4. CLIMATE

The accepted definition of climate is it "represents the average state of the atmosphere during a period of time" (Maidment, 1993). Climate is influenced by the combined response of the earth's water storage, land mass and atmosphere to solar radiation, and is the driving force in a hydrologic system.

The main climatic input to a watershed's water cycle is precipitation, in the form of rain and snowfall. The amount of precipitation is the primary control on the amount of water that may be available within the watershed. But other factors also influence this system including temperature, evaporation/evapotranspiration and water consumption. In addition, to fully understand a watershed's water cycle it is important to understand climate variability. Climate varies within a watershed from day to day as well as over many years. Changes in the topography greatly affect climate from town to town and sub-basin to sub-basin.

Climate variables discussed in this section include precipitation, temperature, Snow Water Equivalent (SWE), and snow depth. Continuous (historical) as well as non-continuous GIS data are made available by several agencies, including Western Regional Climate Center, Natural Resource Conservation Service, and Oregon State University.

4.1 Background Issues

The Methow Watershed is mainly a precipitation (both snow and rain) driven system; meaning that precipitation is the only water input to the system. Groundwater may also contribute small amounts of water to the system from other watersheds, but this volume is likely minimal (Walters and Nassar, 1974). The form and amounts of precipitation the Methow Basin receives is extremely variable due to the geographic location and elevation variations of the basin. This creates both technical characterization difficulties and basin management challenges.

Technical issues include:

- The Methow Basin lays within the northeastern part the Cascade Mountain Range, and except for the downstream river valley reaches, is mostly mountainous. These mountainous alpine regions range in elevation from 7,000 to 9,000 feet above mean sea level (msl) (Walters and Nassar, 1974). The river valleys in the southern portion of the basin are at a much lower elevation, with elevations of the Methow River at Pateros at 775 feet above msl. In general the higher mountain areas receive more precipitation and have lower temperature while the lower elevation regions receive much less precipitation and most of this in the form of rain.
- Conversely, even though climate in the basin is highly variable, the system as a whole responds as a snowpack driven system. Much of the precipitation that falls within the basin falls as snow during the winter months in the upper mountainous regions. Therefore there are generally lower flows in the later summer, fall and early winter and a large freshet in the spring due to snowmelt

and rain on snow events. Snowpack comprises the largest surface water storage available within the Methow. Snowpack levels and the timing and rate of snowmelt highly affect how long the spring freshet can feed the lower river system.

- There is little additional traditional surface storage in the basin beyond that of annual snowpack. Once the spring freshet has moved through the system, rainfall and groundwater inputs provide the main inputs to the river causing a "run-of-river economy."

Management challenges include:

- There is no possible way for watershed managers to manage the climate. Decisions must be based on a variable system, about which only semi-accurate predictions can be made.
- Droughts occur in a natural system, adversely affecting the environment regardless of whether it is inhabited. In developed watersheds, drought effects are magnified and there are additional economic impacts to the residents of the area. Without inter-annual storage and an understanding of climate variability there is not a way to effectively cope with this phenomenon.
- Global Climate patterns are just beginning to be understood. While their general effects are understood, their localized effects are not as clear yet.

4.2 Objective and Level of Detail

The broad objective is to describe how climate affects the Methow basin water cycle. Also, since climate varies both spatially and temporally, it is important to identify issues related to scale and detail. In the Methow Basin there is interest in understanding the volume and timing of late season low flows, as well as storage options to alleviate low flows. The analysis must also account for inter-annual climate variations in the climate so that the analysis accounts for both dry and wet years.

To suit these purposes the basin is divided geographically into 8 sub-basins. These basins vary in size, location and elevation and provide enough detail to capture variations across the basin. In addition the data available does not suit a finer geographic resolution. The size and elevation of these basins is summarized in Table 3-1; the basins are displayed in Figure 3-1. The temporal resolution of analysis varies from weekly to inter-annually.

4.3 Available Data

A variety of climate data are available, including long-term and short-term climate stations, snowpack stations and snow course surveys, regional climate model outputs, and miscellaneous climate measurements.

- The National Oceanic and Atmospheric Association (NOAA) and National Weather Service (NWS) co-operative (NOAA/NWS COOP) maintain several continuous climate stations within the basin. These stations record a number of climate variables and are summarized in Table 4-1 and displayed in Figure 4-1. NOAA/NWS COOP stations at Winthrop and Mazama contain data extending to the early 1900's.

