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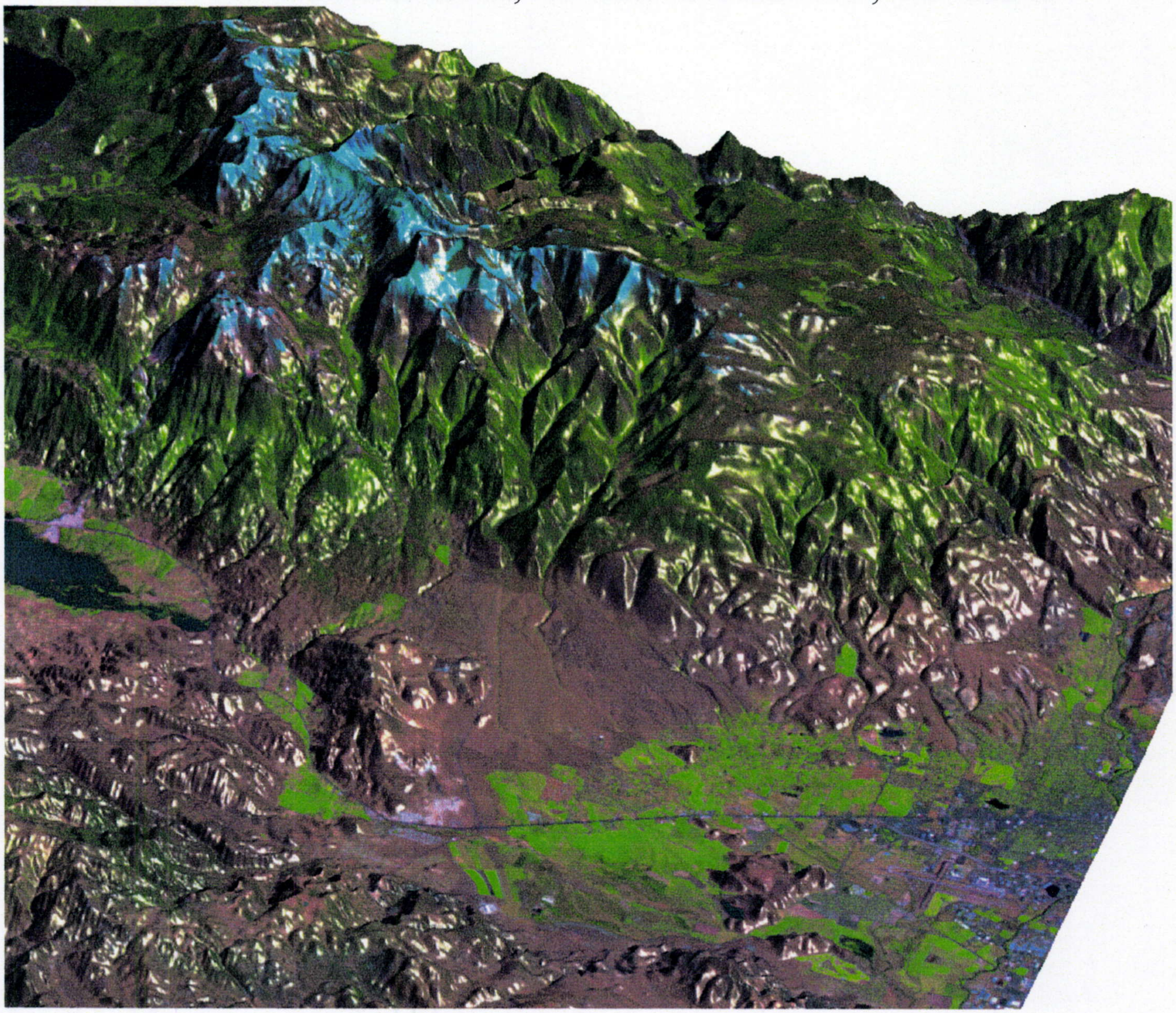
STATISTICAL GENERATION AND ANALYSIS OF STREAMFLOW DATA FOR GALENA, WHITES, THOMAS AND HUNTER CREEKS TRUCKEE MEADOWS, WASHOE COUNTY, NEVADA



Prepared for
Washoe County Regional Water Planning Commission
June 21, 2000

By
Michael C. Widmer
Washoe County Department of Water Resources

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Cover image:
Digital elevation model showing the drainages of Galena, Whites, Thomas, Evans and Hunter Creeks of the Carson Range. View is from the east looking west. South Truckee Meadows is shown in the foreground. Image courtesy of Dr. Ken Smith, Seismological Laboratory, University of Nevada, Reno created from TM Bands 5-4-1 and USGS DEM data using ER Mapper™ and the Silicon Graphics Supercomputer at the Mackay School of Mines Visualization Laboratory.

Volume 2 of this report contains the referenced appendices. Copies of these volumes can be obtained from Washoe County Department of Water Resources, 4930 Energy Way, Reno, Nevada 89502; (775)-954-4655.

TABLE OF CONTENTS

PART ONE
Generation of average monthly streamflow records for Galena, Whites, Thomas and Hunter creeks

PART TWO
Streamflow Frequency Analysis

PART THREE
Public Water Supply and Minimum Instream Flow

LIST OF TABLES AND FIGURES

PART ONE
Generation of average monthly streamflow records for Galena, Whites, Thomas and Hunter creeks

Introduction
The Washoe County Regional Water Planning Commission contracted the Department of Water Resources to statistically analyze the streamflow records of Galena, Whites, Thomas, and Hunter creeks; located in the South Truckee Meadows, Reno, Nevada (Figure 1). The first three creeks are tributaries of Steamboat Creek that flow into the Truckee River east of Sparks, Nevada and Hunter flows into the Truckee west of Reno. The purpose was to generate relatively long term synthetic records (April 28, 1999, Agenda Item 5) so that an average monthly flow could be estimated for future resource planning. The basis of this analysis was to use regression techniques between the individual creeks to generate these records.

Compilation of data
Stream gauges exist for upper and lower Galena, Whites, Thomas and Hunter creeks. Data could not be located for Evans creek. The data that exists for Brown's creek are pygmy meter measurements and staff gauge readings during the period 1983-84. The data have been compiled into monthly averages in units of cubic feet per second (cfs) and are listed in Appendix 1. The data were collected from USGS, SPPCo and Washoe County records.

Brown's creek
During the period of March 1983 through September 1987, 92 pygmy meter measurements and 8 observations were made of stream flow in Brown's creek. A staff gauge was installed at the 5,000 feet elevation in Pleasant Valley. Flow rates were usually less than 1 cfs and consequently, a stilling well site was not located. An upstream diversion occurs whereby water diverted from Galena creek is allowed to flow into Browns creek, then re-diverted out and channeled to Washoe Lake. Browns creek water is also diverted as per the Orr Ditch decree. This comingling of water is neither gauged nor regulated. Therefore, measured streamflow in Browns creek downstream of these diversions is not representative of the watershed discharge.

Lower Galena creek
The USGS installed and operated this gauge mid-way up the alluvial fan (elev. 5,592 feet) that emanates from the Galena Creek canyon. The gauge is a standard USGS design for a stilling well with intake pipe (s?), calibrated to rating curves. A record exists from October 1961 through September 1994 and has since been abandoned due to lack of funding. The record is rated as good although an upstream seasonal diversion exists. The drainage area above the gauge is 8.5 square miles.

The diversion above the gauge is significant (see Browns Creek above). A water right diversion is allowed to divert a significant amount of water during the non-irrigation season. There is no accurate record of this diversion. Additionally, groundwater influxes into and out of the creek occur seasonally on the alluvial fan above the gauge. Consequently, this record should not be used for estimating watershed discharge above the canyon mouth.

Upper Galena creek
The USGS installed and operates this gauge at the mouth of the Galena Creek canyon (elev. 6,320 feet), at the Galena County Park. The gauge is a standard design for a stilling well with intake pipe (s?), calibrated to rating curves. Their record exists from October 1984 to the present. The record is rated as fair with daily discharge measurements rated as poor. The drainage area above the gauge is 7.7 square miles. This gauge measures only the Galena creek portion of the upper watershed as Jones creek tributary is not measured.

Whites creek

The Washoe County Department of Water Resources installed and operated this gauge at the mouth of the Whites Creek canyon (elev. 5,980 feet). The gauge consists of a buried stilling well and intake pipe, calibrated to rating curves. The record exists from May 1982 to present. The record is rated as fair (Washoe County). The drainage area above the gauge is approximately 8 square miles. During April of 1983, this gauge washed out and was replaced in June 1987. During the period of non-continuous record, weekly pygmy meter measurements were made (good to fair) of the streamflow.

Thomas creek

The Washoe County Department of Water Resources installed and operated this gauge at the mouth of the Thomas Creek canyon (elev. 5,960 feet). The gauge consisted of a buried stilling well and intake pipe, calibrated to rating curves. The record exists from May 1982 through December 1996. The record is rated as good (Washoe County). The drainage area above the gauge is approximately 7 square miles. During the floods of January 1997, this gauge was washed out and to date has not been replaced.

Hunter creek

The USGS installed and operated this gauge at the mouth of the Hunter Creek canyon (elev. 5,000 feet), above Steamboat Ditch. The gauge is a USGS standard design for a housed stilling well with intake pipe (s?), calibrated to rating curves. Their record exists from October 1961 through September 1971. The period of record is not continuous. Sierra Pacific Power Co. resumed the operations of this gauge from October 1977 through September 1993 with the period October 1985 through September 1986 incomplete. The record is rated by the USGS as good. The drainage area above the gauge is 11.5 square miles.

Evans creek

No data for Evans creek has been located (USGS, Federal Watermaster, SPPCo).

Table 1 lists periods of records and drainage areas for these creeks.

Table 1
Period of record

creek	**years of record**	**period**	**drainage area (mi^2)**
Browns	4 (spot msmnts)	83-87	≈3
Upper Galena	14	84-99	7.7
Lower Galena	33	61-84	8.5
Whites	17	82-99	≈8
Thomas	15	82-99	≈7
Hunter	25 (w/ gaps)	61-94	11.5

Table 2 lists the available records for each creek in relation to the other creeks and shows the time period for which there is no record for any of the creeks, water years 1972-1977.

Table 2
Comparison of recorded data

Water Year	Hunter creek	Thomas creek	Whites creek	Upper Galena creek
1962	X			
1963	X			
1964	X			
1965	X			
1966	X			
1967	X			
1968	X			
1969	X			
1970	X			
1971	X			
1972				
1973				
1974				
1975				
1976				
1977				
1978	X			
1979	X			
1980	X			
1981	X			
1982	X			
1983	X	X	X	
1984	X	X		
1985	X	X		
1986		X		X
1987	X	X		X
1988	X	X	X	X
1989	X	X	X	X
1990	X	X	X	X
1991	X	X	X	X
1992	X	X	X	X
1993	X	X	X	X
1994		X	X	X
1995		X	X	X
1996		X	X	X
1997			X	X
1998			X	X

Hydrographs
Appendix 2 contains hydrographs for creeks based upon their measured record. No attempt was made to estimate missing data. Table 3 lists the average monthly flows for each creek.

Table 3
Average monthly flow based upon measured record (cfs)

	Lower Galena	Upper Galena	Whites	Thomas	Hunter
October	6.9	7.3	4.7	2.7	5.7
November	3.7	7.4	4.6	3.4	5.9
December	2.5	6.6	4.9	3.8	6.0
January	2.2	6.6	5.1	3.1	6.2
February	2.3	7.0	4.8	3.7	6.5
March	2.9	8.5	5.7	5.1	6.6
April	6.8	13.9	7.0	5.8	9.0
May	18.5	22.0	12.8	8.3	20.1
June	27.0	25.2	19.2	8.1	23.8
July	16.2	15.9	12.4	4.4	12.7
August	9.0	8.8	6.9	2.6	7.0
September	7.0	7.0	5.1	2.4	5.7
Average	**8.8**	**11.4**	**7.8**	**4.4**	**9.6**

Coefficient of variance
Table 4 shows the mean, standard deviation and coefficient of variance for each creek. The coefficient of variance (standard deviation divided by the mean) is graphed in Figure 2. This indicates that Thomas has the greatest deviation within a normal year and Hunter has the least. Therefore Hunter creek is probably the better creek to use as a predictor in regression analysis.

