POTOMAC RIVER AT POINT OF ROCKS

PROBABILITIES OF LOW FLOWS ONE AND TWO SEASONS AHEAD

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Introduction

Hydrologists have long known that in rivers, low flows tend to follow low flows and high flows tend to follow high flows, across both short and long term time frames (Hurst, 1957). The Water Supply Outlook (WSO) produced by ICPRB CO-OP in summer and early fall capitalizes on this concept. The WSO provides an estimate of the conditional probability of low flow occurring through the end of September as based on antecedent flow conditions.

The persistence of low flows across one and two seasons in the Potomac River basin through statistical analysis of historical data was examined. Persistence in Potomac low flow conditions allows the water manager to predict the likelihood of low flow occurrences in the Potomac even over two seasons. The ability to assess the probability of low flow in Potomac has implications for Washington metropolitan area (WMA) water supply management. Probabilistic flow assessments may allow for a more efficient, risk based approach to water supply system operation.

Background

The river/reservoir manager would prefer an ideal world in which rainfall could be accurately predicted and good estimates of future river flow obtained. Given current meteorological forecast skill, accurate estimates of Potomac flow three to six months into the future are impossible. Instead, a probabilistic statistical approach can be used to assess the likelihood of Potomac low flows.

Many factors control the rate of flow in a river including soil moisture conditions, groundwater levels, current and recent rainfall, evapotranspiration, surface runoff rates and rainfall interception by tree foliage. These factors are interrelated. For example, low soil moisture conditions can reduce the rate at which groundwater levels are recharged during a storm event by intercepting the water before it reaches the groundwater table.

Many of these factors, such as groundwater levels or soil moisture conditions, tend to cycle through long term seasonal and interseasonal patterns reflecting cumulative effects of long term moisture deficits or surplus. A six month period of low rainfall can result in extremely low soil moisture and groundwater levels. Once dry (or wet), these factors can persist even under normal rainfall conditions. For example, groundwater levels might become lower than normal during a dry fall and winter and remain lower than normal the following spring, even though precipitation may have returned to normal for two or three months in the spring. (This is the case in 1998-1999 in the lower portion of the Potomac River basin.)

When flow in the Potomac is low, most of the water in the river is due to contributions from groundwater. This flow is termed "baseflow." If baseflow is below normal, then it is also true that groundwater, soil moisture, and other factors driving Potomac flow likely are below normal, and baseflow integrates the cumulative moisture deficit or surplus of these underlying factors. A given season's lowest daily flow in the river is an excellent measure of baseflow, since the season's low flow is unlikely to have been a result of recent rainfall events. This seasonal low flow can become a surrogate measure of the relative status of the interrelated factors driving Potomac flow. Because of persistence in these underlying factors, the season's lowest flow is likely to be a valid predictor of low flows in following seasons.

This work examines the persistence of seasonal low flows in the Potomac into the first or second future season.

Method

Four seasons were defined per Table 1. Seasons were selected to correspond to intervals that are of concern to water supply managers–Potomac flow is most likely to drop to levels of concern in the summer and fall seasons.

Table 1: Definition of Seasons

Month	Season
December January February	Winter
March April May	Spring
June July August	Summer
September October November	Fall

Since more than 100 years of flow data were available as measured for the Potomac River at the Point of Rocks gage, these data were selected for use in the examination of low flow persistence.

Minimum Potomac River flows at Point of Rocks were selected for each season and each year. The minimum daily flow that occurred during each season was noted for the 100-year plus period of record (1895 to 1997). Thus, roughly 400 data points were derived, in which each data point corresponds to the lowest daily flow that occurred in a particular three-month season. For example, the winter of 1931 is associated with 90 days of daily flow data (December through February). The lowest of those 90 flows was selected as the low flow data point for winter of 1931. This process was repeated for each season and for each year to derive a total of approximately 400 data points.

All the data points were classified by the four seasons defined in Table 1, resulting in 102-103 data points in each season. These data points were further classified into three descriptive categories: dry, medium and wet. Each descriptive category was defined by ranking each season's 102 or 103 data points from low to high, labeling the lowest third of flows "dry," the middle third of flows "medium," and the highest third of flows "wet." In other words, each season's flows were divided at the 33rd and 66th percentile. Table 2 shows the resulting thresholds which distinguish among dry, medium and wet flows for each season. This table can be interpreted as follows. The 33rd percentile flow for fall is 1,100 cfs. This means that flow in the fall at Point of Rocks was less than 1,100 cfs in 33 years out of 100. Histograms graphically show the thresholds and flow frequencies for each season (Appendix A).

