4.0 Streamflow

4.1 Streamflow Data

In the Wenatchee River watershed, precipitation falls mostly as snow. Some of the snowfall increases the volume of icefields and glaciers; the rest accumulates to the winter snowpack. The warmer temperatures and rain of spring and early summer melt the snowpack, generating water to supply streamflow. A portion of the melt water, as well as some of the rainwater, percolates through the ground to become groundwater. This same groundwater moves through the ground, re-emerging in springs, streams, and rivers, and supplies streamflow through late summer and fall.

The main surface feature of the Wenatchee River watershed is the Wenatchee River. The Wenatchee is formed by the convergence of four large tributaries, the Chiwawa, White, Little Wenatchee Rivers and Nason Creek, at or near Lake Wenatchee. The river then flows southeasterly through the Wenatchee Valley and discharges into the Columbia River at Wenatchee. The drainage area of the Wenatchee River is 1,328 square miles. The Entiat Mountains to the Northeast, the Cascade Mountains to the Northwest, and the Wenatchee Mountains to the Southwest confine the Wenatchee Watershed. The Wenatchee Watershed also includes an area west of the Columbia River from Rocky Reach Dam to just south of the City of Wenatchee.

Several data sources were searched to identify stream-gaging data available in WRIA 45 including the United States Geological Survey (USGS), the Washington Department of Ecology (Ecology), and several local organizations. A list of stations and known data availability were compiled from those sources and sorted by type of data available and subbasin. A description and discussion of specific data sources is contained within the following paragraphs.

4.1.1 United States Geological Survey

The USGS has collected stream flow data in WRIA 45 from 1907 to the present. Selected hydrologic data collected by the USGS can be downloaded from a USGS website through the Internet at the following URL: http://water.usgs.gov/. Real-time continuous data as well as historical data is available online along with descriptions and maps of the station locations. A list of stream gaging stations with known daily or monthly records is shown in Table 4-1. Map 5 shows the location of the stream gaging stations.

Table 4-1
USGS Stream Gaging Stations within WRIA 45
with Daily or Monthly Records

Agency	Station No.	Name/Location	Drainage Area (sq mi)	Data Type	Period of Record	Subbasin
USGS	12456500	Chiwawa River near Plain	170	Continuous	1911-1914, 1936-1949, 1954-1957, 1991-Present	Chiwawa
USGS	12458000	Icicle Creek above Snow Creek	193	Continuous	1936-1971, 1993-Present	Icicle
USGS	12458500	Icicle Creek near Leavenworth	211	Continuous	1911-1915	Icicle
USGS	12461400	Mission Creek above Sand Creek	39.8	Continuous	1958-1971	Mission
USGS	12451500	Sand Creek near Cashmere	18.6	Continuous	1954-1956	Mission
USGS	12462000	Mission Creek near Cashmere	81.2	Continuous	1954-1959	Mission
USGS	12456000	Phelps Creek near Plain	16.4	Continuous	1927-1931	Chiwawa
USGS	12454000	White River near Plain	150	Continuous	1954-1983	White-Little Wenatchee
USGS	12455000	Wenatchee River below Wenatchee Lake	273	Continuous	1932-1958	Wenatchee
USGS	12457000	Wenatchee River at Plain	591	Continuous	1910-1979, 1989-Present	Wenatchee
USGS	12459000	Wenatchee River at Peshastin	1,000	Continuous	1929-Present	Wenatchee
USGS	12461000	Wenatchee River at Dryden	1,155	Continuous	1907-1917	Wenatchee
USGS	12462500	Wenatchee River at Monitor	1,301	Continuous	1962-Present	Wenatchee

In addition to operating gage stations, the USGS collected miscellaneous streamflow measurements in the Wenatchee River watershed. A copy of miscellaneous USGS stream flow data for the Wenatchee watershed is provided in Appendix B.

4.1.2 Washington State Department of Ecology

Washington State Department of Ecology (Ecology) began taking streamflow measurements in WRIA 45 in 1996. They started with two stations, and now have 17 active stations and two inactive stations in the WRIA. Some of the active stations were recently installed using

Watershed Planning grant funding. Those stations include 45A240, 45E070, 45F070, 45G060, 45J070, 45K090, 45L110, and 45N060.

Real time continuous data is available from telemetry sites, while stand-alone and manual stage height sites have continuous or periodic data compiled. Table 4-2 lists the Ecology stream gaging stations with continuous recorded data while Table 4-3 lists the other stations where manual measurements are taken. Map 5 shows the location of the Ecology gaging stations. Data from those sites can be obtained from the Ecology website at: http://www.ecy.wa.gov/apps/watersheds/flows/regions/state.asp .

Table 4-2
Ecology Stream Gaging Stations within WRIA 45
with Daily Records

Agency	Station No.	Name/Location	Drainage Area (sq mi)	Data Type	Period of Record	Subbasin
DOE	45A240	Wenatchee River below Lake Wenatchee	NA	Continuous telemetered	2002-Present	Wenatchee
DOE	45B050	Icicle Creek near mouth	NA	Stand Alone	2002-Present	Icicle
DOE	45E070	Mission Creek near Cashmere	93.1	Continuous telemetered	1996-2000, 2002-Present	Mission
DOE	45F070	Peshastin Creek at Green Bridge Road	NA	Continuous telemetered	2002-Present	Peshastin
DOE	45G060	Chiwaukum Creek near mouth	50.0	Continuous telemetered	2002-Present	Wenatchee
DOE	45J070	Nason Creek near mouth	107.8	Continuous telemetered	2002-Present	Nason
DOE	45K090	White River near Plain	156.2	Continuous telemetered	2002-Present	White-Little Wen.
DOE	45L110	Little Wenatchee River below Rainy Creek	101.2	Continuous telemetered	2002-Present	White-Little Wen.
DOE	45N060	Rock Creek near mouth	NA	Continuous telemetered	2002-Present	Chiwawa

Table 4-3
Ecology Stream Gaging Stations within WRIA 45
with Daily or Monthly Records

Agency	Station No.	Name/Location	Drainage Area (sq mi)	Data Type	Period of Record	Subbasin
DOE	45A100	Wenatchee River at Leavenworth	NA	Manual Stage Height	2002-Present	Wenatchee
DOE	45A110	Wenatchee River near Leavenworth	NA	Manual Stage Height	2002-Present	Wenatchee
DOE	45C070	Chumstick Creek near Leavenworth	NA	Manual Stage Height	1998-2002	Wenatchee
DOE	45D070	Brender Creek near Cashmere	NA	Manual Stage Height	1996-2000	Mission
DOE	45H060	Chiwawa River near Schugart Flat	NA	Manual Stage Height	2002-Present	Chiwawa
DOE	45K070	White River near mouth	NA	Manual Stage Height	2002-Present	White-Little Wen.
DOE	45L070	Little Wenatchee River near mouth	NA	Manual Stage Height	2002-Present	White-Little Wen.
DOE	45M060	Rainy Creek near mouth	NA	Manual Stage Height	2002-Present	White-Little Wen.
DOE	45P050	White Pine Creek at mouth	NA	Manual Stage Height	2002-Present	Nason
DOE	45Q060	Eagle Creek near mouth	28.0	Manual Stage Height	2002-Present	Wenatchee

Because the continuous Ecology gaging stations were installed in summer 2002, sufficient data are not yet available to analyze. Streamflow data from those stations can be obtained from the Ecology website address provided on the previous page.

4.2 Analysis Of Surface Water Data

Daily streamflow data were analyzed to find seasonal, annual, and long-term climate trends. The seasonal and annual analyses were conducted by water year. The long-term climate trends were examined using data compiled into calendar years because the PDO and ENSO indices are compiled by calendar year.

4.2.1 Seasonal Data Analysis

Most WRIA 45 rivers and streams follow a snowmelt pattern of flow, where streamflow increases in spring and early summer due to melting snow in the mountains. The spring snowmelt generally begins in April, and streamflow returns to base flow by September. Figures 4.1 through 4.13 present a statistical analysis of the variation of flow throughout the year in the 13 gaged streams in the basin.

The statistical analysis uses recorded daily streamflow but analyzes that data on a weekly basis. The analysis produces low, median, and high flow exceedence probability estimates for each week during the year. Low flow is defined as the 90 percent exceedence probability, and is equal to the flow rate that occurred 9 years out of 10 for a particular period of time. The median flow is defined as the 50 percent exceedence probability, and is equal to the flow rate that occurred five years out of ten. High flow is defined as the 10 percent exceedence probability, and is equal to the flow rate that occurred one year out of ten. Tabulated summaries of the statistical analyses are provided in Appendix C.

As an example of the distribution of streamflow through the year, the percentage of streamflow in the Wenatchee River as measured at the Monitor gage is shown in Table 4-4. The greatest volume of flow (approximately 75% of the annual total) occurs in the March through July time period. In the August through October time period, less than 10% of the annual flow occurs. The lowest flow in the Wenatchee River occurs in late September and early October and ranges from approximately 500 cfs at Plain to 670 cfs at Monitor, both estimated for median streamflow years. In low flow years, streamflow ranges from 320 cfs at Plain to 370 cfs at Monitor.

Table 4-4
Distribution of Streamflow for Wenatchee River at Monitor Gage

Month	Estimated Monthly % of Annual	Cumulative %
October	3	3
November	4	7
December	4	11
January	4	15
February	3	18
March	7	25
April	11	36
May	21	57
June	27	84
July	9	93
August	4	97
September	3	100

4.2.2 Annual Data Analysis and Variations Due to Climate Cycles

A summary of annual average flows at various locations in the Wenatchee basin is presented in Table 4-5. The table includes historical streamflow records from stations no longer operating as well as stations that are still in service. Each gaged location is included, along with the percent of flow it contributes to the Wenatchee River at Monitor. Two of the major subbasins, Nason Creek and Peshastin Creek, do not have historical gages. Their annual streamflow and percent contribution was not estimated.

Table 4-5
Mean Annual Flows in WRIA 45

Name/Location	Drainage Area		Period of Record Streamflows [b]		
	Square Miles	Percent [a]	Mean Annual Flow (cfs)	Mean Annual Volume (acre-feet)	Percent [a]
Chiwawa River near Plain	170	13.1%	501	361,716	14.6%
Icicle Creek above Snow Creek	193	14.8%	620	448,385	18.1%
Icicle Creek near Leavenworth	211	16.2%	669	483,484	19.5%
Mission Creek above Sand Creek	39.8	3.1%	13	9,565	0.4%
Sand Creek near Cashmere	18.6	1.4%	5	3,403	0.1%
Mission Creek near Cashmere	81.2	6.2%	30	21,587	0.9%
Phelps Creek near Plain	16.4	1.3%	54	39,075	1.6%
Nason Creek[c]	108	8.3%	N/A	N/A	N/A
Peshastin Creek[c]	133	10.2%	N/A	N/A	N/A
White River near Plain	150	11.5%	811	586,107	23.7%
Wenatchee River below Wenatchee Lake	273	21.0%	1,319	952,977	38.5%
Wenatchee River at Plain	591	45.4%	2,285	1,651,470	66.8%
Wenatchee River at Peshastin	1,000	76.9%	3,099	2,239,941	90.5%
Wenatchee River at Dryden	1,155	88.8%	3,280	2,370,422	95.8%
Wenatchee River at Monitor	1,301	100.0%	3,423	2,474,040	100.0%

a Compared to values for the Wenatchee River at Monitor.
b From USGS for varying periods of record.
c Gage data not available, no estimate provided.

4.2.3 Effects of Climate Variability on Streamflow

Section 3.3.2 described the effects of climatic cycles on precipitation. The changes in precipitation directly affect the volume and timing of streamflow. The mean annual flow for the Wenatchee River at Peshastin, the stream gage with the longest record in the basin, is compared to the PDO index in Figure 4.14. The Wenatchee River at Peshastin generally shows a trend of lower mean annual flows during warm and dry periods and higher mean annual flows during cold and wet periods. Table 4-6 shows the mean annual streamflow during cold and wet PDO phases as well as warm and dry PDO phases. There is an approximate 300 cfs difference in flow between both PDO phases and the mean annual flow. The difference in flow between the warm, dry PDO phase and cold wet phases of the PDO cycle is almost 600 cfs.

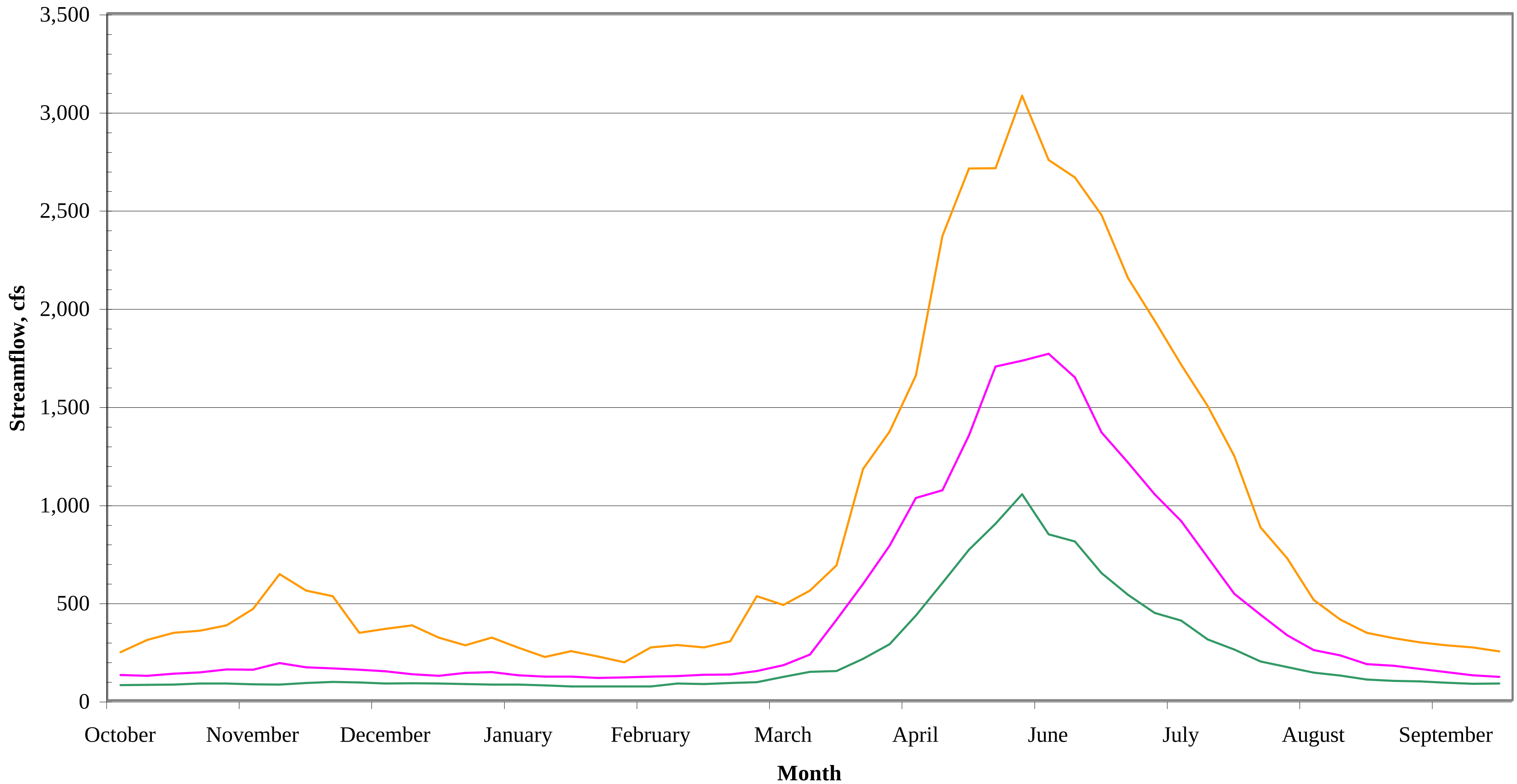
Table 4-6
Mean Annual Streamflow in the Wenatchee River at Peshastin

Entire Period of Record		Warm, Dry PDO Phase		Cool, Wet PDO Phase	
Period	**Mean Annual Streamflow, cfs**	**Period**	**Mean Annual Streamflow, cfs**	**Period**	**Mean Annual Streamflow, cfs**
1910-Present	3,112	1925-1945	2,815	1946-1976	3,424
		1977-1995	2,847	1996-Present	3,360
		All Warm, Dry Years	2,830	All Cold, Wet Years	3,404
		Difference from Entire Period of Record	-282	Difference from Entire Period of Record	+292

Trends in late summer and fall streamflows do not always correspond to trends in annual flows because the majority of runoff volume occurs during springtime. Trends in low flows were evaluated by examining the annual 7-day and 30-day low flows in the White River near Plain, Wenatchee River below Wenatchee Lake, Wenatchee River at Plain, Wenatchee River at Peshastin, and Wenatchee River at Monitor (Figures 4.15 through 4.24). Not all of the streamflow records are long enough to ascertain trends or effects on low flows from climatic cycles but the stations with the two longest records (Wenatchee River at Plain and Wenatchee River at Peshastin) generally show lower low flows in the warm, dry PDO phase than the cool, wet PDO phase. Table 4-7 presents a comparison of the means of the annual 30-day low flows during warm, dry and cold, wet PDO phases. The comparison shows the 30-day low flows during a warm, dry PDO phase are approximately 100 cfs less than the mean of the annual 30-day low flows for the entire period of record. The 30-day low flow during a cool, wet PDO phase is approximately 90 cfs greater than the mean of the annual 30-day low flows for the period of record.