Regression analysis
Appendix 3 contains various regression analyses for the creeks. The record with the least amount of estimation and the longest record determined the predictor creek (X). There was no analysis made for outliers. Table 5 lists the creeks tested and their correlation coefficients (Galena is Upper Galena).

Table 5
Regression coefficients

X	Y	R	R^2	Observations
Galena	Whites	0.90	0.82	168
Galena	Thomas	0.83	0.69	147
Galena	Hunter	0.89	0.80	93
Hunter	Thomas	0.92	0.85	122
Hunter	Whites	0.92	0.84	122
Thomas	Whites	0.84	0.71	176

Synthetic streamflow generation
Regression equations (Excel™ software) were used to generate long term records for each watershed. It was assumed that the data follow a normal distribution as per the hydrographs. The hydrographs are quite similar between these creeks. Hunter creek was used to generate a record for Upper Galena (1962-1984), Thomas (1962-1982) and Whites (1962-1982, 1984-1987), exclusive of years 1972-1977. Upper Galena was used to generate records for Hunter (1986, 1994-1998) and Thomas (1997-1998). Table 6 lists the regression equations used.

Table 4
General statistics for creeks

	Upper Galena Cr.			Whites Creek			Thomas Creek			Hunter Creek		
	Mean	std dev	coeff var	Mean	std dev	coeff var	Mean	std dev	coeff var	Mean	std dev	coeff var
Oct	7.3	3.4	0.46	4.7	2.0	0.43	2.7	1.7	0.6	5.7	1.9	0.3
Nov	7.4	3.6	0.48	4.6	1.7	0.36	3.4	2.1	0.6	5.9	2.1	0.4
Dec	6.6	2.5	0.38	4.9	1.6	0.32	3.8	2.5	0.7	6.0	2.6	0.4
Jan	6.6	3.0	0.45	5.1	3.3	0.65	3.1	1.3	0.4	6.2	2.3	0.4
Feb	7.0	2.8	0.40	4.8	1.6	0.33	3.7	1.4	0.4	6.5	3.0	0.5
Mar	8.5	3.3	0.38	5.7	2.3	0.40	5.1	2.2	0.4	6.6	2.3	0.3
Apr	13.9	5.2	0.37	7.0	2.8	0.40	5.8	2.8	0.5	9.0	3.2	0.4
May	22.0	13.2	0.60	12.8	8.5	0.67	8.3	5.9	0.7	20.1	11.7	0.6
Jun	25.2	18.9	0.75	19.2	13.1	0.68	8.1	7.0	0.9	23.8	19.1	0.8
Jul	15.9	13.5	0.85	12.4	9.4	0.76	4.4	3.9	0.9	12.7	9.4	0.7
Aug	8.8	6.1	0.69	6.9	5.1	0.75	2.6	2.1	0.8	7.0	3.5	0.5
Sep	7.1	3.7	0.53	5.1	2.4	0.47	2.4	1.6	0.7	5.7	2.2	0.4

Table 6
Regression equations

Predictor	Creek	Equation
Hunter	Galena	-0.25 + 1.38 X
Hunter	Whites	1.65 + 0.55 X
Hunter	Thomas	1.25 + 0.31 X
Galena	Thomas	0.97 + 0.26 X
Galena	Hunter	1.37 + 0.58 X

No data for any of the creeks exist for the water years 1972-1977. These years are important to include in the analysis since 1976 and 1977 were extreme drought periods. Two long term creek records, Daggett and Blackwood creeks, were analyzed for their correlation to Hunter creek. Their regression coefficients were 0.44 and 0.69, respectively and were considered too low. A unit hydrograph approach was then applied.

Blackwood creek has a 38-year continuous record of streamflow, has an east facing drainage (11.2 mi^2 area) and does not have any diversions above the USGS gauge. The annual streamflow record of Blackwood was compared to the subject creeks. Table 7 lists the correlation coefficients of this comparison indicating that the annual record of Blackwood could be applied to the unit hydrograph of each creek to generate monthly flows for the 1972-1977 record.

Table 7
Annual flow correlation to Blackwood Creek

Upper Galena	Whites	Thomas	Hunter
0.82	0.78	0.79	0.82

Figure 3 shows the dimensionless unit hydrograph for Hunter creek. A dimensionless unit hydrograph is the monthly percentage of the long-term average total annual flow. The Blackwood record was applied in the following manner. The Blackwood creek flows for water years 1972-1977 were compared to its average annual flow to determine the percentage of flow above or below this average; 0.81, 0.92, 1.36, 0.98, 0.42 and 0.23, respectively. These percentages were then assumed to represent the percentage of average annual flow for Hunter creek as well. The percentages were multiplied to the unit hydrograph and monthly flows were generated for Hunter creek. This approach was also applied to the creeks Upper Galena, Whites and Thomas. A final average monthly flow was then generated for these creeks as listed in Table 8. Table 8 represents a 38-year record of both synthetic and measured data. The annual average flow compares quite well with the measured annual averages in Table 3. The synthetic records for each creek are listed in Appendix 4.

Conclusion

None of the creeks investigated has a complete record from 1962 onward. In order to generate the longest possible record for each creek two techniques were required, linear regression and the application of a dimensionless unit hydrograph. Regression between two adjacent watersheds is the better technique because of their geographic location and that the watershed sizes were comparable. The use of a unit hydrograph is not as detailed, but in this case can be considered reliable due to the strong correlation (R^2) between the subject creeks and Blackwood creek, ranging from 0.78 and 0.82.

Table 9 compares the synthetic record to the measured record (Table 3) for the average monthly flows. A visual inspection shows that the respective flows are quite similar. The synthetic record tends to over-predict the average monthly flow of Galena by 12%, under-predicts Whites by 10%, under-

Table 8
Synthetic streamflow monthly average (cfs)

	Galena	Whites	Thomas	Hunter
October	7.4	4.4	2.8	5.5
November	7.6	4.4	3.1	5.7
December	7.4	4.6	3.4	5.7
January	7.7	5.0	4.1	7.7
February	8.0	4.8	3.5	5.9
March	8.6	5.2	4.1	6.2
April	13.1	6.6	5.0	8.3
May	26.6	12.6	7.9	17.7
June	31.8	16.2	8.4	21.4
July	18.0	10.4	4.8	12.0
August	9.5	6.1	2.9	6.6
September	7.6	4.8	2.6	5.3
Average	**12.8**	**7.1**	**4.4**	**9.0**

Table 9
Comparison between synthetic and measured average monthly flow (cfs)

	Galena		**Whites**		**Thomas**		**Hunter**	
	synthetic	measured	synthetic	measured	synthetic	measured	synthetic	measured
October	7.4	7.3	4.4	4.7	2.8	2.7	5.5	5.7
November	7.6	7.4	4.4	4.6	3.1	3.4	5.7	5.9
December	7.4	6.6	4.6	4.9	3.4	3.8	5.7	6.0
January	7.7	6.6	5.0	5.1	4.1	3.1	7.7	6.2
February	8.0	7.0	4.8	4.8	3.5	3.7	5.9	6.5
March	8.6	8.5	5.2	5.7	4.1	5.1	6.2	6.6
April	13.1	13.9	6.6	7.0	5.0	5.8	8.3	9.0
May	26.6	22.0	12.6	12.8	7.9	8.3	17.7	20.1
June	31.8	25.2	16.2	19.2	8.4	8.1	21.4	23.8
July	18.0	15.9	10.4	12.4	4.8	4.4	12.0	12.7
August	9.5	8.8	6.1	6.9	2.9	2.6	6.6	7.0
September	7.6	7.1	4.8	5.1	2.6	2.4	5.3	5.7

predicts Thomas by 1.5% and under-predicts Hunter by 7%. These errors occur primarily during the spring run-off period.

No attempt was made to estimate flows for Browns and Evans creeks as little record exists for Browns and no record could be found for Evans. There does not appear to be any precipitation records for these drainages as well. Interestingly, the drainage areas for Thomas, Whites, Galena, Hunter and Evans are similar, yet the flow rates are dissimilar. This is probably due to different watershed orientations and areas above certain elevations. It is doubtful that techniques available today would be able to generate estimates for Evans within reasonable errors. Therefore, future work should focus on constructing a staff gage at Browns and Evans and taking spot measurements. Within a couple of years, a correlation should be possible with the other creeks. This would represent a fairly inexpensive program ($5,000 per year per creek).

PART TWO
Streamflow Frequency Analysis

Introduction

The purpose of part two is to estimate the low-flow frequency durations of Galena, Whites, Thomas and Hunter creeks. The low-flow analysis is important in determining minimum instream-flow rates for environmental purposes and is also important to determine the size of an anticipated water treatment plant that may divert water from these creeks for municipal supply. Statistically significant data sets of daily flows are needed to accomplish this. As shown in Table 2 (page 4) incomplete data sets exist and, except for Hunter Creek, these records mostly reflect years of either record snow-pack run-off or record drought. For these creeks it is reasonable to generate a 38-year record of daily flow using synthetically generated data and the actual data for each creek.

There are various ways to accomplish this. The easiest is to use the Blackwood Creek record (38 years of daily flows measured) and linear regression to generate synthetic records. However, as diagramed in Figure 4 the correlation coefficient (R^2) between Blackwood and Galena creeks is 0.50 and is unacceptable. Using a unit hydrograph method was also unacceptable because it over-predicted low flows. This is illustrated in Figure 5 whereby a synthetic data set is compared to the actual data set. A final method made use of "dimensionless specific daily flows", but segregated by month. For example, Figure 6 compares the results of synthetically derived and actual daily flows for the month of August for Galena Creek, displayed as a frequency exceedance curve. Each monthly comparison of synthetic and actual data is acceptable such that this method was used to generate daily flows for the missing periods of record spanning 1961 to 1998 for each creek. The method of generating the synthetic data is described below.

Generation of synthetic records

In a spreadsheet, the actual data for Galena Creek (1984-1998) was segregated by specific days (spreadsheet rows as specific days of the year and columns for the different years). Dimensionless specific daily flows were calculated whereby the daily cfs was divided by its monthly total cfs (daily cfs/monthly total cfs). This method was used for each day of the record (5475 entries), for example there were fifteen of these entries for Oct 1. These fifteen entries for each day of the year were averaged resulting in an "averaged dimensionless specific daily flow per month" and segregated for each month. Using the dimensionless specific daily value and the synthetically derived monthly average, as documented in part one of this report, a daily synthetic flow was generated. Figures 7 and 8 show the comparison of actual records to this synthetic method for generating an annual record of daily flows. The method closely approximates the actual record, but there are gaps between each month such that an unrealistic hydrograph results. However, it is not the purpose of this method to generate hydrographs, rather realistic daily flows for minimum and maximum flow duration frequency curves.

As a check, 5,079 daily flows for Galena Creek were generated and compared to the actual record. The actual daily flow was subtracted from the synthetic daily flow to generate a residual for each month. This residual was then averaged over a month and a standard deviation of the residual was made. The average residual was -0.00707 cfs and the residual standard deviation was 3.933 cfs[1]. For the period of record for Galena Creek, the average flow is 11.4 cfs. By dividing this average into the residual standard deviation (3.933/11.4 = 0.345) and subtracting from 1.0, you can explain how much of the synthetic data is determined by the actual data, in this case 65%. This value isn't particularly great, but it was considered good enough to continue because other methods gave poorer results (recall

[1] The month of January 1997 was omitted because of the large skew it placed on the data due to a 50-year flood event and that the gauge was washed out.

that a correlation coefficient of 0.50 was calculated by a linear regression of Blackwood Creek to Galena Creek using daily flows). Frequency exceedance curves were generated for each month of the actual and synthetic records. Graphs were made of both plots for comparison and are included in the appendix. The monthly curves were essentially the same, especially at low flows, which is of most interest. This gives confidence in using the synthetic model to generate daily streamflow. Combining this synthetic data with the actual data gives a 38-year record and was used to generate maximum and minimum flow duration frequencies.