Table 2: Seasonal flow thresholds used to distinguish among dry, medium, and wet flows

Percentile	Winter flow	Spring flow	Summer flow	Fall flow
	Cubic feet per second (**cfs**)			
33	2,046	3,593	1,403	1,100
66	3,666	5,210	2,006	1,543
	Million gallons per day (**mgd**)			
33	1,323	2,323	907	711
66	2,370	3,368	1,297	997

Seasonal low flows were chronologically ordered in an Excel spreadsheet along with each season's descriptive category of dry, medium, or wet (Appendix B). The number of times flows transition between descriptive categories was tallied, for every combination of categories. For example, for every dry flow in the fall, the number of wintertime dry, medium and wet flows was noted and summed for the 102 year period of record. This tally was conducted between adjacent seasons, for example from winter to spring, and also across seasons, for example from winter to summer. The results were obtained by tallying the total number of transitions between seasons and categories.

Probabilistic assessment—results for adjacent seasons

If there was no persistence between adjacent seasons, one would expect an even distribution (equal probability) of dry, medium and wet flows in subsequent seasons (Table 3).

Table 3: Transition probabilities expected assuming no pattern of persistence in flows for a an example season (number of expected events in parenthesis)

	Spring		
Summer	Dry	Medium	Wet
Dry	33% (11 or 12)	33% (11 or 12)	33% (11 or 12)
Medium	33% (11 or 12)	33% (11 or 12)	33% (11 or 12)
Wet	33% (11 or 12)	33% (11 or 12)	33% (11 or 12)

Analysis of the data reveals a departure from the pattern shown in Table 3, indicating flow persistence across seasons. Results are shown in Table 4. Note that Table 4 also shows the number of historical events for each transition in parenthesis.

Table 4: One-season transition probabilities (number of historical events in parenthesis)

Spring to summer	Summer dry	Summer medium	Summer wet
Spring dry	59% (20)	26% (9)	15% (5)
Spring medium	21% (7)	45% (15)	33% (11)
Spring wet	19% (7)	28% (10)	53% (19)
Summer to fall	Fall dry	Fall medium	Fall wet
Summer dry	59% (20)	29% (10)	12% (4)
Summer medium	29% (10)	47% (16)	24% (8)
Summer wet	9% (3)	26% (9)	66% (23)
Fall to winter	Winter dry	Winter medium	Winter wet
Fall dry	55% (18)	33% (11)	12% (4)
Fall medium	37% (13)	29% (10)	34% (12)
Fall wet	9% (3)	35% (12)	56% (19)
Winter to spring	Spring dry	Spring medium	Spring wet
Winter dry	56% (19)	21% (7)	24% (8)
Winter medium	30% (10)	33% (11)	36% (12)
Winter wet	14% (5)	43% (15)	43% (15)

Note: Shaded cells show persistence in transition to like flows.

Table 4 can be interpreted per the following example, which assumes that the date is May 31 (end of spring) and the minimum flow was 2,900 cfs in the previous three months. From Table 2, the dry, medium or wet ranking of the spring season can be determined–in this case, the ranking is "dry." The probability of a dry summer is found by identifying the "Spring dry" cell in the left most column of Table 4, and reading across to the appropriate column to determine the transition probabilities for the summer season. In this example, the probability of a dry summer is 59%, a medium summer is 26%, and a wet summer is 15%. These results can be interpreted to mean that there is a 59% chance that at some time in the summer, flow will drop below the summertime dry threshold as reported in Table 2 (907 mgd). Note that each cell in Table 4 also gives the total number of historical events in the Potomac flow record on which the percentages are based. For example, the 34 dry springs tracked in the historic record were followed by a total of 20 dry summers, 9 medium summers, and 5 wet summers.

Table 4 shows that spring and summer dry, medium and wet categories are persistent. Fall dry and fall wet categories are persistent. Fall medium is not persistent, i.e., fall medium is about equally likely to transition to a dry, medium or wet winter. Although winter dry is persistent, winter medium is not. Winter wet is weakly persistent but often is followed by a medium spring. Key persistence periods are summer wet (strongest), spring dry and summer dry. The periods showing least transition correlation are fall medium and winter medium. It is interesting to note that wet summers and falls have a relatively low probability of being followed by dry falls and winters, respectively.

Probabilistic assessment—results across two seasons

Table 5 shows the transition probabilities two seasons ahead. Here again, the empirical probabilities depart from the equal probability model shown in Table 3, indicating a pattern of flow persistence in the Potomac across two seasons.