Table 4-7
Comparison of Mean of Annual 30-Day Low Flows
In The Wenatchee River At Peshastin

Entire Period of Record		Warm, Dry PDO Phase		Cool, Wet PDO Phase	
Period	**Mean of Annual 30-day low flow, cfs**	**Period**	**Mean of Annual 30-day low flow, cfs**	**Period**	**Mean of Annual 30-day low flow, cfs**
1910-Present	664	1925-1945	523	1946-1976	780
		1977-1995	600	1996-Present	643
		All Warm, Dry Years	565	All Cold, Wet Years	755
		Difference from Entire Period of Record	-99	Difference from Entire Period of Record	+91



Legend

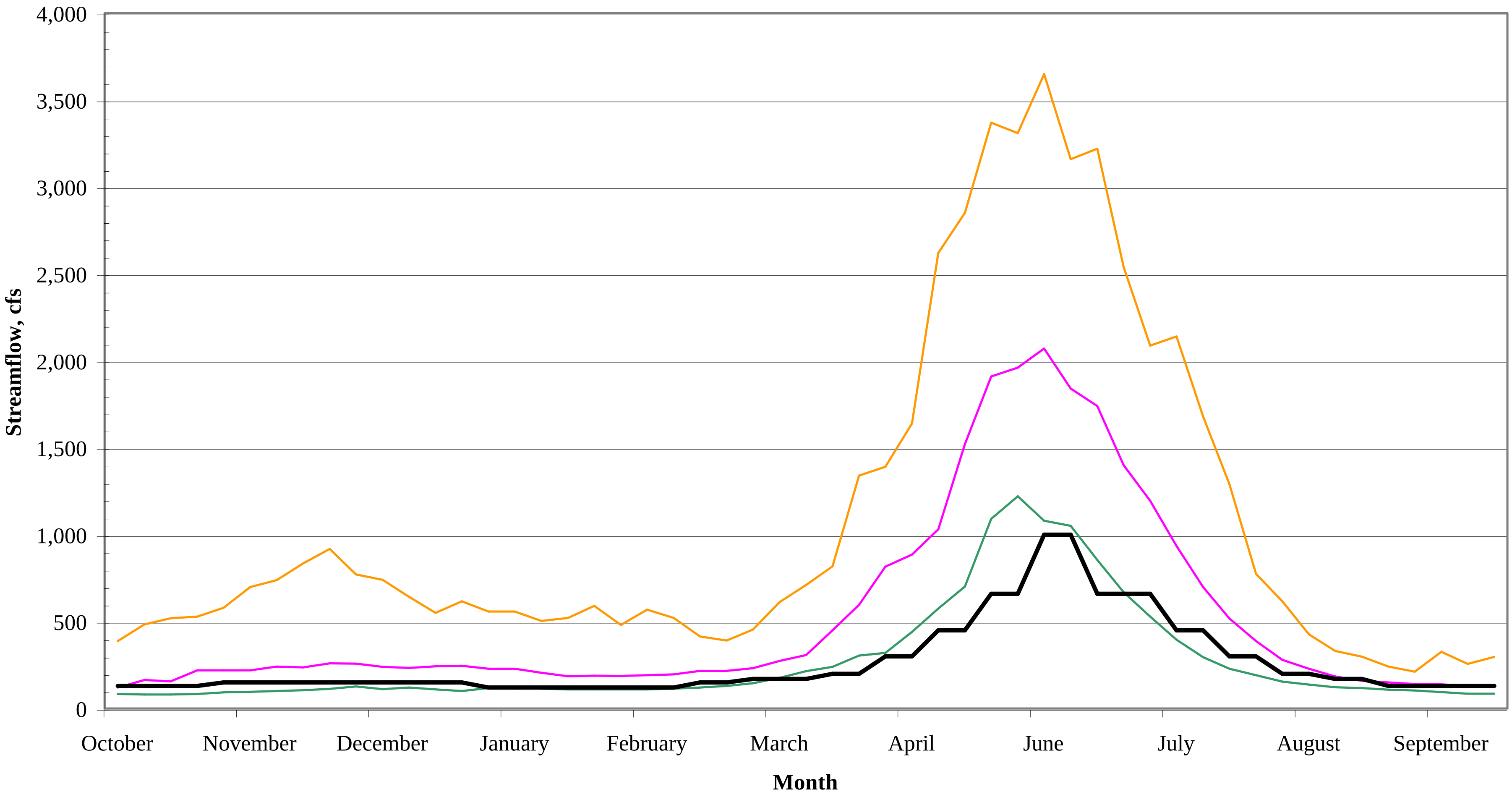
USGS Gage 12456500
Period of Record 1911-1914, 1936-1950,
1954-58, 1967, 1970, 1975-1977, 1991-2002

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.1 Weekly Streamflow Exceedence Probability
Chiwawa River near Plain, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

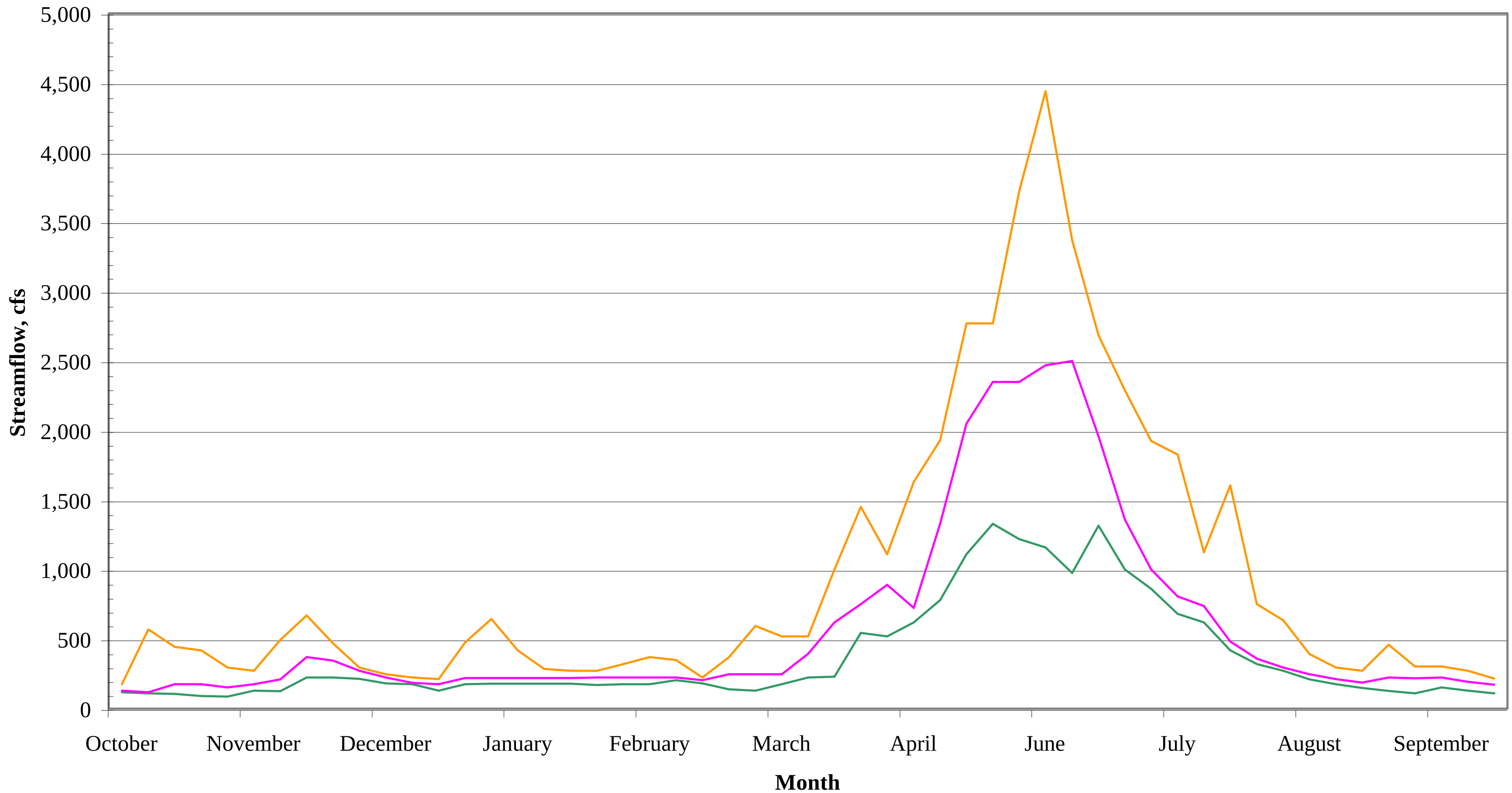
USGS Gage 12458000
Period of Record 1936-1972, 1975, 1976, 1977, 1994-2001

90% Exceedence
50% Exceedence
10% Exceedence
Minimum Flow from WAC

Figure 4.2 Weekly Streamflow Exceedence Probability
Icicle Creek above Snow Creek near Leavenworth, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

USGS Gage 12458500
Period of Record 1911-1914

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.3 Weekly Streamflow Exceedence Probability
Icicle Creek near Leavenworth, WA

Wenatchee River Basin Watershed Assessment

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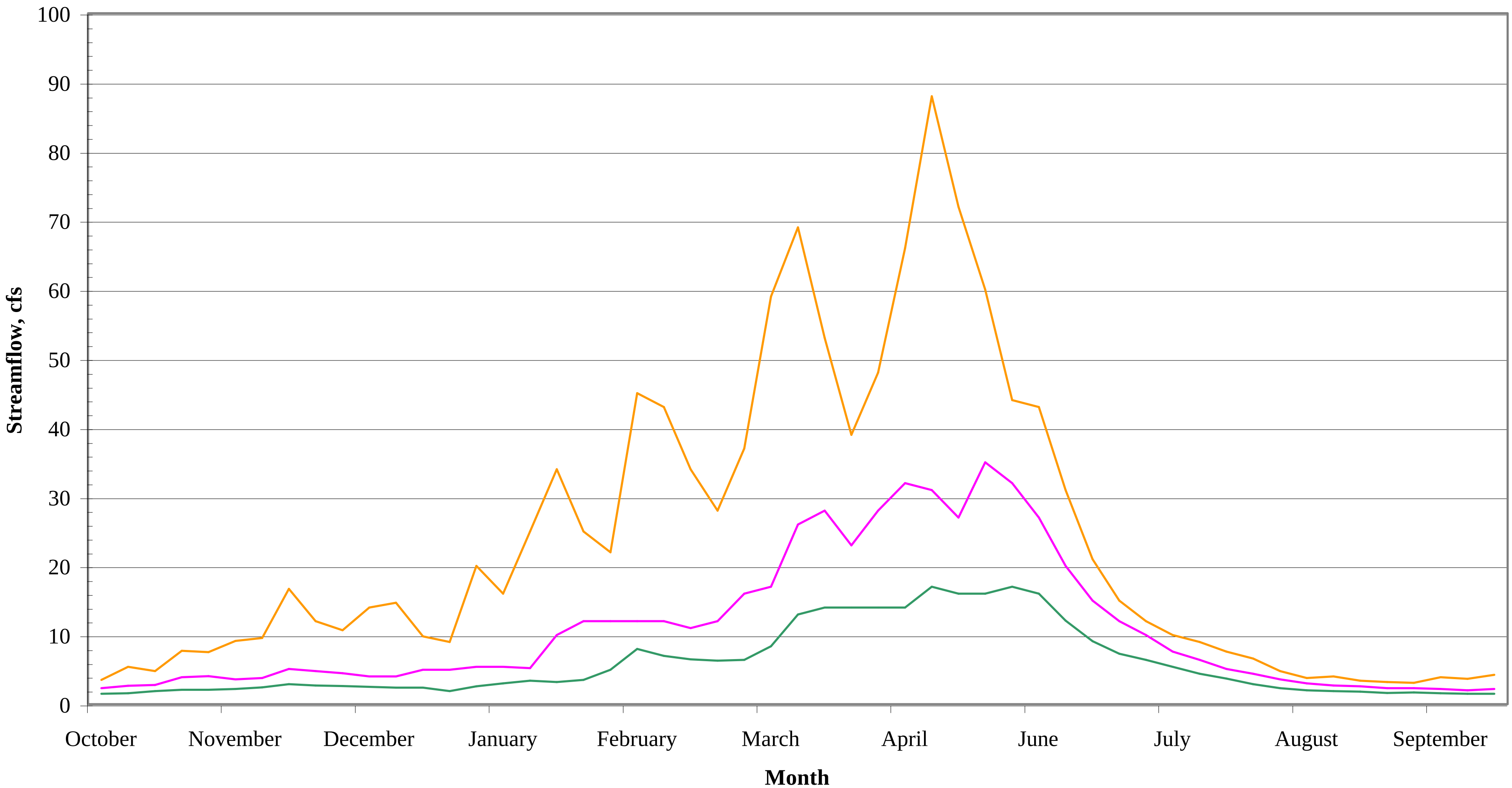


