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REPORT TO ECONOMIC AND ENGINEERING SERVICES INC.

ON

WATER BUDGET FOR THE METHOW BASIN

Prepared in conjunction with the Methow Valley Pilot Planning Project by Golder Associates Inc, Redmond, WA.

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1. INTRODUCTION

This report was prepared to document the results of a water budget which has been developed for the Methow Basin in conjunction with the Methow Valley Pilot Planning Project. The main objective of the study was to quantify streamflow within each of the seven major sub-basins of the Methow Basin and incorporate these flows into a geographic information system (GIS) formatted layer which will be compatible with other GIS data sets for the basin. Estimates of the streamflow in each sub-basin were made for high-flow, median-flow, and low-flow conditions. Of particular interest is a comparison of the estimated flows in each sub-basin with the minimum instream flows or "baseflows" which have been established by the Washington State Department of Ecology (WDOE) for each of the sub-basins.

The water budget was developed as a surface water accounting model, in which the flow within a particular sub-basin can be related to the flow in adjacent sub-basins using a relationship which accounts for the primary sources of inflow and outflow from the sub-basin. The budget relies primarily on the existing streamflow data, as well the hydrographs presented in the Methow River Basin Fish Habitat Analysis Using the Instream Flow Incremental Methodology (IFIM) report (WDOE, 1992). The water budget is used as a tool to account for surface water in the Methow Basin, and is used to help estimate streamflow in the sub-basins where little or no data are available.

2. PREVIOUS WATER BUDGET STUDIES IN THE METHOW BASIN

Several previous studies have been published which address the hydrology and the water resources of the Methow Basin. Some of the more recent studies which have focused on surface water flow are summarized below:

- Walters and Nasser (1974) published a comprehensive report on the water resources of the basin, in which they presented an annual water budget for the basin and discussed the use and management of surface water and ground water resources. The only measured component of their budget was runoff, which was based on 17 years of discharge data of the Methow River at Pateros (1903-20). Based on their assumptions of basin-wide mean annual precipitation and evapotranspiration, they estimated that the amount of groundwater leaving the basin each year was 740,000 acre-feet, or on the order of 1,000 cubic feet per second (cfs).

- Milhous, Sorlie, and Richardson (1976) presented a revised water budget of the basin, in which precipitation and evapotranspiration estimates were revised, resulting in a much lower estimate of groundwater exiting the basin (85 cfs). Estimates of mean monthly streamflow were made for all of the sub-basins with the exception of the Early Winters Sub-basin. Estimated flows in several of the sub-basins were generated using regression with other records, or were based on miscellaneous (e.g. discontinuous) streamflow measurements.

- 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. This study also presented estimated monthly flows for the upper Methow River (above Winthrop) and the Chewuch River based on the correlation of short-term discharge records with the Methow River at Pateros.

- Kauffman and Bucknell (1976) prepared a water resource management program for the Methow Basin, which presents the minimum instream flows or "baseflows" for the basin. These baseflows were established by the WDOE in response to the Water Resources Act of 1971, Chapter 90.54 RCW, which directs WDOE to formulate a management and use plan for the waters of Washington State.

- Recently, a study of the Methow River Basin fish habitat analysis using an instream flow incremental methodology (WDOE, 1992) was performed to evaluate the minimum instream flows for the basin which were adopted by WDOE in 1976 (Kauffman and Bucknell, 1976). In this report, hydrographs are presented for low-flow, median-flow, and high-flow conditions for the Methow River at Pateros (Lower Methow), Twisp (Middle Methow), and Winthrop (Upper Methow), as well as the Chewuch River at Winthrop and the Twisp River at Twisp. Hydrographs for the Methow River at Mazama (Methow

Headwaters) and Early Winters Creek are not presented due to the limited data available in these sub-basins when the report was produced. Hydrographs for the Methow River at Winthrop and the Chewuch River at Winthrop were synthesized based on a correlation of discharge data from water year 1992 with data from the Methow River at Pateros.

Several of the above studies have attempted to estimate streamflow within the sub-basins of the Methow Basin, mostly in terms of mean annual flow. Milhous et al. (1976) presented a table of estimated mean monthly flows throughout the basin and listed the difference in flow between gaging locations as the amount of flow gained (or lost) from the incremental area between stations. Unfortunately, many of the "residual" runoff values from the incremental area between gages were unrealistically high, and no attempt was made to break down the residuals into separate components of the water budget. Although more streamflow data are needed to properly characterize flow in each sub-basin, a water budget analysis can be preformed using the existing data to better estimate streamflow in the sub-basins where little data exist.

3. OVERVIEW OF METHOW BASIN HYDROLOGIC SYSTEM

This section presents an overview of the hydrology of the Methow Basin, including a summary of precipitation patterns, basin topography and sub-basin definition, and the factors affecting streamflow in the basin. Also included in this section is a summary of the existing streamflow data in the basin and an explanation of how synthetic hydrographs were derived for the sub-basins in which little or no streamflow data are available.

3.1 Basin Description

The Methow River Basin is located in north central Washington State, and drains roughly a 1,780 square mile catchment. The basin extends from its headwaters located along the Cascade Crest and Canadian border southward to the confluence of the Methow River with the Columbia River at Pateros, Washington. Topography within the basin is varied, and ranges from mountainous sub-alpine and alpine terrain along the Cascade Crest to the gently sloping, wide valley found along the middle reaches of the Methow River. Elevation ranges from over 8,500 feet in the headwaters of the basin to approximately 800 feet at the confluence of the Methow and Columbia Rivers.

Most of the basin is forested, with Douglas fir, spruce, and lodgepole pine common at moderate altitudes (Walters and Nasser, 1974). Smaller trees, shrubs, and grasses are found in the higher altitudes and reflect the alpine conditions encountered at these altitudes. Vegetation in the lower altitudes of the basin is somewhat sparse in response to the semi-arid conditions which prevail. Sagebrush and grassland are common in the lower elevations of the valley between Winthrop and Pateros, although narrow belts of deciduous trees and shrubs are common along the Methow River and its tributaries.

3.2 Definition of Sub-Basins

In accordance with the water resources management program for the Methow River Basin presented by the WDOE (Kauffman and Bucknell, 1976), unappropriated surface waters in the Methow River Basin are to be allocated and managed according to specific stream management units. These stream management units represent the seven primary sub-basins which form the basis for the water budget analysis and are listed below:

- Lower Methow — Methow River from its mouth at Wells Pool (Columbia River) to its confluence with the Twisp River. (River Mile [RM] 0.0 to RM 40.0)
- Middle Methow — Methow River from its confluence with the Twisp River to its confluence with the Chewuch River. (RM 40.0 to RM 50.2)

- Upper Methow — Methow River from its confluence with the Chewuch River to its confluence with Little Boulder Creek. (RM 50.2 to 67.3)
- Methow Headwaters — Methow River from its confluence with Little Boulder Creek to its headwaters. (RM 67.3 to headwaters)
- Early Winters Creek — Early Winters Creek from its confluence with the Methow River to its headwaters.
- Chewuch River — Chewuch River from its confluence with the Methow River to its headwaters. (RM 0 to headwaters)
- Twisp River — Twisp River from its confluence with the Methow River to its headwaters. (RM 0 to headwaters)

These sub-basins are shown on Figure 1. Although the streamflow within a given sub-basin will vary depending on the location along the stream management reach, all sub-basin flows as designated in this report will correspond to the control stations identified by the WDOE (Kauffman and Bucknell, 1976). Flows in the Chewuch sub-basin are designated at the current gaging station which is located on the Chewuch River just upstream of Winthrop (RM 0.18). The control stations are essentially located at the lowest elevation within each particular sub-basin, so the flows at these locations represent the flow at the "outlet" of the sub-basin.

3.3 Basin Hydrology

3.3.1 Precipitation

The climate of the Methow Basin is influenced by topography, elevation, and its location on the leeward side of the Cascade Mountain Range. Annual precipitation within the basin is spatially highly variable, and ranges from over 80 inches in the higher altitudes of the basin along the Cascade Crest to roughly 10 inches near the town of Pateros (Richardson, 1976). In general, the upper reaches of the Methow River, Chewuch River, Twisp River, and Early Winters Creek receive well above 30 inches of precipitation annually, whereas the Methow Valley from Mazama to Winthrop averages from 10 to 20 inches annually depending on elevation and location in the basin.

The temporal distribution of precipitation exhibits a high degree of seasonality, with roughly two-thirds of the precipitation occurring between October and March (Washington Climate, 1975). Summers are hot and dry, with much of the summer precipitation coming as thunderstorms. Precipitation increases in the fall and generally peaks in the winter, with most precipitation in the basin between December and February falling as snow.

3.3.2 Runoff

Mean annual runoff in the Methow Basin is directly related to the precipitation patterns in the basin, and therefore decreases substantially from the headwaters region to the lower elevations in the basin. Richardson (1976) estimated that the mean annual runoff in the basin ranges from roughly 60 inches near Washington Pass to about one inch near Pateros. Since much of the precipitation occurs as snow, the seasonal distribution of runoff is strongly affected by snow storage. The magnitude of winter runoff is relatively low as precipitation is stored in the snowpack, but increases to a seasonal high during the late spring and early summer in response to melting snow.

3.3.3 Streamflow

Streamflow in the basin is primarily driven by runoff from melting snow, and therefore exhibits a strong peak during the late spring and early summer (Figure 2). Based on the median, two-week averaged flow of the Methow near Pateros, roughly 60 percent of the mean annual discharge occurs during May and June. Streamflow typically remains relatively high during July, but decreases substantially from August through October in response to a low snowpack, low precipitation, and decreased soil moisture. Streamflow in the Methow River at Pateros generally reaches an annual low during late September and early October before autumn precipitation causes a slight increase in streamflow. Winter flows are typically low in response to freezing temperatures which retain moisture in the snowpack and freeze soil moisture, although warmer temperatures in the winter can melt snow or cause precipitation to fall as rain.

The monthly distribution of streamflow varies with altitude throughout the basin because of the pronounced effect of temperature on runoff. At higher altitudes (generally above 5,000 feet), the spring snowpack is deeper and temperatures can remain below freezing well into the spring. Streamflows in the these higher elevations are generally greatest during June. This is common in the Methow headwaters, as well as the upper reaches of the Chewuch River, Twisp River, and Early Winters Creek. At lower altitudes, snowmelt commences earlier in the spring, such that the peak runoff and streamflow occur in April or May. Since most of the snowpack in the lower portions of the basin is typically gone by late April, runoff at the lower altitudes is expected to be relatively low by June. In an attempt to quantify the natural monthly streamflow in the basin, Richardson (1976) estimated the monthly distribution of runoff within the basin based on elevation, and presented runoff distributions for four elevation zones in the basin. The elevation zones were defined for areas of the basin between 2,000 and 3,000 feet, 3,000 to 4,000 feet, 4,000 to 5,000 feet, and for areas above 5,000 feet.

3.4 Basin Water Budget

Water budgets are used to account for all of the primary elements of the hydrologic cycle including precipitation, evapotranspiration, surface water discharge, and groundwater. A water budget is generally calculated at an annual time-step, and is often a useful tool for determining the general magnitude of the above components.

In the Methow Basin, the only significant source of water entering the basin is from precipitation which falls on the basin as rain and snow. Water exits the basin as surface flow in the Methow River, evapotranspiration from non-irrigated lands, irrigated lands, free water surfaces (lakes and streams), and groundwater flow. Rarely, if ever, are all of these elements adequately measured. The only adequately measured quantity in the Methow Basin is surface water outflow in the Methow River, which has been measured by two separate gaging stations (over different periods) located near Pateros. Precipitation, although historically measured at several locations in the basin (Winthrop, Mazama, Methow, Pateros, as well as other locations), is spatially highly variable, and is not well quantified in many parts of the basin. Evapotranspiration is even more difficult to quantify, and is typically estimated based on climate data and available evaporation pan data. Groundwater outflow from the basin cannot be measured directly, and must also be estimated. Although unconsolidated glacial and alluvial deposits are found along the valley floor and underlying much of the Methow River, the lateral and vertical (depth) extent of these materials is expected to be limited where the river exits the basin near Pateros and joins the Columbia River. Thus, groundwater outflow from the basin as a whole is expected to be a minor component of the overall water budget. Groundwater components within each sub-basin, however, could be significant.

Table 1 presents an estimate of the long-term annualized basin-wide water balance for the Methow Basin, modified from the water balance presented by Milhous et al. (1976). Several of the components have been updated to reflect more recent data, namely additional streamflow data from the Methow River at Pateros and an increase in the amount of irrigated land in the basin. The estimate of basin-average precipitation, the only significant source of inflow to the basin, has been rounded-off to 30 inches annually (from 30.08 inches), and evapotranspiration has been adjusted slightly to balance the budget. The two largest components of outflow from the basin are evapotranspiration and streamflow. The majority of the water exiting the basin leaves as evapotranspiration from non-irrigated lands and represents roughly 58 percent of the budget. Streamflow in the Methow River accounts for 40 percent of the water exiting the basin. A small fraction of the outflow from the basin can be attributed to additional evapotranspiration from irrigated lands, estimated to be about 1.5 percent of the budget. Groundwater leaving the basin is estimated to be on the order of 5 to 20 cfs, therefore representing only 0.5 percent of the overall annual water budget.

The long-term annualized water budget presented in Table 1 illustrates the relative orders of magnitude of water budget components in the basin. At an annual time-step, evapotranspiration from non-irrigated lands and surface flow in the Methow River collectively represent most of the water exiting the basin. A component which is not shown in Table 1 is the effect of storage in the basin. Storage effects are typically minimal when considering long-term average conditions. Storage effects can be significant when considering relatively short periods of time (generally one year or less). For instance, the storage of water in the snowpack, and the storage of water as soil moisture or in the groundwater can provide significant storage for an extended period of time (over several years). As a result, water falling over the basin as precipitation during a wet year may not all exit the basin during the particular year, but rather may be stored as groundwater or snowpack and remain in storage for an extended period of time. Therefore, during a wet year, the amount of water entering the basin may be greater than that leaving the basin, where the difference represents the increase in basin storage. During a dry year, the amount of water exiting the basin may exceed yearly precipitation due to a reduction in the amount of surface and groundwater storage. The effects of storage need to be included in a water budget comprised of periods shorter than one year.

3.5 Available Streamflow Data

As indicated in Section 3.4, streamflow is typically the only component of a basin-wide water budget which is well quantified. In the Methow Basin, stream gages have been operated for various periods over the past ninety years at several locations throughout the basin. However, only two locations on the Methow River have been monitored sufficiently to allow a valid statistical analysis of the data.

As shown in Table 2, streamflow has been gaged on a daily basis by the United States Geological Survey (USGS) on the Methow River at Pateros (RM 6.7) for the last 33 years. Measurements of streamflow were also made at a site further downstream from the current gaging site during a period from 1903 to 1920. A comparison of the data from these two periods of record (Figure 3) indicates that the mean annual flow was slightly higher during the earlier period (1611 cfs vs. 1551 cfs). The mean monthly flow for April through November from 1903 to 1920 was higher than it was during 1960 to 1989, with the most significant differences occurring in April and July. Higher consumptive use during the latter part of this century may partly account for these differences, although it probably does not account for the larger differences observed in April and July. Thus, much of the difference in the records can probably be attributed to natural variability.

A long-term record of daily streamflow also exists on the Methow River at Twisp (RM 40), in which streamflow data were collected from 1919 to 1929, 1934 to 1962, and 1991 to present. Streamflow data are also available for the Twisp River near Twisp, but only for a seven year period (1975 to 1979, 1989 to present). Several other short-term gaging stations are currently operated in the basin. Short-term records exist on the Methow River at Winthrop (RM 49.8) and near Mazama (RM 63.8), as well as on the Chewuch River near Winthrop (RM 0.18). Although the period of record from these stations is generally not adequate for estimating the statistical frequencies of selected streamflows, it is possible to synthesize hydrographs for these locations based on a correlation of the existing data with data from another station which has a longer-term record. Since only miscellaneous (e.g. discontinuous) measurements have been made on Early Winters Creek, it becomes much more difficult to synthesize a hydrograph for the Early Winters Sub-basin with any degree of reliability.

3.6 Hydrograph Analysis

The available long-term streamflow records for the Methow River at Pateros and Twisp were used to perform a statistical analysis of the data in order to determine hydrographs for these locations which represent the 10, 50, and 90 percent exceedance flows. The 10, 50, and 90 percent exceedance flows have been established by WDOE in order to represent a typical range of flows encountered in the Methow basin (WDOE, 1992). The 10 percent exceedance flows were chosen to represent high flow conditions; in other words, flows which are equaled or exceeded only ten percent of the time. Normal flow conditions in the basin are represented by the 50 percent exceedance flows, or flows which are equaled or exceeded half of the time. These flows are also known as the median flows. Low flow conditions are represented by 90 percent exceedance flows, which are flows that are equaled or exceeded ninety percent of the time. In a given year, there is a ten percent chance that the flow for a given period will be equal to or less than the 90 percent exceedance flow for that period.

It is important to note that the exceedance flows presented in this report are based on an analysis of all historical flows over successive ten-day periods. When these ten-day averaged flows are combined to construct an annual hydrograph, the resulting annual mean is not the same as the mean annual flow calculated from the raw data because of a different statistical basis. For example, the mean annual flow of the 90 percent exceedance hydrograph does not equal the 90 percent exceedance mean annual flow, based on a statistical analysis of the historical mean annual flows. It is highly unlikely that the 90 percent exceedance flows will be observed on every 10-day flow period. Thus, while the 90 percent exceedance flows are valid for a given 10-day period, when taken as an entire hydrograph, they are conservatively low in predicting the mean annual flow. For example, the mean annual flow determined from the 90 percent exceedance hydrograph for the Methow River at Pateros is 745 cfs. However, a Log-Pearson fit to the historical mean annual flows from Pateros indicates that a year with an annual flow of 745 cfs or less has only a two percent probability (98 percent exceedance). Table 3 provides a comparison of the average annual flows from the 10, 50, and 90 percent exceedance hydrographs and the 10, 50, and 90 percent exceedance flows determined from a statistical analysis of the historical mean annual flows from the Methow River at Pateros.