- The Natural Resource Conservation Service (NRCS) operates 4 Snowpack Telemetry (SNOTEL) stations in the Methow Basin, and one station just west in the Skagit Basin. These stations record continuous snow accumulation, precipitation, and temperature. Only data from the past 10 or 20 years are available electronically. SNOTEL stations are summarized in Table 4-2 and displayed in Figure 4-1.
- The Parameter-elevation Regressions on Independent Slopes Model (PRISM) provides an integrated basin-scale analysis of climate for the basin. PRISM is a model developed by Oregon State University that uses point data and a digital elevation model (DEM) to generate gridded estimates of climate parameters (Daly et al., 1994). Unlike other statistical methods in use today, PRISM was written by a meteorologist specifically to address climate. PRISM is well suited to mountainous regions because the effects of terrain on climate play a central role in the model's conceptual framework. Data input to the model consisted of 1961-1990 mean monthly precipitation from over 8,000 National Oceanic and Atmospheric Administration (NOAA) Cooperative sites, Snowpack Telemetry (SNOTEL) sites, and selected state network stations. PRISM is used to estimate mean annual, mean monthly and event-based precipitation, temperature, and other variables. The model grid resolution is 4-km (latitude and longitude). The outputs used in this study are re-sampled to 2-km resolution using mathematical filtering procedures (Daly et al., 1994). Figure 4-2 and 4-3 display data obtained from PRISM model output.

Several studies have attempted to quantify climatic inputs in order to understand the hydrologic regime of the basin.

- Milhous, Sorlie, and Richardson (1976) presented a revised water budget of the basin, in which precipitation and evapotranspiration estimates were revised.
- Richardson (1976) estimated mean monthly streamflow under natural conditions in various tributary streams to the Methow River using estimated rainfall-runoff relationships for four elevation ranges in the basin.
- USGS (2001) presented results from the first phase of model development to simulate natural streamflow conditions. They used available precipitation, solar radiation, and temperature data to calculate distributed climatic inputs across the basin.
- Mullan et. al. (1992) addresses climatic conditions in the Methow Basin with respect to the environment it poses for fish survival.

4.4 Data Presentation

4.4.1 Annual and Monthly Aggregate

Annual averages are commonly used to evaluate inter-year trends. A total yearly flow volume plot can be highly useful in visualizing or calculating if there has been an overall decline in precipitation or snowpack within the period of record. Monthly averages can be used to evaluate inter-year trends on a monthly basis as well as intra-year trends. Monthly averages aid in visualizing how individual months contribute to total annual precipitation volumes. In addition, monthly averages can indicate how monthly values vary with annual increases or declines in precipitation or snowpack.

Annual and mean monthly precipitation for available stations are displayed in Table 4-3. Precipitation is generally greatest from November through February, with December receiving the greatest amount of precipitation. Precipitation is lowest from July through September.

Model output from PRISM provides a comprehensive view of how precipitation varies spatially and seasonally. Table 4-4 displays results of aerial averaging of PRISM precipitation in each sub-basin. Spatial presentations of annual and mean monthly precipitation output from PRISM are displayed in Figure 4-2 and 4-3. Note that the basin-scale mean annual precipitation of 33.5 inches is approximately 10% higher than values reported by Sorlie (1975) and Milhous et. al. (1976).

4.4.2 Time-Series Hydrographs

Time series plots display climatic parameters, such as temperature, precipitation or evaporation versus time. These plots are useful in understanding the actual characteristics of the system and how they vary over the basin. Time series plots utilize different time intervals to understand different processes. Time step should be chosen based on the process that is being analyzed. Single storm events or diurnal variations are best viewed on a smaller time step, such as hourly or less. Long-term variations such as seasonal or annual variations are best viewed using longer time steps such as daily, weekly or monthly.

Total annual precipitation plots of gage data provide an indication of annual variations. These plots are displayed in Figures 4-4(a-f).

Precipitation during the summer months, after the spring freshet, is important for human and ecological needs in the basin. Exceedance curves display the same data but in a different format. Exceedance curves present a probability for how often a certain precipitation level is likely to occur. Monthly precipitation and exceedance curves for the July through October period each of the NOAA/NWS COOP stations are displayed in the Technical Appendix.