Table 5: Two-season transition probabilities (number of historical events in parenthesis)

Spring to fall	Fall dry	Fall medium	Fall wet
Spring dry	62% (21)	18% (6)	21% (7)
Spring medium	27% (9)	39% (13)	33% (11)
Spring wet	8% (3)	44% (16)	47% (17)
Summer to winter	Winter dry	Winter medium	Winter wet
Summer dry	35% (12)	41% (14)	24% (8)
Summer medium	48% (16)	18% (6)	33% (11)
Summer wet	17% (6)	37% (13)	46% (16)
Fall to spring	Spring dry	Spring medium	Spring wet
Fall dry	64% (21)	15% (5)	21% (7)
Fall medium	14% (5)	43% (15)	43% (15)
Fall wet	24% (8)	38% (13)	38% (13)
Winter to summer	Summer dry	Summer medium	Summer wet
Winter dry	47% (16)	24% (8)	29% (10)
Winter medium	30% (10)	36% (12)	33% (11)
Winter wet	22% (8)	39% (14)	39% (14)

Note: Shaded cells show persistence in transition to like flows.

Low flow persistence two seasons ahead is most likely following a dry spring (62%) and a dry fall (64%). Low flow persistence is less likely from winter to summer (47%) and from summer to winter (35%). The summer medium category is the least persistent, i.e. lowest (18%).

Probabilistic assessment—conclusions

Persistence in Potomac low flow conditions allows for relatively accurate forecasting of low flow occurrences in the Potomac over a three to six month forecast period (1-2 seasons).

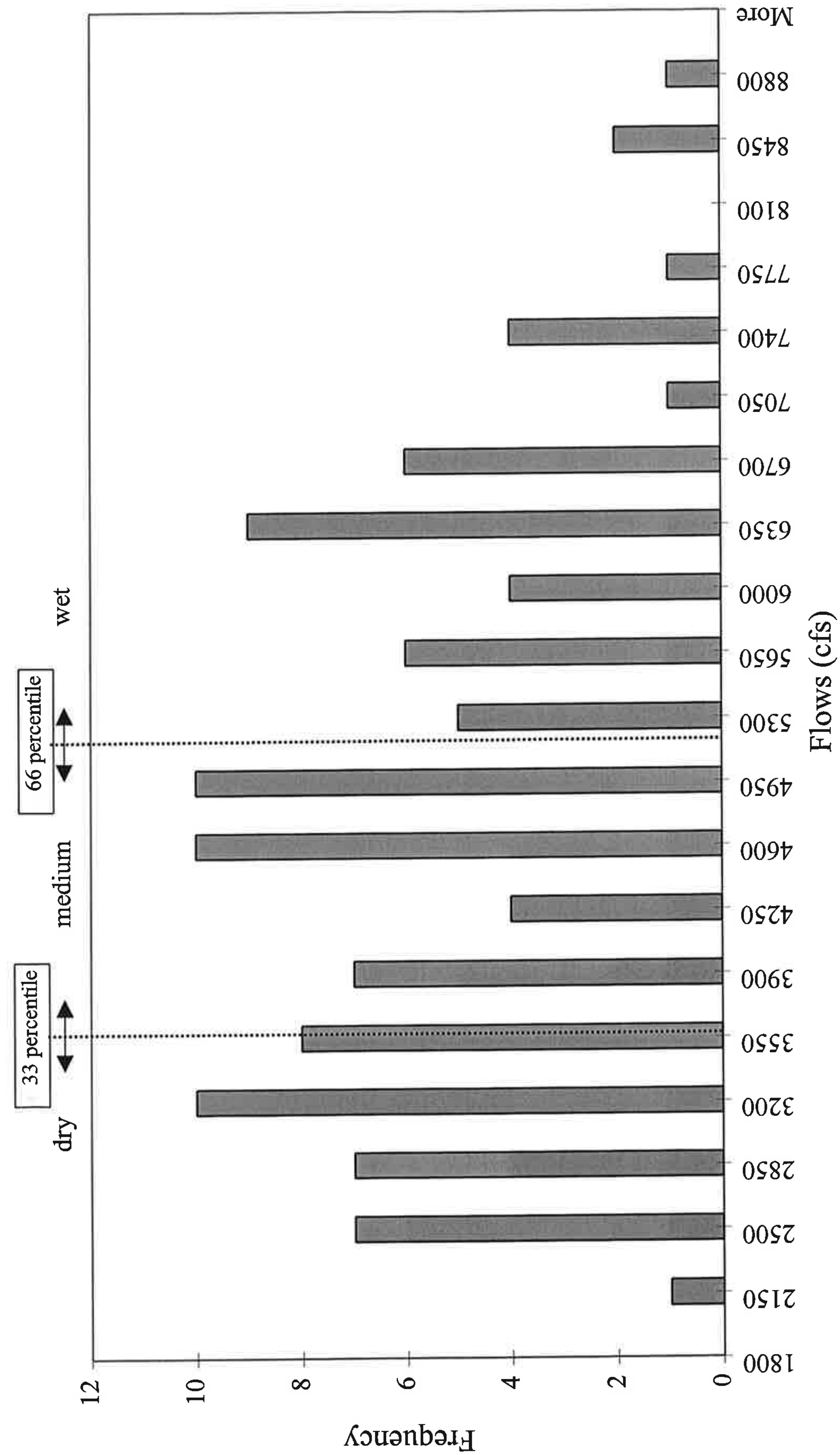
Although current levels of Washington metropolitan area (WMA) demand are not predicted to stress the regional water resources during a drought of record, growing demands may do so in the future. Assessed probabilities of low flow in the Potomac have implications for WMA water supply management. Probabilistic flow assessments may allow for a risk-based approach to water supply system operation, for example reserving more water in the water supply reservoirs during the spring and early summer when dry summers or falls are predicted on the Potomac. Risk based management schemes might extend the time that the current system of WMA reservoirs can meet growing levels of demand, and also provide for more efficient use of off-Potomac reservoirs during wet years.