The 10, 50, and 90 percent exceedance flows for the Methow River at Pateros and Twisp, and the Twisp River near Twisp were determined by WDOE by fitting a Log-Pearson distribution to the historical ten-day averaged flows. The exceedance flows determined for the Twisp River near Twisp do not have the same reliability as the hydrographs determined for the Methow River at Pateros and Twisp because of the relatively short streamflow record on the Twisp River. The flows presented in this report for these locations were obtained from the IFIM report (WDOE, 1992) and were aggregated to a fifteen-day (bi-monthly) time-step using a weighted average. In most cases, the flows presented in the IFIM report were not modified, although in several instances modifications were made to the hydrographs for the Methow River at Twisp (e.g. the

May exceedance flows for the Methow River at Twisp were decreased to make them smaller than the corresponding flows at Pateros).

3.7 Derivation of Synthetic Hydrographs

Hydrographs representing the 10, 50, and 90 percent exceedance flows were constructed for each of the seven sub-basins in the Methow Basin. As noted in Section 3.6, sufficient streamflow data exist in the Lower Methow, Middle Methow, and Twisp Sub-basins in order to derive the exceedance hydrographs directly from the existing data. Synthetic hydrographs were derived for the other sub-basins using a limited record of streamflow data. The hydrographs were synthesized by performing a direct comparison of streamflow data at a given sub-basin gage with streamflow data for the same period from the Methow River at Pateros. The correlation was performed by comparing the ten-day average flow from a sub-basin gage with the ten-day average flow from the same ten-day period at the Pateros gage. Similar correlations were made by breaking up one complete year of daily streamflow values into ten-day averages, and comparing them with the corresponding ten- day averages using the data at Pateros. A correlation coefficient was thereby determined for each ten-day period in the year, which related the flow at the gage to the corresponding flow at Pateros. Synthetic streamflow data were developed for the sub-basin by using the correlation coefficients to calculate the 10, 50, and 90 percent exceedance flows based on the data from Pateros. The synthetic hydrographs were initially developed using ten-day averaged flows, but these were subsequently aggregated to fifteen-day averaged flows by taking a weighted average of the ten-day flows. The underlying assumption in this method is that the correlation coefficient used to relate streamflow between two stations will remain valid for all similar time periods (e.g. the correlation coefficient for May of 1977 is the same as the correlation coefficient for May of 1993). This assumption is not strictly valid, but in the absence of a longer period of record in the sub-basins, this method provides a reasonable means of estimating streamflow at locations where only a short period of record exists.

Synthetic hydrographs were developed for the Upper Methow, Methow Headwaters, and Chewuch sub-basins. Listed below for each of these sub-basins are the gage location and the period of record used to generate the synthetic hydrographs from the data at Pateros.

• Upper Methow	Gage: Period:	Methow River at Winthrop (RM 49.8) January to December, 1991
• Methow Headwaters	Gage: Period:	Methow River near Mazama (RM 63.8) Selected data from Water years 1991, 1992
• Chewuch River	Gage: Period:	Chewuch River near Winthrop (RM 0.18) October 1991 to September 1992 (Water Year '92)

Since no continuous record of streamflow data exists for Early Winters Creek, it is difficult to synthesize a set of hydrographs for the Early Winters Sub-basin. In order to estimate the streamflow in this sub-basin, it was assumed that the mean annual runoff from the Early Winters Sub-basin would be similar to that of the Methow Headwaters Sub-basin, based on similar geographic location in the Methow Basin and a similar distribution of elevation. The short-term streamflow record from the Methow Headwaters and estimates by Richardson (1976) suggest a mean annual runoff in the Early Winters Sub-basin of roughly 25 inches. This was assumed to be distributed seasonally according to the six-year streamflow record from Andrews Creek, which is located in the headwaters of the Chewuch Sub-basin and is expected to have a similar temporal distribution of runoff. The synthetic hydrographs for the Early Winters Sub-basin, as well as the other sub-basins, are shown in Appendix A. The bi-monthly streamflow values are presented in tabular format in Appendix C.

4. FORMULATION OF WATER BUDGET

The primary objective of this study was to prepare a detailed water budget for the seven stream management sub-basins within the Methow Basin. A second objective was to develop the water budget in a GIS-formatted layer in order to provide an interactive method of accessing water budget information. Incorporation of the water budget into a GIS system also provides an environment where the user can observe the water budget in relation to other GIS-formatted layers such as hydrography, surficial geology, and irrigated acreage.

4.1 Approach

The water budget for the basin was developed as a surface water accounting system which tracks all of the primary inflows and outflows of water to the surface water system in each of the sub-basins. Water budget relationships have been established for all of the sub-basins, with flows between sub-basins linked. These relationships and linkages allow the flow in a given sub-basin to be related to the flow in an adjacent sub-basin, thereby providing a mechanism for balancing the surface water budget for the entire basin. The water budget relies on synthetic hydrographs developed from existing streamflow data. The water budget only considers the direct exchange of water with the primary stream in each sub-basin, and therefore does not incorporate precipitation or evapotranspiration from non-irrigated lands. Water transpired from irrigated crops is considered in the budget, since this water represents water withdrawn from the stream network and used consumptively. Due to the high degree of hydraulic continuity which generally exists along the Methow River and the lower reaches of its primary tributaries, groundwater withdrawn for irrigation purposes is also considered as a withdrawal from the system and is indirectly accounted for in the budget.

4.2 GIS Structure

The water budget was incorporated into the geographic information system ARC/INFO by defining a network of discrete nodes within the Methow Basin. There are seven flow nodes which represent the WDOE control stations, as well as three additional flow nodes which are used in the GIS water budget calculations but are not associated with a particular control point. The control points are located at the furthest downstream location in each sub-basin, so the flow at these locations is a representation of the integrated effect of all hydrologic processes in the sub-basin. Since a considerable amount of the water used for agricultural purposes is diverted from the stream network via canals, nine diversion nodes were incorporated into the GIS system to represent the largest of the surface diversions (several additional diversion points are shown on Figure 1 for graphical purposes only). Many of the largest diversions are represented by individual nodes, although several of the smaller diversions are accounted for at adjacent nodes. Figure 1 shows the node network used to perform the water balance.

The water budget is not intended to characterize streamflow at discrete locations within a given sub-basin. The streamflow at a flow node is a function of the streamflow at each of the upstream nodes, including the losses or gains to the stream which occur in the sub-basin. Gains (inflows) to the stream may come from natural runoff within the sub-basin, return flows from irrigation diversions made in other sub-basins, and inflows to the stream from groundwater. Losses (outflows) from the stream network are due to the consumptive use of water for agricultural purposes, the transfer of surface water to adjacent sub-basins, and losses of surface water to the ground.

4.3 Water Budget Components

The primary components of the water budget are summarized in the following section. With the exception of the groundwater flow/storage component, values for the water budget components for each sub-basin are stored in tabular format in the GIS system. The water budget has been calculated at a bi-monthly time-step, so the components are represented as 15-day average values.

4.3.1 Streamflow

Streamflow at the control point (outlet) in each of the sub-basins was entered into the water budget from actual and synthetic streamflow data, as discussed in Section 3.7.

4.3.2 Runoff

Natural runoff was estimated based on available discharge data in the basin and estimates of the mean monthly discharge in a number of small drainages in the basin as presented by Richardson (1976). Discharge data from Beaver Creek (located in the upper reaches of the Lower Methow Sub-basin) were useful for determining runoff in the Lower Methow Sub-basin. The water budget considers only the runoff which joins the stream network between consecutive nodes. Therefore, natural runoff is only calculated in the Methow Headwaters, Upper Methow, Middle Methow, and Lower Methow Sub-basins. Natural runoff within the three remaining sub-basins (Early Winters, Chewuch, and Twisp) is incorporated in the sub-basin streamflow estimates. Estimated bi-monthly runoff values are presented in tabular format in Appendix D.

4.3.3 Irrigation Diversions

Surface water diversions are accounted for in the water budget as a loss of water from the surface water network in the sub-basin where the diversion occurs. In situations where the diversion is made in a particular sub-basin but used consumptively elsewhere (e.g. the MVID west canal on the Twisp River), the actual diversion represents the reduction in flow from the sub-basin. In reality, some leakage from the un-lined canals will return to the stream network as return flow. However, it was assumed that all return flow re-enters the stream network in the sub-basin where the water is used consumptively. In cases where a canal enters a sub-basin with water from an adjacent sub-basin, the return flow is considered as an addition of water to the stream network.

Information concerning surface water diversions was obtained from several sources. Bill Zachmann of the WDOE assembled an inventory of active diversions in the basin (personal communication, 1992) which included the location of the major active canals and several spot discharge measurements from each canal. Additional discharge measurements for the MVID east and west canals are available from a study conducted by the Central Regional Office of the WDOE (WDOE, 1991). In addition, Klohn Leonoff (1990) produced a study which focused on the efficiency of the existing MVID conveyance system. Available discharge data for the canals were used to estimate the discharge in the primary diversions throughout the irrigation season, which generally runs from late April through mid-October. Although the discharge in the canals is expected to vary on an annual basis, the same diversion schedule was applied to all three flow scenarios (high flow, median flow, low flow).

4.3.4 Consumptive Use

Consumptive use in the water budget accounts for the net removal of water from the basin due to additional evapotranspiration from irrigated crops. Klohn Leonoff (1990) estimated that a majority of the water diverted by the MVID canals is not used consumptively by crops due to conveyance losses. Since much of the water diverted for irrigation will not be used consumptively, the consumptive use for a given crop is calculated as the estimated crop irrigation requirement multiplied by the acreage of the crop. The crop irrigation requirement is based on the consumptive use of the particular plant during the irrigation season, less precipitation. The crop irrigation requirements for several irrigated crops in the Methow Basin (pasture, alfalfa, apples, pears) have been determined based on a study by James et. al (1982), and are distributed at a bi-monthly time-step similar to the monthly distributions presented by Milhous et. al (1976). The amount of irrigated acreage in each sub-basin is based on an inventory conducted as part of the Methow Basin Plan by Economic and Engineering Services (EES) in 1993, which concluded that roughly 17,500 acres are irrigated basin-wide. Most of the irrigated acreage is located in a narrow band along the bottom of the Methow Valley below Mazama, although some irrigated land is present in the Chewuch and Twisp Sub-basins. The amount of irrigated land in each sub-basin represents a small fraction of the sub-basin area (generally between one-half to three percent). The amount of irrigated land by sub-basin is shown in Table 4.

The consumptive use in each sub-basin is calculated in the water budget by multiplying the acreage of each crop in the sub-basin by the appropriate crop irrigation requirement. Since the irrigated lands inventory does not provide information on the crop types in each sub-basin, the relative acreage of each crop was estimated based on historical land use. In general, consumptive use represents a relatively small part of the overall budget within a sub-basin, although consumptive use can become a significant proportion of the water budget during periods of low flow (late summer and fall).

4.3.5 Groundwater Flow/Storage

Past hydrogeologic studies of the Methow Valley have indicated that, in certain regions of the valley, a significant component of the down-valley flow occurs as groundwater flow (WDOE, 1992; Golder Associates, 1991). In addition, a high degree of communication exists between the Methow River and shallow groundwater, such that large quantities of water are exchanged between surface water and groundwater.

Due to the complicated nature of the exchange of water between surface water and groundwater, the effects of aquifer storage, and the variability in the exchange of water over short reaches, it is unfortunately very difficult to quantify the exchange of surface water and groundwater in the water budget. Instead, the residual flow component remaining to balance the estimated values of the other water budget components is taken to represent groundwater.

4.4 Calculation of Water Budget

Using the node network shown in Figure 1 and the components as outlined in the previous section, water budget relationships were developed to link streamflow between each of the seven sub-basins. The specific water budget equation for each control point (node) varies depending on the sub-basin, but the general format of the equation is as follows:

$$\text{Residual} = \text{Sum}(S_{UN}) + R + RF - \text{Div} - CU - S_{DN}$$

where:
S_{DN} is the streamflow at a node;
Sum(S_{UN}) is the sum of the streamflow at adjacent, upstream nodes;
R is the natural runoff from the contributing area between nodes;
RF is the return flow from irrigation canals originating in adjacent sub-basins;
Div are surface diversions which exit the sub-basin;
CU is the consumptive use from irrigated lands; and
Residual represents changes in groundwater storage within the sub-basin.

All of the components have the units of cubic feet per second (cfs). The groundwater component (exchange of aquifer storage with surface water) is generally the least understood component of the budget, and is therefore represented by the residual of the water budget. Use of the GIS provided a means of balancing the water budget for the basin as a whole through adjustments to individual water budget components in the sub-basins. For example, the residual in the Middle Methow Sub-basin (where groundwater exchange with surface water is expected to be relatively small) can be reduced by adjusting one or a combination of several of the water budget components in the sub-basin. In this particular example, a large residual could be reduced by adjusting the exceedance flows for the Methow River at Winthrop. Adjustment of the exceedance flows at Winthrop is somewhat justified considering the relative uncertainty them.

4.5 Water Budget Balancing and Uncertainty

Achieving a balance of the water budget is difficult due to the large number of variables in each of the sub-basins. Balancing the budget at short time-steps becomes extremely difficult due to the transient effects of storage in the basin. It has been well documented that large quantities of surface water are exchanged with aquifer storage (WDOE, 1992; Golder Associates, 1991; EMCON, 1993), especially during spring runoff. In addition, there are also storage effects involved with irrigation diversions in the basin. For instance, water losses from the conveyance systems and return flows from excess irrigation water do not immediately return to the stream network, but rather may be stored in the ground for an extended period of time before re-emerging as surface flow. The water budget was developed using the assumption that all return flows occur within a 15-day period, such that storage effects related to man-made diversions are not modelled.

The approach to balancing the budget was to begin with a satisfactory balance of the basin budget at an annual time-step, and then refine the budget at seasonal and bi-monthly time-steps. The basin-wide residual at an annual time-step is expected to be relatively small due to minimal long-term storage effects. At shorter (bi-monthly) time-steps, many of the calculated residuals are large when compared with streamflow (up to 35 percent of the flow at some control points). These large residuals reflect the relative magnitude of storage during certain times of the year, but also reflect uncertainty in all of the water budget components.

Balancing of the budget was constrained by the lack of long-term streamflow data in the upper sub-basins of the Methow Basin. The magnitude of the residual was used as the main criterion for budget adjustment. For example, if large residuals occurred in sub-basins with limited groundwater storage or flow, it was necessary to adjust the exceedance hydrographs in order to produce reasonable results. In sub-basins where the exceedance hydrographs were based on a statistical analysis of the existing streamflow record, little or no adjustments were made to the exceedance hydrographs. As outlined in Section 3.6, several modifications were made to the hydrographs for the Methow River at Twisp. No modifications were made to the hydrographs for the Methow River at Pateros or the Twisp River near Twisp.

5. WATER BUDGET RESULTS AND INTERPRETATION

Presented in this section is a brief summary of the water budget for each of the seven sub-basins. The hydrology of each sub-basin is summarized, and in some cases, an estimate of the mean annual runoff is given. The mean annual runoff should not be confused with the values of annual runoff shown in Appendix C, which are based on the average value of the 50 percent exceedance hydrographs.

Estimated streamflow hydrographs for the 10 percent, 50 percent, and 90 percent exceedance flows are presented for each of the sub-basins in Appendix A. Appendix B contains the comparisons of the estimated flows in each sub-basin with the minimum instream flows (baseflows) as established by the Washington State Department of Ecology (a listing of the baseflows is available in Appendix E). These are presented as the difference between the estimated flows and the baseflows, such that a positive value indicates that the estimated streamflow is greater than the baseflow. It is important to consider that the actual flows for every year will always be unique, and are a function of a complex hydrological system. The flows presented in this water budget are intended to estimate streamflow during three flow conditions which have been defined based solely on statistical exceedance, and are intended to be used as a tool for general water resources planning in the basin.

5.1 Methow Headwaters Sub-basin

The mean annual runoff in the Methow Headwaters Sub-basin is estimated to be roughly 25 inches. A majority of the mean annual discharge occurs during spring snowmelt during late May and June. Consumptive use in the basin is low, and is primarily confined to the irrigation season. According to the recent survey of irrigated lands, the irrigated acreage in the Methow Headwaters Sub-basin is roughly 630 acres, which would account for about 5 cfs of actual consumptive use during the warmest months (July and August). Actual diversions in the sub-basin are higher, but probably do not exceed 25 cfs. Very little consumptive use occurs in the sub-basin during the winter, so streamflow during the winter is essentially equivalent to the "natural streamflow" in the basin. This is to say that winter flows are not influenced by human activities such as irrigation.

A map of the Methow Headwaters Sub-basin showing the major components of the water budget is shown in Figure 4. This figure is presented as a graphical representation of how the water budget is formulated within a given sub-basin (similar figures for the other sub-basins are not presented). The values shown on Figure 4 are the average annual values of the water budget components for median-flow conditions. The streamflows presented on this figure are the average values of the median exceedance hydrographs for the Early Winters and Methow Headwaters Sub-basins, and therefore are not the same as the actual median annual flows for these locations (see Section 3.6, Hydrograph Analysis).

The estimated hydrographs for the Methow Headwaters Sub-basin are shown in Appendix A. A comparison of the estimated high flows (10 percent exceedance flows) with the WDOE baseflows (Appendix B) shows that in all cases, streamflow will exceed the baseflows. Median flows exceed the baseflows by at least 500 cfs during peak flow (May and June), but by a smaller amount during other times of the year. The median flows exceed the baseflows by only several cfs (in January and early February by only 3 cfs) during the late fall and winter (November through February). The low flows exceed the baseflows from March through September (except for early July), but fall below the baseflows from late October through February.

