	1997	1997	8	0.04
10	1/15/1952	3060	1	1952	1952	9	0.04
11	1/16/1978	3040	1	1978	1978	10	0.05

Figure 7. Example of filtered data display using mean daily discharge data.

Step 2. Copy the data from the month of interest to a new worksheet. Do not copy over previously assigned ranks or exceedence probabilities that were calculated when working with the entire data table. Create a new worksheet for each month desired.

Step 3. Compute exceedence probability for the selected data as outlined in Section 2, steps 2, 3, and 4 (see Figure 8).

Step 4. Generate the monthly exceedence probability graph for the selected data as described in Section 3. Label graphs as described in Section 3 step 3, and include the month of focus in the title (see Figure 9).

Step 5. Repeat all steps in Section 4 to generate a flow exceedence graph for each month of data included in the study (i.e. compile data, sort data, compute exceedence probabilities and develop flow exceedence graph for each month).

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	A	B	C	D	E	F	G
1	Date	Flow (cfs)	Month	Year	WY	Rank (M)	Exceedence Probability % (P)
2	1/31/1963	3830	1	1963	1963	1	0.05
3	1/1/1997	3160	1	1997	1997	2	0.11
4	1/15/1952	3060	1	1952	1952	3	0.16
5	1/16/1978	3040	1	1978	1978	4	0.21
6	1/2/1997	2970	1	1997	1997	5	0.27
7	1/25/1969	2950	1	1969	1969	6	0.32
8	1/26/1969	2890	1	1969	1969	7	0.38
9	1/14/1980	2800	1	1980	1980	8	0.43
10	1/10/1995	2760	1	1995	1995	9	0.48
1854	1/23/1991	7.2	1	1991	1991	1853	99.57
1855	1/30/1991	7.2	1	1991	1991	1854	99.62
1856	1/6/1991	7.1	1	1991	1991	1855	99.68
1857	1/7/1991	7.1	1	1991	1991	1856	99.73
1858	1/17/1991	7.1	1	1991	1991	1857	99.79
1859	1/31/1991	7.1	1	1991	1991	1858	99.84
1860	1/1/1991	6.3	1	1991	1991	1859	99.89
1861	1/2/1991	6.3	1	1991	1991	1860	99.95
1862				TOTAL DAYS:		1860	

Figure 8. Example of calculation of exceedence probabilities for all January flows in the mean daily discharge dataset.

Wet River Annual Flow Exceedence
January Months 1951 - 2010
USGS Gaging Station 55522211
Average Daily Mean Discharges