Results

The appendix contains the minimum and maximum flow frequency duration curves for the creeks Galena, Whites, Thomas and Hunter. The data for the curves were generated using a DOS computer software program "Statistical Analysis of Time Series Data" (STATS) developed by the US Army Corps of Engineers (USACE, 1996). A portion of the detailed results for the data generated is found in the appendix for each creek. You will note that each frequency curve is plotted on log-probability paper with the 0.05 and 0.95 confidence intervals plotted as well. Exponential curve fits were plotted for the data. Minimum flow frequency curves are plotted with mean flow for duration vs. percent chance **non-exceedance** whereas the maximum flow curves are plotted vs. percent chance **exceedance.** For each creek an annual minimum and maximum flow frequency curve was also generated. These graphs are used to estimate probabilities of the range of flows. Maximum and minimum flow frequency duration curves were generated for 3-day, 7-day, 15-day, 30-day, 60-day, 90-day, 120-day and 183-day durations. These graphs are used to determine expectations of maximum and minimum flows over the prescribed time durations.

Galena Creek

Figures 9 and 10 show the annual minimum and maximum flow frequency curves for Galena Creek. Using the 20 percent chance non-exceedance for the minimum flows and the 80 percent chance exceedance for the maximum flows, a range of flows from 3.5 cfs to 18 cfs is estimated. Using 10 and 90 percent values, respectively, a range of 3 cfs to 13 cfs is estimated. Low-flow and high-flow frequency curves for 3-day, 7-day, 15-day, 30-day, 60-day, 90-day, 120-day and 183-day durations are included in the appendix for Galena, Whites and Thomas creeks. As an example on the use of these curves, Figure 11 would estimate that there is a 90 percent chance that on any three-day interval the lowest flow would be 3 cfs and that there is a 60 percent chance that the flow would not be less than 4 cfs. Table 10 shows the 10, 20 and 40 percent chance of non-exceedance, low flows for the durations listed above.

Table 10
Results from low-flow frequency duration analysis (cfs)

low flow duration	10% non-exceedance	20% non-exceedance	40% non-exceedance
3-day	3.0	3.7	4.0
7-day	3.0	3.8	5.0
15-day	3.0	3.9	5.0
30-day	3.1	4.0	5.5
60-day	3.2	4.1	5.6
90-day	3.3	4.3	6.0
120-day	3.4	4.4	6.0
183-day	3.8	4.6	6.1

This Table may be difficult to conceptualize because you will notice that as the time duration increases, so does the flow. Another way to read this frequency duration table (see second column **10% non-exceedance**) is to understand that over any 3-day period, 10% of the flow will be less than or equal to 3.0 cfs and 90% of the flows will be greater than 3.0 cfs. Over a 183-day period, 10% of the flows will be less than or equal to 3.8 cfs and 90% of the flows will be greater than 3.8 cfs. You can also think of these flow occurrences as probabilities and 10% non-exceedance is the same as 90% exceedance.

Table 11 lists the 90, 80 and 60 percent chance of exceedance, high flows for the durations listed above. Again, looking at the second column, over a 3-day period 10% of the flows will be less than or equal to 12 cfs and 90% of the flows will exceed 12 cfs. Over a period of 183-days, 90% of the flows will be greater than 7.0 cfs and 10% of the flows will be less than or equal to 7.0 cfs.

Table 11
Results from high-flow frequency duration analysis (cfs)

high flow duration	90% exceedance	80% exceedance	60% exceedance
3-day	12	20	24
7-day	12	17	23
15-day	11.5	17	21
30-day	11.0	15	20
60-day	10.5	14	20
90-day	10	12	17
120-day	9	12	15
183-day	7	9	13

These charts and graphs are also estimating, to a large degree, the probabilities of the range of high and low flows. For example, over a 30-day period during late summer (Table 10) there is a 90% chance that the flows for Galena Creek will be 3.1 cfs or greater. Over a 30-day period during the spring run-off (Table 11) there is a 90% chance that the flows will be at least 11 cfs or an 80% chance the flows will be at least 15 cfs. From the above tables the overall streamflow rates can be surmised as, for example (see Table 10, second column), there is a 90% probability that the low flows for Galena will be at least 3 to 4 cfs. There is also a 90% probability that the high flows will be greater than 7 to 12 cfs. However, it is more accurate to consider the tables as the percentage of flows that will or will not exceed certain flow rates.

<u>Whites, Thomas and Hunter Creeks</u>
Tables 12 through 17 are the same tables as 10 and 11, but for Whites, Thomas and Hunter Creeks, respectively.

Table 12
Results from low-flow frequency duration analysis, Whites Creek (cfs)

Low flow duration	10% non-exceedance	20% non-exceedance	40% non-exceedance
3-day	1.2	1.7	2.6
7-day	1.2	1.8	2.7
15-day	1.3	1.9	2.9
30-day	1.3	2.0	3.0
60-day	1.4	2.2	3.3
90-day	1.6	2.4	3.5
120-day	1.8	2.6	3.8
183-day	2.3	3.1	4.3

Table 13
Results from high-flow frequency duration analysis, Whites Creek (cfs)

high flow duration	90% exceedance	80% exceedance	60% exceedance
3-day	7.5	10.3	15.4
7-day	7.1	9.9	15.0
15-day	6.8	9.4	14.2
30-day	6.3	8.9	13.4
60-day	5.8	8.0	12.0
90-day	5.3	7.2	10.7
120-day	4.9	6.6	9.5
183-day	4.3	5.7	8.0

Table 14
Results from low-flow frequency duration analysis, Thomas Creek (cfs)

low flow duration	10% non-exceedance	20% non-exceedance	40% non-exceedance
3-day	0.6	0.9	1.3
7-day	0.6	0.9	1.4
15-day	0.7	1.0	1.5
30-day	0.7	1.0	1.6
60-day	0.8	1.2	1.8
90-day	0.9	1.3	1.9
120-day	1.0	1.4	2.2
183-day	1.4	1.9	2.7

Table 15
Results from high-flow frequency duration analysis, Thomas Creek (cfs)

high flow duration	90% exceedance	80% exceedance	60% exceedance
3-day	5.0	6.6	9.6
7-day	4.6	6.2	9.2
15-day	4.2	5.7	8.5
30-day	3.9	5.2	7.7
60-day	3.6	4.7	6.8
90-day	3.3	4.4	6.2
120-day	3.1	4.0	5.6
183-day	2.7	3.5	4.8

Table 16
Results from low-flow frequency duration analysis, Hunter Creek (cfs)

low flow duration	10% non-exceedance	20% non-exceedance	40% non-exceedance
3-day	1.3	2.0	3.1
7-day	1.4	2.1	3.2
15-day	1.4	2.2	3.4
30-day	1.6	2.3	3.5
60-day	1.7	2.6	3.9
90-day	1.9	2.8	4.2
120-day	2.1	3.1	4.6
183-day	2.8	3.9	5.3

Table 17
Results from high-flow frequency duration analysis, Hunter Creek (cfs)

high flow duration	90% exceedance	80% exceedance	60% exceedance
3-day	9.7	13.9	22.1
7-day	9.5	13.7	21.6
15-day	9.1	13.1	20.6
30-day	8.4	12.2	19.1
60-day	7.5	10.7	16.5
90-day	6.8	9.5	14.3
120-day	6.2	8.5	12.6
183-day	5.5	7.3	10.4

Table 18 compares the 70% non-exceedance of high and low flows for all the creeks over 30-day durations. These durations would represent conservative estimates of the annual creek fluctuations characteristic of high snowmelt runoff and late summer base flows.

Table 18
30-day duration, 70% non-exceedance of minimum and maximum flow (cfs)

	30-day duration 70% non-exceedance of minimum flow	30-day duration 70% non-exceedance of maximum flow
Galena Creek	5	37
Whites Creek	2.5	22
Thomas Creek	1.3	12.9
Hunter Creek	3.0	32.9

PART THREE

Public Water Supply and Minimum Instream Flow

Creek diversions for public water supply
Washoe County's Comprehensive Regional Water Plan (1995-2015) discusses the water supply alternative of constructing a surface water treatment plant in the South Truckee Meadows (page 9-10). The surface water would originate from various sources such as Galena Creek, Thomas Creek, Whites Creek and the Truckee River. The report also estimates that the South Truckee Meadows will require 7,800 af of potable water supply by the year 2015 to support a population of 26,000 (see pages 4-2 and 4-4). Four different surface water diversion scenarios are presented herein where diversions are made from both Galena and Whites creeks (scenario 1 and 2) and from Galena, Whites and Thomas creeks (scenario 3 and 4). Average monthly flows estimated in part one of this report are used to estimate what diversion rates of 40% and 60% would be for each creek. The annual 7800 af demand is segregated to monthly demands as estimated from a previous report (Kennedy/Jenks Consultants, 1991). Scenarios 1 and 2 represent diversions of 40% and 60%, respectively, from both Galena and Whites creeks to meet the monthly demands. This is illustrated in Figure 12. The Figure indicates that the 40% diversion rate (scenario 1) is not enough to meet demands other than during the months of May and June. The 60% diversion (scenario 2) meets demands November through July. Figure 13 illustrates the effects if 40% and 60% diversions include Thomas Creek. The 40% diversion rate will meet the demand curve November through June. With the addition of Thomas creek, the 60% diversion rate does not do much better for the months July, August and September in meeting the demand curve (compare Figures 12 and 13). However, excess supply is available in all these scenarios

that could be banked via artificial groundwater recharge and later pumped during excessive demand periods. Another more passive approach would be to use surface water for winter and spring demands supplemented by groundwater during low flow periods.

Minimum flow duration frequency curves can be used to determine the percentage of daily creek flows meeting treatment plant demands. For example, a 4-MGD plant would require 6.2 cfs. Table 19 lists low-flow frequency durations at different exceedance percentages for the combined flows of Galena and Whites creeks. This table indicates that the 6.2 cfs requirement will be met 80% of the time over a 60-day period. It indicates that 70% of the flows will meet that demand over any period of time. Table 20 includes Thomas creek in the analysis and indicates that at least 80% of the flows will meet the 6.2 cfs requirement over any period.

Table 19
Low-flow frequency duration exceedance, Galena and Whites Creeks (cfs)

low flow duration	80% of flows exceed	70% of flows exceed	60% of flows exceed
3-day	5.4	6.0	6.6
7-day	5.6	6.6	7.7
15-day	5.8	6.9	7.9
30-day	6.0	7.2	8.5
60-day	6.3	7.6	8.9
90-day	6.7	8.1	9.5
120-day	7.0	8.4	9.8
183-day	7.7	9.0	10.4

Table 20
Low-flow frequency duration exceedance, Galena, Whites and Thomas Creeks (cfs)

low flow duration	80% of flows exceed	70% of flows exceed	60% of flows exceed
3-day	6.3	7.1	7.9
7-day	6.5	7.8	9.1
15-day	6.8	8.1	9.4
30-day	7.0	8.6	10.1
60-day	7.5	9.1	10.7
90-day	8.0	9.7	11.4
120-day	8.4	10.2	12.0
183-day	9.6	11.3	13.1

Figure 14 graphs the 40% and 60% diversions from Galena, Whites and Thomas against a monthly demand given an annual demand of 7,800 af. It also plots 4-MGD and 6-MGD plant diversion requirements. This Figure indicates that the 40% diversion rate will meet the 4-MGD requirement during all periods of an average streamflow year. Figure 14 illustrates that the 6-MGD plant requirement can be met during the period April through July for the 40% diversion and March through August for the 60% diversion. Figure 14 is used to estimate an annual capacity of 5,580 af of potable supply given a 6-MGD plant versus a 4,480 af supply from a 4-MGD plant. The subtraction shows that a 6-MGD plant could supply an additional 1,100 af over six months that satisfies 14% of the annual demand (7,800 af) as compared to a 4-MGD plant. It would also serve as plant redundancy for O&M considerations.