It is important to note that the uncertainty in the estimated hydrographs is high because of the limited streamflow record available in the basin. During periods when the flow in the Methow River is typically low (August through March), the difference between the estimated flow and the baseflow falls within the uncertainty of the synthetic hydrographs. It is also important to consider that the hydrographs presented in this report for the Methow Headwaters Sub-basin are intended to represent general flow conditions in the Methow River near Mazama, and do not specifically represent the reaches within the sub-basin which may go dry. It has been well documented that streamflow in the lower reaches of the sub-basin is spatially highly variable, and that certain reaches of the Methow River may be dry while other reaches may have 40 cfs or more (WDOE, 1992). Many of these observed variations in flow take place within the sub-basin, and are therefore not represented in the water budget.

Residuals from the water budget indicate that there is a net loss of streamflow to groundwater in the Methow Headwaters Sub-basin which averages around 75 cfs (median conditions) on an annual basis (Table 5). The magnitude of the losses to groundwater are variable, however, depending on the time-step and the flow scenario. Based on historical observations of streamflow in the Methow River in the vicinity of Mazama, it appears as if the reach between the confluence of the Lost River (RM 73) and Weeman bridge represents a losing reach where surface water leaves the river and flows into the shallow aquifer thereby becoming groundwater (WDOE, 1992). Observed changes in water levels in the shallow aquifer suggest that seasonal changes in aquifer storage are large (Golder Associates, 1991), which makes it difficult to balance the budget at short time-steps.

5.2 Early Winters Sub-basin

Estimated median annual flows in the Early Winters Sub-basin are based on an estimated mean annual runoff of 25 inches. Over half of the mean annual discharge in Early Winters Creek is expected during May and June (Appendix A). There are roughly 35 irrigated acres located in the sub-basin, thus consumptive use is low. Significant diversions from Early Winters Creek occur from two irrigation ditches located near the confluence of the Methow River. Although the flow in these ditches is expected to vary throughout the irrigation season, several spot measurements indicate that the combined flow is around 15 cfs. Water diverted in these ditches exits the sub-basin and is used consumptively in the Upper Methow Sub-basin near Mazama (personal communication with Nim Titcomb, March 1993). Streamflow in the sub-basin is similar to the "natural streamflow" due to the small amount of consumptive use in the sub-basin.

A comparison of the estimated hydrographs with the WDOE baseflows is shown in Appendix B. The high flows always exceed the baseflows. Median flows are well above the baseflows from May through July, but only slightly exceed the baseflows during the remainder of the year. The estimated low flows also exceed the baseflows throughout the year, although typically by only 2 to 10 cfs from October through April.

Due to the lack of any long-term, continuous stream gaging on Early Winters Creek, it is difficult to synthesize hydrographs for the Early Winters Sub-basin with any degree of reliability. The estimated hydrographs presented for the sub-basin have a high degree of uncertainty. It is therefore only possible to estimate the relative magnitude of streamflow in relation to the baseflows throughout the year.

5.3 Chewuch Sub-basin

The Chewuch River drains the northeastern portion of the Methow Basin, and with a drainage area of 525 square miles, is the largest of the seven sub-basins. Due to the overall distance of the sub-basin from the Cascade Crest, precipitation in the sub-basin is lower than it is in the sub-basins located along the crest (Methow Headwaters, Early Winters, and Twisp). As a result, runoff in the Chewuch Sub-basin is much lower than it is in other areas of the Methow Basin. Based on estimates made by Richardson (1976), as well as several years of streamflow record, the average annual runoff in the basin is about 10 inches.

Although much of the sub-basin is undeveloped, a significant amount of water is diverted from the river by four major canals located between Eightmile Creek (RM 11.5) and Winthrop. Collectively, these four canals divert on the order of 90 cfs during peak irrigation, which can represent a significant diversion depending on streamflow in the Chewuch River. It appears that most of the water diverted via the Eightmile and Skyline canals is used to irrigate land in the Chewuch sub-basin. Roughly 1,550 acres are irrigated along the Chewuch River near Winthrop, representing a peak consumptive use of about 11 cfs. A majority of the water diverted via the Chewuch and Fulton canals is used to irrigate land south of Winthrop, which represents a direct transfer of water from the Chewuch Sub-basin to the Middle Methow Sub-basin. Since streamflow in the Chewuch River averages only 100 cfs (or less) during the fall, these four diversions represent a significant percentage of the streamflow during this period.

The amount of groundwater that is exchanged with the Chewuch River is poorly understood. The Chewuch River joins the Methow River at Winthrop over what appear to be a series of bedrock ledges (EMCON, 1993), which indicates that little down-valley flow exits the sub-basin. Although some groundwater is likely exchanged with the river within the sub-basin, the groundwater component leaving the basin is assumed to be zero.

Estimated hydrographs for the Chewuch River near Winthrop are shown in Appendix A. A comparison of the estimated hydrographs with the WDOE baseflows is shown in Appendix B. The high flows exceed the baseflows by at least 40 cfs throughout the year, and during many months exceed them by over 100 cfs (late March through August). Median streamflows exceed the baseflows by several hundred cfs during peak runoff (late April through July), but exceed them by only several cfs from September through early March. Low streamflows exceed the baseflows from late April through August with the exception of early July, when the flow falls 3 cfs below the baseflow. Low flows fall below the baseflows from September through early April, but generally by only several cfs. A recent example of this occurring was during September of 1992 (which was a low-flow year), during which the recorded flow over the last fifteen days of the month was 39 cfs, or 8 cfs lower than the established baseflow (47 cfs).

The uncertainty in the estimated hydrographs for the Chewuch Sub-basin is high because of the short period of record available in the sub-basin. The variability in flow on the Chewuch River is likely higher than the variability on the Methow River at Pateros, so the use of the exceedance flows at Pateros to determine the exceedance flows on the Chewuch River is not strictly valid.

5.4 Upper Methow Sub-basin

The water budget for the Upper Methow Sub-basin is relatively complex, complicated by return flows from the Early Winters Sub-basin, several diversions within the sub-basin, and a relatively large groundwater component. Streamflow in the sub-basin is represented by the flow in the Methow River at Winthrop, and therefore includes the flow of the Chewuch River. The average annual runoff of the Methow River at Winthrop is estimated to be about 15 inches.

Inflows to the sub-basin are streamflow in the Methow River at Mazama, streamflow in the Chewuch River, tributary runoff within the sub-basin, and a small amount of return flow from diversion canals which originate on Early Winters Creek. Outflows from the sub-basin occur primarily as consumptive use from the 2,910 irrigated acres in the sub-basin, as well as water diverted via the Foghorn Canal which bypasses Winthrop and is used in the Middle Methow Sub-basin. Peak consumptive use during the summer is expected to be roughly 20 cfs, although considerably more water is diverted to meet this need. Major diversions in the upper reaches of the sub-basin include the Rockview and McKinney canals, with minor diversions from the Kumn-Holloway and Mazama canals. It is also understood that a small proportion of the consumptive demand is met with groundwater pumpage.

In the lower reaches of the sub-basin, the largest surface diversions occur via the Foghorn canal and the Wolf Creek diversion. Similar to the Foghorn canal, much of the water diverted by the Wolf Creek diversion is used consumptively in the Middle Methow Sub-basin. However, since the water diverted from Wolf Creek is stored in Patterson Lake during most of the summer, there is a considerable lag between when the water is diverted, and when it is used. Due to the difficulty involved in modelling the storage effects of Patterson Lake, and the relatively small amount of water which is diverted to the Middle Methow, the transfer of water from Patterson Lake to the Middle Methow is not included in the water budget.

A comparison of the estimated streamflow in the Methow River at Winthrop with the WDOE baseflows is shown in Appendix B. It is interesting to note that there appears to be sufficient streamflow to satisfy the baseflows year-round, even during low flow conditions. The main reason for this is that the baseflows appear to be set according to the original location of the control station in the sub-basin, which was located above the confluence of the Chewuch River at river mile 50.2. An addendum was made to the Water Resources Management Program in 1978 (WDOE, 1978) which changed the control station to its present location (river mile 49.8) which is located below the confluence of the Chewuch River. However, even if the flow of the Chewuch River is removed from the exceedance hydrographs when comparing streamflow in the Upper Methow Sub-basin with the established baseflows, several of the Upper Methow baseflows appear to be set much lower relative to the other sub-basins. In fact, the June baseflow is set to only 790 cfs, which is considerably lower than the 1,160 cfs baseflow set for the Methow Headwaters Sub-basin. The baseflows for late August and September are set at 100 cfs, which appear to be easily obtainable even during low flow conditions (90 percent exceedance flows). As an example, the observed streamflow during September of 1992 never fell below 190 cfs, thereby exceeding the established baseflow by a minimum of 90 cfs.

The least understood component of the water budget is the effect of groundwater interaction with the Methow River. Streamflow measurements indicate that in general, the Upper Methow Sub-basin is a gaining reach, such that there is a net flow of groundwater to the Methow River (WDOE, 1992). As shown in Table 5, it is estimated that an average of roughly 50 cfs of groundwater discharges to the Methow River in the Upper Methow Sub-basin based on the results of the water budget. This agrees with an estimate of the down-valley flow based on water-level data and assumed aquifer properties (Golder Associates, 1991).

5.5 Twisp Sub-basin

The Twisp River drains a 245 square mile basin which is located along the western margin of the Methow Basin. Based on a six-year record of daily streamflow measurements on the Twisp River near Twisp, average annual runoff in the sub-basin is slightly above 14 inches. Streamflow in the Twisp River has a seasonal distribution similar to the other sub-basins located along the Cascade Crest, with a pronounced peak in May and June coinciding with peak snowmelt (Appendix A).

Consumptive use in the sub-basin is relatively low. Most of the agriculture is limited to a narrow belt along the Twisp River, with a total of only 882 acres being irrigated. It is estimated that the peak consumptive use from these irrigated acres will be about 6 cfs. Most of the water used to irrigate crops in the sub-basin is diverted from the Twisp River from one of several small diversions located along the lower 10 miles of the river. The largest diversion in the sub-basin is the MVID West canal, located about four miles upriver from Twisp. The flow in the MVID West canal averages about 30 cfs during the irrigation season (WDOE, 1991), but is mostly used in the Lower Methow Sub-basin and therefore represents a direct loss from the Twisp Sub-basin.

Little is known about the amount of water which exits the sub-basin as groundwater flow. EMCON (1993) reported that the Twisp River joins the Methow River at Twisp in conjunction with what appears to be a fluvial valley aquifer. However, since the possible extent and hydraulic properties of the aquifer are not well understood, groundwater flow exiting the Twisp Sub-basin has been assumed to be negligible.

A comparison of the estimated hydrographs from the Twisp River with the WDOE baseflows is shown in Appendix B. The high flows always exceed the baseflows. Median streamflows also exceed the baseflows during all periods, and generally exceed the baseflows during low-flow periods (September through March) by 20 to 40 cfs. However, the low flows are equal to or below the baseflows throughout most of the year. In particular, it appears as if low flows on the Twisp River could fall well below the baseflows during June and July (300 cfs below the early July baseflow). The early July baseflow has been set only 50 cfs below the June baseflows, which is a difficult target to meet during a low-flow year when the peak of the hydrograph is expected to decline much earlier than under normal conditions.

The exceedance hydrographs for the Twisp River are based on a statistical analysis of only seven years of data, so the uncertainty in the exceedance flows is relatively high. In particular, some of the low flows (90 percent exceedance flows) listed in Appendix C may be too small. The short period of streamflow record from the Twisp River contains data from 1977, which had the lowest mean annual flow on record on the Methow River. The presence of such an abnormally low flow year within a seven year record would significantly bias the estimated 90 percent exceedance flows.

5.6 Middle Methow Sub-basin

The Middle Methow Sub-basin, at 49 square miles, is the smallest of the seven sub-basins in the Methow Basin. The median annual flow of the Methow River at Twisp is 1,356 cfs, based on the fit of a normal distribution to 39 years of mean annual streamflow data. Most of the water which enters the sub-basin enters as surface flow from the Methow River at Winthrop and the Twisp River at Twisp. Tributary runoff in the sub-basin is small because of the small size of the sub-basin and its semi-arid climate. Runoff within the sub-basin is estimated to be around two inches annually.

Additional surface water inflow enters the sub-basin from the approximately 80 cfs of water which is imported during the irrigation season from canals which originate in the Chewuch and Upper Methow Sub-basins. Since not all of this water is used consumptively, the excess water either remains in the canals and is sent to the Lower Methow Sub-basin, or eventually returns to the Methow River in the Middle Methow Sub-basin as return flow. Most of the water which exits the sub-basin leaves via surface flow in the Methow River at Twisp. Surface flow also exits the sub-basin in the MVID East canal, which diverts an average of about 40 cfs to the Lower Methow Sub-basin during irrigation season (WDOE, 1991).

Consumptive use from the 3,637 irrigated acres in the sub-basin is estimated to peak at around 25 cfs. It is estimated that the exchange of streamflow with groundwater is relatively small, mainly due to the small size of the basin. The residual for median conditions (Table 5) indicates that an average of 40 cfs of surface flow is lost to groundwater in the sub-basin, although it is unclear whether the Methow River is a gaining or losing stream in the Middle Methow Sub-basin. Balancing the water budget in the sub-basin was difficult due to the complexity of the budget and the uncertainty in the hydrographs of the Methow River at Winthrop. As a result, the residual in the Middle Methow Sub-basin mostly represents uncertainty in the sub-basin water budget.

A comparison of the hydrographs for the Middle Methow Sub-basin (Methow River at Twisp) with the WDOE baseflows is shown in Appendix B. The quality of these hydrographs is considered good. The high flows exceed the baseflows by at least 200 cfs during all periods of the year. The median flows are also above the baseflows throughout the year, although the median flows from January through early March only exceed the baseflows by 15 to 40 cfs. Low flows (90 percent exceedance flows) fall below the baseflows during most of the year, with the exception of during May and June. The 90 percent exceedance flow appears to fall well below the baseflow (over 600 cfs) during early July. The early July baseflow is set the same as the baseflows during peak runoff (1,500 cfs during late May and June), which will be difficult to achieve during low-flow years when the peak of the hydrograph is expected to decline earlier than it does during more normal years.

5.7 Lower Methow Sub-basin

The Lower Methow Sub-basin comprises the southern quarter of the Methow Basin, representing the Methow Valley from Twisp to Pateros. The median annual flow of the Methow River at Pateros is 1,522 cfs, based on the fit of a Log-Pearson Type III distribution to 30 years of mean annual streamflow data. Most of the sub-basin is undeveloped, although about 7,955 acres of the valley along the Methow River are irrigated, with orchards comprising a large portion of the irrigated acreage. Most of the irrigation water used in the sub-basin near Twisp comes from the MVID canals, which import water from the Twisp and Middle Methow Sub-basins. Below the MVID canals (near the town of Carlton) most of the irrigation water comes from wells located near the river (personal communication with Nim Titcomb, 1993). There are no major surface water diversions which originate in the sub-basin. Consumptive use in the basin from irrigated lands is expected to peak around 50 cfs.

Surface water entering the basin originates as streamflow in the Methow River at Twisp (including the Twisp River). Surface water also enters the sub-basin during the irrigation season from two MVID canals as described above. Tributary runoff is estimated to average about four inches annually, thereby providing an average tributary inflow of 140 cfs to the sub-basin. Almost all of the surface water in the Lower Methow Sub-basin exits the sub-basin as surface flow in the Methow River. A small component of groundwater may exit the basin at Pateros (5 to 20 cfs). It is unknown how much water enters the sub-basin as groundwater from the Middle Methow. However, it is expected that most of the groundwater which enters the sub-basin discharges to the Methow River (e.g. little water is expected to exit the basin as groundwater). The residual from the water budget suggests that the Lower Methow Sub-basin is generally an area of groundwater discharge to the Methow River (Table 5). The residuals shown in Table 5 are only estimates of the quantity of groundwater being exchanged with the Methow River. However, it seems likely that the Lower Methow River becomes a gaining reach as the lateral and vertical extent of the alluvial aquifer becomes limited below the town of Carlton.

A comparison of the hydrographs for the Lower Methow Sub-basin (Methow River at Pateros) with the WDOE baseflows is shown in Appendix B. The quality of these hydrographs is considered good. The high flows always exceed the baseflows by a minimum of 200 cfs. The median flows exceed the baseflows during all periods of the year, although they exceed the baseflows by less than 20 cfs during several periods from late October through December. Low flows (90 percent exceedance flows) fall below the baseflows throughout the year except during May and early June. The 90 percent exceedance flows during early July fall roughly 1,000 cfs below the 2,150 cfs baseflow.

6. SUMMARY AND CONCLUSIONS

A water budget analysis of the Methow River Basin was performed in order to quantify streamflow within the seven major sub-basins of the Methow Basin. The results were incorporated into a geographic information system (GIS) formatted layer which is compatible with existing GIS data sets of the basin. For each sub-basin, an estimate of bi-monthly streamflow for high-flow (10 percent exceedance), median-flow (50 percent exceedance), and low-flow (90 percent exceedance) conditions was developed using existing streamflow data. In cases where little data were available, streamflow was estimated based on the existing data. Due to difficulties in obtaining a balance of the budget at the bi-monthly time-step during many parts of the year, the components of the budget were adjusted to reduce the water budget residuals to acceptable values. Water budget residuals are an estimate of the exchange of surface water with groundwater through changes in aquifer storage, but also reflect uncertainty in the other components of the budget.

Also included in the GIS system are the minimum instream flows or "baseflows" which have been established by WDOE for each of the sub-basins. A comparison of the baseflows with the estimated hydrographs provides an estimate as to how streamflow compares with the baseflows over a typical range of flow conditions.