Reference

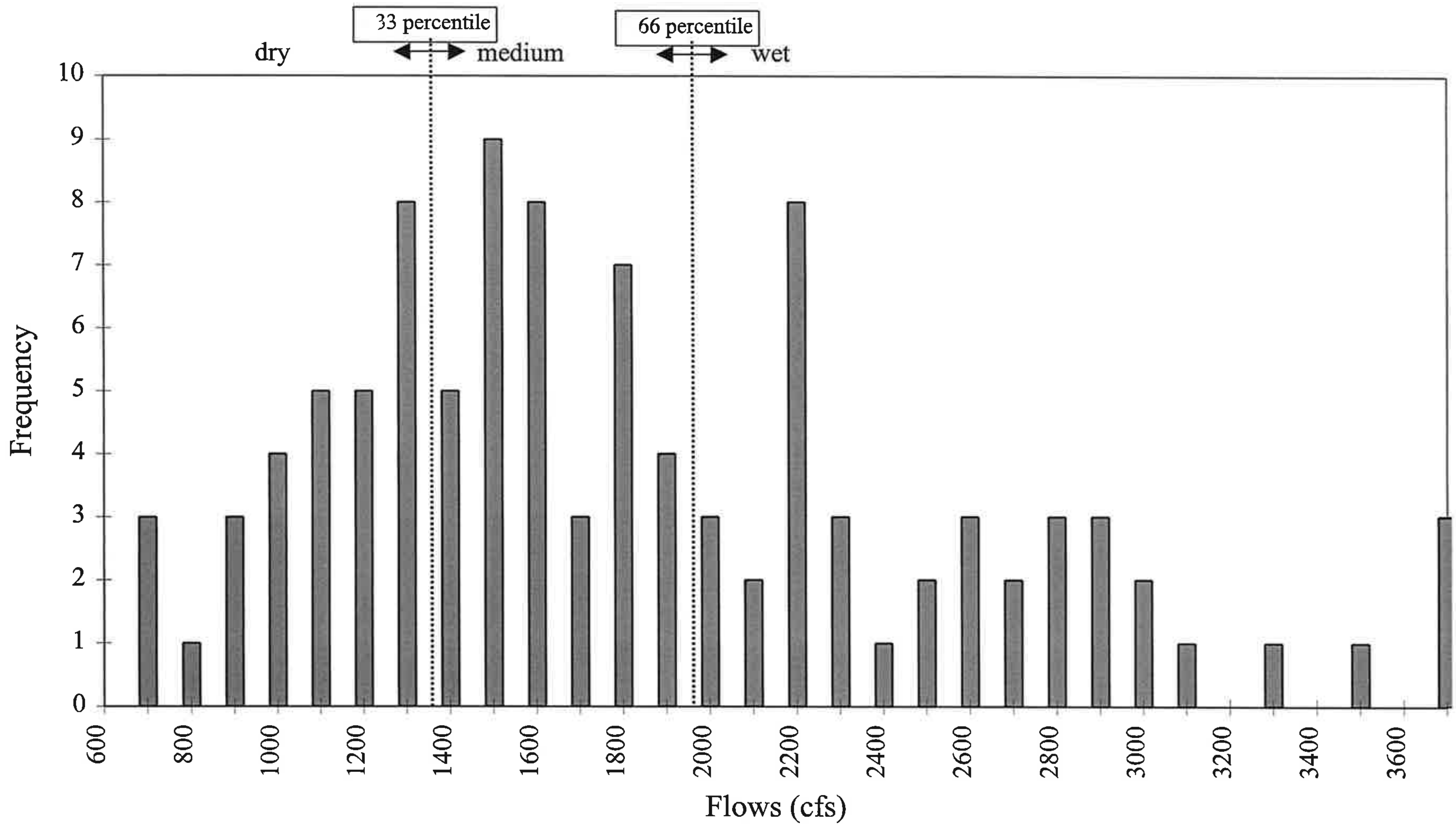
Hurst, H.E. 1957. A suggested statistical model of some time series which occur in nature, *Nature* vol. 180, p. 494.