Time series plots of Snow Water Equivalent (SWE) and precipitation are displayed in Figures 4-5(a-d) for three Snotel gages. Data for every gage is considered by NRCS to be provisional for the years of 1999 and 2000. Salmon Meadows Data shows erratic results in 2000 and this year is not used for further evaluations. In addition, note that the Harts Pass data were found to contain frequent errors occurring throughout the period of record. Notably, recorded SWE exceeds total precipitation almost every year on record. Since precipitation includes snow and rain, precipitation should always be greater than snow, or Snow Water Equivalent (SWE). These data errors may be due to precipitation can expansion in sub-freezing conditions, precipitation undercatch due to extreme winds, and/or plugging of the precipitation can with snow.

Daily snowpack accumulation and melt at Rainy Pass is displayed in Figure 4-6. The rapid decline of snowpack in May, which feeds the spring freshet, is clearly visible in this figure.

Temperature varies considerably across the basin from an annual average of 6.8 degrees Celsius (°C) in the lower-lying areas to 0.5 °C in the mountains. Average temperatures for each sub-basin estimated from SNOTEL station data are displayed in Table 4-5. The method used to transport the station data to the various sub-basins is described in the Technical Appendix. Estimated mean annual temperatures for Early Winters and Methow Headwaters are significantly lower than values reported by Sorlie (1975).

Average annual precipitation at Rainy Pass is 61 inches while precipitation near Methow is approximately 13 inches (SNOTEL, NOAA/NWS COOP Station data). Average annual temperatures in the mountainous portions of the basin are approximately 0.5 °C while in the lower elevation areas average annual temperatures are approximately 3.0 °C (estimated from SNOTEL station data). For this reason, point source climate data must be carefully applied in its representation of climate in the basin as a whole.

4.4.3 Exceedance Probability Analysis of Precipitation

Exceedance probability plots are useful in understanding how often or how probable it is that that a certain precipitation level will occur in a specified time frame. Because exceedance probability plots are created based on past precipitation levels, their reliability increases with longer periods of record. The time frame used for an exceedance probability plot varies with its intended purpose. Exceedance plots can be completed for discrete periods such as months or seasons to understand better how precipitation varies within that time frame. An annual plot can aid in determining how large a storage structure should be to guard against precipitations below a certain level. Seasonal or monthly plots could then indicate when storage should be drained and filled based on an expected probability of precipitation. Exceedance curves for July through October for NOAA/NWS COOP stations are displayed in the Technical Appendix.

4.4.4 Cumulative Departure Analysis

Cumulative departure plots provide a concise view of climate variability while also taking into account location in the climate cycle. A Rescaled Cumulative Departure (RCD) plot displays whether a system is exhibiting above or below average precipitation, how severe current conditions are (i.e. how far from average conditions) and the duration of the wet or dry period. A declining slope in a RCD plot indicates that precipitation was below average during much of the interval (a dry or drought period) while an increasing slope indicates that precipitation was above average during much of the interval. The slope of the RCD plot and duration of the cycle indicate the relative severity of the drought, for example a high rate of decline persisting for a long period of time indicates a severe drought.

In order to calculate the cumulative departure it is necessary to first determine the base period. The base period should be a period of record, which is representative of a normal cycle of wet and dry seasons. The base period could be the entire period of record or a shorter representative period. In a study completed by the USGS (Kresch, 1994) it was determined that a base period of 1937-1976 accurately reflected long-term average conditions in Washington (mean-monthly values and standard deviations of the base period accurately represent long-term average conditions).

Cumulative Departure analysis is best completed using long data sets that encompass an even balance of wet and dry years; the Winthrop NOAA/NWS COOP station has a long enough period of record and is presented in Figure 4-7.

4.5 QA/QC

4.5.1.1 NOAA/NWS COOP

A cooperative station is a site at which observations are taken or other services rendered by volunteers or contractors who are not NWS employees and who are not required to take or pass observation certification examinations. Automatic observing stations are considered cooperative stations if their observed data are used for services which otherwise would be provided by cooperative observers. Many types of data may be collected at a COOP station including, but not limited to, precipitation, temperature, wind, evaporation and snowfall and various parameters relating to these fields.

Data preparation personnel review all incoming data for correct station information and other supporting data. As the data are being key entered, data entry software checks for and resolves basic internal inconsistencies by deleting or rearranging observational elements. Finally data is checked using interactive areal edits where stations are compared with nearest neighbor stations, manual outlier review and resolution of internal data inconsistencies.