The conclusions of the Methow Basin water budget analysis in relation to the established baseflows (Kauffman and Bucknell, 1976) are as follows:

- Streamflows for high-flow conditions (10 percent exceedance flows) exceed the established baseflows for all sub-basins at all times of the year;

- Streamflows for median-flow conditions (50 percent exceedance flows) exceed the established baseflows for all of the sub-basins at all times of the year. Median flows generally exceed the established baseflows by several hundred cfs (or more) during peak runoff (May and June). Median flows throughout the fall and winter (September through February) are only slightly above the baseflows in most of the sub-basins, and in some cases exceed the baseflows by only several cfs;

- Streamflows for low-flow conditions (90 percent exceedance flows) are below the established baseflows in the Methow Headwaters, Chewuch, Twisp, Middle Methow, and Lower Methow Sub-basins for many periods except May and June. In these sub-basins, the 90 percent exceedance flows are roughly equal to or below the baseflows from September through March;

- Streamflow in the Upper Methow Sub-basin exceeds the established baseflows at all times, including the low flows, mainly because the baseflows in the Upper Methow Sub-basin were established for a control point which was originally located above the confluence of the Chewuch River. An addendum to the

Water Resources Management Program has moved the control point to a location below the confluence of the Chewuch River;

- Early July streamflow during low-flow conditions (90 percent exceedance flow) is several hundred cfs below the established baseflows for the Lower Methow, Middle Methow, and Twisp Sub-basins. The early July baseflows established for these sub-basins have been set equal to (or just below) the baseflows set for peak runoff (June). During low-flow years, streamflow in early July is typically well below the average June flows.

General conclusions are summarized as follows:

- The hydrographs presented for the Middle Methow and Lower Methow Sub-basins are good representations of the exceedance flows in these sub-basins, and are based on a statistical analysis of over thirty years of streamflow data;

- The hydrographs presented for the Twisp Sub-basin are expected to have a relatively high degree of uncertainty because they are based on a statistical analysis of only seven years of streamflow data. In particular, estimates of streamflow for the 90 percent exceedance flows are expected to be lower than the true 90 percent exceedance flows because of a skewed data set;

- The hydrographs presented for the Upper Methow, Chewuch, Methow Headwaters, and Early Winters Sub-basins are based on limited streamflow data and therefore have a relatively high degree of uncertainty;

- Streamflow in the Methow Basin during the winter is essentially equivalent to the "natural streamflow" in the basin because of little consumptive use;

- Residuals from the water budget analysis indicate that roughly 50 cfs of groundwater discharges to the Upper Methow Sub-basin, which agrees with an estimate of the down-valley flow based on groundwater data (Golder Associates, 1991). Conjunctive use of groundwater and surface water should be explored further to satisfy increased demand in the basin while minimizing impacts to streamflow.

There is some scope for the potential improvement in the accuracy of the water budget. In order to reduce the sub-basin residuals at short time-steps (bi-monthly) and reduce the uncertainty in the water budget at bi-monthly time-steps, additional information would be needed to better characterize several components of the budget. This would include a better understanding of groundwater flow and changes in aquifer storage, stream gaging to determine tributary runoff in each of the sub-basins, more information regarding the transfer of surface water between sub-basins, and a better understanding of return flows. Many of these components are part of a complex hydrologic system and would be difficult, expensive, and time-consuming to characterize. The best method of characterizing streamflow in the sub-basins is through the use of continuous stream gaging, operated over a long period of record. With the exception of the Early Winters

Sub-basin, all of the sub-basins now have continuously operated stream gages. Measurements should continue at these stations, and as longer-term records are obtained, statistical methods can be used to provide more reliable hydrographs for these sub-basins.

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TABLES

TABLE 1

ESTIMATED MEAN ANNUAL WATER BUDGET OF METHOW VALLEY

	Annual volume (acre-feet)	Percentage of water budget
INFLOW		
Precipitation[1]	2,835,000	100%
Groundwater	Insignificant	
OUTFLOW		
Evapotranspiration		
Irrigated Land (17,500 acres)[2]	40,800	1.50%
Non-Irrigated Land[3]	1,656,000	58%
Surface Water[4]	1,131,000	40%
Groundwater[5]	7,200	0.50%

(1) Milhous, et al., 1976.
(2) Based on 1992 irrigated lands survey. Estimated mean annual irrigation requirement is 28 inches.
(3) Estimated.
(4) Based on gaged flow of Methow River at Pateros, 1959-1991.
(5) Estimated.

Summary of Historical Continuous Streamflow Records in the Methow Basin

Sub-Basin	Gage Location	Period of Record
Lower Methow	Methow River near Pateros	(49 years) 1903-1920 1959-1993
Middle Methow	Methow River at Twisp	(43 years) 1919 -1929, 1934 - 1962, 1991 - 1993
Upper Methow	Methow River at Winthrop	(5 years) 1912, 1971 - 1972, 1989 - 1993
Twisp	Twisp River near Twisp	(7 years) 1975-1979, 1989 - 1993
Chewuch	Chewuch River near Winthrop	(4 years) 1911 - 1912, 1920 - 1921, 1991 - 1993
Methow Headwaters	Methow River near Mazama	(2 years) 1991 - 1993

Comparison of Mean Values of Exceedance Hydrographs with Mean Annual
Exceedance Flows Methow River at Pateros

	Low Flow	Medium Flow	High Flow
	90 Percent Exceedance	50 Percent Exceedance	10 Percent Exceedance
Mean Value of Exceedance Hydrograph	745	1396	2614
Mean Annual Exceedance Flow	990	1522	2249

All Values are in cfs
Mean Annual Exceedance Flows Determined Assuming a Log-Person Type III Distribution

TABLE 4

IRRIGATED LAND IN THE METHOW BASIN BY SUB-BASIN

Sub-basin	Irrigated Acreage (Acres)	Percent of Sub-basin
Methow Headwaters	627	0.3
Upper Methow	2,910	3.3
Early Winters	35	0.1
Chewuch	1,546	0.5
Middle Methow	3,637	10.1
Twisp	882	0.6
Lower Methow	7,955	2.5

TABLE 5

AVERAGE ANNUAL SUB-BASIN RESIDUALS

Sub-basin	Methow Headwaters	Upper Methow	Middle Methow	Lower Methow
90% Exceedance	-51	25	-16	76
Median Conditions	-74	52	-40	42
10% Exceedance	-73	114	-109	29

All values are in cfs
Negative values indicate surface water surplus (net loss of streamflow to groundwater)
Positive values indicate surface water deficit (net gain of streamflow from groundwater)

FIGURES

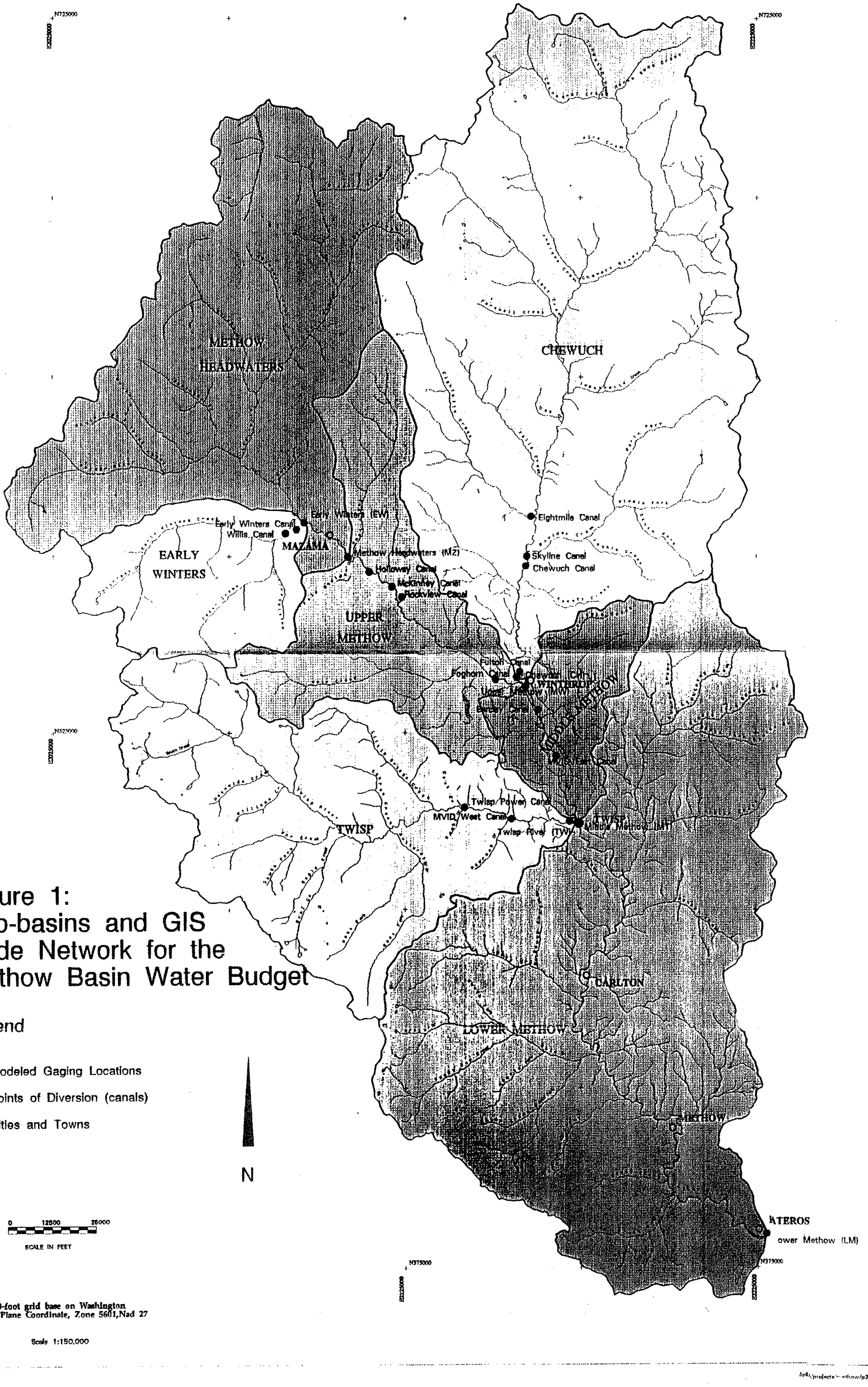
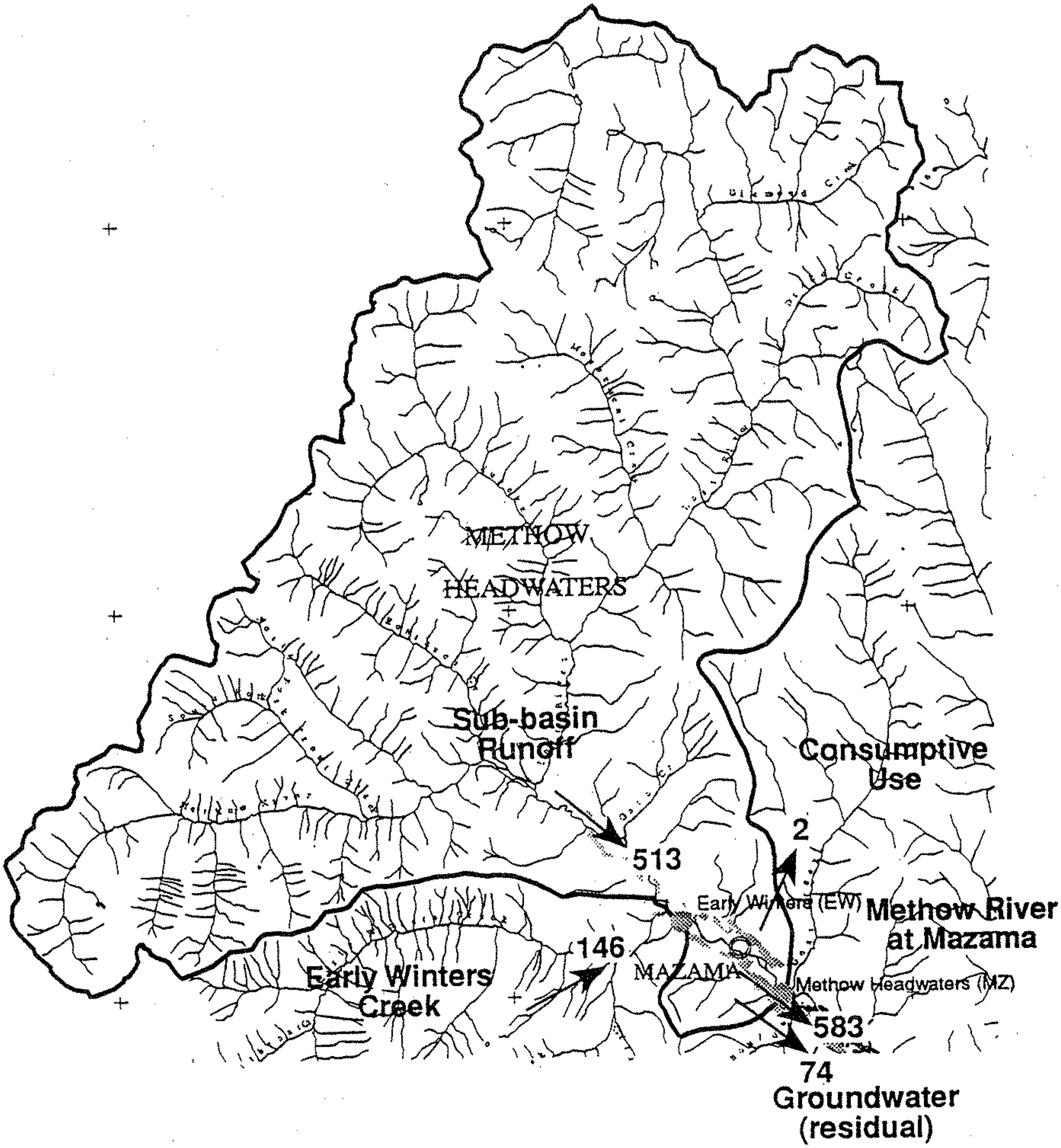


Figure 1: Sub-basins and GIS Node Network for the Methow Basin Water Budget

Legend

- Modeled Gaging Locations
- Points of Diversion (canals)
- Cities and Towns



——— Sub-Basin boundary

Notes: All values are average annual values in cfs for median flow conditions. Shaded areas are irrigated land.

FIGURE 4

GRAPHICAL REPRESENTATION OF THE WATER BUDGET FOR THE METHOW HEADWATERS SUB-BASIN

EES/METHOW WATER BUDGET/WA

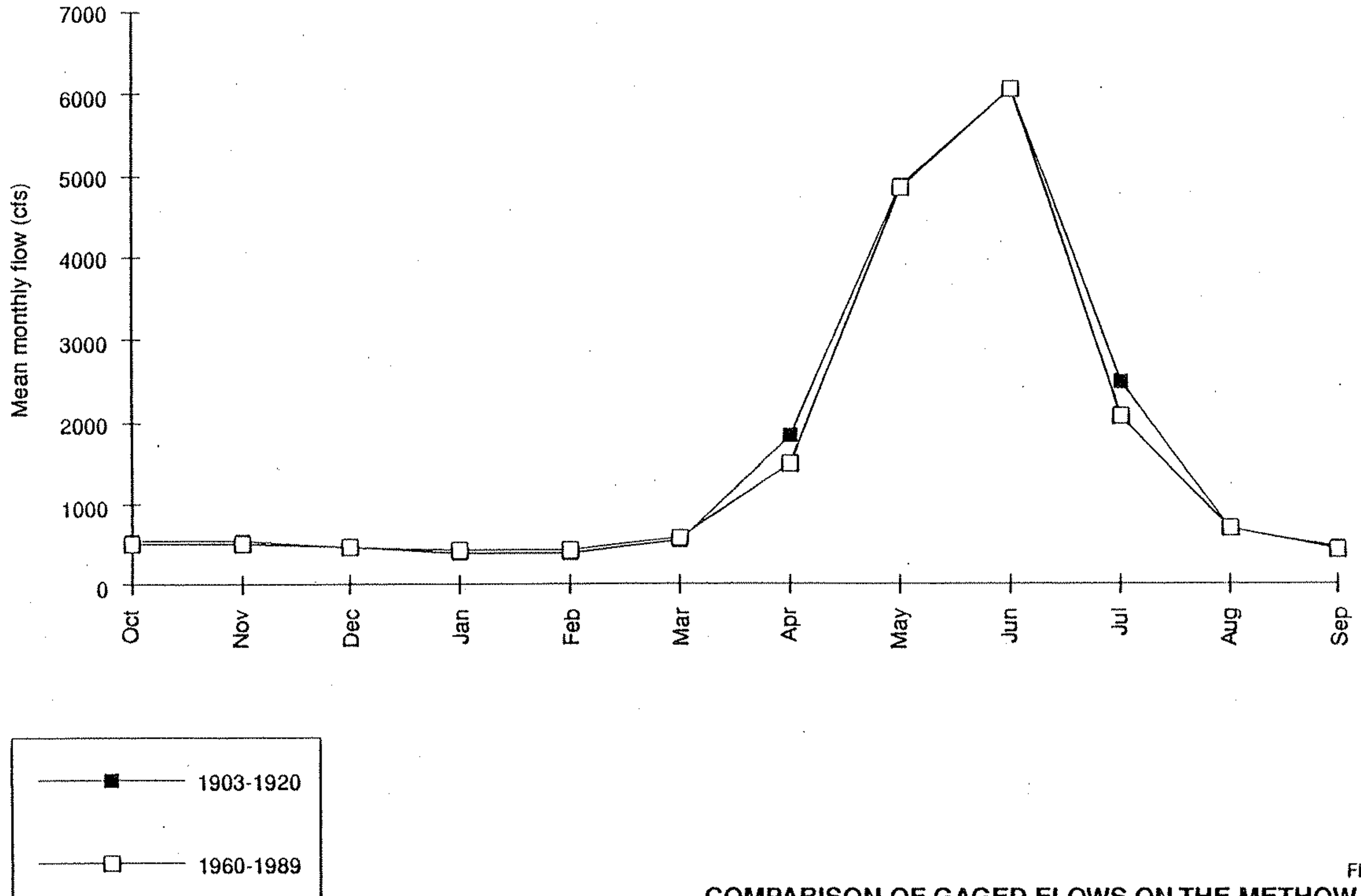


FIGURE 3

COMPARISON OF GAGED FLOWS ON THE METHOW RIVER NEAR PATEROS, WA DURING 1903-1920 AND 1960-1989

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46789 DATE 8/3/93 DRAWN BY CB