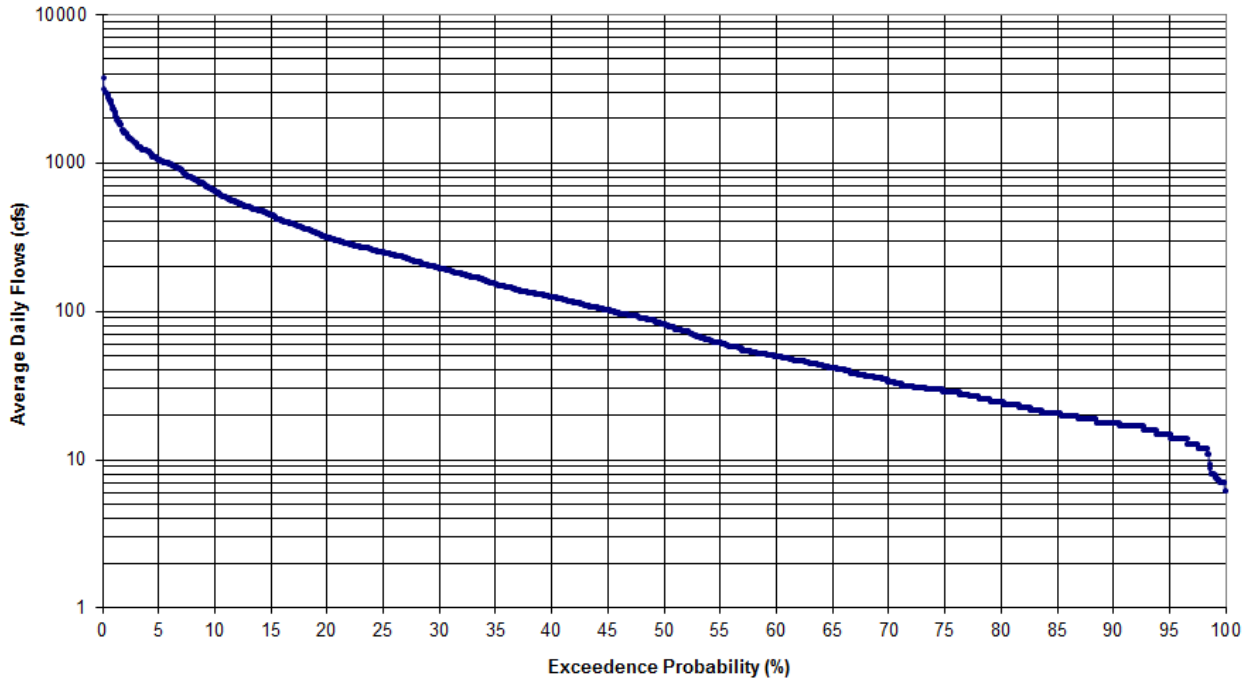Figure 9. Example of flow exceedence probability graph for all January flows in the mean daily discharge dataset.