4.5.1.2 Snow Accumulation (SNOTEL)

The Natural Resources Conservation Service (NRCS) installs, operates, and maintains an extensive, automated system to collect snowpack and related climatic data in the Western United States called SNOTEL (for SNOwpack TELemetry). The sites are generally located in remote high-mountain watersheds. Basic SNOTEL sites have a pressure sensing snow pillow, storage precipitation gage, and air temperature sensor. Time series plots of SWE (snow-water-equivalent) for each SNOTEL gage show generally predictable responses. However, the Harts Pass and Salmon Meadows data were found to contain frequent errors occurring throughout the period of record. Notably, recorded SWE often exceeds the reported total precipitation. Since precipitation includes both snow and rain, precipitation should always be greater than SWE.

4.5.1.3 PRISM

PRISM uses point climate data, a digital elevation model, and other spatial datasets to generate gridded, GIS-compatible estimates of annual, monthly, and event-based climatic elements to develop high quality maps (Daly et al. 1994, 1997). PRISM modeling results are the result of collaboration between Oregon State University, USDA-NRCS, and other agencies.

The PRISM modeling system and the climate maps it produces are routinely evaluated for climatological and statistical accuracy using statistical parameterization to achieve to lowest possible prediction error and peer review by a group composed of State and Regional Climatologists, a National Climatic Data Center representative, a National Weather Service representative, and engineers, hydrologists, GIS experts and a meteorologist from the NRCS. Due to the vast amount of data used in the analysis and the high degree of peer review since publication, PRISM precipitation data are considered high quality.

Within the Methow Basin, PRISM outputs correlate well with measured annual precipitation of both the NOAA/NWS COOP and the SnoTel stations. Table 4-6 displays both annual precipitation from a measured station and annual precipitation from the grid in which that station falls.

TABLE 4-1

Climate Station Summary
NOAA/NWS COOP

Station Name	Station Number	Lat.	Long.	Elevation.	Period of Record
Mazama	455133-6	48.62	120.42	2,147 ft	4/5/50-4/30/00
Mazama 2 W	455133-5	48.60	120.43	2,180 ft	
Mazama 6 SE	455128-5	48.53	120.33	1,960 ft	6/1/48-10/31/76
Methow	455325-6	48.13	120.00	1,160 ft	
Methow 2	455327-7	48.13	120.02	1,170 ft	8/11/57-6/30/70
Methow 2 S	455326-7	48.10	120.02	1,150 ft	7/1/70-4/30/00
Methow 2 W	455327-6	48.13	120.05	1,230 ft	
Stockdill Ranch	458115-5	48.37	120.33	2,200 ft	6/1/48-11/30-63
Winthrop 1 WSW	459376-5	48.28	120.11	1,760 ft	1/5/31-4/30/00
Pateros	456410-W	48.03	119.54	830 ft	1/1/37-12/1/43

TABLE 4-2

SNOTEL Station Summary

Station #	Location	Latitude	Longitude	Elevation	Period of Record	Avg Snow Pack (in)
450012	Harts Pass	48.43	120.39	6,500 ft	10/1/81-present	N/A
450032	Rainy Pass	48.33	120.43	4,780 ft	10/1/81-present	45
450033	Salmon Meadows	48.40	119.50	4500 ft	1982 -present	12
450043	Thunder Basin	48.31	120.59	4,200 ft	10/1/87-present	32

TABLE 4-3

Mean Monthly and Annual Precipitation
Derived from NOAA/NWS COOP Meteorological Gaging Stations
(All units in inches)

NOAA/NWS COOP Station	Annual	O	N	D	J	F	M	A	M	J	J	A	S
Mazama	21.66	1.36	3.29	4.05	3.48	2.64	1.47	0.98	1.05	1.14	0.67	0.69	0.85
Mazama 6 SE	19.14	1.27	2.75	3.52	3.12	2.25	1.29	0.87	0.96	1.21	0.48	0.73	0.69
Methow	12.53	0.88	1.70	1.86	1.74	1.26	1.11	1.23	0.74	0.80	0.32	0.47	0.42
Methow 2 S	13.13	0.71	1.84	2.03	1.56	1.39	1.13	0.81	1.12	0.87	0.47	0.61	0.59
Pateros	13.12	0.48	1.53	2.47	1.09	2.00	1.03	1.08	0.93	1.15	0.41	0.26	0.70
Stockdill Ranch	17.52	1.39	2.36	3.13	2.50	1.84	1.42	0.78	0.99	1.27	0.48	0.59	0.75
Winthrop 1 WSW	14.12	0.92	1.89	2.53	1.99	1.41	0.87	0.72	0.92	1.09	0.58	0.60	0.61

Note: Data derived from NOAA/NWS COOP gage data for the period of record available (see Table 2-2).