Golder Associates

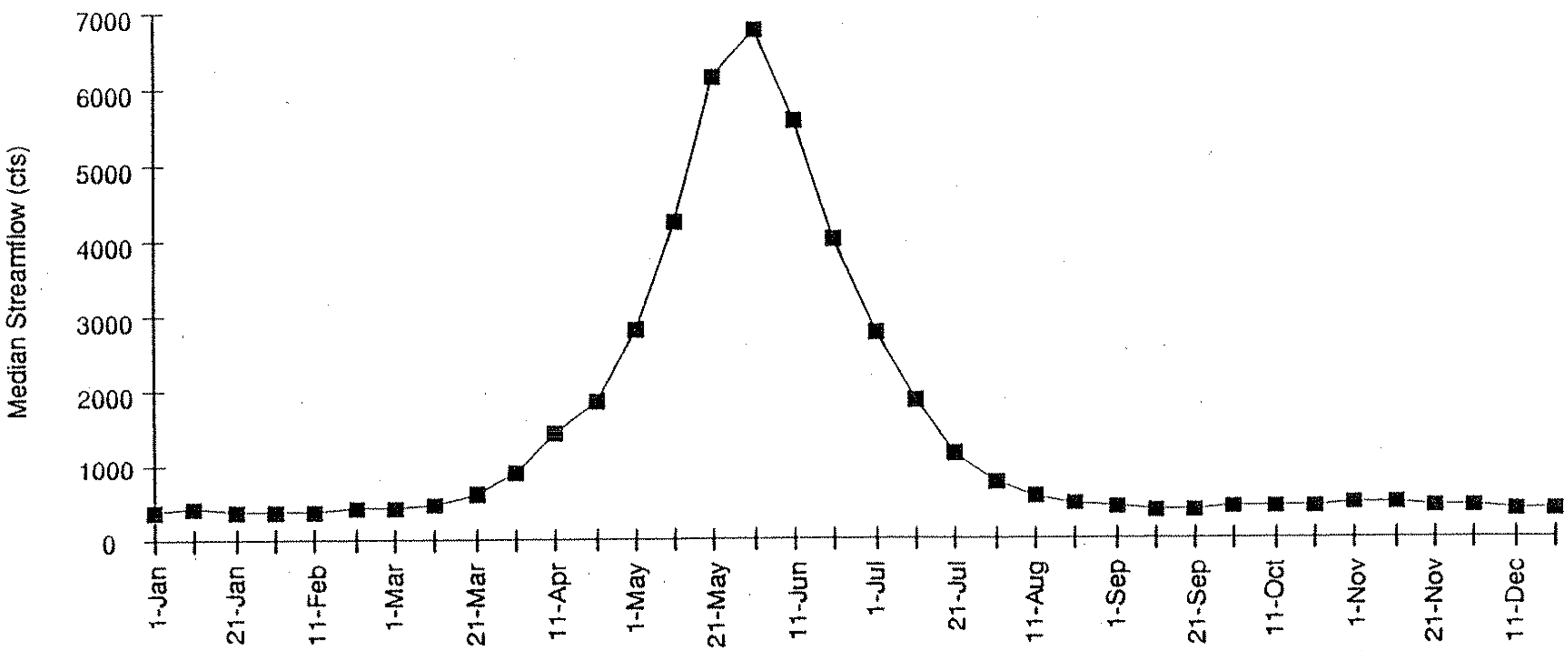


FIGURE 2
MEDIAN ANNUAL HYDROGRAPH OF THE METHOW RIVER AT PATEROS (1959-1992)
EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46788 DATE 8/3/93 DRAWN BY CB

Golder Associates

APPENDIX A

ESTIMATED SUB-BASIN HYDROGRAPHS

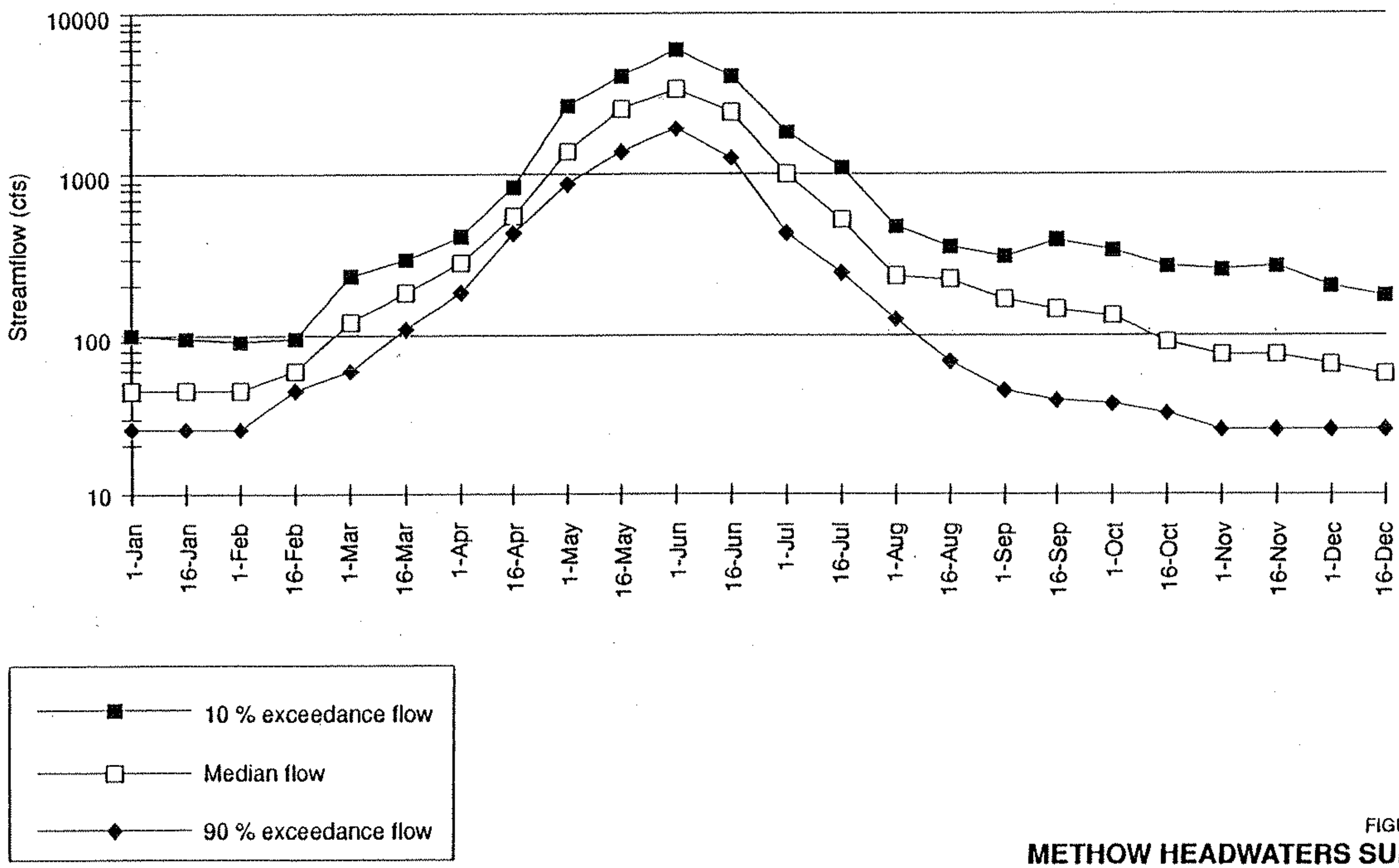


FIGURE **A-1**

METHOW HEADWATERS SUB-BASIN
METHOW RIVER NEAR MAZAMA, WA
FLOW DERIVED FROM STATION 12447383
EES/METHOW WATER BUDGET/WA

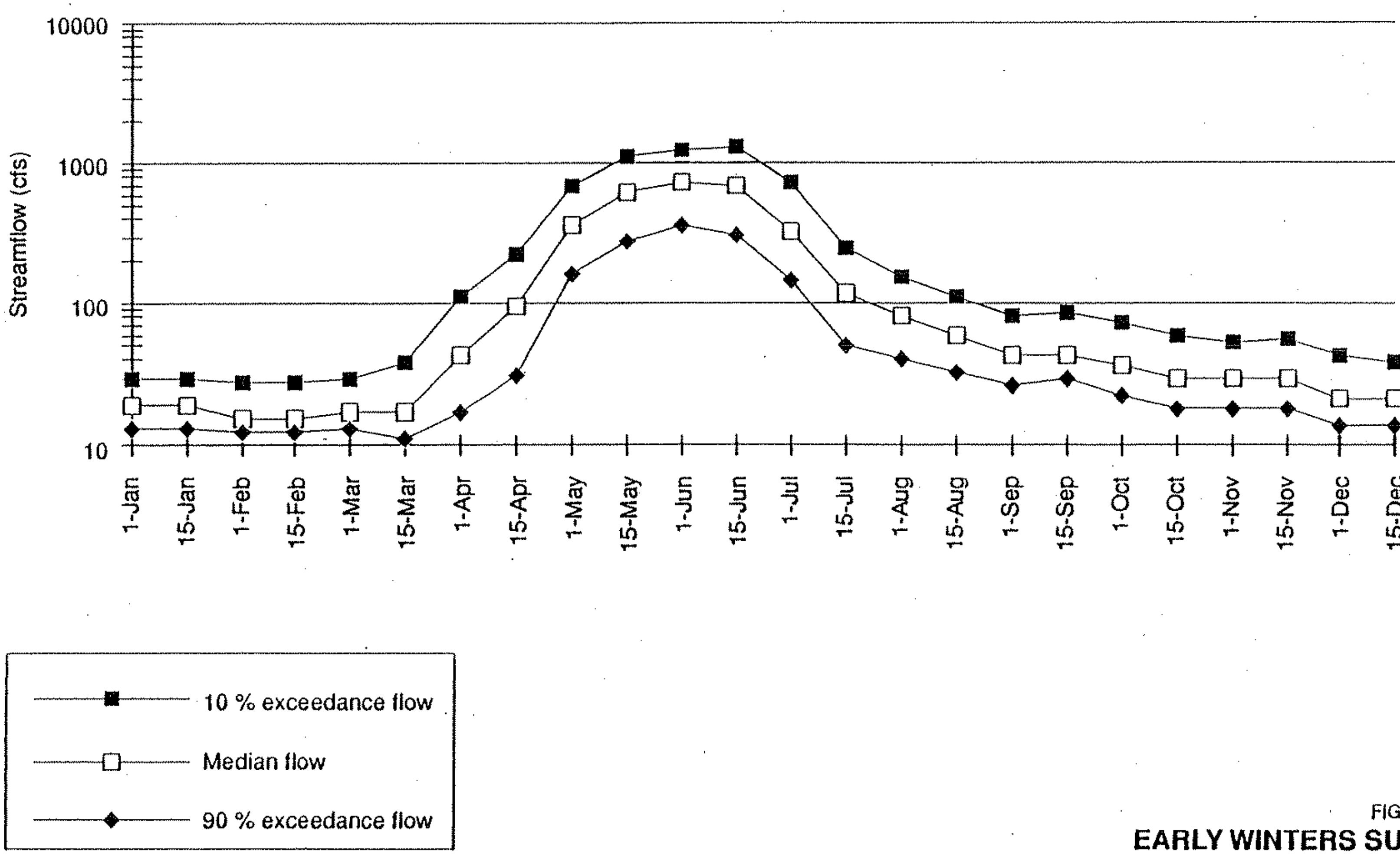


FIGURE **A-2**

EARLY WINTERS SUB-BASIN
EARLY WINTERS CREEK AT CONFLUENCE WITH METHOW RIVER ESTIMATED FLOW
EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46791 DATE 8/3/93 DRAWN BY CB

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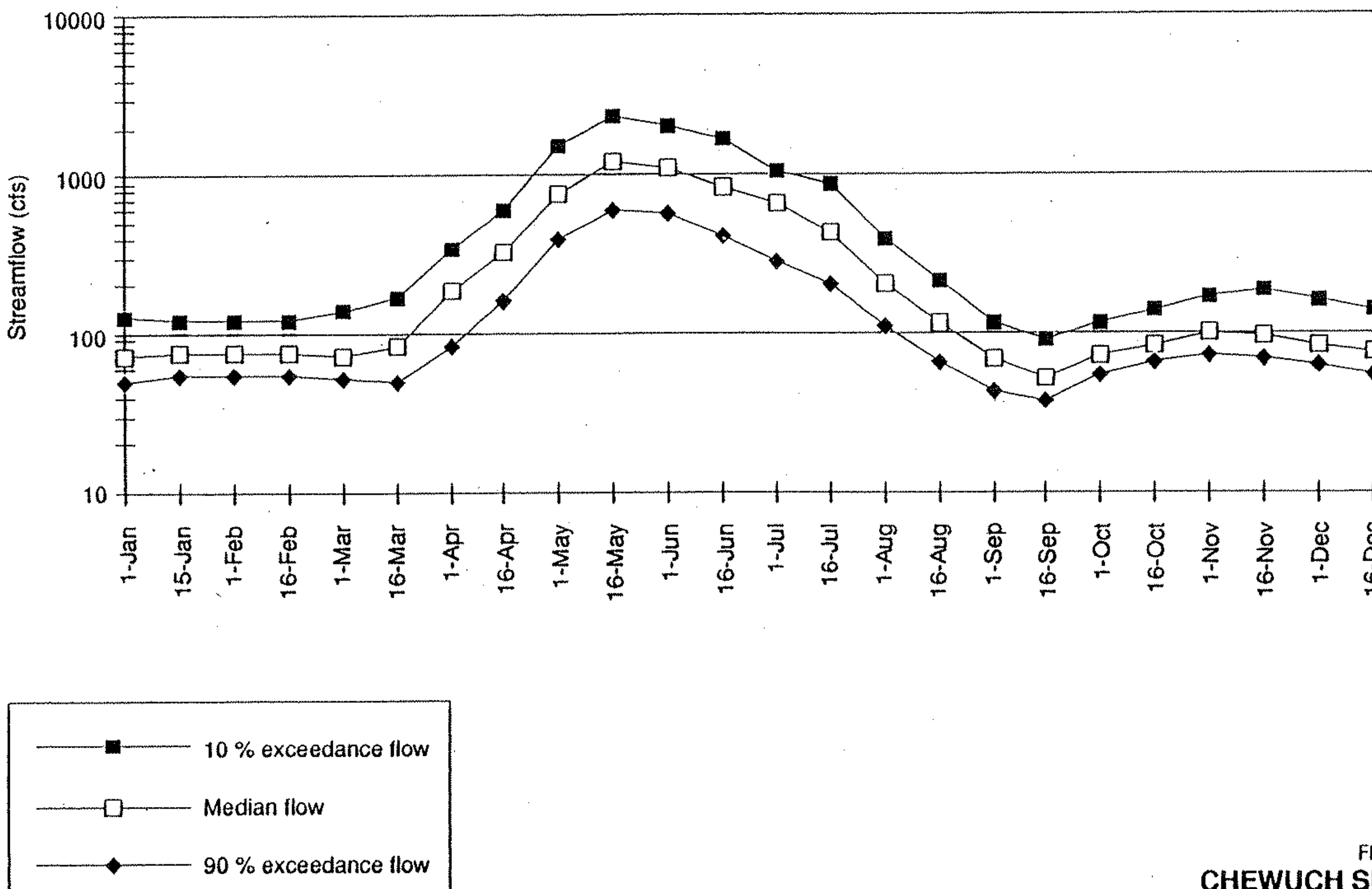

FIGURE **A-3**

CHEWUCH SUB-BASIN
CHEWUCH RIVER NEAR WINTHROP
FLOW DERIVED FROM STATION 12448000
EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46792 DATE 8/3/93 DRAWN BY CB