Table 21 lists 40% and 60% diversion rates and total creek flows in order to meet 4-MGD and 6-MGD requirements. For example, diverting 40% of creek flow to meet a 4-MGD plant demand (6.2 cfs) requires that the creeks diverted must be flowing at 15.5 cfs. This is also the creeks flow rate for a 60% diversion to meet a 6-MGD plant demand (9.3 cfs).

Table 21
Flow requirements on creeks (cfs)

treatment plant size and flow requirement	total creek flow for 40% diversion	total creek flow for 60% diversion
4-MGD (6.2 cfs)	15.5	10.3
6-MGD (9.3 cfs)	23.2	15.5

Relating Table 21 to a low flow frequency analysis that combines Galena, Whites and Thomas creeks is shown in Table 22. This Table is for flow occurring during the lowest flow period, i.e. fall and winter months. For a 4-MGD plant requirement of 6.2 cfs, a 40% diversion rate (total creek flow of 15.5 cfs) could be expected to meet this demand at least 40% of the time over a 90-day interval. For a 6-MGD plant requirement of 10.3 cfs, a 60% diversion rate could be expected to meet the demand a least 60% of the time over a 60-day period.

Table 22
Low-flow frequency duration exceedance for Galena, Whites and Thomas creeks (cfs)

low flow duration	60% of flows exceed	50% of flows exceed	40% of flows exceed
3-day	7.9	10.7	12.3
7-day	9.1	11.1	12.5
15-day	9.4	11.6	12.8
30-day	10.1	12.3	13.4
60-day	10.7	12.9	14.2
90-day	11.4	13.4	15.0
120-day	12.0	13.9	16.1
183-day	13.1	15.9	17.9

Montana Method

Donald Leroy Tennant, working for the U.S. Fish and Wildlife Service in Billings, Montana apparently derived the Montana Method to determine minimum instream flow requirements "west of the Mississippi". This minimum flow would protect aquatic life and provide sufficient flow to maintain existing riparian vegetation and, consequently, wildlife (Tennant, unk). The minimum instream flow is quickly calculated by knowing the average annual flow in units of cubic feet per second (units are not confirmed in the Tennant reference). Table 23 indicates the minimum flow rate to be left in the stream in order to maintain the desired "subjective" results.

Table 23
Montana Method minimum instream flows

narrative description of flows	Recommended base flow regimens as a percentage of the Average annual flow Oct.-Mar.	Apr.-Sept.
Flushing	200% of avg. flow	200% of avg. flow
Optimum Range	60-100%	60-100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%

Using Galena Creek as an example, its average annual flow is 9,260 af that translates to 12.8 cfs. This 12.8 cfs is the average annual flow as determined from part one of this report. If it is required to maintain a "good" stream flow, then 20% of the average annual flow (12.8 cfs), or 2.56 cfs would be kept in the stream during the months of October through March. Flows above that base level could be used, in this case, for public water supply. During the months of April through September, 40% of the average annual flow (12.8 cfs) would be kept in the stream. Additionally, "flushing" flows are required to maintain the health of the stream. It is therefore recommended that during at least a 14-day period of the spring runoff, 200% of the average annual flow be kept in the stream (25.6 cfs).

Figure 15 illustrates the Montana Method by plotting the average monthly flows or "natural" hydrograph of Galena Creek versus "outstanding", "excellent" and "good" minimum instream flows including the "flushing" flows. This Figure illustrates that the natural flow pattern is closely copied by the minimum instream flow and illustrates how much diversion is volumetrically available. Figure 16 illustrates these same flow patterns for Galena, Whites and Thomas creeks combined. Figure 17 shows the natural flow of Galena Creek reduced 50% to mimic an extreme drought condition. It is seen that an extreme drought condition may not produce flows sufficient for diversions over and above the "excellent" instream flow requirement especially during August and September. Further, the 200% of average annual "flushing" flows would not be met regardless of diversions though flushing would still occur.

Table 24 lists the instream flow rates for each creek under the three different flow regimes. Flow rates are for winter (October through March), summer (April through September) and flushing (two weeks in May or June) periods. These flow rates would remain constant throughout their respective periods.

Table 24
Instream flow rates (cfs)

		outstanding		excellent		good	
	flushing	winter	summer	winter	summer	winter	summer
Galena	25.6	5.1	7.7	3.8	6.4	2.6	5.1
Whites	14.2	2.8	4.3	2.1	3.6	1.4	2.8
Thomas	8.8	1.8	2.6	1.3	2.2	0.9	1.8

Table 25 lists the average annual water treatment plant diversions, in acre-feet per year, for each creek given the "outstanding", "excellent" and "good" base flow regimen (including "flushing" flows). Under the Montana Method and diverting Galena, Whites and Thomas creeks, 7,450 af, 10,070 af and 11,749 af could be used for public water supply at the "outstanding", "excellent" and "good" flow regimens, respectively.

Table 25
Expected diversions allowed under the Montana Method

	avg. annual flow		outstanding		excellent		good	
	af/yr	cfs	af/yr	cfs	af/yr	cfs	af/yr	cfs
Galena	9,260	12.8	3,919	5.4	5,214	7.2	6,083	8.4
Whites	5,140	7.1	2,176	3.0	3,002	4.2	3,503	4.8
Thomas	3,175	4.4	1,344	1.9	1,854	2.6	2,162	3.0
Total	17,575	24.3	7,439	10.3	10,070	14.0	11,749	16.2

Conclusions

Several methods were used to generate synthetic, daily average, discharge values for the Galena, Whites, Thomas and Hunter creeks. The best results were obtained by generating monthly dimensionless specific daily values and the synthetic monthly averages. From this synthetic and measure data, high and low flow frequency duration curves were generated. In Table 18 the data are used to estimate a conservative, annual range of high and low flows for each creek. The synthetic/actual record provides a good basis for determining volumetric flow rates with respect to minimum instream flows and diversions for public water supply. Depending upon anticipated institutional decisions, minimum flows are sufficient to satisfy both instream flows and public water supply demands.

Published literature about the Montana Method is not apparent and so this report cannot determine the successful application of the Montana Method or if it is appropriate for instream flow management in the South Truckee Meadows. If this method is applied and depending upon the flow regime implemented, diversions for public water supply range from 7,400 acre-feet per year (Outstanding Regime) to 11,750 acre-feet per year (Good Regime). Water left in creeks as minimum instream flow rates would amount to 10,150 acre-feet per year (Outstanding Regime) to 6,800 acre-feet per year (Good Regime). These estimates are based upon an average year of streamflow.

Treatment plant capacity is in the range of 4- to 6-MGD on an annual basis given diversions of 40 to 60 percent, respectively. A 4-MGD plant requires a flow rate of 6.2 cfs. If a 40% diversion is implemented on all three creeks (minimum total creek flow of 15.5 cfs), it is estimated that 60% of the daily flows may not meet this demand during a low-flow, 90-day interval (Tables 21 and 22). At a 60% diversion rate (minimum total creek flow of 10.3 cfs) it is estimated that 40% of the daily flows may not meet this demand during a low-flow, 30-day interval. Consequently, a 4-MGD plant should anticipate short periods of flow rates below plant capacity given these diversion constraints.

For a 6-MGD plant requirement of 10.3 cfs, a 60% diversion rate is necessary and could be expected to meet the demand at least 60% of the time during a low-flow, 60-day period. During the spring run-off (April through July) there does not appear to be any problem meeting treatment plant flow requirements during normal years of streamflow. There is additional supply for groundwater recharge practices, both injection and infiltration, on a 4 to 6-MGD scale from April through July. Conservatively, this could amount to 1,500 to 2,200 acre-feet annually.

Future work

Concurrent to this body of work, ECO-LOGIC has been contracted to publish an updated water and wastewater facility plan for the South Truckee Meadows. In their work, projections for water demand will be revisited. Alternatives will be proposed for water supply as well as instream flow necessities. If alternatives require a surface water treatment plant, capacities will be outlined. Minimum instream flow recommendations will also be made that will impose constraints on water treatment facilities. It is also anticipated that the available surface water supply for municipal needs will be identified. Until these objectives are reached, no further work will continue on the timing and quantity of surface water generated from the Galena, Whites, Thomas and Hunter watersheds.

Acknowledgements

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Washoe County, 1997. 1995-2015 Washoe County Comprehensive Water Plan. Washoe County, Department of Water Resources, Reno, Nevada.

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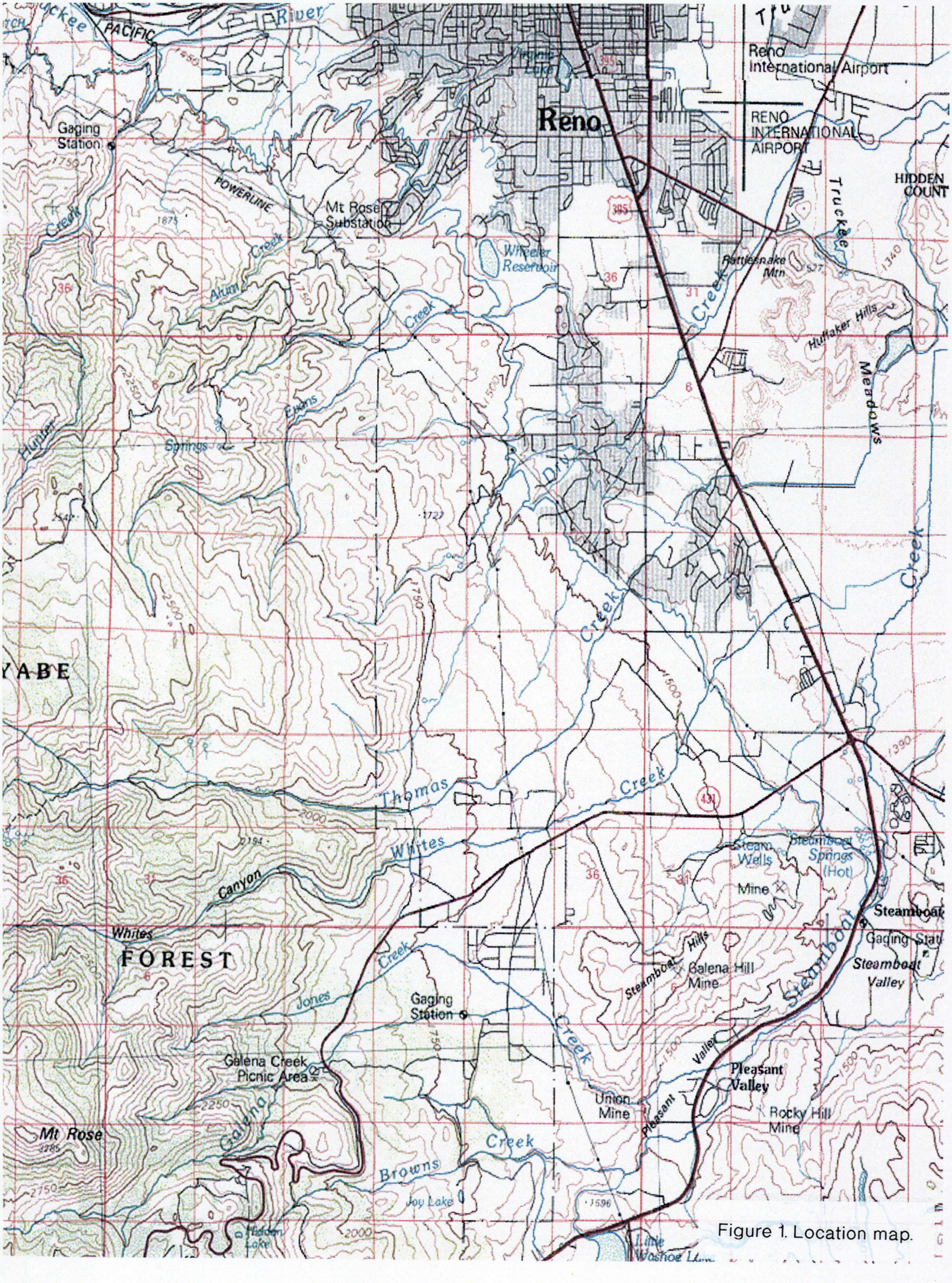


Figure 1. Location map.