Appendix A: Histogram analysis of each season's low flows

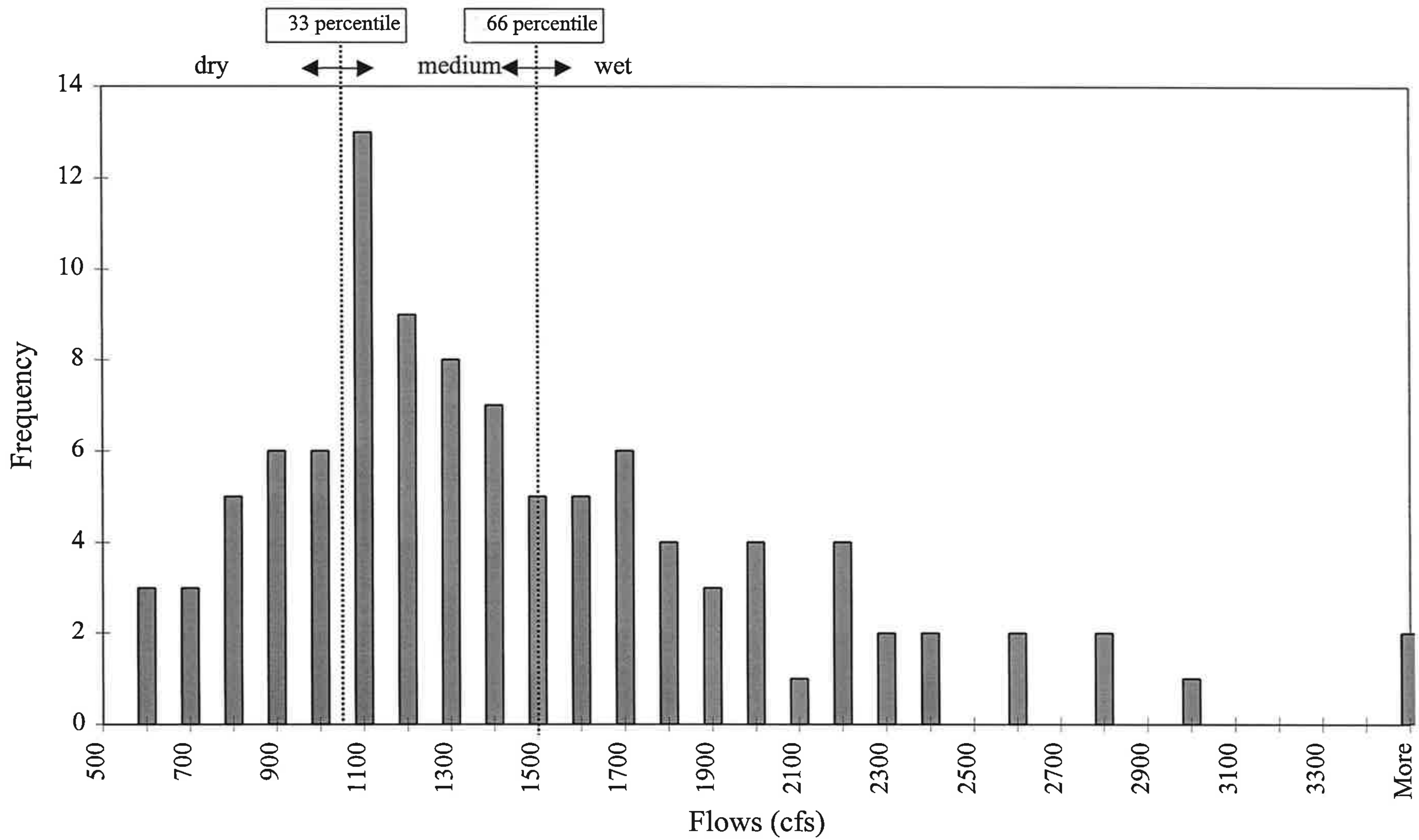
100 years of minimum spring flows at Point of Rocks
Distribution frequency
(Spring = March, April, and May)