Golder Associates

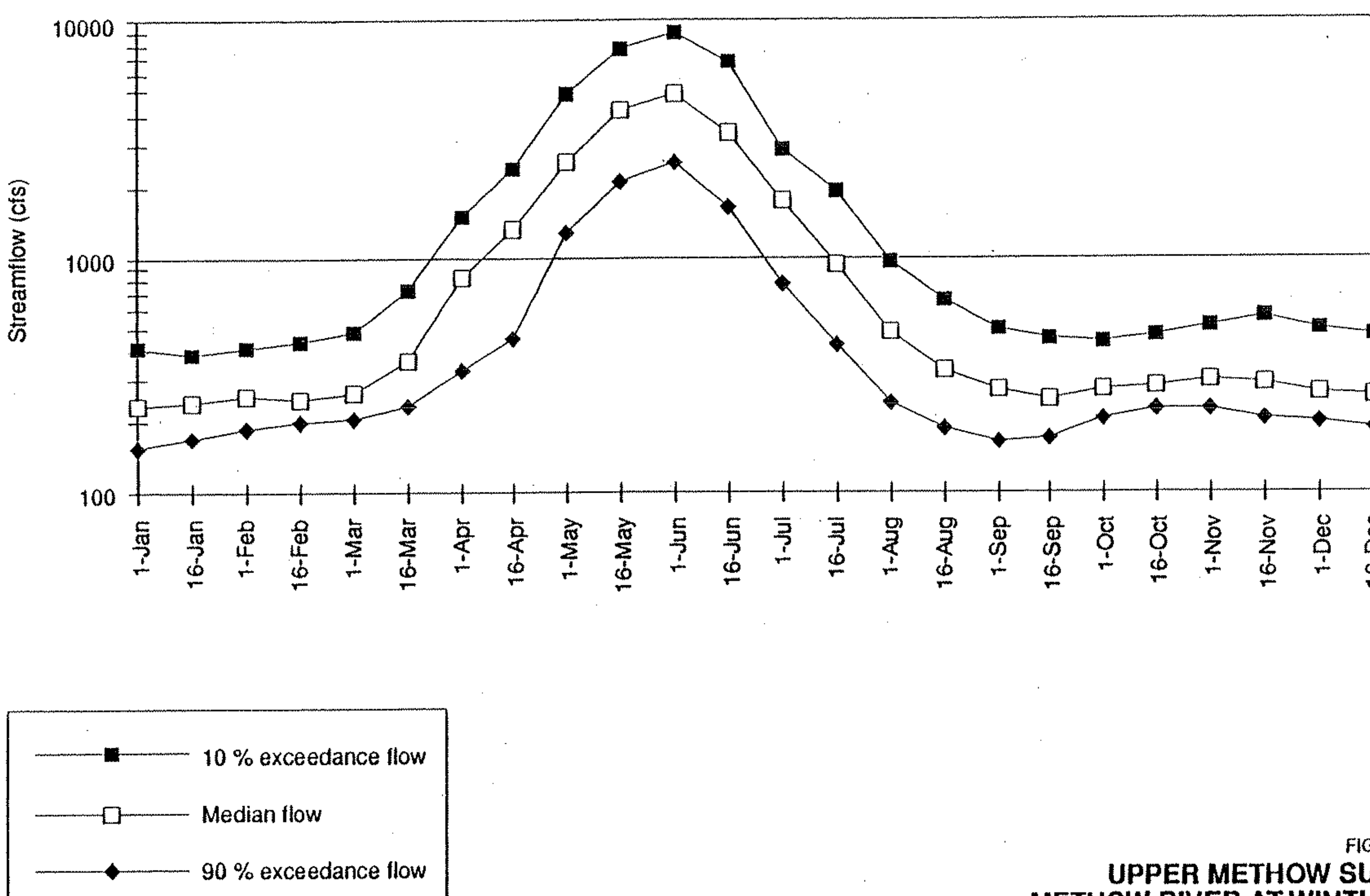

FIGURE **A-4**

UPPER METHOW SUB-BASIN
METHOW RIVER AT WINTHROP, WA
FLOW DERIVED FROM STATION 12448500
EES/METHOW WATER BUDGET/WA

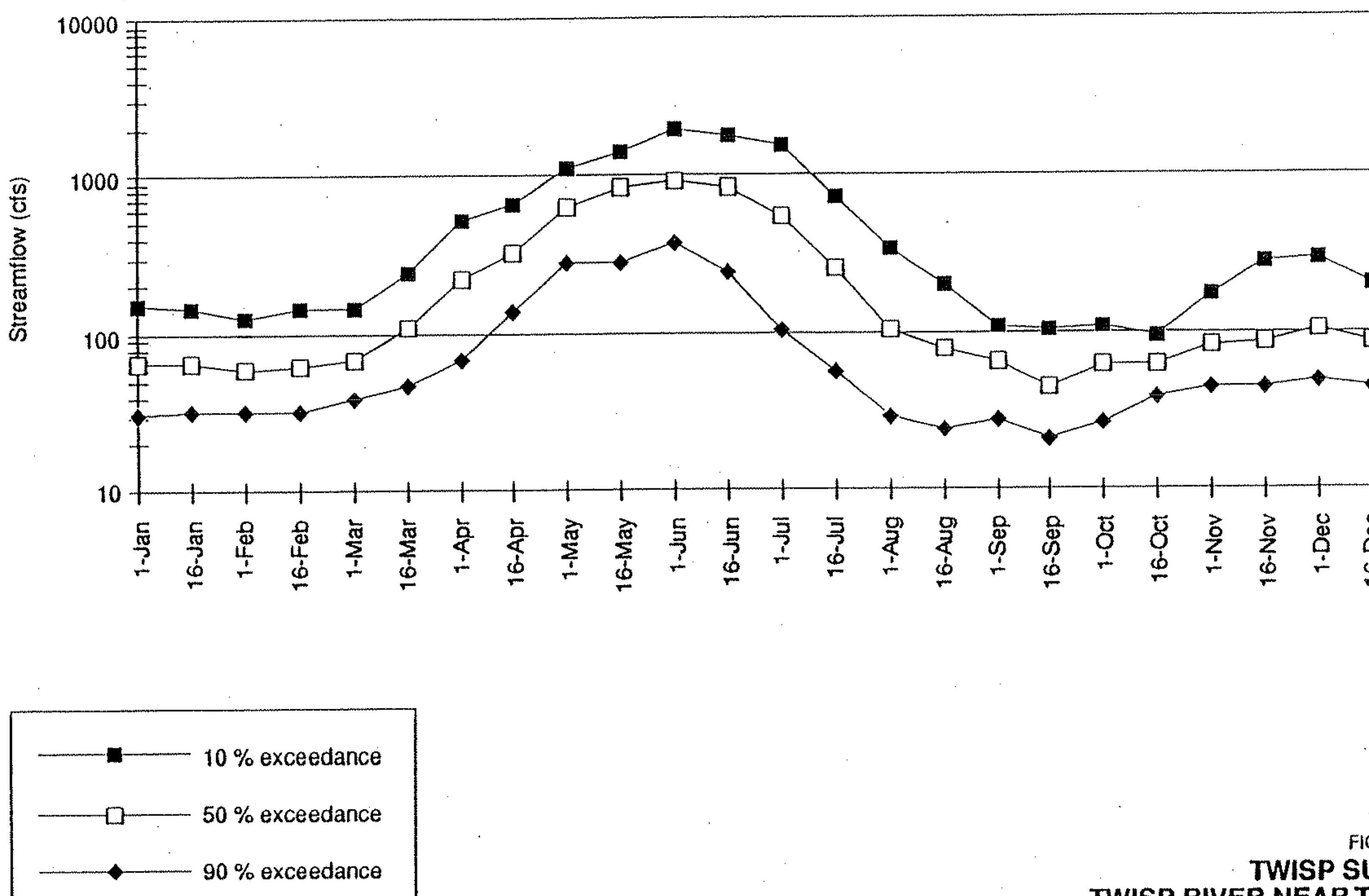

FIGURE **A-5**

TWISP SUB-BASIN

TWISP RIVER NEAR TWISP, WA

FLOW DERIVED FROM STATION 12448998

EES/METHOW WATER BUDGET/WA

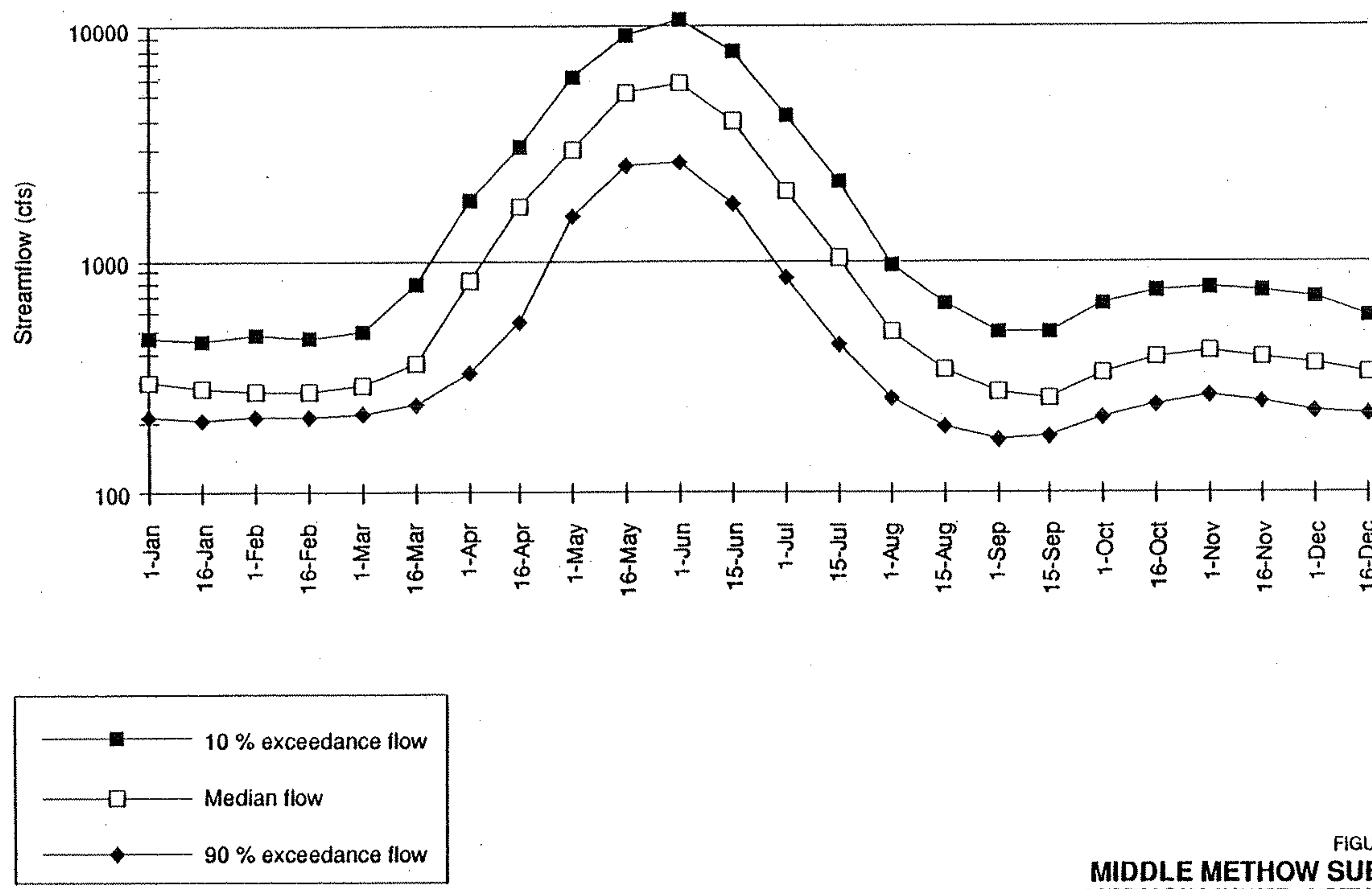

FIGURE **A-6**

MIDDLE METHOW SUB-BASIN
METHOW RIVER AT TWISP, WA
STATION ID 12449500 (1919-1962, 1991-1992)

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46795 DATE 8/3/93 DRAWN BY CB

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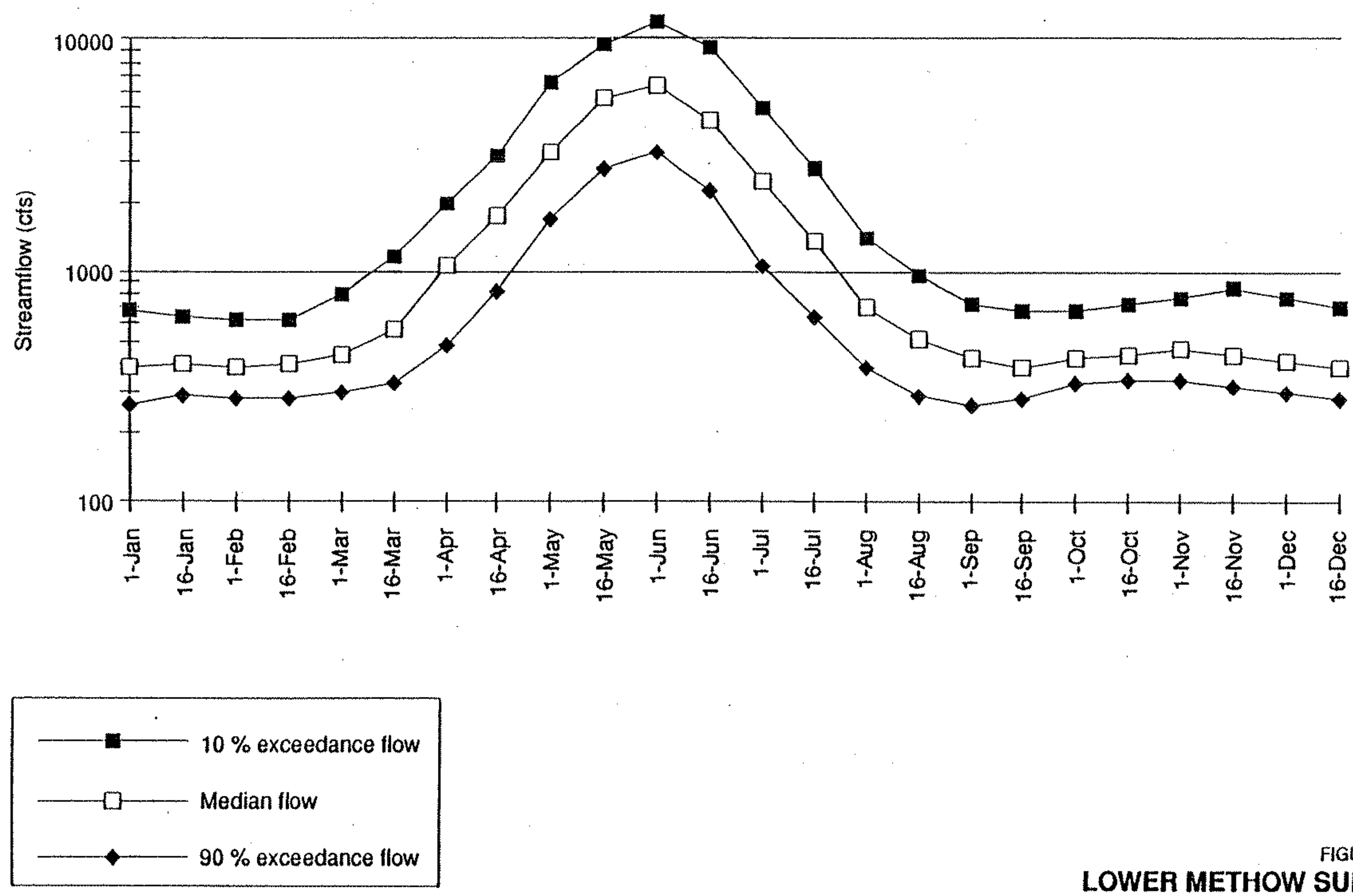

FIGURE **A-7**
LOWER METHOW SUB-BASIN
METHOW RIVER NEAR PATEROS, WA
STATION ID 12449950 (1959-1992)
EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46796 DATE 8/3/93 DRAWN BY CB

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APPENDIX B

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS

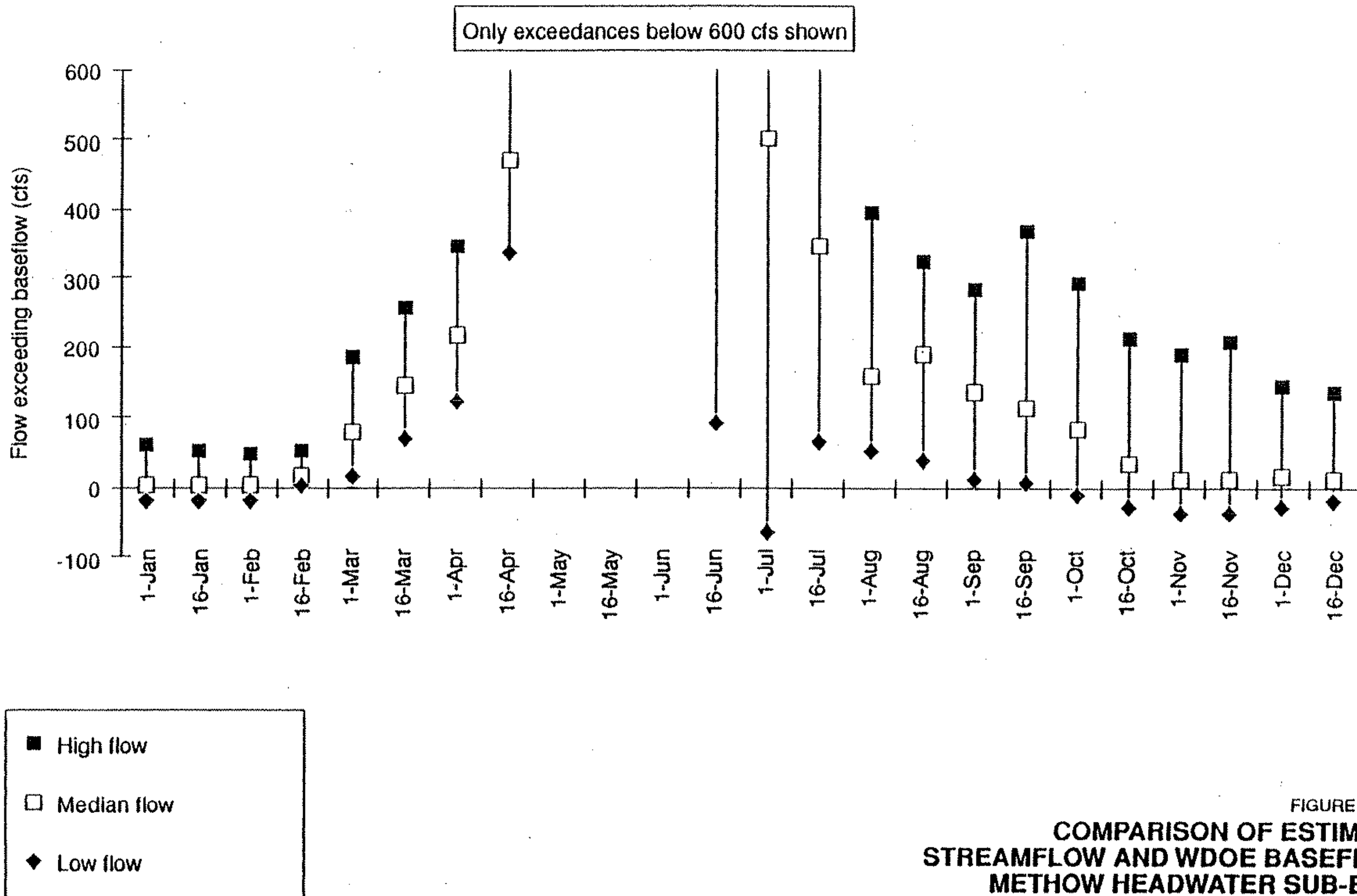

FIGURE **B-1**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS METHOW HEADWATER SUB-BASIN (METHOW RIVER NEAR MAZAMA)