Figure 2. Coefficient of variance for creeks

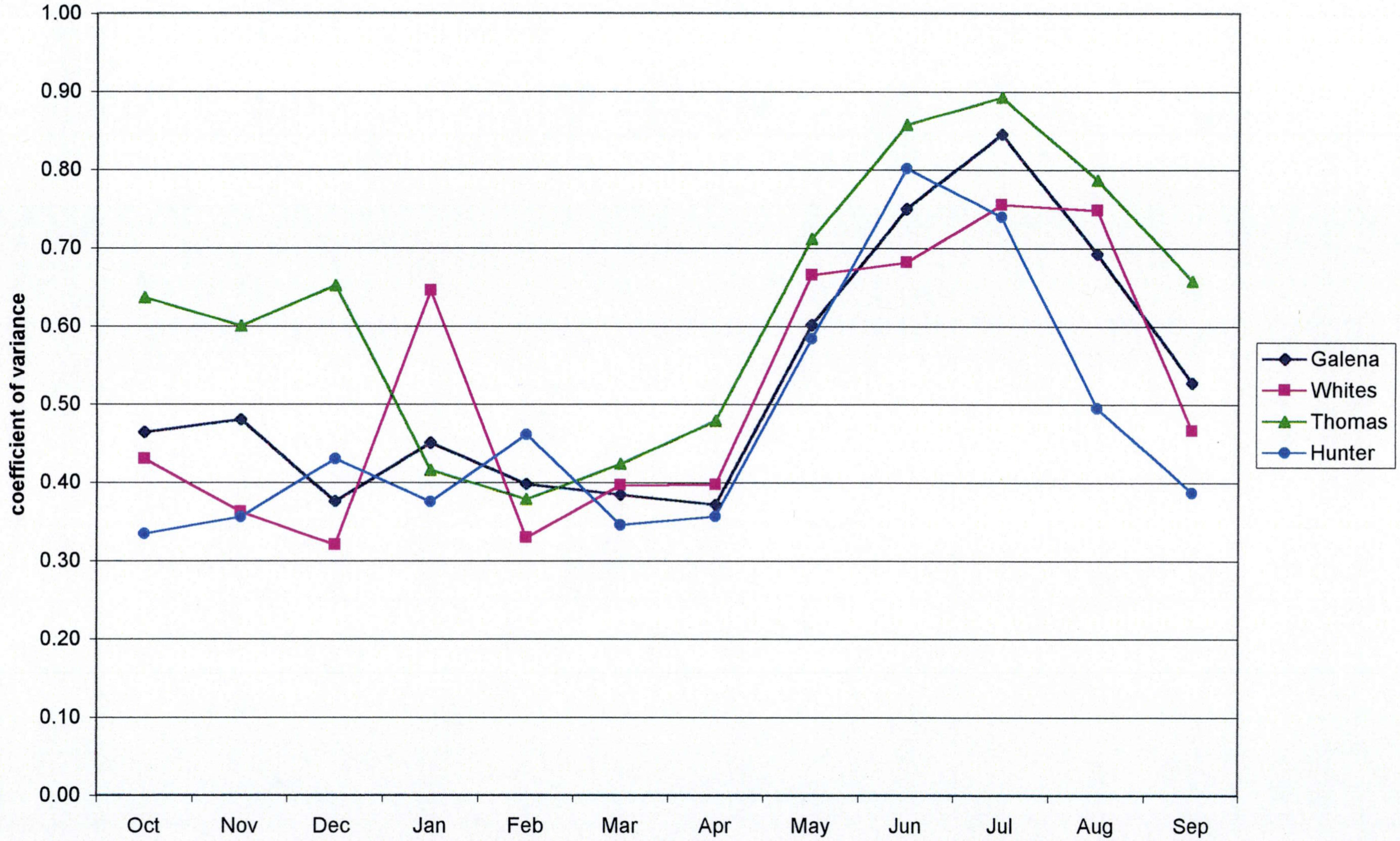


Figure 3. Hunter Creek Unit Hydrograph

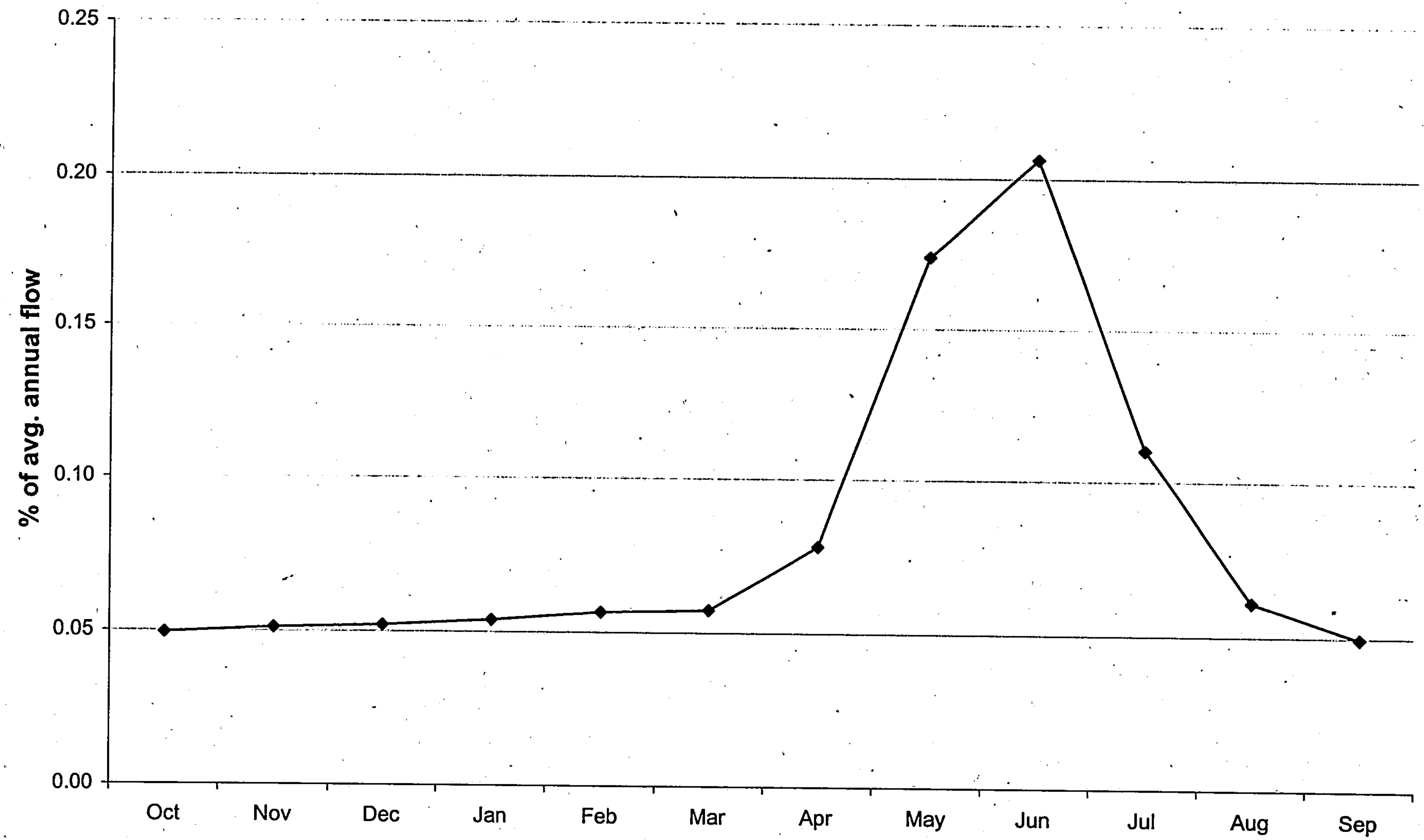


Figure 4. Linear Regression between Blackwood Creek and Galena Creek

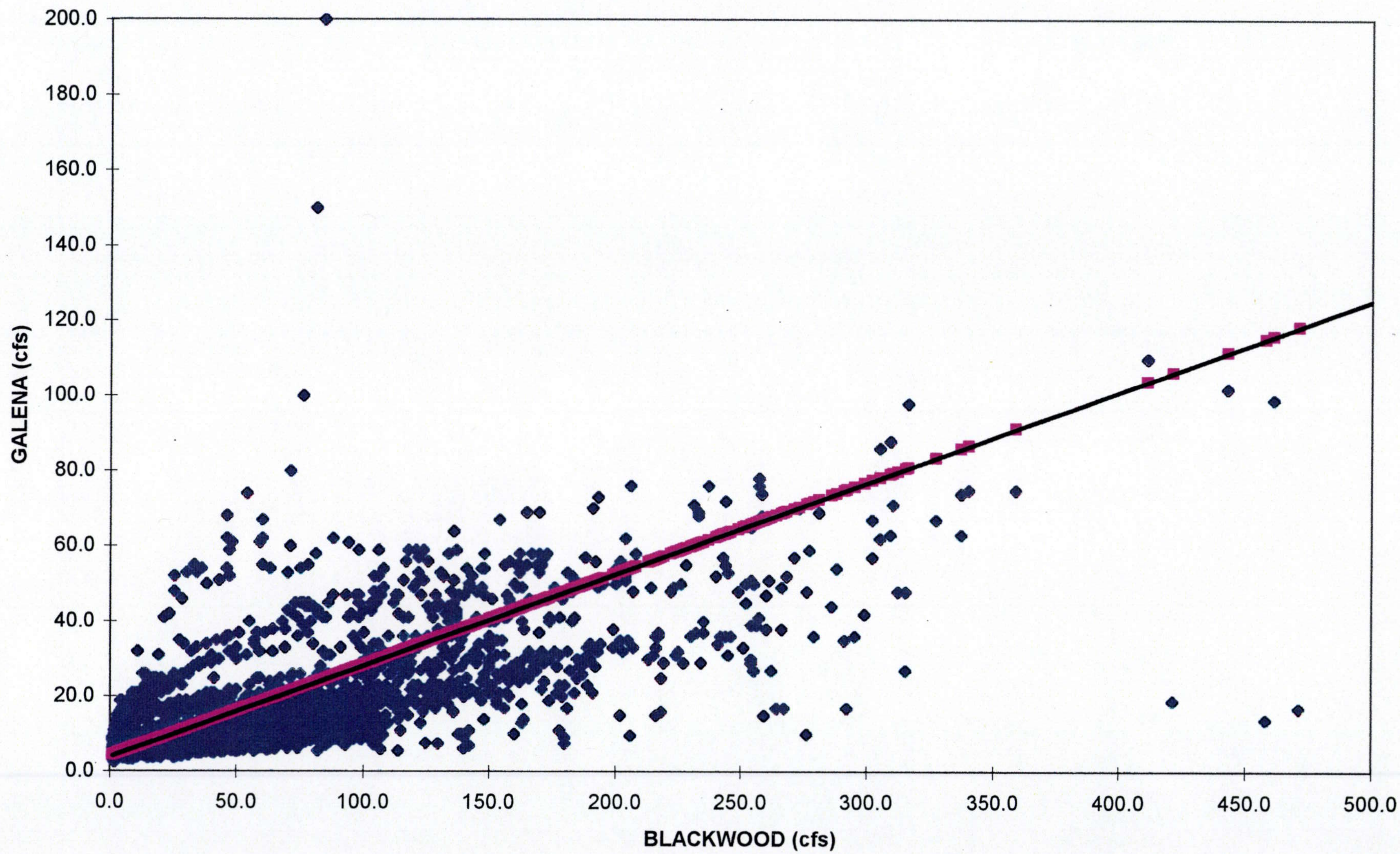


Figure 5. Actual record vs. synthetic (based on annual unit hydrograph), Galena Creek.