Legend

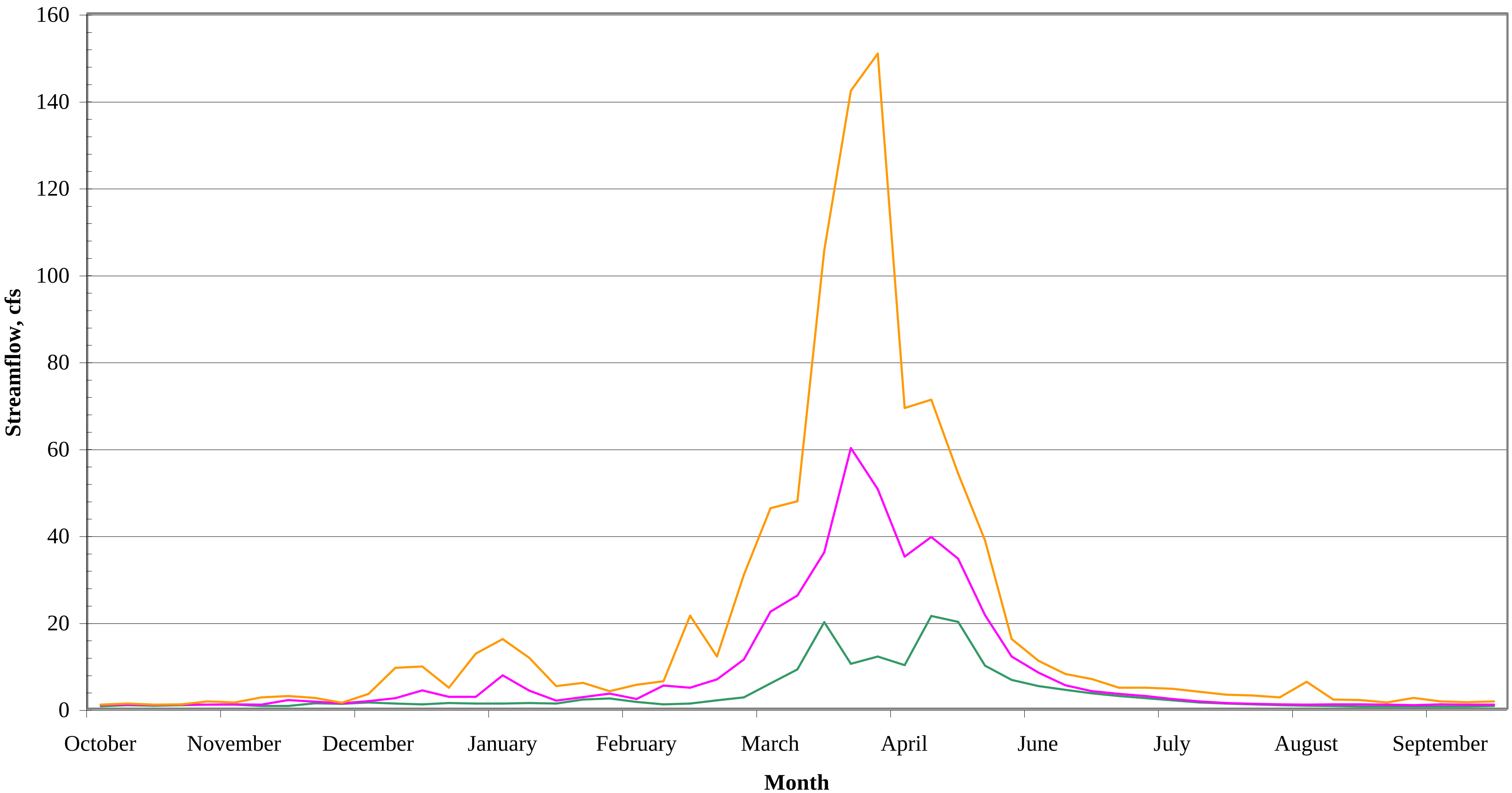
USGS Gage 12461400
Period of Record 1959-1972, 1975-1977

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.4 Weekly Streamflow Exceedence Probability
Mission Creek above Sand Creek near Cashmere, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

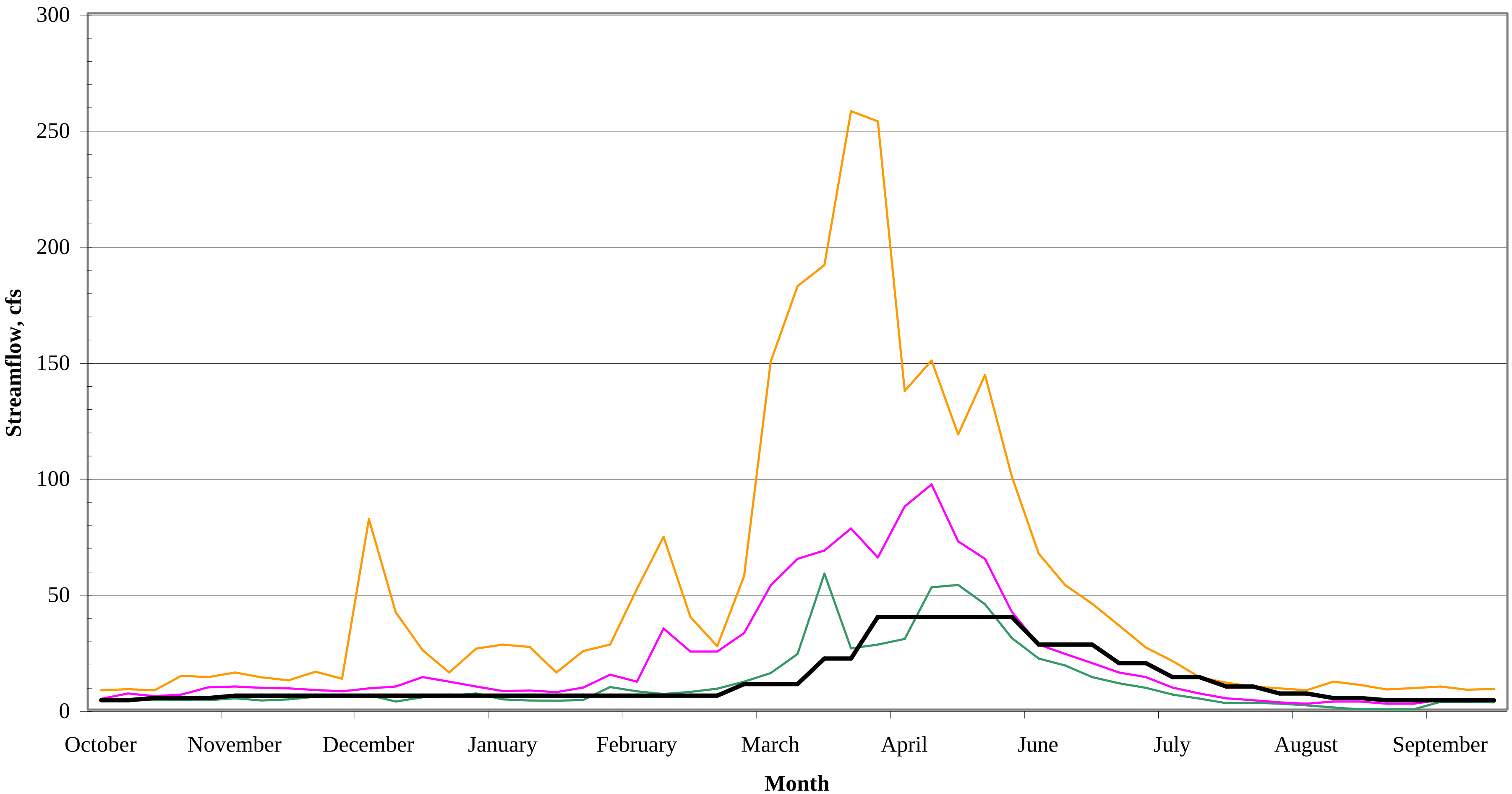
USGS Gage 12461500
Period of Record 1954-1956

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.5 Weekly Streamflow Exceedence Probability
Sand Creek near Cashmere, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

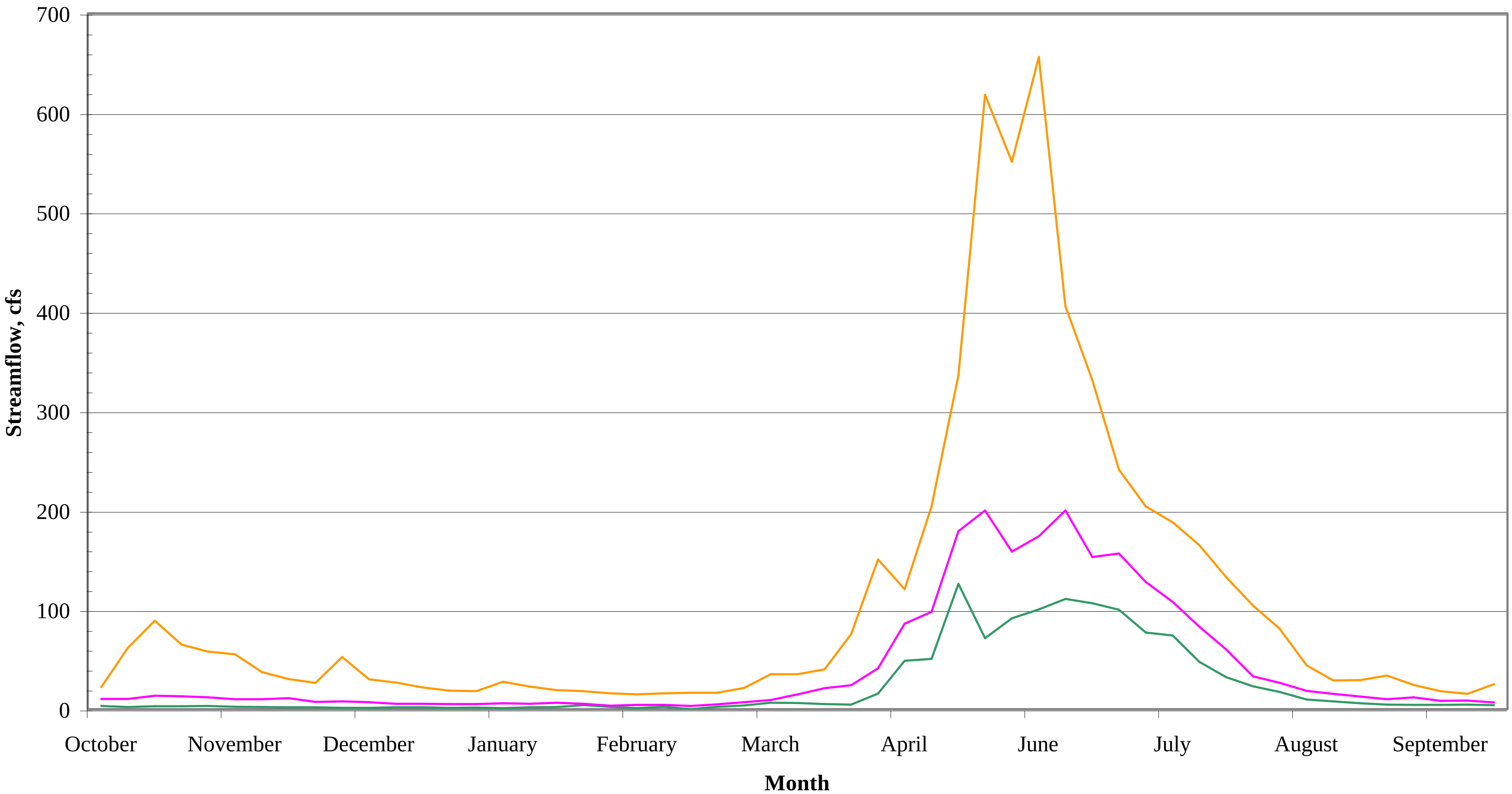
USGS Gage 12462000
Period of Record 1954-1958

90% Exceedence
50% Exceedence
10% Exceedence
Minimum Flow from WAC

Figure 4.6 Weekly Streamflow Exceedence Probability
Mission Creek near Cashmere, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

USGS Gage 12456000
Period of Record 1926-1931

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.7 Weekly Streamflow Exceedence Probability
Phelps Creek near Plain, WA

Wenatchee River Basin Watershed Assessment

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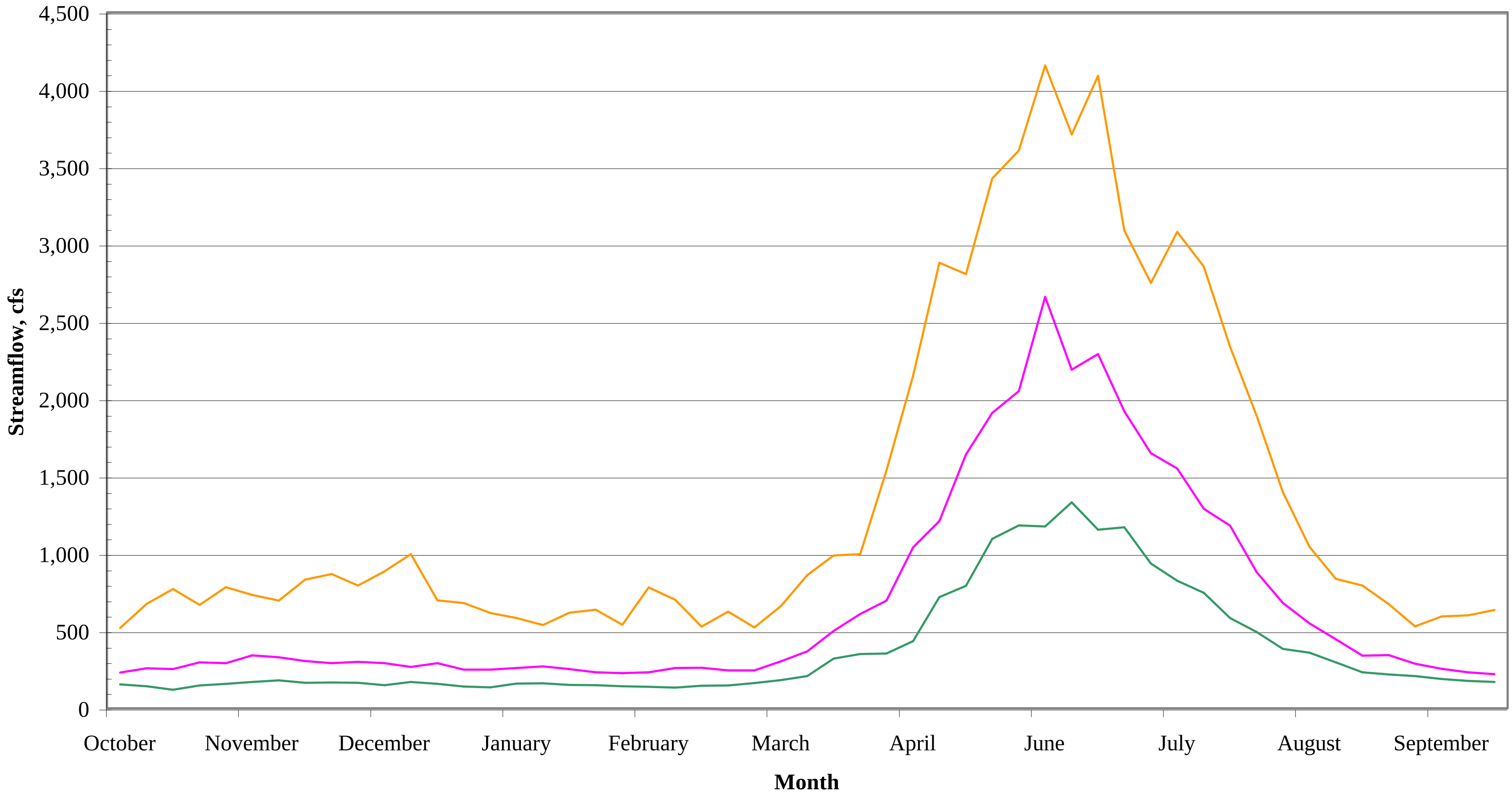

Legend

USGS Gage 12454000
Period of Record 1954-1984

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.8 Weekly Streamflow Exceedence Probability
White River near Plain, WA