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46797 DATE 8/19/93 DRAWN BY CB

Golder Associates

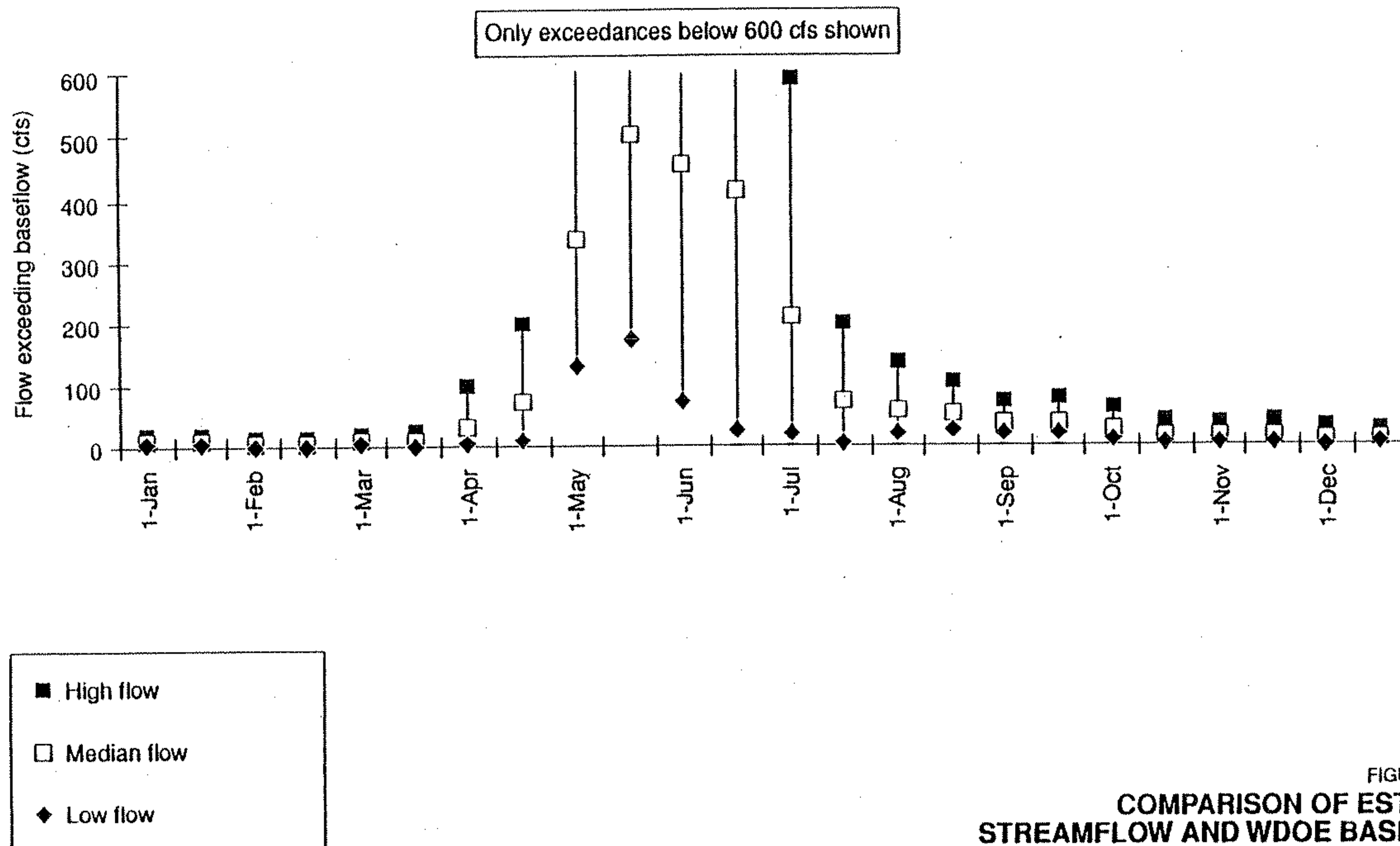

FIGURE **B-2**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS EARLY WINTERS SUB-BASIN (EARLY WINTERS CREEK AT CONFLUENCE WITH METHOW RIVER)

EES/METHOW WATER BUDGET/WA

PROJECT IO. 933 1224.300 DRAWING NO. 46798 DATE 8/19/93 DRAWN BY CB

Golder Associates

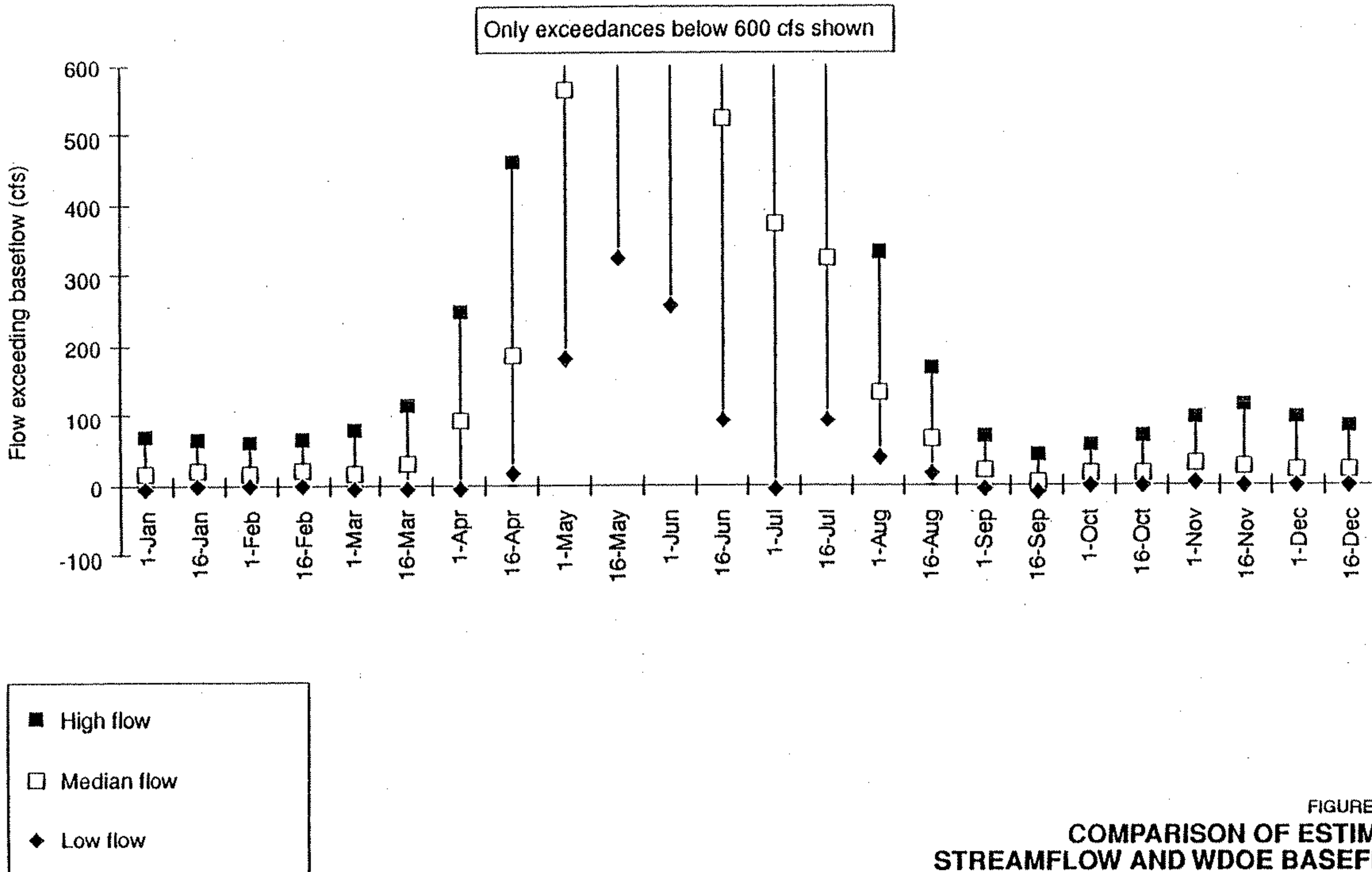

FIGURE **B-3**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS CHEWUCH SUB-BASIN (CHEWUCH RIVER NEAR WINTHROP)

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46799 DATE 8/17/93 DRAWN BY CB

Golder Associates

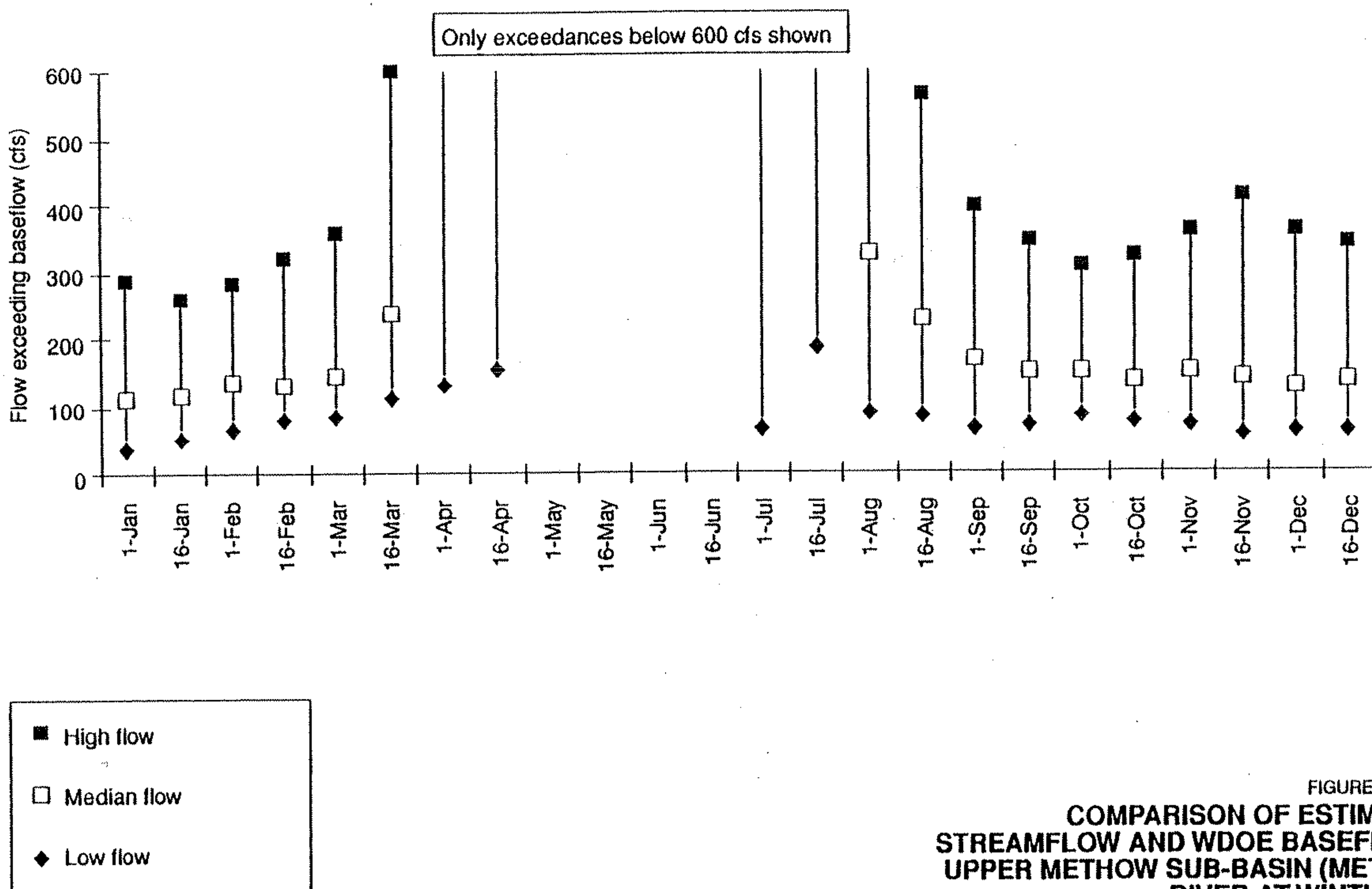

FIGURE **B-4**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS UPPER METHOW SUB-BASIN (METHOW RIVER AT WINTHROP)

EES/METHOW WATER BUDGET/WA

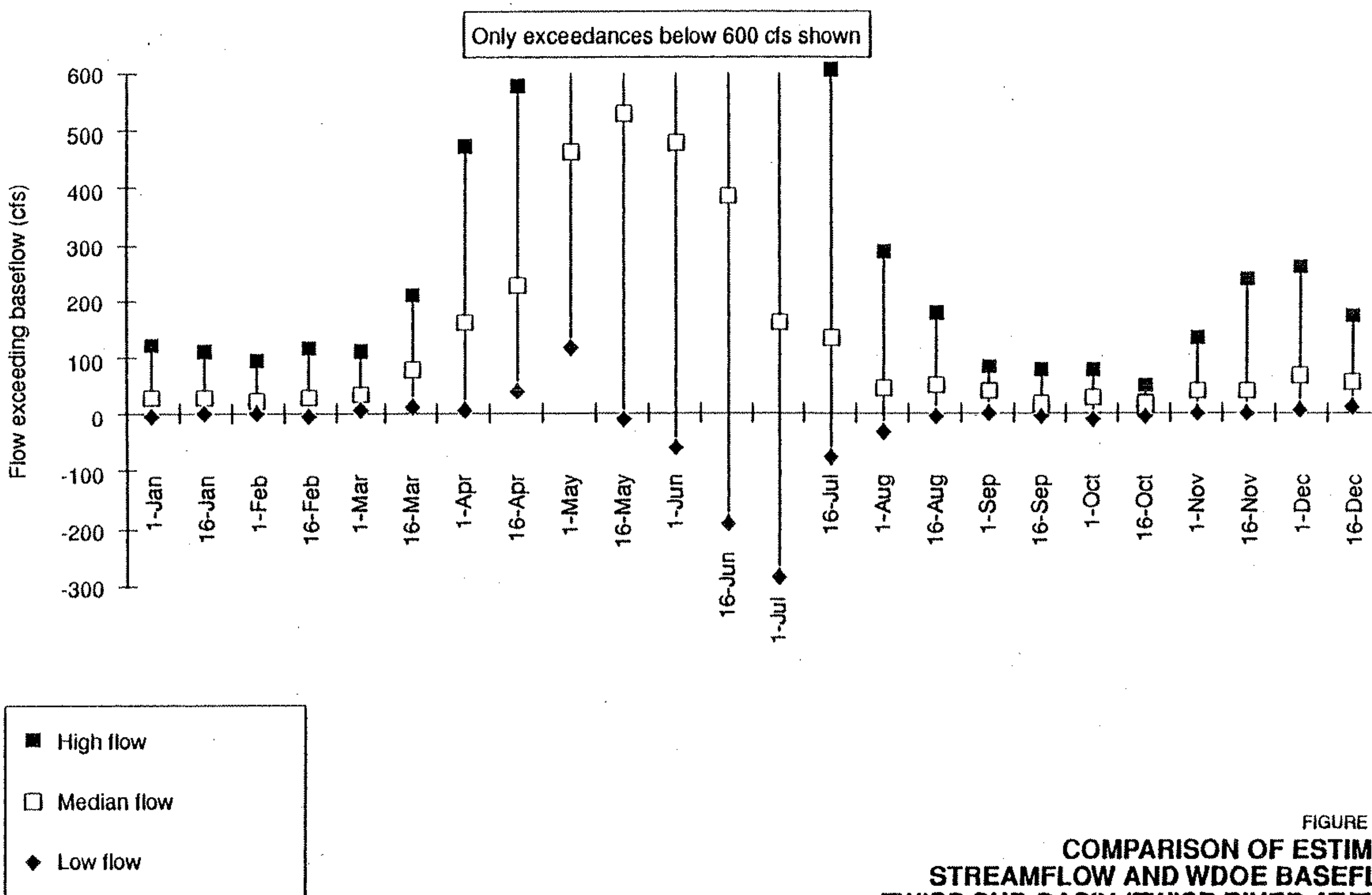

FIGURE **B-5**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS TWISP SUB-BASIN (TWISP RIVER AT TWISP)

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46801 DATE 8/19/93 DRAWN BY CB