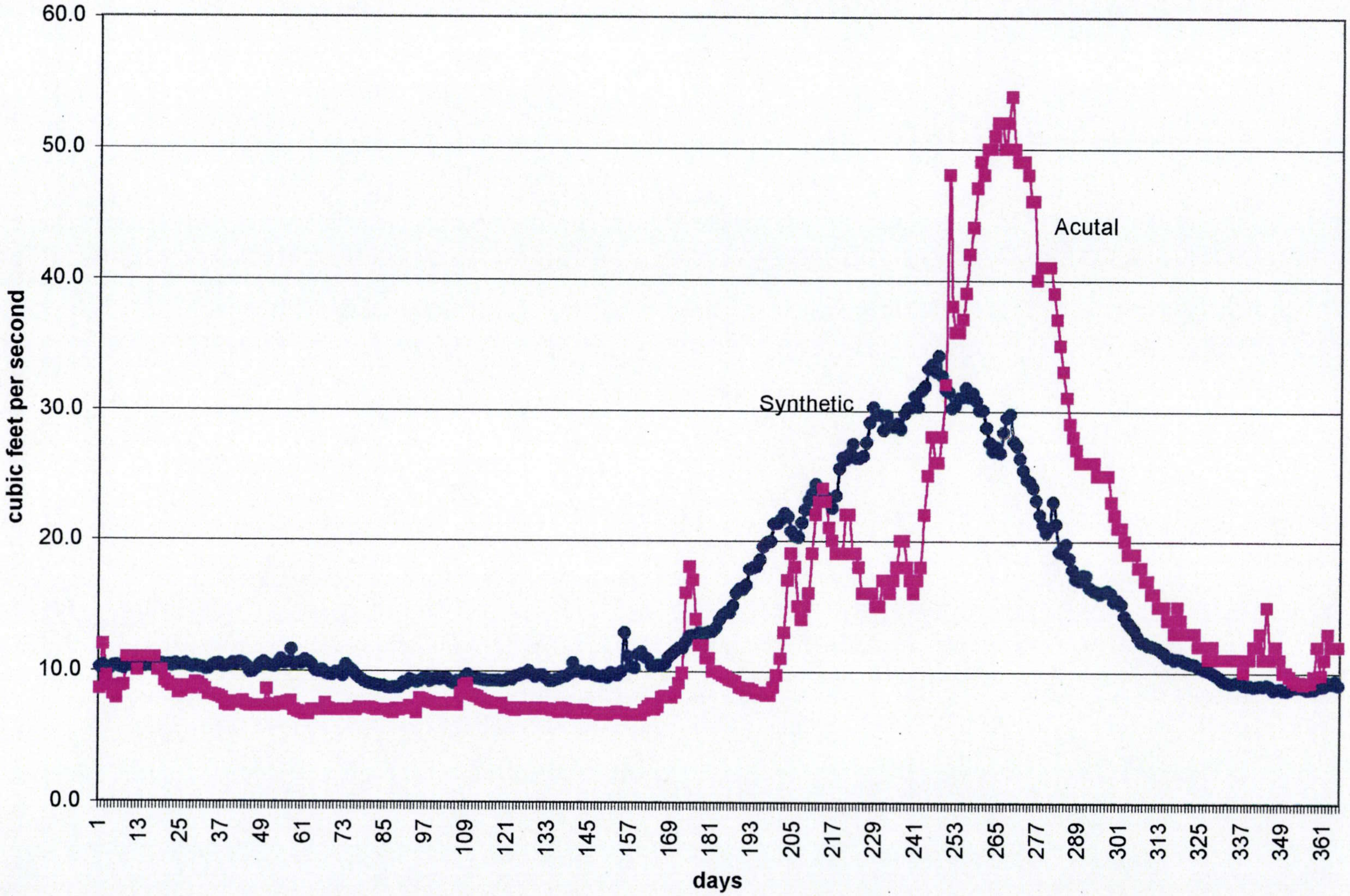


Figure 6. Comparison of actual and synthetic daily flows for August as frequency exceedance, Galena Creek.

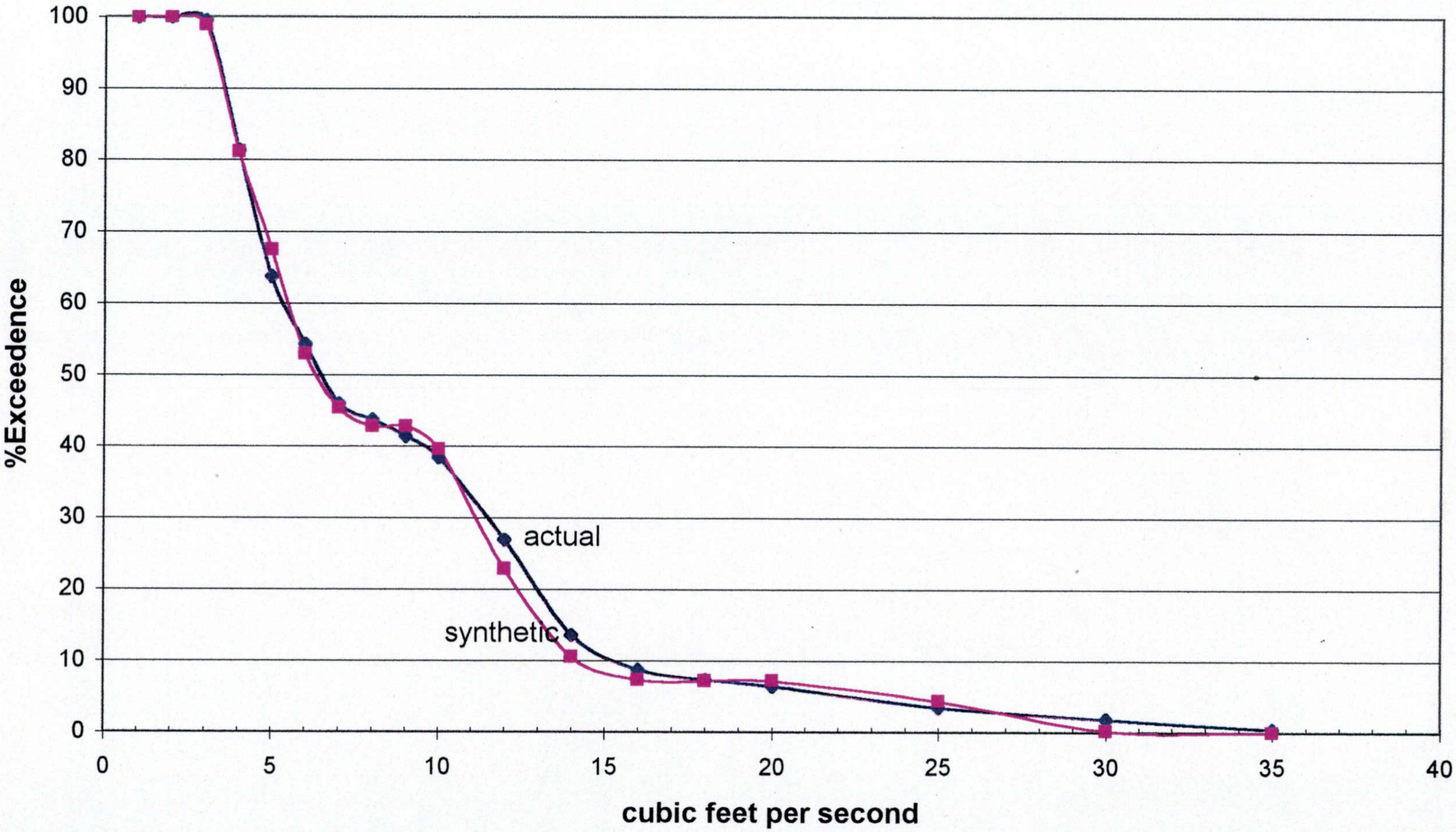


Figure 7. Galena Creek actual vs. synthetic flows for 1985-86 based upon monthly dimensionless values.

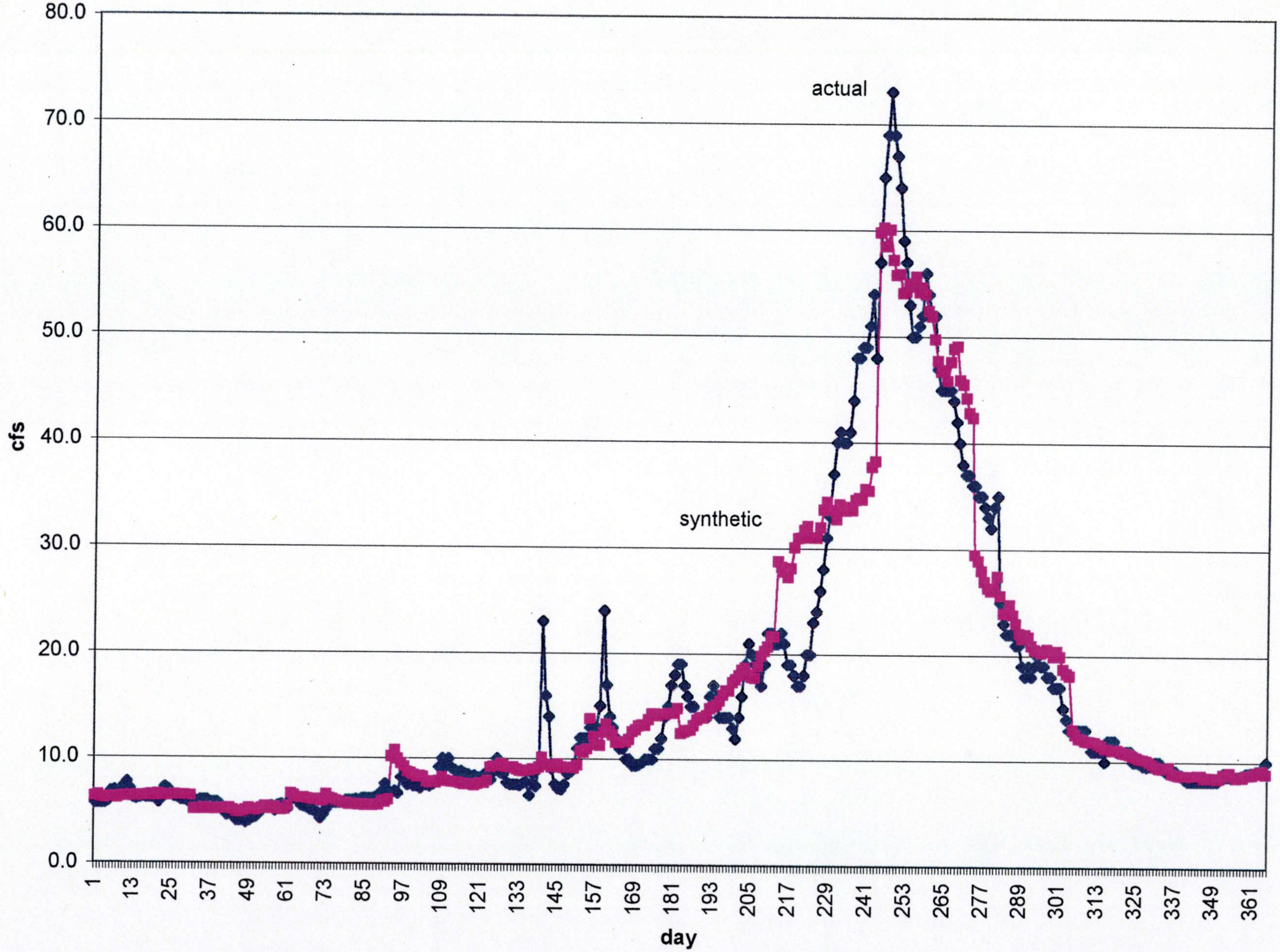


Figure 8. Galena Creek actual vs. synthetic flows for 1984-85, based upon monthly dimensionless values .