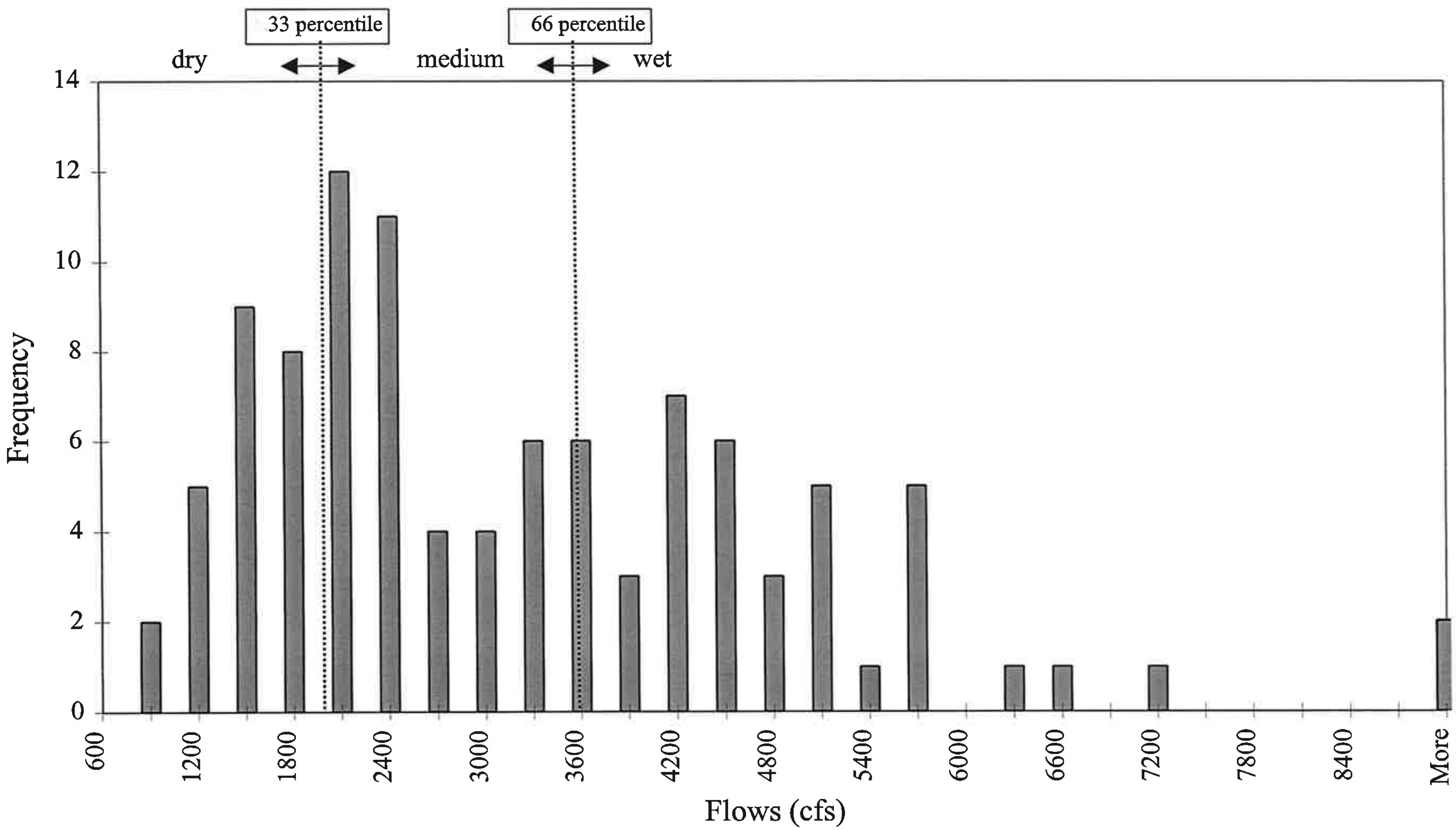
100 years of minimum summer flows at Point of Rocks
Distribution frequency
(Summer = June, July, and August)



100 years of minimum fall flows at Point of Rocks
Distribution frequency
(Fall = September, October, and November)



100 years of minimum winter flows at Point of Rocks
Distribution frequency
(Winter = December, January, and February)



Appendix B: Seasonal low flows at Point of Rocks by season and corresponding dry, medium and wet designations