Wenatchee River Basin Watershed Assessment

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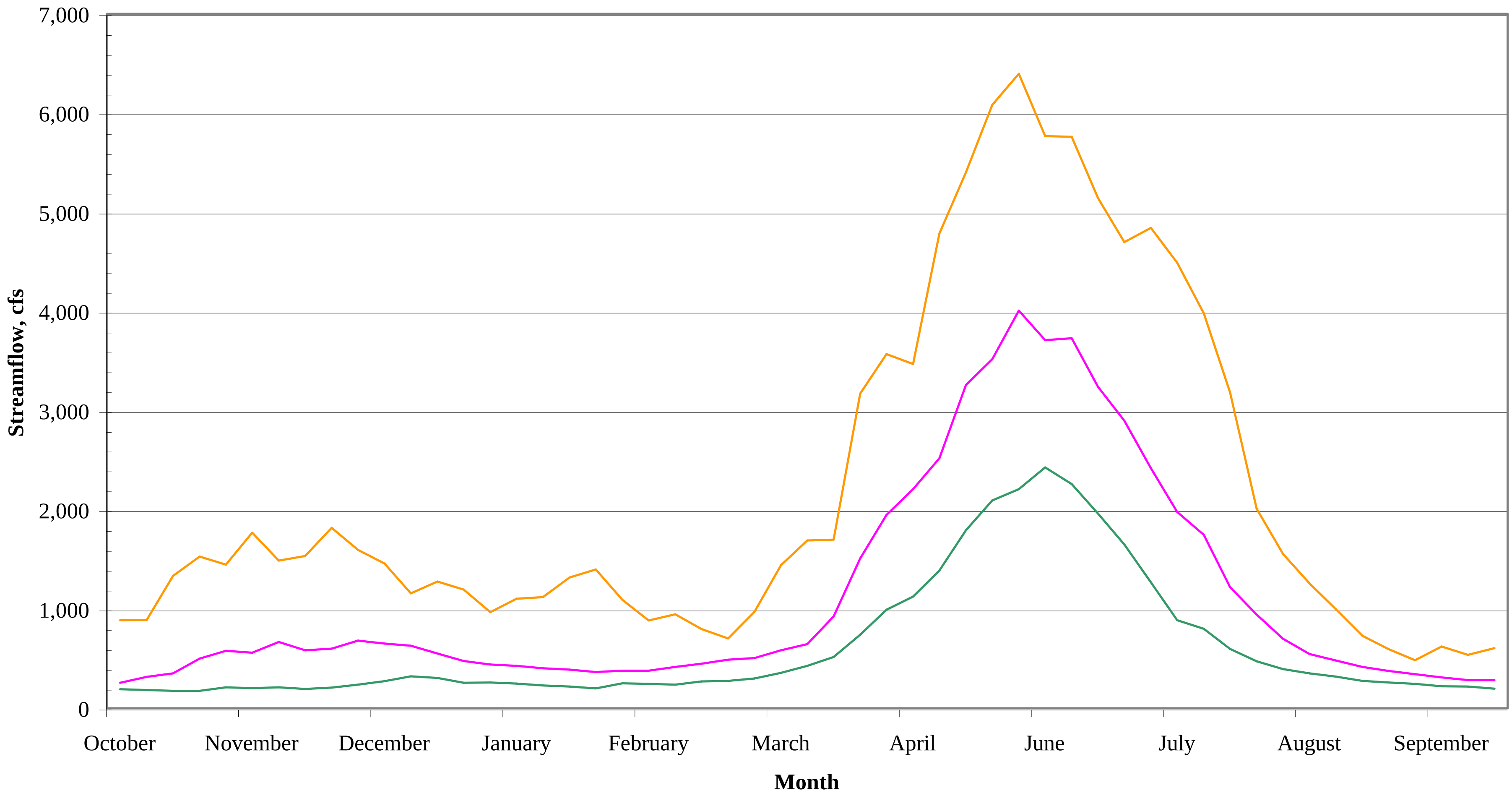


Legend

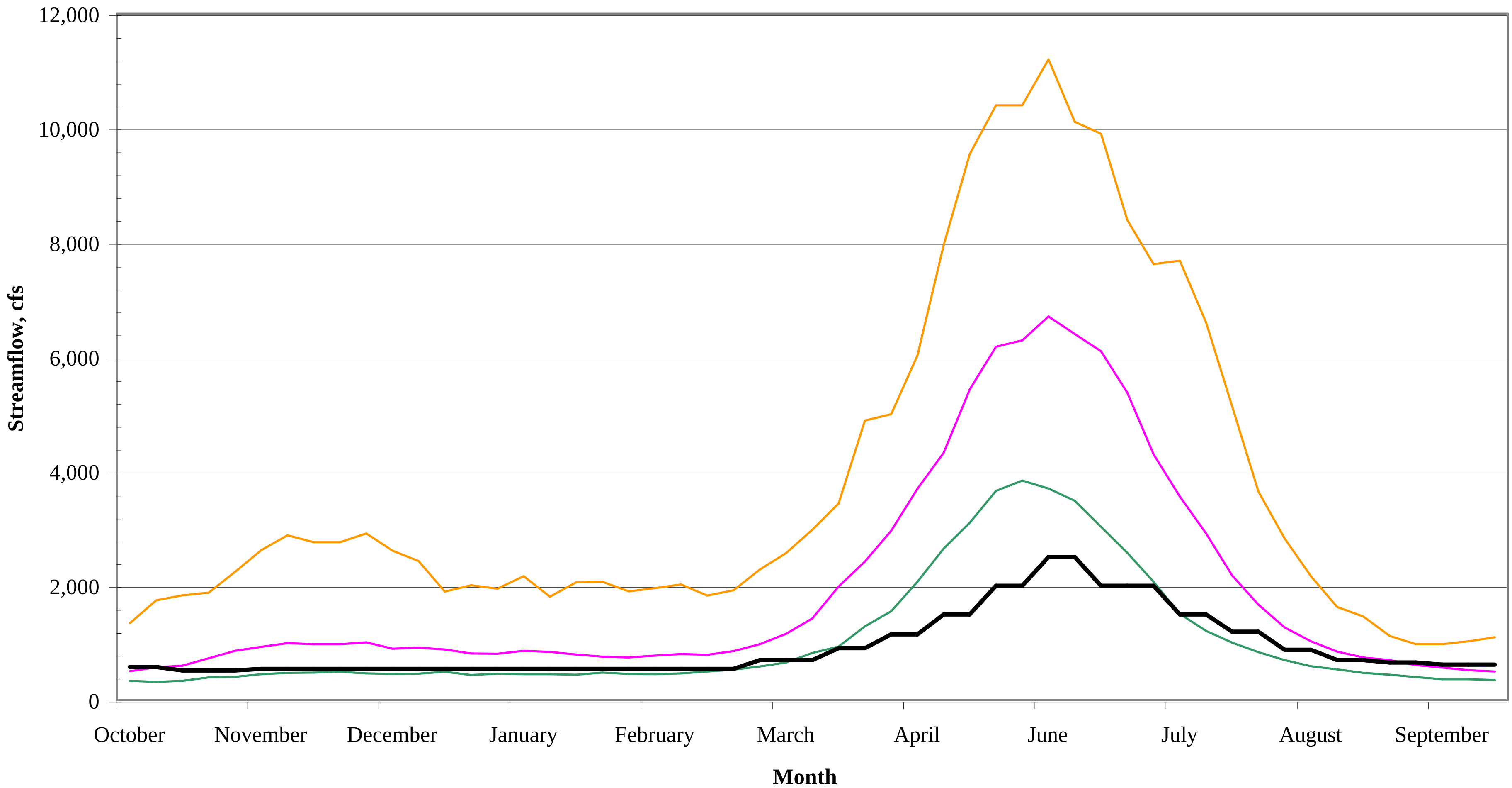
USGS Gage 12455000
Period of Record 1932-1958

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.9 Weekly Streamflow Exceedence Probability
Wenatchee River below Wenatchee Lake, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

USGS Gage 12457000
Period of Record 1911-1929,
1930-1980, 1989-2002

90% Exceedence
50% Exceedence
10% Exceedence
IRPP Flows

Figure 4.10 Weekly Streamflow Exceedence Probability
Wenatchee River at Plain, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.

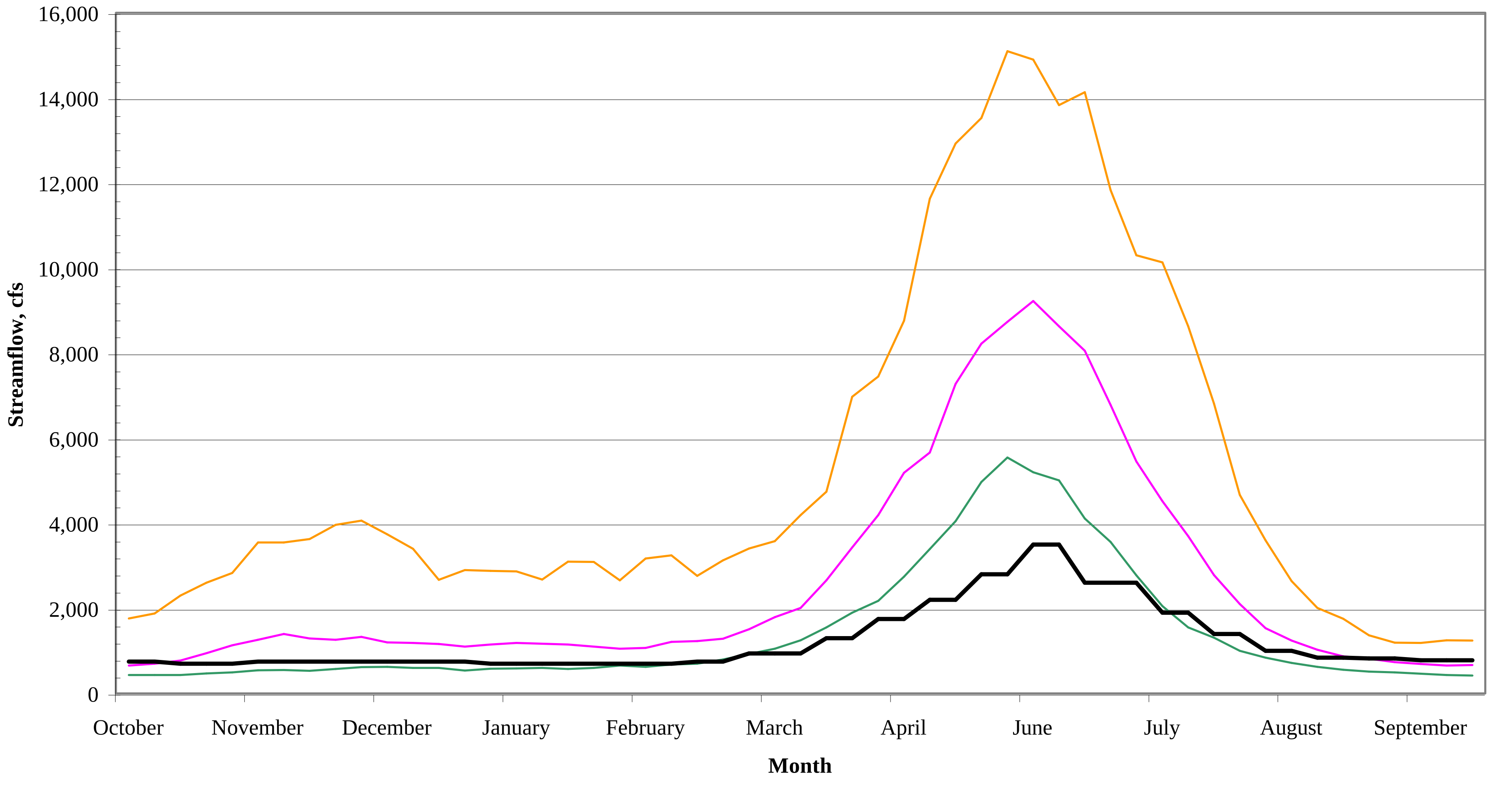
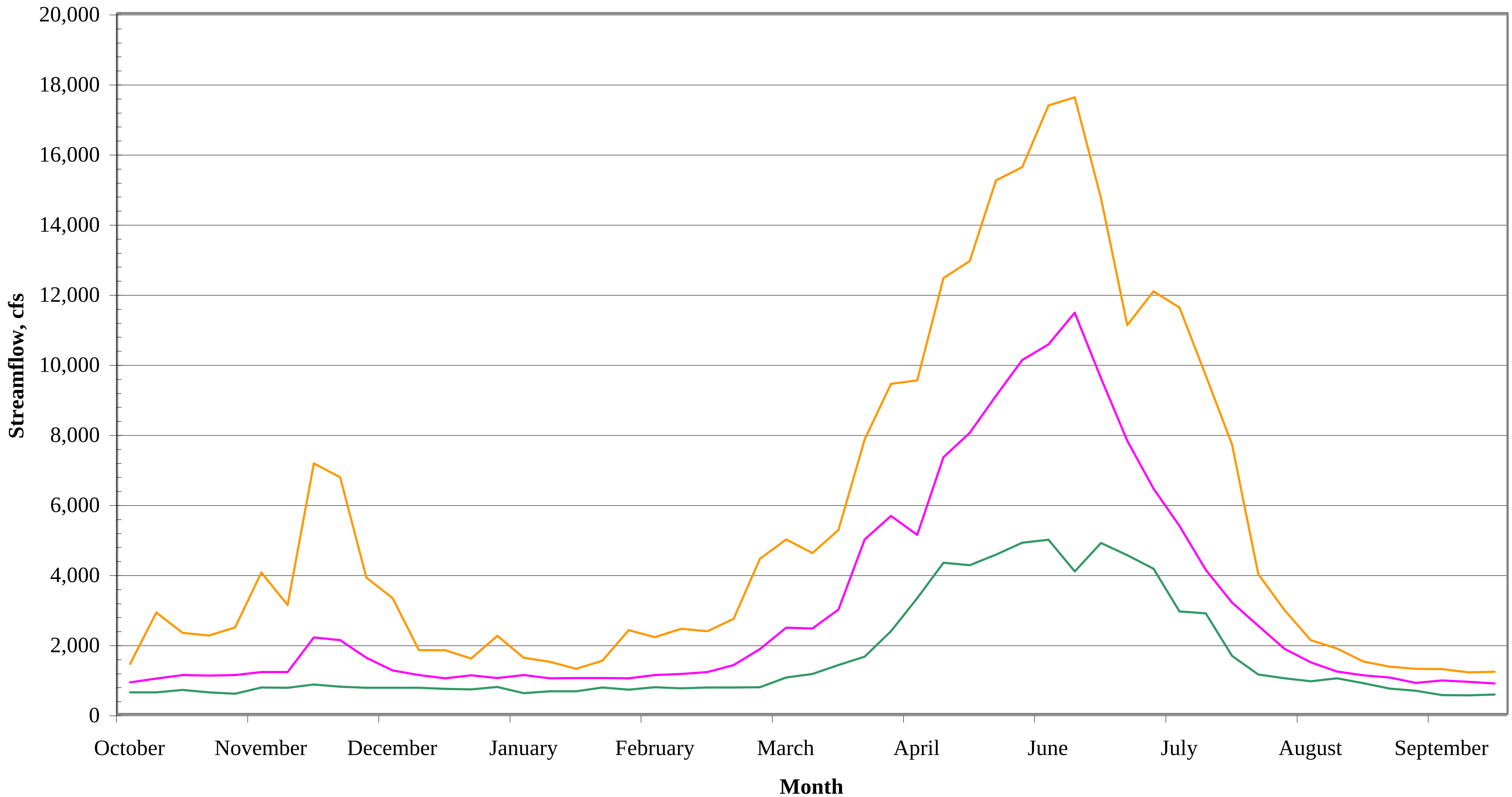


Figure 4.11 Weekly Streamflow Exceedence Probability
Wenatchee River at Peshastin, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