Golder Associates

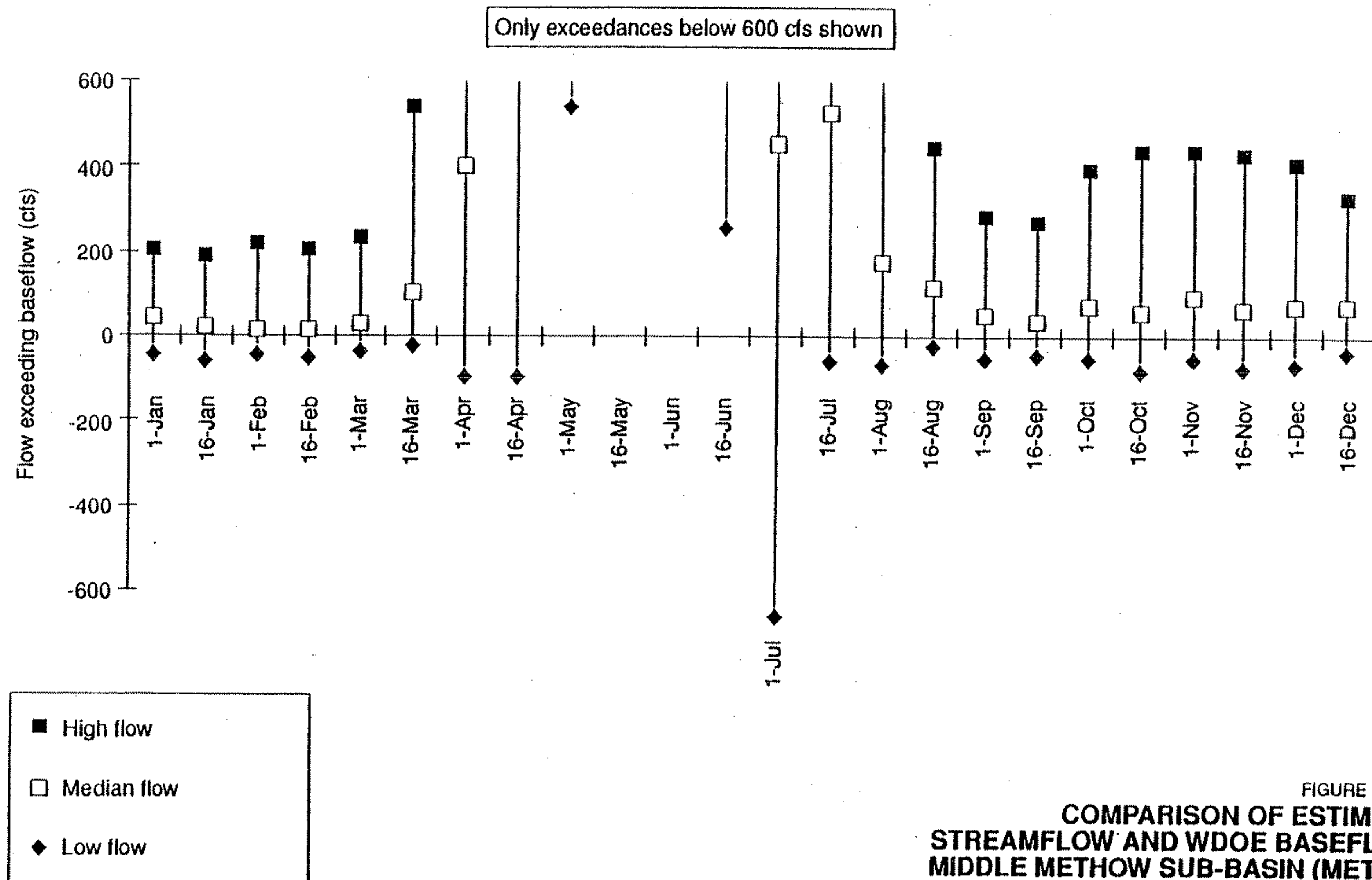

FIGURE **B-6**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS MIDDLE METHOW SUB-BASIN (METHOW RIVER AT TWISP)

EES/METHOW WATER BUDGET/WA

PROJECT NO. 933 1224.300 DRAWING NO. 46802 DATE 8/19/93 DRAWN BY CB

Golder Associates

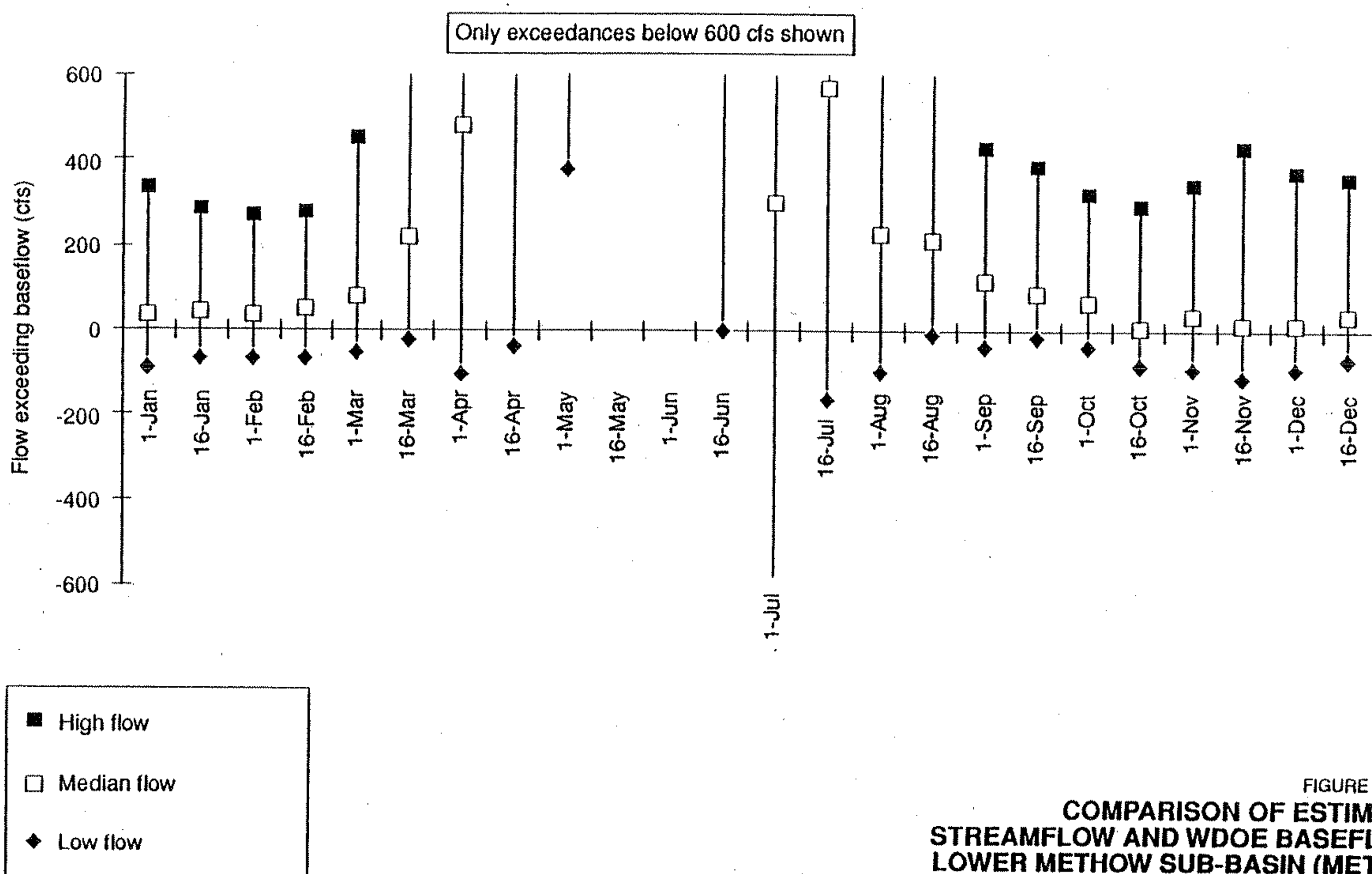

FIGURE **B-7**

COMPARISON OF ESTIMATED STREAMFLOW AND WDOE BASEFLOWS LOWER METHOW SUB-BASIN (METHOW RIVER NEAR PATEROS)

EES/METHOW WATER BUDGET/WA

ROJECT 'IO. 933 1224.300 DRAWING NO. 46803 DATE 8/19/93 DRAWN BY CB

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APPENDIX C

ESTIMATED SUB-BASIN EXCEEDANCE FLOWS

Methow Headwaters Sub-basin					
Methow River near Mazama, WA					
Estimated Flows (Derived from station 12447383)					
drainage area (sq. miles)			373		
Month	Begin day	End day	10%	50%	90%
January	1	15	102	45	25
	16	31	95	45	25
February	1	15	92	45	25
	16	29	94	60	45
March	1	15	230	121	60
	16	31	298	187	112
April	1	15	410	280	187
	16	30	821	560	429
May	1	15	2692	1417	877
	16	31	4118	2574	1410
June	1	15	6178	3432	1939
	16	30	4244	2425	1253
July	1	15	1865	1000	436
	16	31	1090	528	247
August	1	15	472	236	128
	16	31	354	224	70
September	1	15	317	168	45
	16	30	401	149	40
October	1	15	338	131	37
	16	31	274	93	32
November	1	15	252	75	25
	16	30	267	75	25
December	1	15	199	67	25
	16	31	181	56	25
	Average flow (cfs)		1058	583	313
	Runoff (inches)		38.5	21.2	11.4

Chewuch Sub-basin					
Chewuch River near Winthrop, WA					
Estimated Flows (Derived from station 12448000)					
drainage area (sq. miles)			525		
Month	Begin day	End day	10%	50%	90%
January	1	15	127	72	49
	16	31	122	76	55
February	1	15	119	75	55
	16	29	121	77	55
March	1	15	137	74	51
	16	31	172	85	49
April	1	15	339	185	84
	16	30	600	328	158
May	1	15	1540	781	397
	16	31	2326	1229	615
June	1	15	2042	1111	576
	16	30	1713	846	414
July	1	15	1067	663	289
	16	31	891	432	202
August	1	15	402	201	109
	16	31	217	115	66
September	1	15	118	68	43
	16	30	92	51	38
October	1	15	115	72	55
	16	31	139	84	67
November	1	15	166	99	73
	16	30	182	95	68
December	1	15	159	84	63
	16	31	138	76	55
	Average flow (cfs)		543	291	154
	Runoff (inches)		14.1	7.5	4.0

Upper Methow Sub-basin					
Methow River at Winthrop, WA					
Estimated Flows (Derived from station 12448500)					
drainage area (square miles)			1,007		
Month	Begin day	End day	10%	50%	90%
January	1	15	410	231	157
	16	31	381	238	172
February	1	15	405	255	187
	16	29	441	252	201
March	1	15	480	265	203
	16	31	720	360	233
April	1	15	1501	815	330
	16	30	2398	1314	453
May	1	15	4955	2505	1278
	16	31	7665	4152	2079
June	1	15	8952	4874	2527
	16	30	6725	3328	1629
July	1	15	2896	1745	761
	16	31	1894	918	428
August	1	15	956	478	244
	16	31	665	330	185
September	1	15	494	270	165
	16	30	446	250	170
October	1	15	431	271	206
	16	31	470	284	225
November	1	15	508	302	223
	16	30	558	289	207
December	1	15	496	263	197
	16	31	461	254	184
	Average flow (cfs)		1888	1010	527
	Runoff (inches)		25.4	13.6	7.1

Twisp Sub-basin					
Twisp River near Twisp, WA					
Station ID: 12448998					
drainage area (sq. miles) =			245		
Month	Begin day	End day	10%	50%	90%
January	1	15	157	65	30
	16	31	144	65	33
February	1	15	130	60	33
	16	29	148	63	32
March	1	15	144	68	40
	16	31	245	112	47
April	1	15	534	221	68
	16	30	677	328	142
May	1	15	1105	633	289
	16	31	1421	831	290
June	1	15	1939	918	383
	16	30	1772	826	248
July	1	15	1572	548	104
	16	31	734	262	57
August	1	15	343	105	29
	16	31	202	78	24
September	1	15	111	67	28
	16	30	106	45	21
October	1	15	111	62	27
	16	31	97	64	39
November	1	15	176	84	44
	16	30	285	85	45
December	1	15	297	107	48
	16	31	206	88	45
	Average flow (cfs)		527	241	89
	Runoff (inches)		29.2	13.4	5.0

Middle Methow Sub-basin					
Methow River at Twisp, WA					
Station ID: 12449500					
drainage area (sq. miles) =			1,301		
Month	Begin day	End day	10%	50%	90%
January	1	15	465	302	212
	16	31	452	282	203
February	1	15	476	276	212
	16	29	467	272	210
March	1	15	493	289	220
	16	31	802	365	241
April	1	15	1821	829	333
	16	30	3105	1688	552
May	1	15	6221	3010	1539
	16	31	9340	5300	2551
June	1	15	10760	5850	2660
	16	30	7800	3906	1755
July	1	15	4175	1956	837
	16	31	2156	1023	441
August	1	15	967	498	255
	16	31	666	340	195
September	1	15	503	272	169
	16	30	492	253	173
October	1	15	656	333	210
	16	31	757	380	241
November	1	15	759	413	265
	16	30	754	388	249
December	1	15	696	360	227
	16	31	586	334	220
	Average flow (cfs)		2307	1205	590
	Runoff (inches)		24.1	12.6	6.2

Lower Methow Sub-basin					
Methow River near Pateros, WA					
Station ID: 12449950					
drainage area (sq. mi.) =			1772		
Month	Begin day	End day	10%	50%	90%
January	1	15	683	385	262
	16	31	632	395	286
February	1	15	617	387	285
	16	29	624	399	285
March	1	15	803	431	296
	16	31	1158	570	331
April	1	15	1972	1070	486
	16	30	3131	1716	824
May	1	15	6499	3286	1677
	16	31	9587	5558	2784
June	1	15	11709	6372	3303
	16	30	9174	4538	2221
July	1	15	5048	2450	1068
	16	31	2823	1367	638
August	1	15	1411	705	384
	16	31	961	510	292
September	1	15	729	420	266
	16	30	686	384	283
October	1	15	682	428	324
	16	31	717	433	343
November	1	15	772	459	339
	16	30	854	441	317
December	1	15	765	406	304
	16	31	705	388	282
	Average flow (cfs)		2614	1396	745
	Runoff (inches)		20.0	10.7	5.7

APPENDIX D

ESTIMATED TRIBUTARY RUNOFF

Estimated Runoff in Methow Headwaters Sub-basin						
Drainage area between mouth of Early Winters Creek and Mazama						
Estimated Drainage Area (sq. miles)				8		
Month	Begin day	End day	10%	50%	90%	
January	1	15	3	2	1	
	16	31	3	2	2	
February	1	15	4	2	2	
	16	29	4	3	2	
March	1	15	6	4	3	
	16	31	14	7	4	
April	1	15	38	15	6	
	16	30	36	16	5	
May	1	15	33	17	8	
	16	31	29	16	7	
June	1	15	12	8	4	
	16	30	9	5	2	
July	1	15	7	3	1	
	16	31	5	2	1	
August	1	15	4	2	1	
	16	31	2	1	1	
September	1	15	2	1	1	
	16	30	2	1	1	
October	1	15	2	1	1	
	16	31	2	1	1	
November	1	15	3	1	1	
	16	30	3	1	1	
December	1	15	3	2	1	
	16	31	3	2	1	
	Average flow (cfs)		9.5	4.7	2.3	
	Runoff (inches)		16.2	8.0	3.9	

Estimated Runoff in Upper Methow Sub-basin					
Drainage area between Mazama and Winthrop					
Estimated Drainage Area (sq. miles)				109	
Month	Begin day	End day	10%	50%	90%
January	1	15	30	19	14
	16	31	31	19	14
February	1	15	33	19	15
	16	29	50	29	22
March	1	15	66	39	29
	16	31	106	48	32
April	1	15	199	77	31
	16	30	383	164	54
May	1	15	576	299	133
	16	31	754	414	188
June	1	15	568	347	168
	16	30	510	279	126
July	1	15	350	164	70
	16	31	223	106	46
August	1	15	122	63	32
	16	31	85	43	25
September	1	15	62	34	21
	16	30	47	24	16
October	1	15	38	19	12
	16	31	38	19	12
November	1	15	35	19	12
	16	30	37	19	12
December	1	15	37	19	12
	16	31	34	19	13
	Average flow (cfs)		184	96	46
	Runoff (inches)		22.9	12.0	5.8

Estimated Runoff in Lower Methow Sub-basin					
Drainage area between Twisp and Pateros					
Estimated Drainage Area (sq. miles)				471	
Month	Begin day	End day	10%	50%	90%
January	1	15	75	49	34
	16	31	100	62	45
February	1	15	108	62	48
	16	29	131	76	59
March	1	15	142	83	63
	16	31	244	111	73
April	1	15	429	167	67
	16	30	422	180	59
May	1	15	482	250	111
	16	31	606	333	151
June	1	15	795	486	236
	16	30	963	527	237
July	1	15	770	361	154
	16	31	410	194	84
August	1	15	162	83	43
	16	31	54	28	16
September	1	15	51	28	17
	16	30	54	28	19
October	1	15	68	35	22
	16	31	69	35	22
November	1	15	76	42	27
	16	30	81	42	27
December	1	15	94	49	31
	16	31	85	49	32
	Average flow (cfs)		270	140	70
	Runoff (inches)		7.8	4.0	2.0

APPENDIX E

WDOE BASEFLOWS

Base Flows in the Methow River
(All Figures in Cubic Feet Per Second)

Month	Day	Lower Methow (12.4499.50)	Middle Methow (12.4495.00)	Upper Methow (12.4473.89)	Methow Headwaters (12.4473.83)	Early Winters Creek	Chewack River (12.4475.00)	Twisp River (12.4489.98)
Jan	1	350	260	120	42	10	56	34
	15	350	260	120	42	10	56	34
Feb.	1	350	260	120	42	10	56	34
	15	350	260	120	42	10	56	34
Mar.	1	350	260	120	42	10	56	34
	15	350	260	120	42	10	56	34
Apr.	1	590	430	199	64	14	90	60
	15	860	650	300	90	23	140	100
May	1	1,300	1,000	480	130	32	215	170
	15	1,940	1,500	690	430	108	290	300
Jun.	1	2,220	1,500	790	1,160	290	320	440
	15	2,220	1,500	790	1,160	290	320	440
Jul.	1	2,150	1,500	694	500	125	292	390
	15	800	500	240	180	45	110	130
Aug.	1	480	325	153	75	20	70	58
	15	300	220	100	32	8	47	27
Sep.	1	300	220	100	32	8	47	27
	15	300	220	100	32	8	47	27
Oct.	1	360	260	122	45	11	56	35
	15	425	320	150	60	15	68	45
Nov.	1	425	320	150	60	15	68	45
	15	425	320	150	60	15	68	45
Dec.	1	390	290	135	51	12	62	39
	15	350	260	120	42	10	56	34