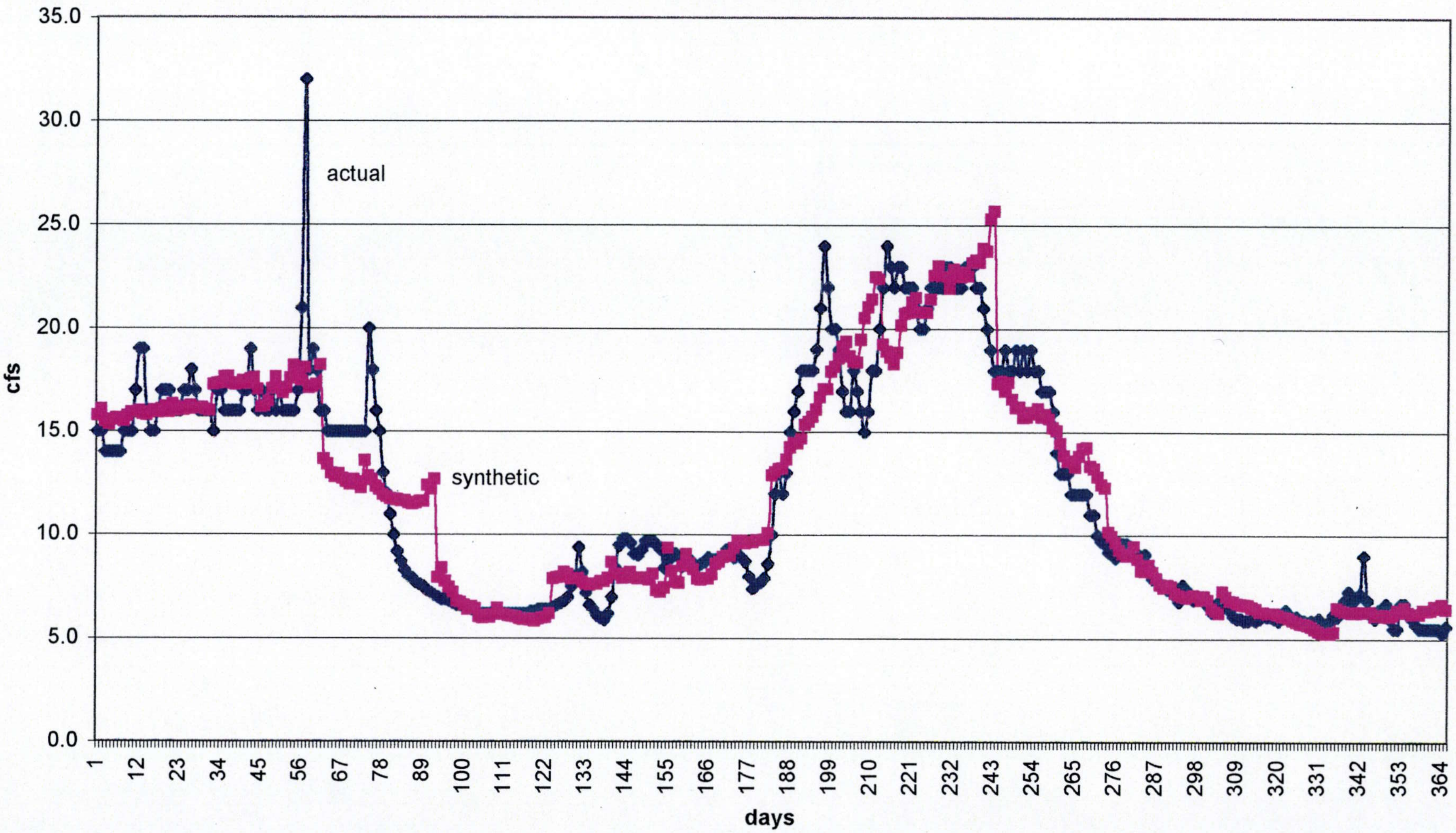


Figure 9. Average year minimum flow frequency curve for Galena Creek

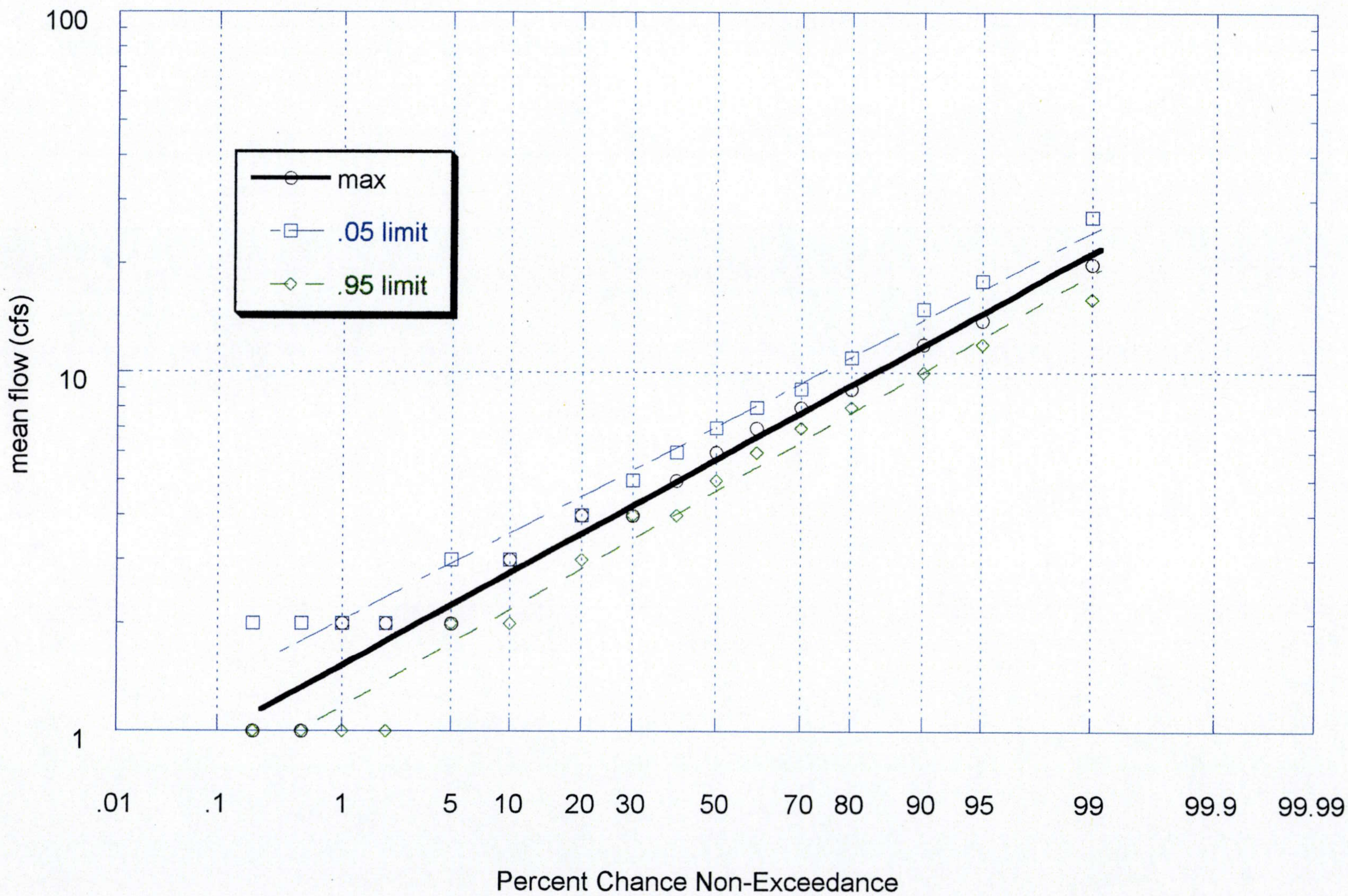


Figure 10. Average year maximum flow frequency curve, Galena Creek

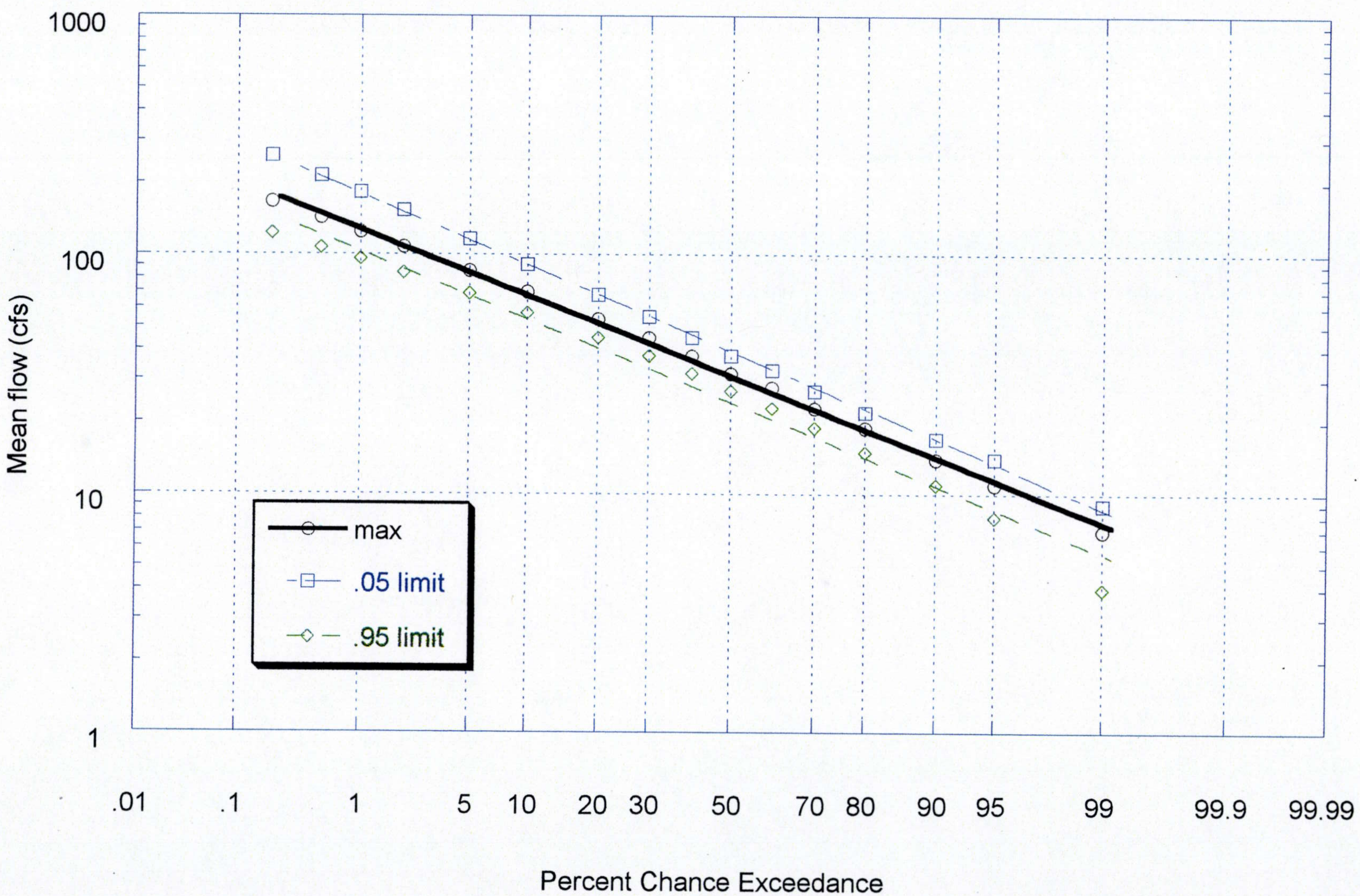


Figure 11. Low flow, 3-day duration, frequency curve for Galena Creek

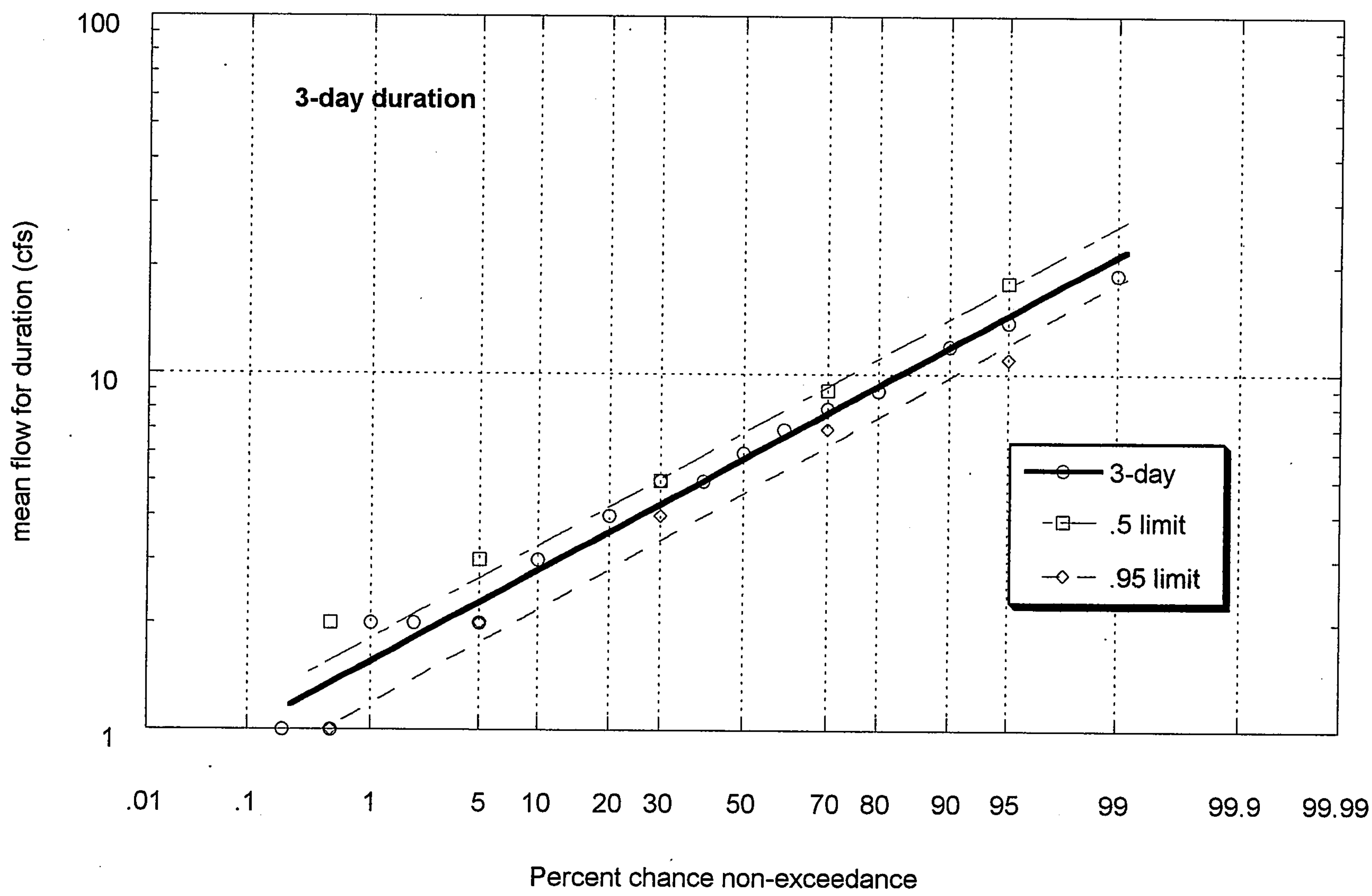