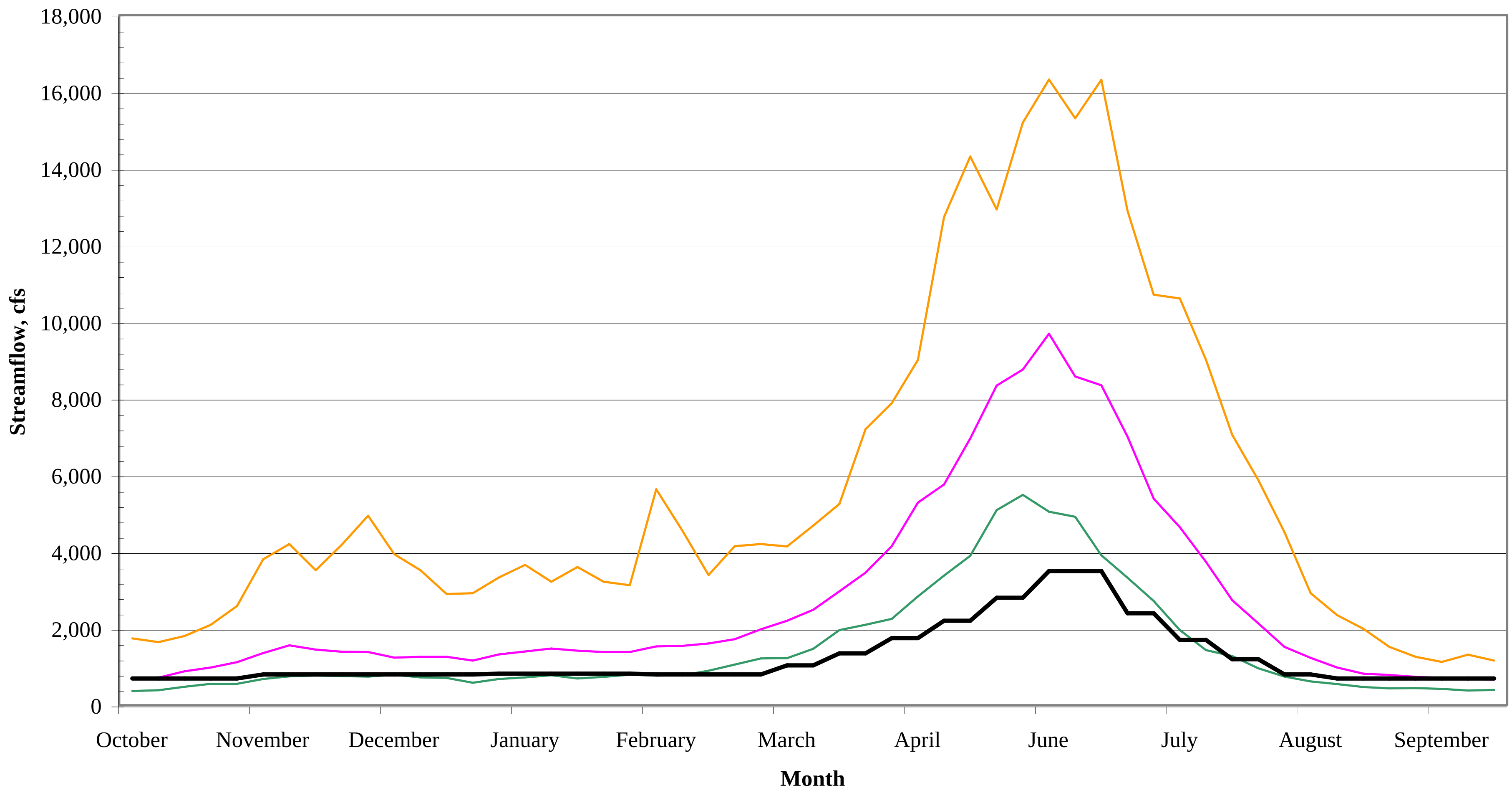
USGS Gage 12461000
Period of Record 1907-1915,1917

90% Exceedence
50% Exceedence
10% Exceedence

Figure 4.12 Weekly Streamflow Exceedence Probability
Wenatchee River at Dryden, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Legend

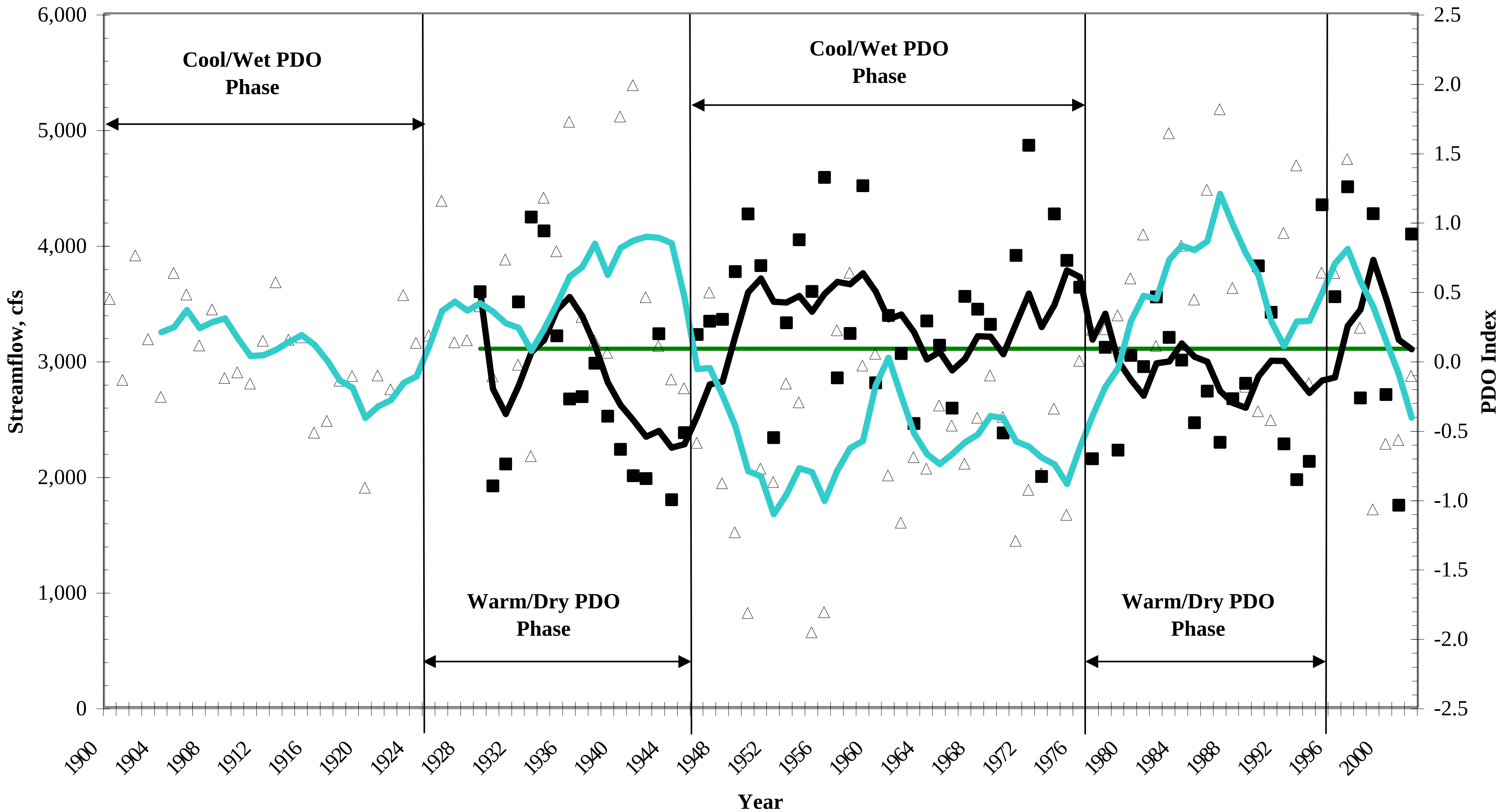
USGS Gage 12462500
Period of Record 1963-2002

90% Exceedence
50% Exceedence
10% Exceedence
Minimum Flow from WAC

Figure 4.13 Weekly Streamflow Exceedence Probability Wenatchee River at Monitor, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



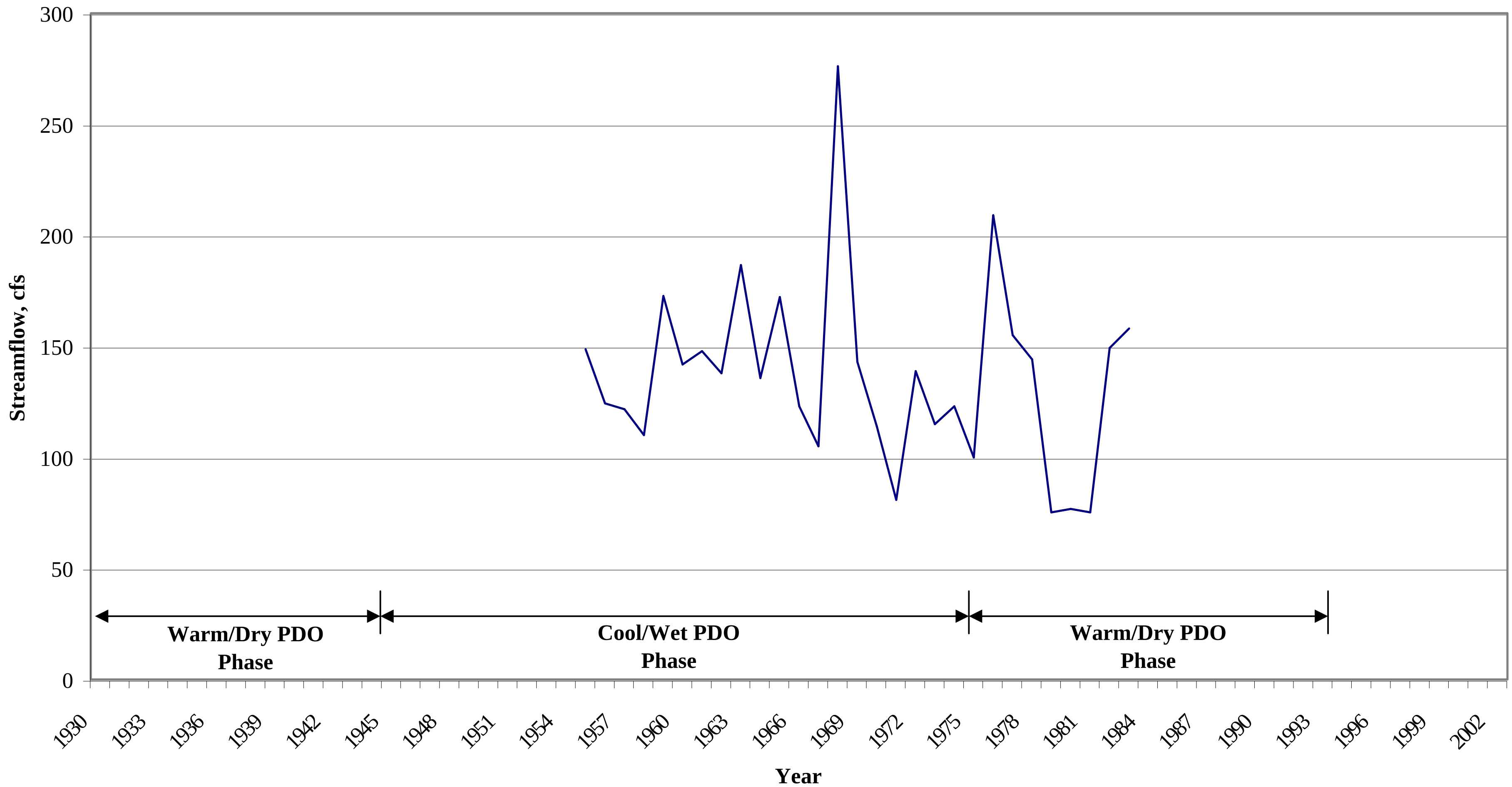
Legend

- Wenatchee at Peshastin
- Mean Annual Wenatchee at Peshastin Flow
- Wenatchee Flow: 5-Year Moving Average
- PDO Index: 5-Year Moving Average

Figure 4.14 Trend Analysis
PDO Index and Wenatchee River
Mean Annual Flow at Peshastin

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Note: Only includes years with a full data set.

Legend

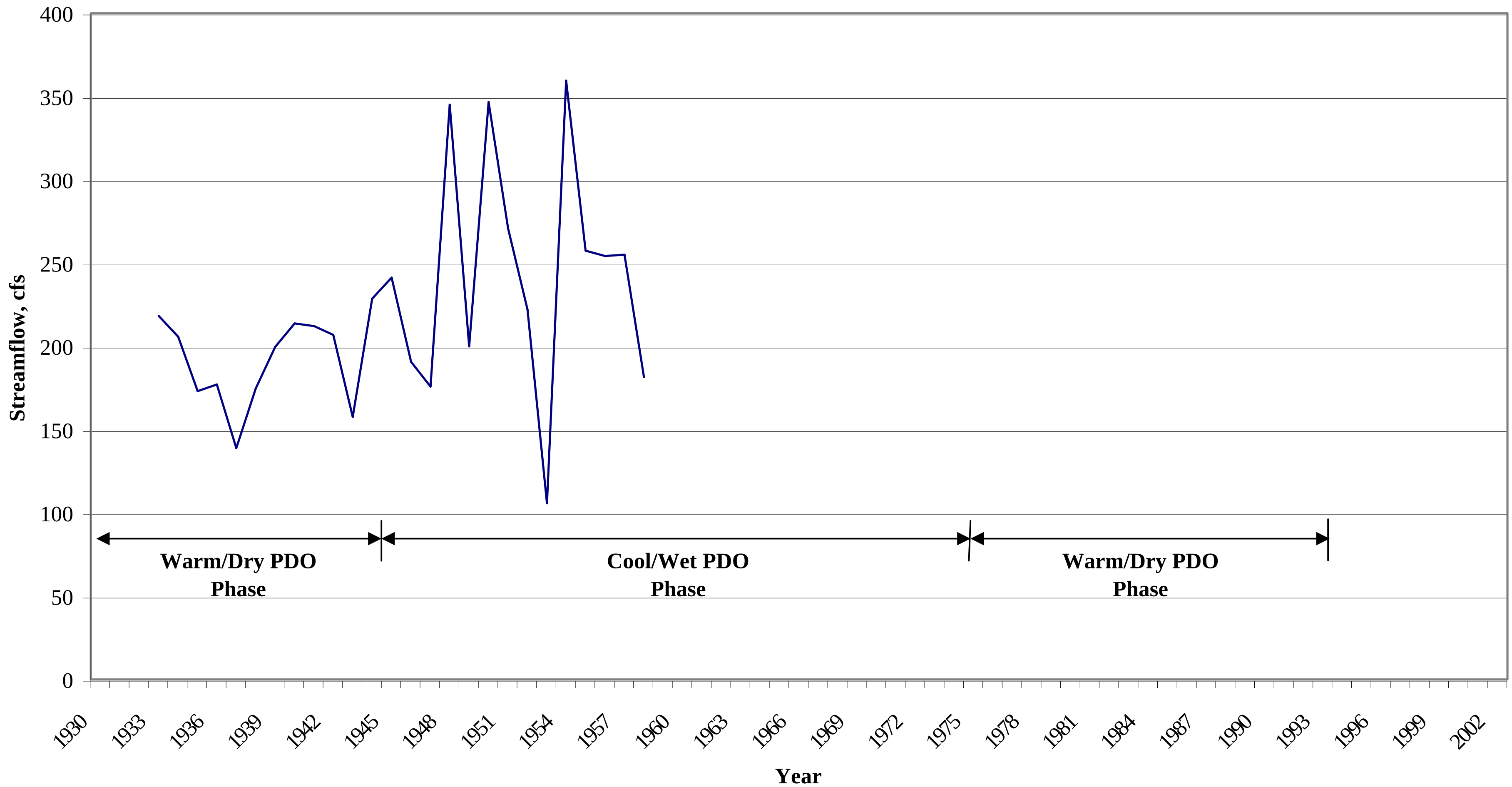
USGS Gage 12454000
Period of Record 1954-1984

Annual 7 - Day Low Flow

Figure 4.15 7-Day Low Flows
White River near Plain, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Note: Only includes years with a full data set.