	1895 - 1907			1907 - 1919			1919 - 1931			1931 - 1943			1943 - 1955			1955 - 1967		
Season	Year	Min. Flow (cfs)	Cat.	Year	Min. Flow (cfs)	Cat.	Year	Min. Flow (cfs)	Cat.	Year	Min. Flow (cfs)	Cat.	Year	Min. Flow (cfs)	Cat.	Year	Min. Flow (cfs)	Cat.
Spring	1895	6200	wet	1907	6920	wet	1919	4670	med.	1931	2610	dry	1943	6600	wet	1955	4540	med.
Summer	1895	1340	dry	1907	3100	wet	1919	1480	med.	1931	1450	med.	1943	1600	med.	1955	1460	med.
Fall	1895	1040	dry	1907	2260	wet	1919	1010	dry	1931	845	dry	1943	995	dry	1955	2020	wet
Winter	1896	1180	dry	1908	5380	wet	1920	3700	wet	1932	982	dry	1944	1000	dry	1956	1500	dry
Spring	1896	2280	dry	1908	5750	wet	1920	4840	med.	1932	2940	dry	1944	6420	wet	1956	4300	med.
Summer	1896	1540	med.	1908	2530	wet	1920	1990	med.	1932	890	dry	1944	1110	dry	1956	2160	wet
Fall	1896	1180	med.	1908	1520	med.	1920	1480	med.	1932	702	dry	1944	1100	med.	1956	1860	wet
Winter	1897	2000	dry	1909	1520	dry	1921	4010	wet	1933	2880	med.	1945	3040	med.	1957	2390	med.
Spring	1897	5760	wet	1909	4670	med.	1921	4010	med.	1933	7120	wet	1945	6060	wet	1957	3820	med.
Summer	1897	2940	wet	1909	1240	dry	1921	1370	dry	1933	2210	wet	1945	2000	med.	1957	863	dry
Fall	1897	1340	med.	1909	1010	dry	1921	1040	dry	1933	1830	wet	1945	2530	wet	1957	806	dry
Winter	1898	2600	med.	1910	1740	dry	1922	2920	med.	1934	1680	dry	1946	5550	wet	1958	2240	med.
Spring	1898	4480	med.	1910	2800	dry	1922	3250	dry	1934	2400	dry	1946	4540	med.	1958	6040	wet
Summer	1898	1540	med.	1910	1480	med.	1922	1320	dry	1934	1110	dry	1946	1740	med.	1958	2660	wet
Fall	1898	1760	wet	1910	900	dry	1922	780	dry	1934	1150	med.	1946	1090	dry	1958	1210	med.
Winter	1899	6200	wet	1911	1360	dry	1923	780	dry	1935	4940	wet	1947	1450	dry	1959	1600	dry
Spring	1899	5320	wet	1911	2250	dry	1923	2920	dry	1935	5850	wet	1947	2680	dry	1959	3030	dry
Summer	1899	1540	med.	1911	680	dry	1923	950	dry	1935	2160	wet	1947	1780	med.	1959	1270	dry
Fall	1899	1540	med.	1911	2940	wet	1923	676	dry	1935	1280	med.	1947	995	dry	1959	787	dry
Winter	1900	2000	dry	1912	3390	med.	1924	2920	med.	1936	4000	wet	1948	1850	dry	1960	4290	wet
Spring	1900	2940	dry	1912	6130	wet	1924	6130	wet	1936	3600	med.	1948	5210	wet	1960	4350	med.
Summer	1900	1340	dry	1912	2120	wet	1924	2600	wet	1936	1590	med.	1948	2620	wet	1960	1660	med.
Fall	1900	1040	dry	1912	1640	wet	1924	1420	med.	1936	1130	med.	1948	2000	wet	1960	1510	med.
Winter	1901	1760	dry	1913	2120	med.	1925	3580	med.	1937	1860	dry	1949	9880	wet	1961	1250	dry
Spring	1901	2280	dry	1913	3090	dry	1925	3580	dry	1937	6540	wet	1949	6600	wet	1961	6040	wet
Summer	1901	4080	wet	1913	1640	med.	1925	1000	dry	1937	1900	med.	1949	2720	wet	1961	1450	med.
Fall	1901	2280	wet	1913	748	dry	1925	822	dry	1937	2160	wet	1949	1660	wet	1961	1230	med.
Winter	1902	4480	wet	1914	4170	wet	1926	1990	dry	1938	4220	wet	1950	3600	med.	1962	2010	dry
Spring	1902	4670	med.	1914	3090	dry	1926	2920	dry	1938	3420	dry	1950	5210	wet	1962	6150	wet
Summer	1902	1520	med.	1914	769	dry	1926	1370	dry	1938	1420	med.	1950	1290	dry	1962	1050	dry
Fall	1902	1300	med.	1914	540	dry	1926	2140	wet	1938	1110	med.	1950	2360	wet	1962	1070	dry
Winter	1903	6520	wet	1915	1100	dry	1927	3920	wet	1939	2130	med.	1951	7140	wet	1963	2120	med.
Spring	1903	4330	med.	1915	3090	dry	1927	4270	med.	1939	4830	med.	1951	5380	wet	1963	3220	dry
Summer	1903	2810	wet	1915	1240	dry	1927	2290	wet	1939	1850	med.	1951	1760	med.	1963	1060	dry
Fall	1903	2000	wet	1915	1310	med.	1927	970	dry	1939	1120	med.	1951	1130	med.	1963	820	dry
Winter	1904	2000	dry	1916	2380	med.	1928	3200	med.	1940	1900	dry	1952	2290	med.	1964	2100	med.
Spring	1904	3400	dry	1916	5020	med.	1928	5370	wet	1940	5500	wet	1952	6420	wet	1964	3130	dry
Summer	1904	1750	med.	1916	2120	wet	1928	1700	med.	1940	1880	med.	1952	2110	wet	1964	1000	dry
Fall	1904	900	dry	1916	966	dry	1928	1340	med.	1940	1990	wet	1952	1500	med.	1964	665	dry
Winter	1905	1520	dry	1917	1260	dry	1929	1650	dry	1941	4650	wet	1953	5460	wet	1965	3230	med.
Spring	1905	2810	dry	1917	2380	dry	1929	5590	wet	1941	2590	dry	1953	7250	wet	1965	3320	dry
Summer	1905	2810	wet	1917	1030	dry	1929	1130	dry	1941	1430	med.	1953	1300	dry	1965	915	dry
Fall	1905	1750	wet	1917	643	dry	1929	1130	med.	1941	928	dry	1953	1100	med.	1965	734	dry
Winter	1906	3400	med.	1918	1700	dry	1930	3730	wet	1942	1250	dry	1954	1400	dry	1966	1000	dry
Spring	1906	2810	dry	1918	2660	dry	1930	1900	dry	1942	3280	dry	1954	4470	med.	1966	2930	dry
Summer	1906	2530	wet	1918	2120	wet	1930	643	dry	1942	2060	wet	1954	1080	dry	1966	629	dry
Fall	1906	2530	wet	1918	1080	dry	1930	594	dry	1942	2390	wet	1954	1040	dry	1966	547	dry
Winter	1907	4010	wet	1919	2520	med.	1931	775	dry	1943	4100	wet	1955	2450	med.	1967	4850	wet