Section 5: Interpretation of Curve Results

The shape of an exceedence probability curve is determined by the hydrologic and geologic characteristics of the stream being analyzed (USGS 1969). The curve reflects the percentage of time that streamflow is likely to equal or exceed a value of interest. For example, in the flow duration analysis using the annual flow exceedence curve, the daily average flow in Figure 10 was at least 100 cfs 20% of the time, 30 cfs 50% of the time, and 15 cfs 80% of the time during the period of 1950-2010. In this example, the FDA indicates that sampling this river between 14-100 cfs may adequately capture the representative range of flows. In Figure 11, using the monthly flow exceedence curve for January, the daily average flow in January 1950-2010 was at least 300 cfs 20% of the time, 80 cfs 50% of the time, and 25 cfs 80% of the time.
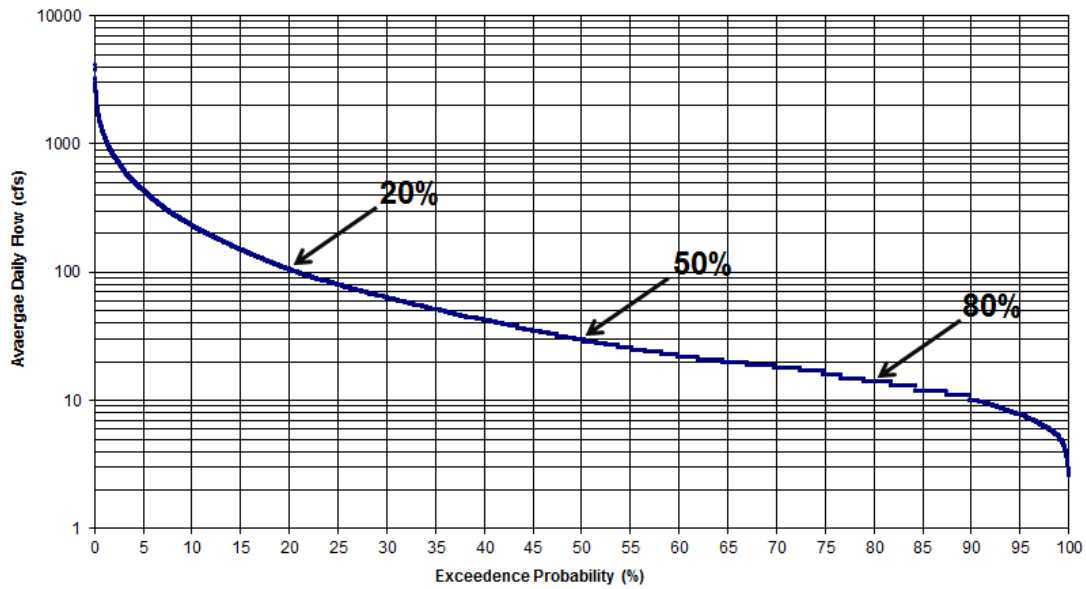
Figure 10. Annual flow exceedence probability curve using mean daily discharge data - identifying 20%, 50% and 80% probability points.
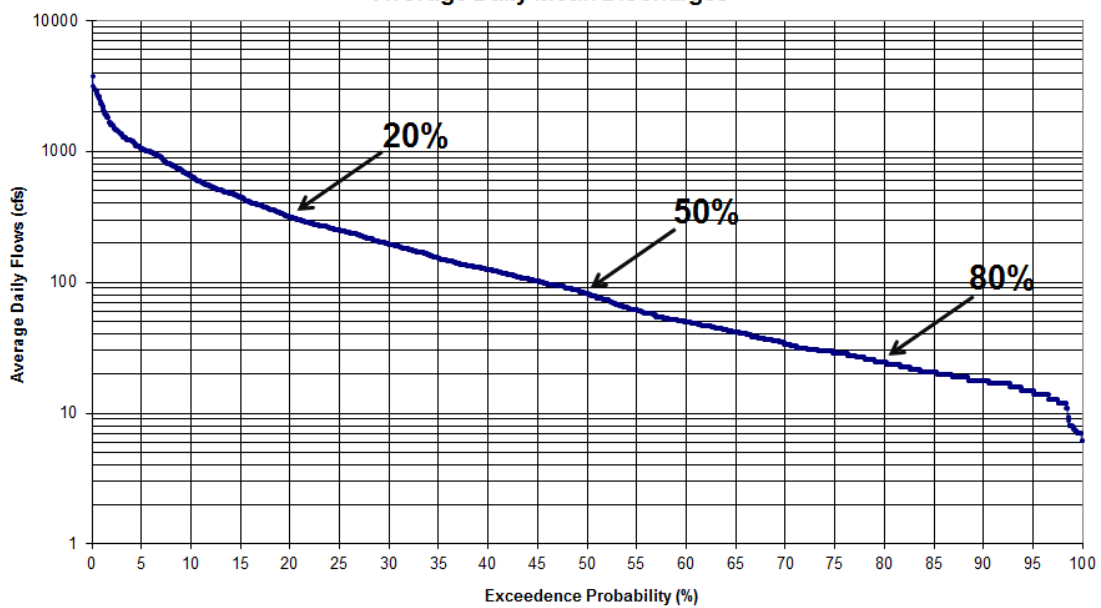

Figure 11. Monthly flow exceedence probability graph for all January flows in the mean daily discharge dataset

Glossary

Exceedence Probability	The probability that a certain flow value is going to be exceeded.
Flow Gage	Devices at fixed locations used by hydrologists or environmental scientists to monitor and test terrestrial bodies of water. Water stage (water surface elevation) and discharge (flow) measurements are most commonly taken and recorded by the device on a frequent and consistent basis.
Water Year	A continuous 12-month period for which hydrologic records are compiled and summarized. The 12-month period begins October 1 and ends September 30 of the following year. For example, a flow measurement taken in December of 1955 would be considered part of the 1956 water year.

References

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other authors. 2004. Instream flows for riverine resource stewardship, revised edition. Instream Flow Council, Cheyenne, WY.

U.S. Geological Survey (USGS), 1969. Flow-Duration Curves Manual of Hydrology: Part 2. Low-Flow Techniques. Geological Survey Water-Supply Paper 1542-A. 33p.
Available at: http://pubs.usgs.gov/wsp/1542a/report.pdf