Legend

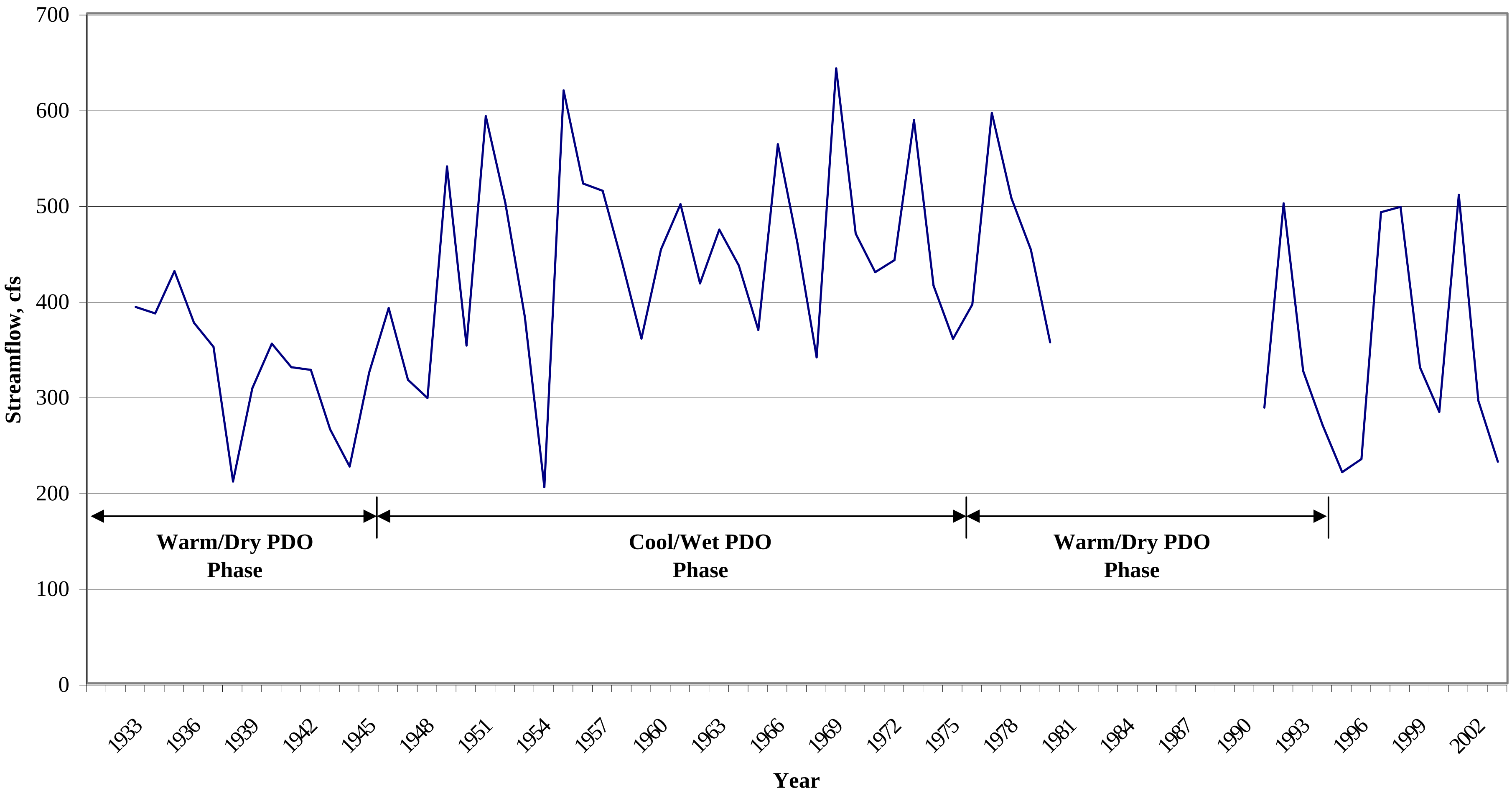
USGS Gage 12455000
Period of Record 1932-1958

Annual 7 - Day Low Flow

Figure 4.16 7-Day Low Flows
Wenatchee River below Wenatchee Lake, WA

MONTGOMERY WATER GROUP, INC.

Wenatchee River Basin Watershed Assessment



Note: Only includes years with a full data set.

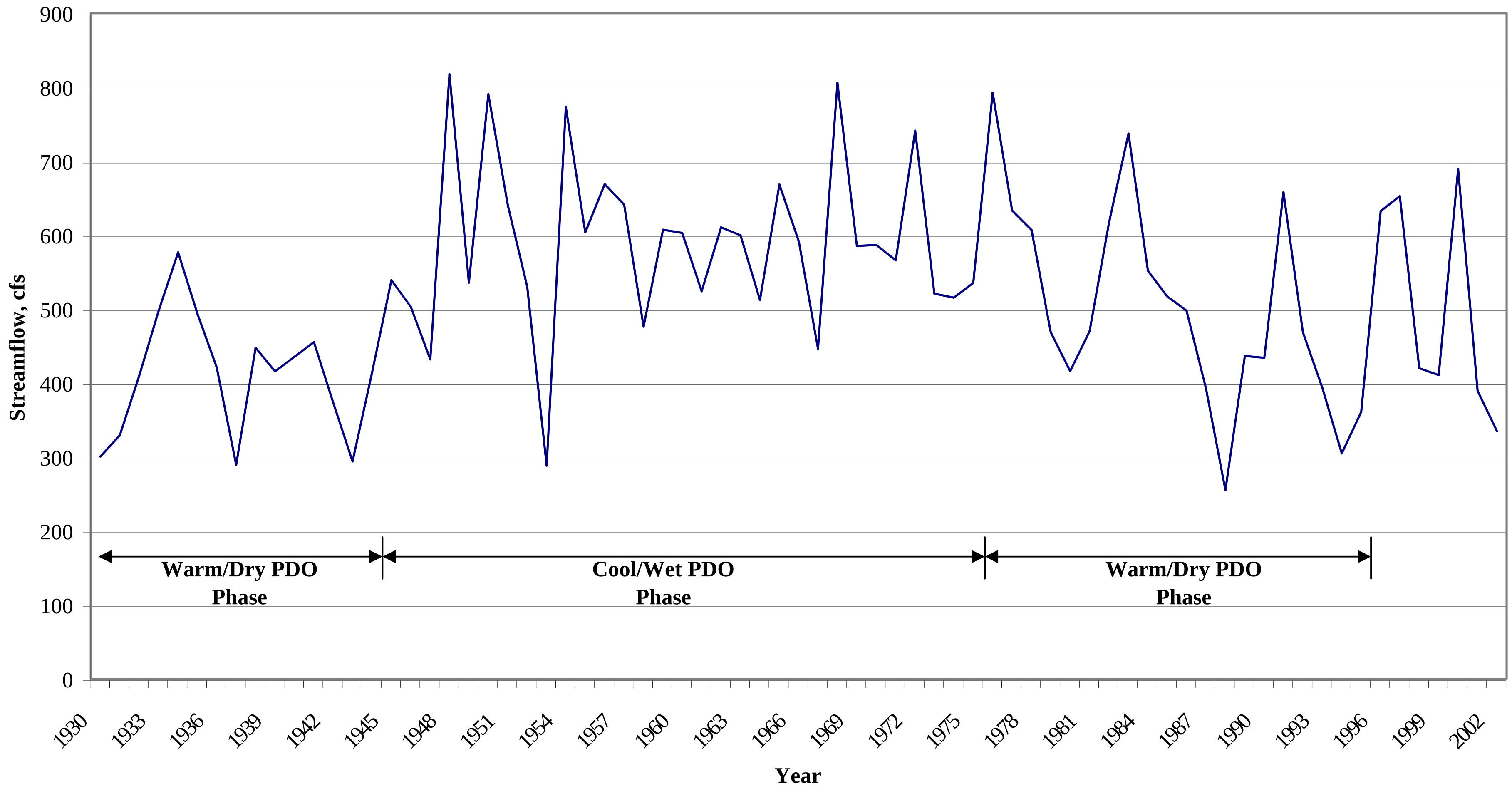
Legend

USGS Gage 12457000
Period of Record 1911-1929,
1930-1980, 1989-2002

Annual 7 - Day Low Flow

Figure 4.17 7-Day Low Flows
Wenatchee River at Plain, WA

MONTGOMERY WATER GROUP, INC.



Note: Only includes years with a full data set.

Legend

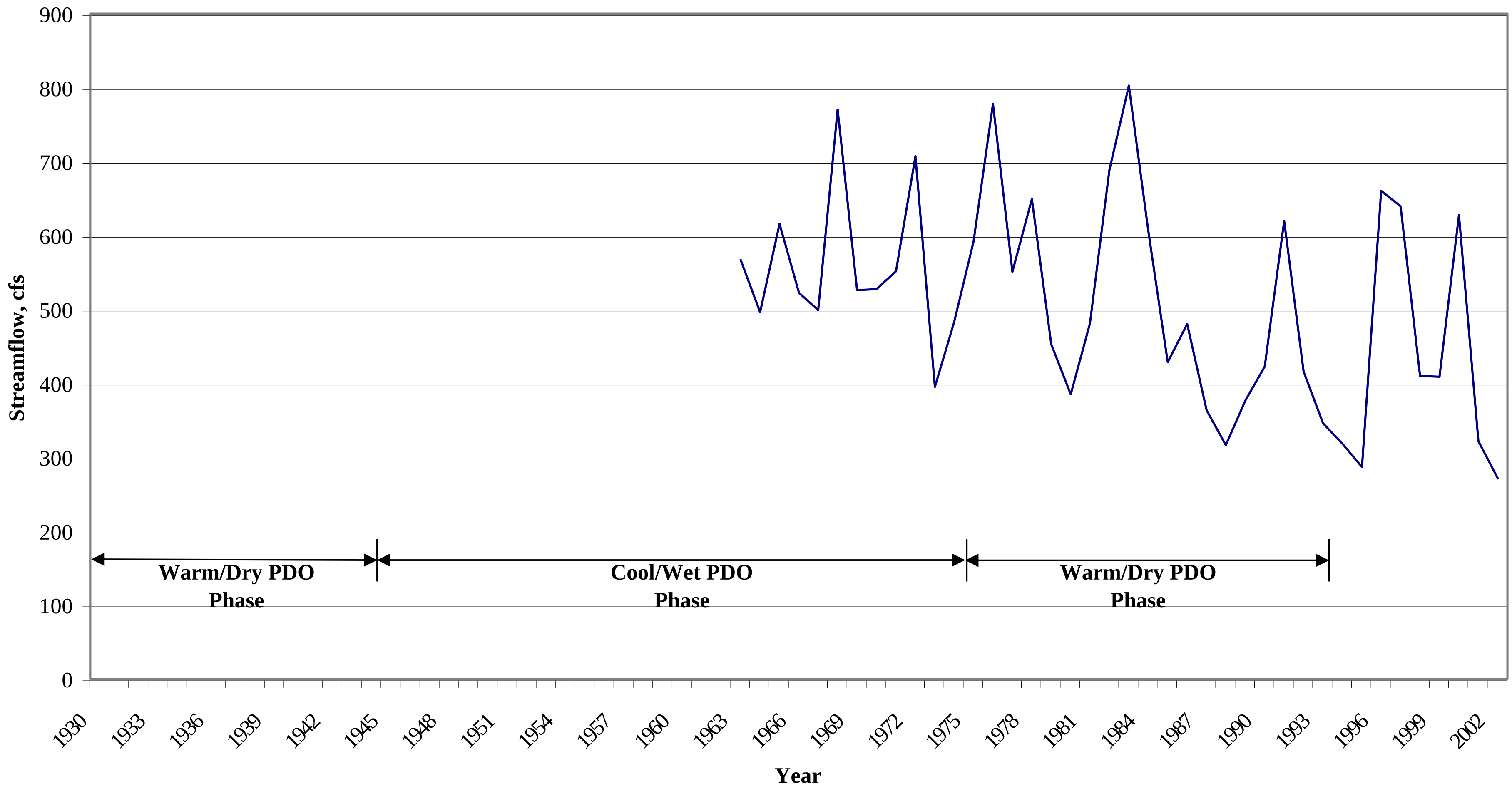
USGS Gage 12459000
Period of Record 1929-2002

Annual 7 - Day Low Flow

Figure 4.18 7-Day Low Flows
Wenatchee River at Peshastin, WA

Wenatchee River Basin Watershed Assessment

Montgomery Water Group, Inc.



Note: Only includes years with a full data set.

Legend

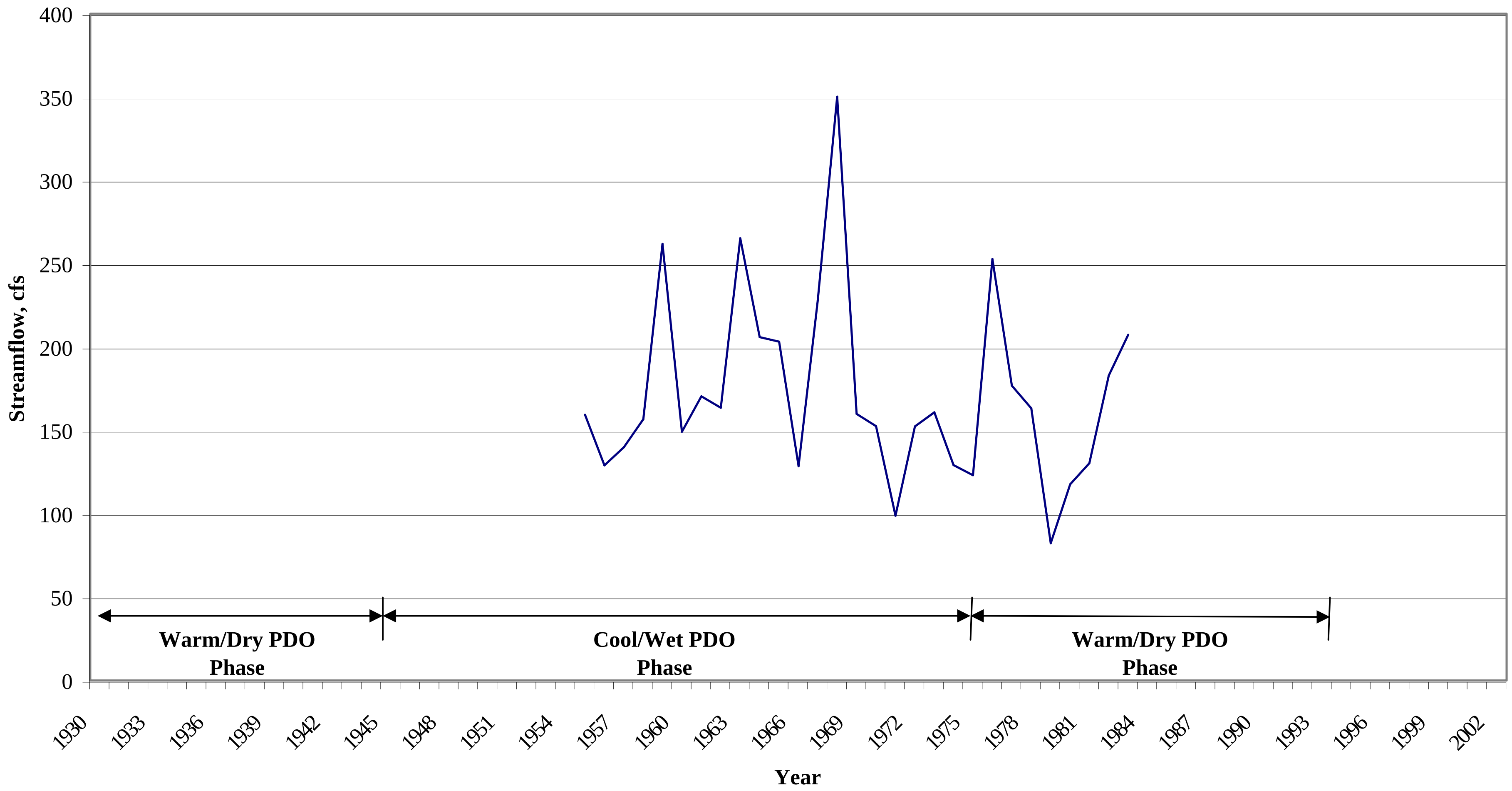
USGS Gage 12462500
Period of Record 1963-2002

Annual 7 - Day Low Flow

Figure 4.19 7-Day Low Flows
Wenatchee River at Monitor, WA

MONTGOMERY WATER GROUP, INC.