Season	1967 - 1979 Year	Min. Flow (cfs)	Cat.	1979 - 1991 Year	Min. Flow (cfs)	Cat.	1991 - 1998 Year	Min. Flow (cfs)	Cat.
Spring	1967	6210	wet	1979	7660	wet	1991	3380	dry
Summer	1967	1750	med.	1979	2730	wet	1991	1500	med.
Fall	1967	1640	wet	1979	4440	wet	1991	1000	dry
Winter	1968	3520	med.	1980	5040	wet	1992	1920	dry
Spring	1968	3710	med.	1980	5890	wet	1992	4630	med.
Summer	1968	1080	dry	1980	2230	wet	1992	2460	wet
Fall	1968	1010	dry	1980	1270	med.	1992	1610	wet
Winter	1969	2150	med.	1981	1300	dry	1993	3740	wet
Spring	1969	2170	dry	1981	3640	med.	1993	4840	med.
Summer	1969	885	dry	1981	1180	dry	1993	1550	med.
Fall	1969	1610	wet	1981	1190	med.	1993	1500	med.
Winter	1970	2410	med.	1982	2020	dry	1994	5500	wet
Spring	1970	4230	med.	1982	3690	med.	1994	5150	med.
Summer	1970	2340	wet	1982	2140	wet	1994	2460	wet
Fall	1970	1220	med.	1982	1550	wet	1994	1760	wet
Winter	1971	4230	wet	1983	2760	med.	1995	4180	wet
Spring	1971	5110	med.	1983	8770	wet	1995	3690	med.
Summer	1971	2140	wet	1983	1530	med.	1995	1770	med.
Fall	1971	1810	wet	1983	1380	med.	1995	1370	med.
Winter	1972	4990	wet	1984	3600	med.	1996	4620	wet
Spring	1972	8410	wet	1984	7060	wet	1996	7330	wet
Summer	1972	3610	wet	1984	2940	wet	1996	3930	wet
Fall	1972	2160	wet	1984	2190	wet	1996	4960	wet
Winter	1973	8830	wet	1985	2300	med.	1997	5650	wet
Spring	1973	8160	wet	1985	4020	med.	1997	4620	med.
Summer	1973	2710	wet	1985	1920	med.	1997	1810	med.
Fall	1973	1960	wet	1985	1350	med.	1997	1560	wet
Winter	1974	5060	wet	1986	3200	med.	1998	4430	wet
Spring	1974	4900	med.	1986	4120	med.	1998	6840	wet
Summer	1974	2020	wet	1986	1440	med.	1998	2010	wet
Fall	1974	1430	med.	1986	1170	med.	1998	1500	med.
Winter	1975	2360	med.	1987	4680	wet	1999	1865	dry
Spring	1975	6050	wet	1987	6380	wet	1999	3500	dry
Summer	1975	2860	wet	1987	1290	dry			
Fall	1975	2780	wet	1987	1300	med.			
Winter	1976	4440	wet	1988	4400	wet			
Spring	1976	3250	dry	1988	4290	med.			
Summer	1976	1280	dry	1988	1230	dry			
Fall	1976	1260	med.	1988	1320	med.			
Winter	1977	2200	med.	1989	1440	dry			
Spring	1977	2450	dry	1989	4320	med.			
Summer	1977	1120	dry	1989	3450	wet			
Fall	1977	1100	med.	1989	2790	wet			
Winter	1978	5500	wet	1990	2100	med.			
Spring	1978	5400	wet	1990	4680	med.			
Summer	1978	3290	wet	1990	1740	med.			
Fall	1978	1610	wet	1990	1800	wet			
Winter	1979	3230	med.	1991	3270	med.			