TABLE 4-4

Mean Monthly and Annual Precipitation
Estimated from PRISM Outputs for the State of Washington
(All units in inches)

Sub-Basin	Annual	O	N	D	J	F	M	A	M	J	J	A	S
EARLY WINTERS	50.5	4.2	8.4	8.4	8.2	6.0	4.6	2.7	1.9	1.7	1.1	1.2	2.1
METHOW HEADWATERS	44.7	3.5	7.1	6.2	6.6	4.7	4.5	3.1	2.5	2.0	1.3	1.2	2.0
UPPER METHOW	32.6	2.5	5.0	5.7	5.5	3.4	2.7	1.7	1.5	1.4	0.9	1.0	1.3
CHEWUCH	29.3	2.1	4.0	3.6	3.2	2.5	2.7	2.2	2.5	2.6	1.4	1.3	1.2
TWISP	45.0	3.6	7.7	7.7	7.6	5.3	4.1	2.2	1.6	1.4	0.9	1.1	1.8
MIDDLE METHOW	18.9	1.2	2.5	3.2	2.8	1.8	1.5	1.0	1.2	1.1	0.8	0.9	0.9
WEST LOWER METHOW	30.0	2.2	4.9	5.1	5.0	3.3	2.7	1.5	1.3	1.2	0.7	0.9	1.2
EAST LOWER METHOW	20.8	1.4	2.9	3.0	2.6	2.0	1.9	1.3	1.6	1.4	0.8	1.0	0.9
BASIN-SCALE	**33.6**	**2.5**	**5.2**	**5.0**	**4.9**	**3.5**	**3.1**	**2.1**	**2.0**	**1.8**	**1.1**	**1.1**	**1.4**

Note: Numbers derived from outputs of the PRISM Model developed by the Oregon Climate Service– August 1998

TABLE 4-5

Mean Annual and Monthly Temperature
Estimated from SNOTEL Station Data
(All Units in ^{0}C)

Sub-basin Name	Annual	Monthly											
		O	N	D	J	F	M	A	M	J	J	A	S
EARLY WINTERS	0.5	1.4	-4.3	-7.8	-7.0	-5.6	-3.7	-1.1	2.3	6.0	9.9	9.4	6.7
METHOW HEADWATERS	0.5	1.4	-4.3	-7.8	-6.9	-5.6	-3.7	-1.0	2.3	6.0	10.0	9.4	6.7
UPPER METHOW	3.7	4.6	-1.1	-4.7	-3.8	-2.5	-0.6	2.1	5.4	9.1	13.1	12.6	9.9
CHEWUCH	0.6	1.5	-4.2	-7.7	-6.8	-5.5	-3.6	-0.9	2.4	6.1	10.1	9.5	6.8
TWISP	2.1	3.0	-2.7	-6.3	-5.4	-4.1	-2.2	0.5	3.8	7.5	11.5	10.9	8.2
MIDDLE METHOW	6.8	7.4	3.0	-0.9	0.2	0.5	2.7	6.0	8.5	11.4	14.9	15.2	12.4
WEST LOWER METHOW	2.6	3.5	-2.2	-5.7	-4.8	-3.5	-1.6	1.1	4.4	8.1	12.1	11.5	8.8
EAST LOWER METHOW	4.3	5.0	0.5	-3.4	-2.3	-2.0	0.2	3.5	6.0	8.9	12.4	12.7	9.9

TABLE 4-6

Comparison of Annual Observed Precipitation and PRISM Model Output

Station Name	PRISM Annual Precipitation	Measured Annual Precipitation	Percent Error
Mazama	31	22	41%
Mazama 6 SE	19	19	0%
Methow	12	12	0%
Pateros	11	12	8%
Methow 2 S	13	13	0%
Stockdill Ranch	25	18	39%
Winthrop 1 WSW	15	14	7%
Rainy Pass	61	60	2%
Salmon Meadows	25	25	0%
Thunder Basin	101	76	33%