Wenatchee River Basin Watershed Assessment



Note: Only includes years with a full data set.

Legend

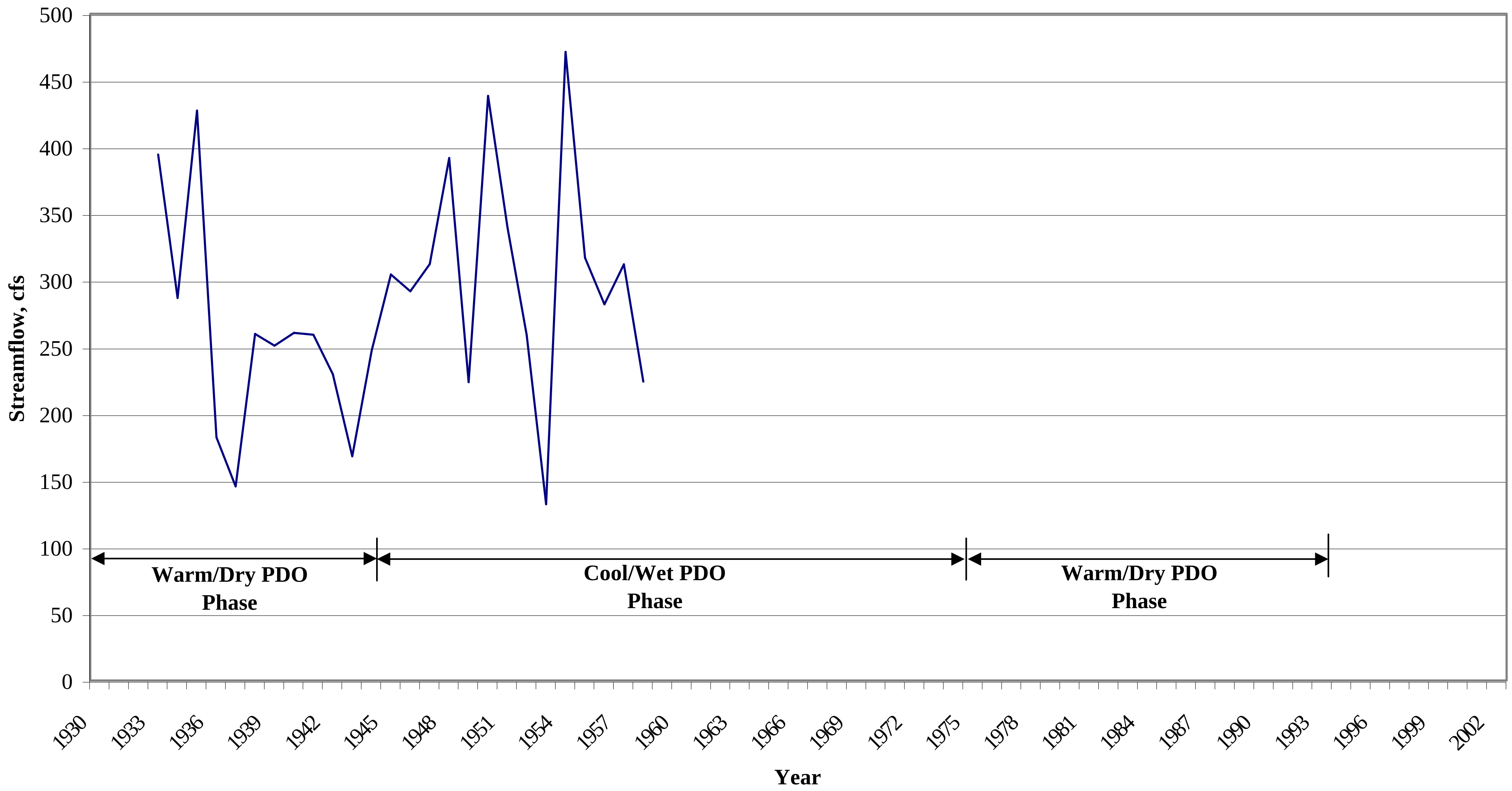
USGS Gage 12454000
Period of Record 1954-1984

Annual 30 - Day Low Flow

Figure 4.20 30-Day Low Flows
White River near Plain, WA

Wenatchee River Basin Watershed Assessment

MONTGOMERY WATER GROUP, INC.



Note: Only includes years with a full data set.

Legend

USGS Gage 12455000
Period of Record 1932-1958

Annual 30 - Day Low Flow

Figure 4.21 30-Day Low Flows
Wenatchee River below Wenatchee Lake, WA

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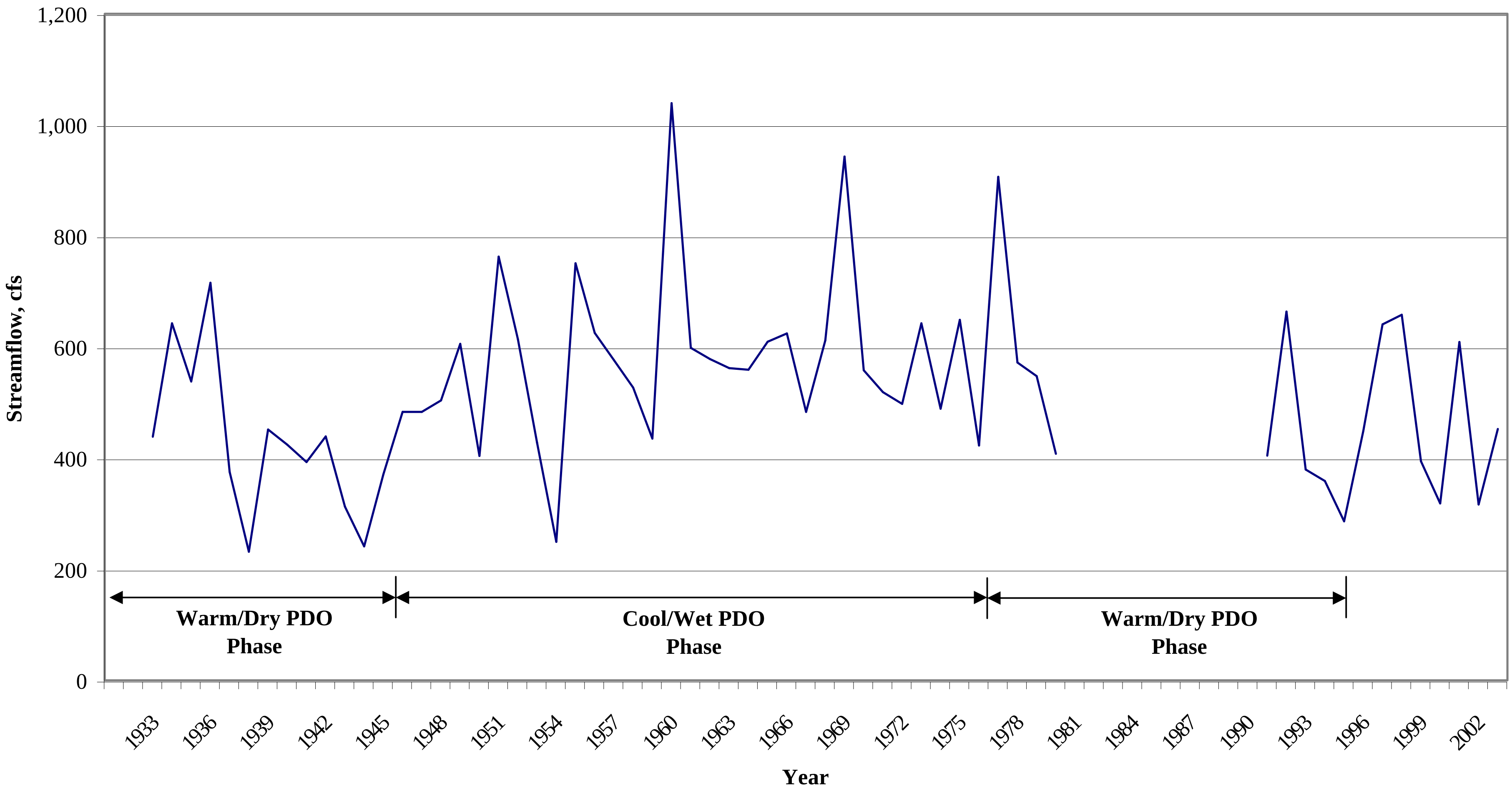

Note: Only includes years with a full data set.

Legend

USGS Gage 12457000
Period of Record 1911-1929,
1930-1980, 1989-2002

Annual 30 - Day Low Flow

Figure 4.22 30-Day Low Flows
Wenatchee River at Plain, WA

Wenatchee River Basin Watershed Assessment

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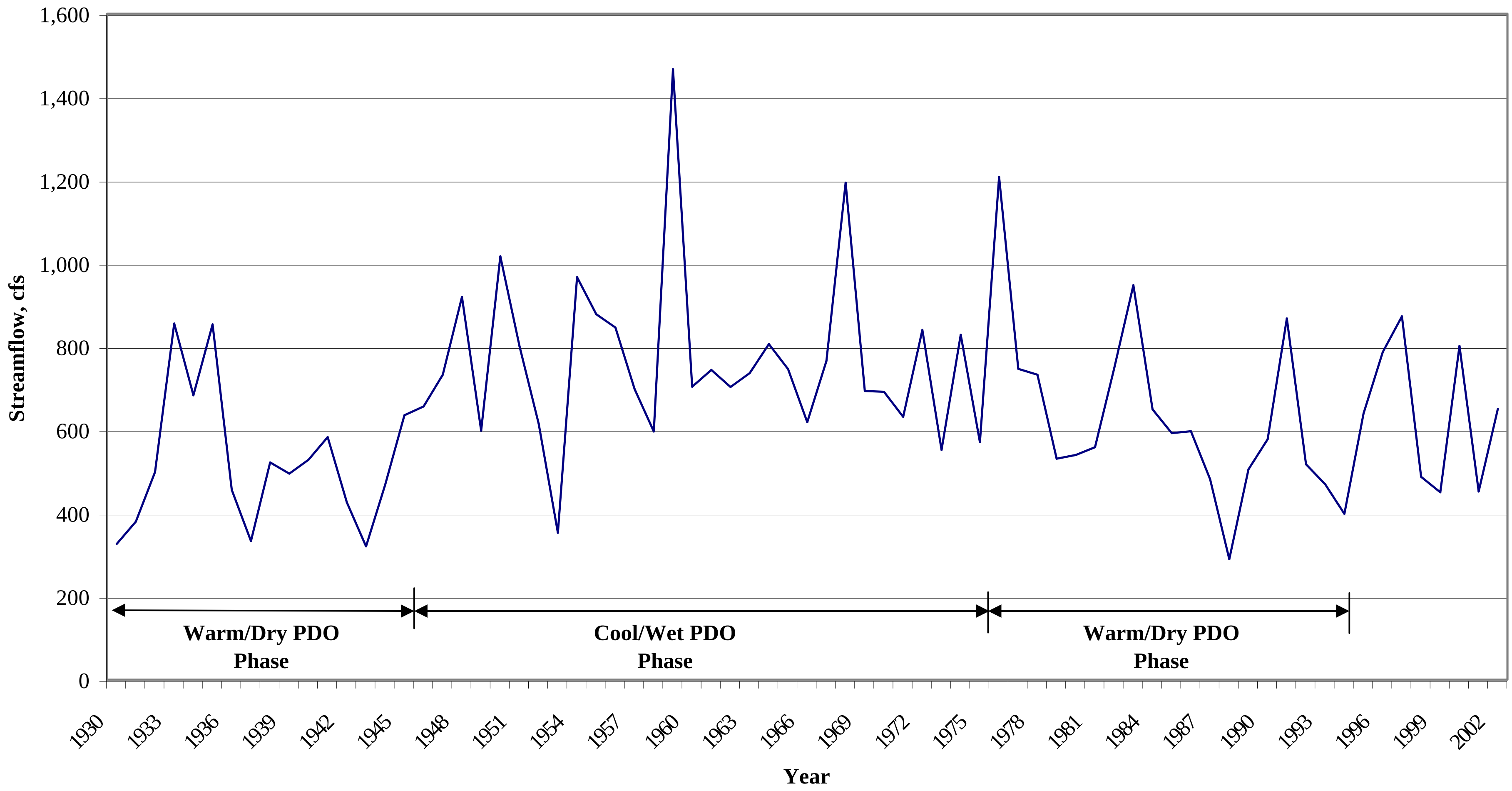

Note: Only includes years with a full data set.

Legend

USGS Gage 12459000
Period of Record 1929-2002

Annual 30 - Day Low Flow

Figure 4.23 30-Day Low Flows
Wenatchee River at Peshastin, WA

Wenatchee River Basin Watershed Assessment

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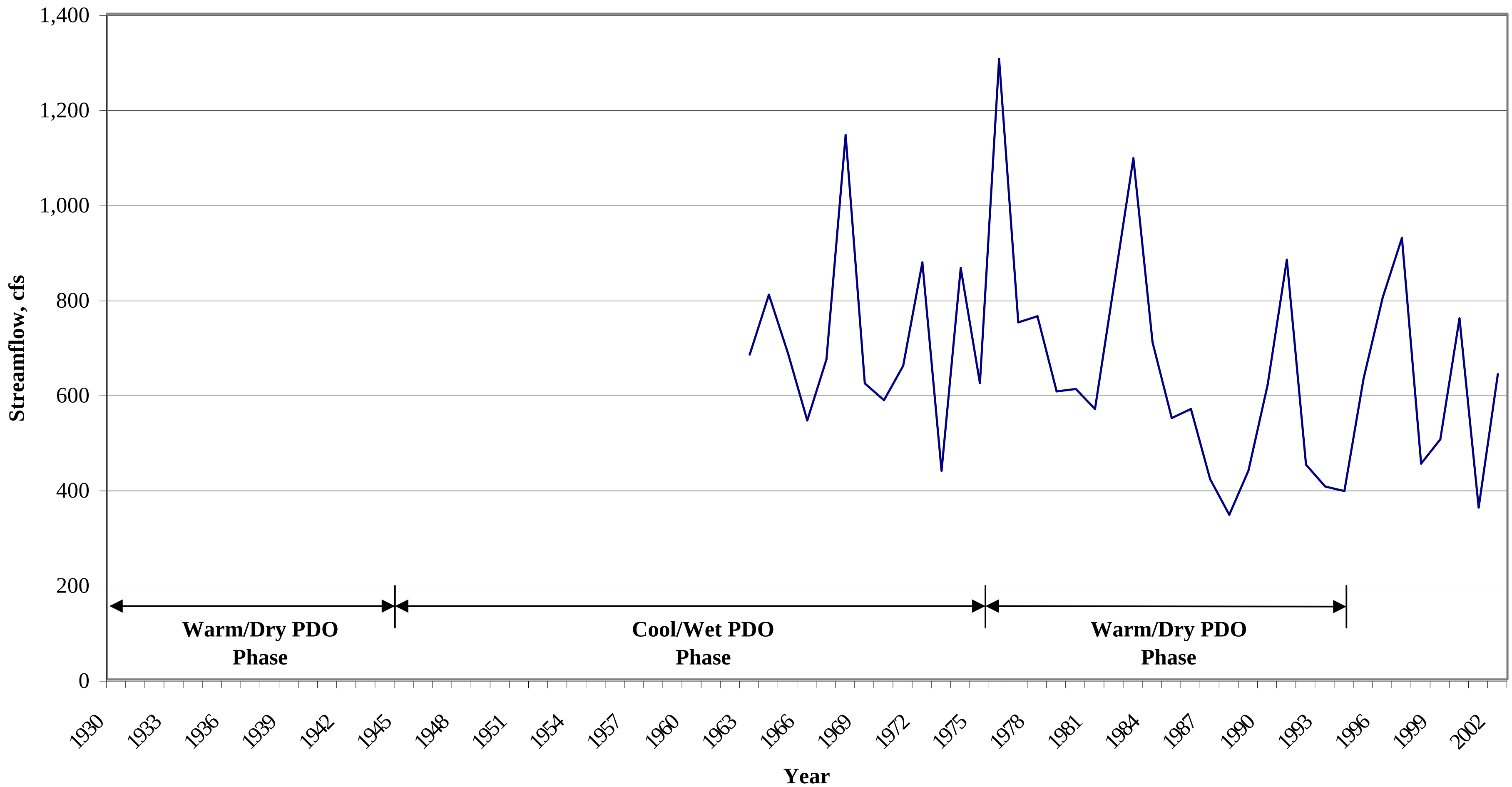

Note: Only includes years with a full data set.

Legend

USGS Gage 12462500
Period of Record 1963-2002

Annual 30 - Day Low Flow

Figure 4.24 30-Day Low Flows
Wenatchee River at Monitor, WA

Wenatchee River Basin Watershed Assessment

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5.0 Groundwater

5.1 Geologic Setting

The geology of WRIA 45 in Chelan County is predominated by igneous and metamorphic bedrock in the upland perimeter areas and by sedimentary bedrock deposited within the Chiwaukum Graben (basin) structure that forms the more central lowland areas. The regional Entiat and Leavenworth Faults form sharp, distinct boundaries that easily define the extent of the lowland sedimentary formation's sandstones and shales and distinguish it from the WRIA's upland perimeter igneous and metamorphic rocks. Geologic processes including erosion, alpine glaciation, formation of streams, etc., have transported and deposited unconsolidated sediments over the bedrock, predominately within areas of relative low relief such as valley bottoms, in the form of interbedded gravels, sands, silts and clays. The geologic description and other local information was derived from discussions with Anna Hoselton of the Department of Ecology.

5.2 Hydrogeology

Much of the precipitation in WRIA 45 occurs as snow in the winter and is retained as snow pack until spring. The generally very low primary permeability[1] characteristics of the upland metamorphic and igneous rocks result in much of the snowmelt discharging in the form of run off to surface water. In areas where the upland bedrock is fractured, some precipitation or snowmelt may percolate into the fracture systems and travel via fracture flow. In the more central and lowland areas where the primary permeability of the sandstones and shales of the Chumstick Formation tends to be moderately low, folding and faulting have primarily caused the shale members to break up or fracture. As a result, groundwater tends to move preferentially within these zones of higher "secondary" permeability. Unconsolidated sediments overlying the bedrock, particularly sands and gravels, exhibit relatively high permeability where groundwater can move easily while interbedded lower permeability silts and clays may impede groundwater flow.

Drillers' well logs indicate that wells within the WRIA are either completed in alluvial valley unconsolidated sediments where sufficient groundwater is encountered, or are drilled into bedrock. Because the majority of the WRIA's population tends to be located within the lowland regions of the Chiwaukum graben, bedrock wells are mostly completed in the sandstone/shale sequence of the Chumstick Formation. Well driller's records suggest that well yields from the alluvium ranges from about five to as much as 100 gallons per minute (gpm). Drilling records may optimistically suggest that Chumstick bedrock wells display similar yields; however, such construction-day estimates often do not reflect the actual or long-term behavior of these wells. More commonly, Chumstick bedrock wells exhibit long-term yields that range from less than one gpm up to around 15 gpm. Wells drilled in the upland igneous and metamorphic rocks, likewise tend to display relatively low yields and

[1] Primary permeability is a result of the porosity of a material, as opposed to secondary porosity, which is a product of fracturing.

are dependant on the size of and connectivity of the fracture system they intersect. As a result, these wells may display irregular yields related to volume depletion and non-laminar flow. Locally, wells completed in tributary valleys such as Brender Canyon, Peshastin Creek, and Mission Creek are more often completed in the Chumstick Formation. Wells completed near Chumstick Creek or the lower Wenatchee River are more likely to be completed in the unconsolidated alluvium.

A hydrogeologic investigation of the Chumstick Creek drainage groundwater flow system was presented in *Hydrogeology and Ground-Water Conditions in the Chumstick Drainage Basin* (Wildrick, 1979). The Chumstick Creek drainage basin is located in the central portion of the WRIA 45, and covers approximately 76 square miles (Department of Ecology, 1983). The thickness of the unconsolidated deposits within the alluvial valleys range from less than five feet to more than 150 feet toward the center of the valleys. Where the unconsolidated deposits are thickest, the report identified three types of deposits listed here in order of increasing depth:

- A thin deposit of silty sand
- Fine-grained deposits (silt and clay) with minor amounts of sand and gravel
- Coarse grained deposits (sand and gravel)

These alluvial deposits are underlain by the Chumstick sandstones and shales. The report classified three types of aquifers in the Chumstick Creek drainage basin:

- Where saturated, a shallow water-table aquifer composed of the uppermost silty sands.
- A lowermost coarse-grained sand and gravel, and
- Underlying Chumstick Formation Bedrock.

5.3 Hydraulic Conductivity

Hydraulic conductivity refers to the ability of a geologic material to transmit water. A map of surficial geology of the WRIA was modified and used to assess hydraulic conductivity. Rock types appearing on the geologic map were grouped into three categories in order of decreasing hydraulic conductivity and re-named High, Moderate to Low and Very Low. These groups were mapped along with the streams of the WRIA and depicted in Map 6.

The relatively High range hydraulic conductivity (example: unconsolidated alluvial sands and gravels) is represented in Map 6 in yellow; Moderate to Low range less conductive material (example: Chumstick formation) is represented in pink, and Very Low hydraulic conductivity (example: igneous and metamorphic bedrock) is represented in green. In general, Very Low range conductivity predominates in upland areas and valley bottoms are comprised of Moderate to Low range conductivity with some areas of High range conductivity. Most of the rivers, especially in the populated areas, flow through areas of Moderate to Low range conductivity (Map 6).

5.4 Recharge / Discharge

Typically, groundwater/surface water interaction is evaluated using field methods such as seepage runs or coincident long-term monitoring of surface water and groundwater levels at multiple locations. Computer models may also be used to assess the impacts of wells on stream flows. Because these methods are out of the scope of this report, readily available data such as geologic maps and well logs have been used to develop the following generalized description of groundwater/surface water interaction within the WRIA.

For purposes of this discussion, the hydraulic gradient is the difference in elevation between two water bodies (i.e., the stream stage and the water table aquifer) divided by the distance between them. Where the groundwater elevation is higher than the stream surface, the gradient is toward the stream; groundwater will discharge in the direction of the stream and cause the stream to gain water. Conversely, where the groundwater elevation is lower than the stream surface, the gradient will be toward groundwater, the stream will lose water as it discharges to the surrounding aquifer. While no map exists of hydraulic gradient as it does for geology, inferences can be made about hydraulic gradient based on geology, hydrogeology, groundwater levels from well logs, and surface water elevations.

Precipitation and snowmelt recharge the WRIA's streams and aquifers. Streams generally act as drains and gain water as they pass through a basin. However, in some areas, stream water may be lost to the underlying groundwater system. The streams that drain WRIA 45 will generally lose water where they transition from low permeability bedrock or low permeability alluvial material to higher permeability alluvial material. Transitions from low to high permeability alluvial material occur along the lower reach of the Chiwawa River, Chumstick Creek near Leavenworth, and the lower reach of Peshastin Creek (Map 6).

Conversely, where bedrock becomes shallower, it tends to force groundwater out of the unconsolidated materials into the streams, creating a gaining stream condition. Where alluvial valley-fill aquifers, composed of relatively higher permeability unconsolidated materials, tend to thin, groundwater will often discharge to stream and river systems. Where alluvial valley-fill aquifers thicken, groundwater will often be recharged by surface water. The occurrence of significant amounts or definable layers of low permeable fine alluvial materials such as silt and clay may act to inhibit direct groundwater/surface water exchange.

Ground water within the sandstone/shale bedrock, as with porous medium, discharges in the direction of high head to low head. Flow paths within the folded and faulted formation are, however, affected by preferential flow along bedding planes as well as boundary conditions formed by geologic structures. As a result, identifying potential points of groundwater discharge becomes challenging and uncertain. Identifying regions where the moderately low permeable formation is likely recharged directly or indirectly by surface water may be more intuitive, however, it should be recognized that geologic structure, secondary permeabilities, etc., would play a role in such determinations. Detailing the recharge and discharge characteristics of this unit are beyond the scope of this analysis. It is perhaps more important to simply recognize the unit as a complex low yield aquifer, generally suitable only for domestic quantities of ground water.

Similarly, fracture system aquifers in the igneous and metamorphic bedrock, discharge from high head to low head. Fracture systems form preferential flow paths that are complex and uncertain to predict. Like the Chumstick Formation, analysis of recharge/discharge characteristics of these units is impractical. It is perhaps more important to recognize these units as minor complex low yield aquifers, generally suitable only for domestic quantities of water.

5.5 Effects of Pumping on Streamflow

The relationship between a stream and adjacent groundwater can be affected by pumping wells. Where groundwater and surface water are connected, drawdown due to pumping can affect local groundwater levels in the vicinity of a stream and thus affect the gradient. The degree of influence a well has on a stream is a function of pumping rate, proximity to the stream, hydraulic conductivity of the underlying aquifer, and presence or absence of low permeable materials that may inhibit surface water – groundwater exchange. Increased pumping, close proximity, and high hydraulic conductivity will all increase stream influences. The analysis of influence is generally evaluated using a computer model. Using models, the influence of future well installations on streamflow can be performed on a case-by-case basis or to predict cumulative effects.

Much of the growth occurring within the WRIA is as small domestic wells located along smaller drainages. This growth may cause significant impact to the small streams within the drainages. A water balance could compare the withdrawals versus the amount of recharge occurring within the basin. However, water exits from a basin both as surface water and as groundwater. A water balance cannot predict whether water pumped from a well will affect water exiting as groundwater or surface water or both. As discussed above, an analytical or numeric groundwater model is required to make that assessment.

5.6 Instream Resource Protection

WAC 173-545 governs water rights within WRIA 45. This administrative code sets instream flows for the Wenatchee River at Plain, Icicle Creek near Leavenworth, and the Wenatchee River at Peshastin. In addition, Peshastin Creek is closed seasonally, from June 15 to October 15. During this time, no new consumptive appropriations are allowed. Outside this time period, instream flows as measured at the Wenatchee river gage at Monitor govern availability within the Peshastin drainage basin. There are no legislated closures to groundwater withdrawals within the basin due to groundwater/surface water continuity issues; however, Ecology evaluates groundwater permit applications and may condition those permits to instream flows or if appropriate deny an application if significant hydraulic continuity is found.

5.7 Groundwater Available

This section provides a discussion of three key terms in Watershed Planning (water present, water available and water available for further appropriation) as they relate to the availability of ground water in the Wenatchee River Watershed. The Watershed Planning Act (RCW 90.82) does not define these terms and no standard definitions have been applied throughout the State. Therefore, for the purposes of this Watershed Assessment the Water Quantity Technical Subcommittee has developed its own interpretation of what these terms mean and how they should be applied to the Wenatchee Watershed.

Very little information is available to complete an assessment of groundwater and provide estimates of groundwater present, available and available for future appropriation. Accurate quantification of these terms would require the collection and analysis of an extensive amount of additional information, which is beyond the scope and budget allotted to this assessment. The Water Quantity Technical Subcommittee decided that it would not be beneficial to produce estimates of groundwater available with existing data, as there is no benefit to providing highly imprecise estimates that also could not be verified.

The Subcommittee's definitions of the terms are presented below, followed by a discussion of the data that would be required to quantify these terms and an approach that could be used to determine the quantity of water available for further appropriation.

5.7.1 Water Present in Context of RCW 90.82

For the purpose of this watershed assessment, the Subcommittee's interpretation of water present is the total quantity or volume of water stored in aquifers in the Wenatchee River Watershed. This volume varies seasonally and annually due to changes in recharge (precipitation, streamflow), discharge and withdrawals from the aquifers. The water present can be represented by the mean annual quantity of water stored in the aquifers. The data requirements to accurately estimate water present are extensive. In addition to reviewing available data, an extensive amount of new information on the characteristics of the aquifers would need to be collected and evaluated. Quantification of water present would require a detailed understanding of the extent and thickness, porosity, and the spatial and temporal distribution of head within each of the aquifers in the Watershed. Available data including geologic maps, wells logs, and water level data for existing wells provide some of the information needed to estimate water available. However, compilation, review and interpretation of the available data (including hundreds of boring logs, water level measurements and pumping records) on a watershed basis is beyond the scope of this watershed assessment.

5.7.2 Water Available in Context of RCW 90.82

For purposes of this Watershed Assessment, the Subcommittee's interpretation of water available is the amount of water that is physically available for withdrawal from the aquifers without impacting the ability of senior water rights holders to use their water right. Water available will vary as ground water levels in the aquifers fluctuate due to changes in recharge and discharge. Estimating water available would first require an estimate of water present. Secondly, the physical characteristics of aquifers would need to be determined. In addition to the physical limitations associated with the withdrawal of ground water there are practical, economic and legal constraints that limit the availability of ground water. For example, it is not generally considered feasible to dewater or dry-up an aquifer and it may not be cost effective to extract ground water from great depths due to the high pumping costs. Economic availability depends in part upon demand and scarcity in the intended use. In areas where water is practically and economically available, legal constraints related to the impairment of senior water rights (particularly where surface water is in continuity with ground water and surface flows are fully appropriated or below established minimums) may reduce the quantity of water available. In some cases, the quality of ground water may limit its uses so that although present, this water may not be considered available for use. Physical management of the resource within legal limits would depend on controlling the annual quantity and location of ground water withdrawals, such that long-term pumping would not lower ground water to levels that could impair other rights.

5.7.3 Water Available for Further Appropriation in Context of RCW 90.82

For the purpose of the watershed assessment, the Subcommittee's interpretation of water available for further appropriation is the additional quantity of water that can be withdrawn from aquifers using the criteria set forth in RCW 90.03.290. According to this statute, Ecology must apply the following four tests when determining whether to grant a water right.

1) The water must be available for allocation;

2) The water must be put to beneficial use;

3) The use must not impair existing rights; and,

4) The use must not be detrimental to the public welfare.

Ecology may constrain an interpretation of "water availability" under the public interest test as indicated by various court proceedings, or by other existing laws and rules. In-stream values may be a factor in Ecology's assessment.

To determine the quantity of ground water available for further appropriation, the hydraulic relationships between the aquifers and surface water need to be better understood. In addition, watershed-wide measurements of ground water levels taken over time need to be made and analyzed, and areas of continuing ground water decline located. These relationships and the existing ground water conditions in the watershed are dependent in part on the quantity of water currently being used and the locations where it is being withdrawn from the aquifers. Therefore, the quantity of water that is currently being diverted from the streams in the basin and pumped from the aquifers needs to be determined, and locations need to be identified. Then to determine the water available for further appropriation, potential impacts or impairment associated with increased ground water withdrawals need to be identified. This assessment would include a determination of the conditions required to prevent or impairment of existing water rights. The general approach used to complete this type of an assessment includes development of a conceptual hydrogeologic model for the basin including a basin-wide water budget, followed by the development and use of a numerical model to assess how the aquifers and surface water bodies respond to different pumping scenarios.