Figure 12. Demand vs. percent diversion from Galena and Whites (cfs)

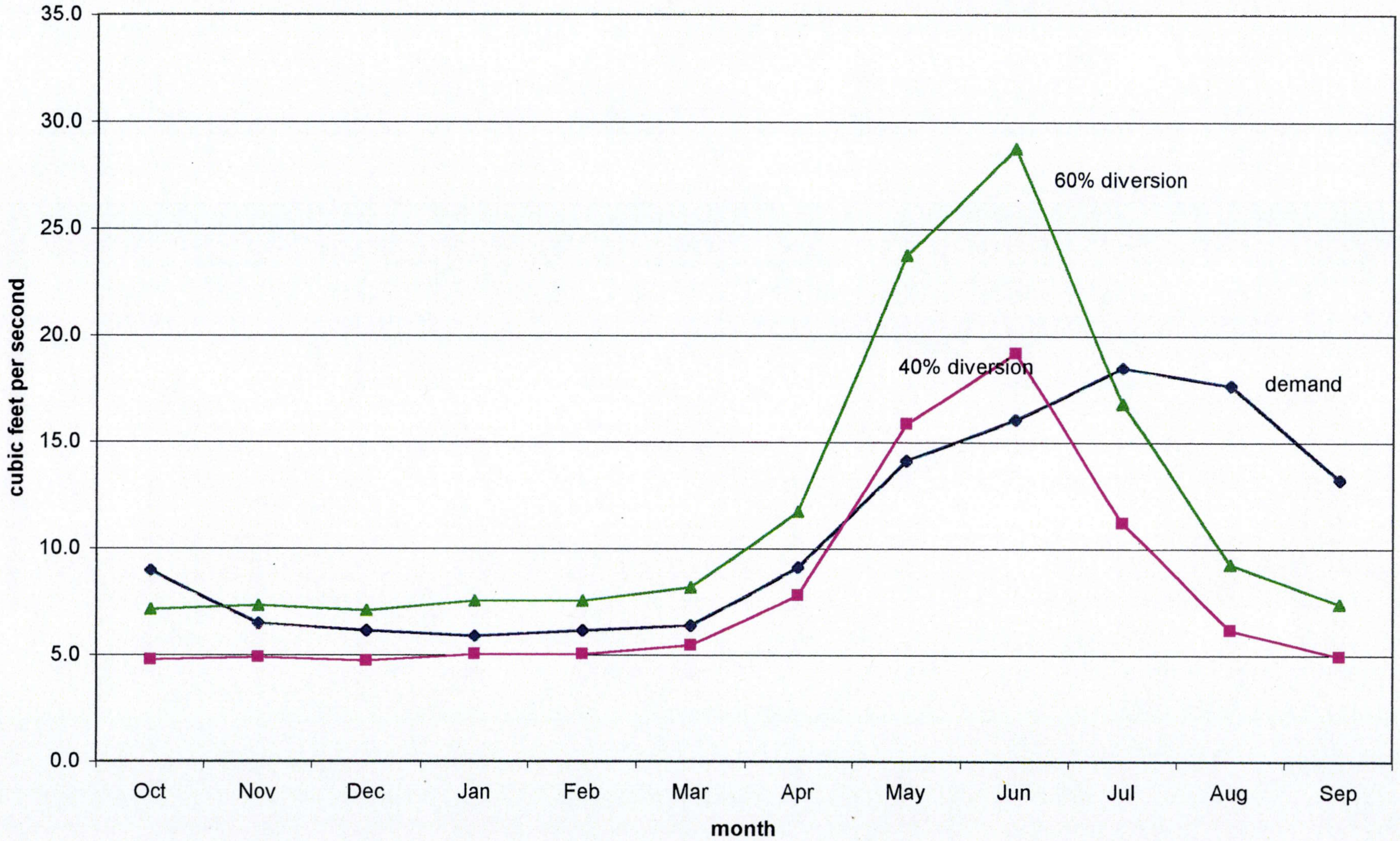


Figure 13. 7800 AF/YR demand vs. percent diversion of Thomas, Whites & Galena (cfs)

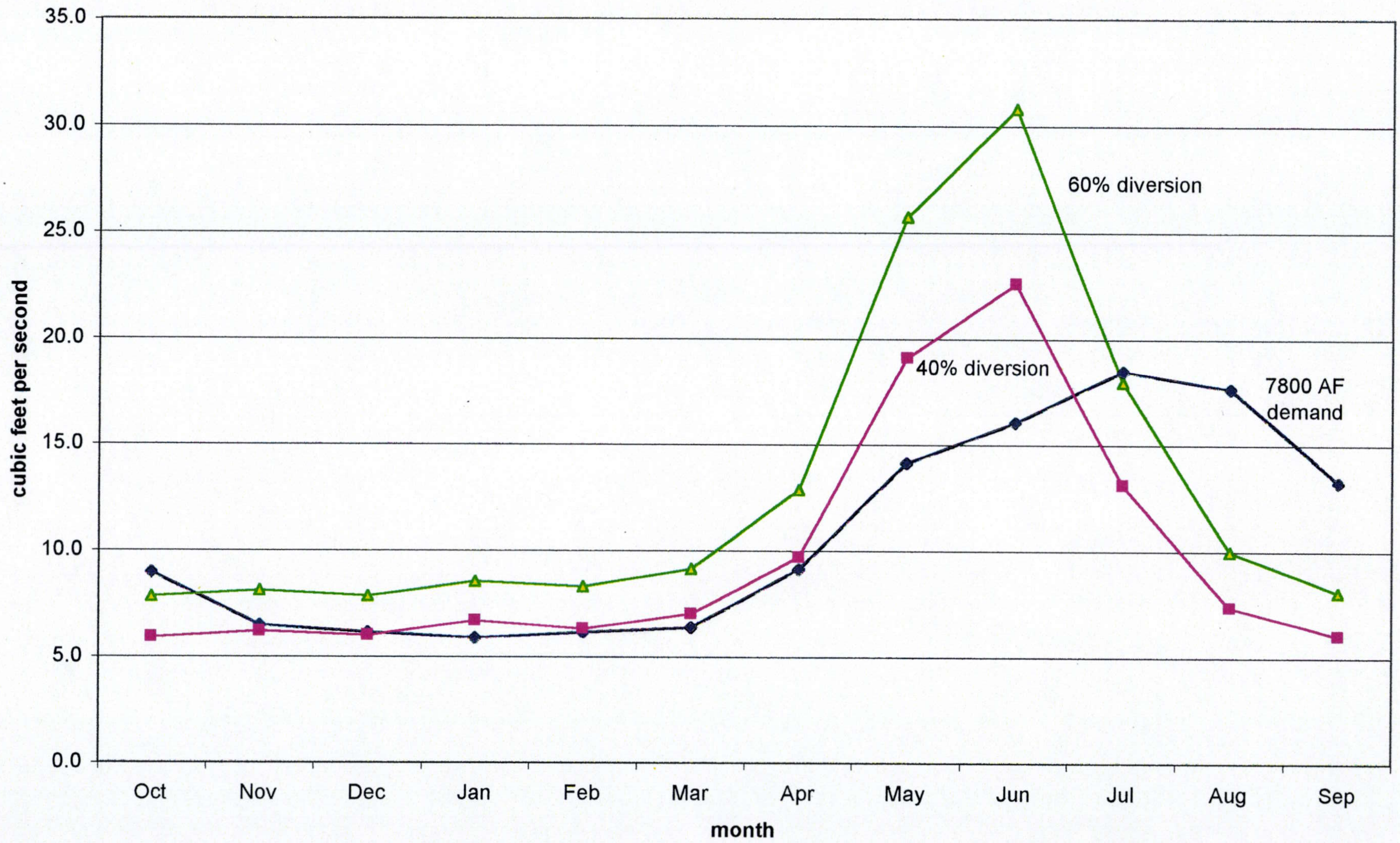


Figure 14. Demand vs. diversion rates and plant requirements (Galena, Whites, Thomas creeks in cfs)

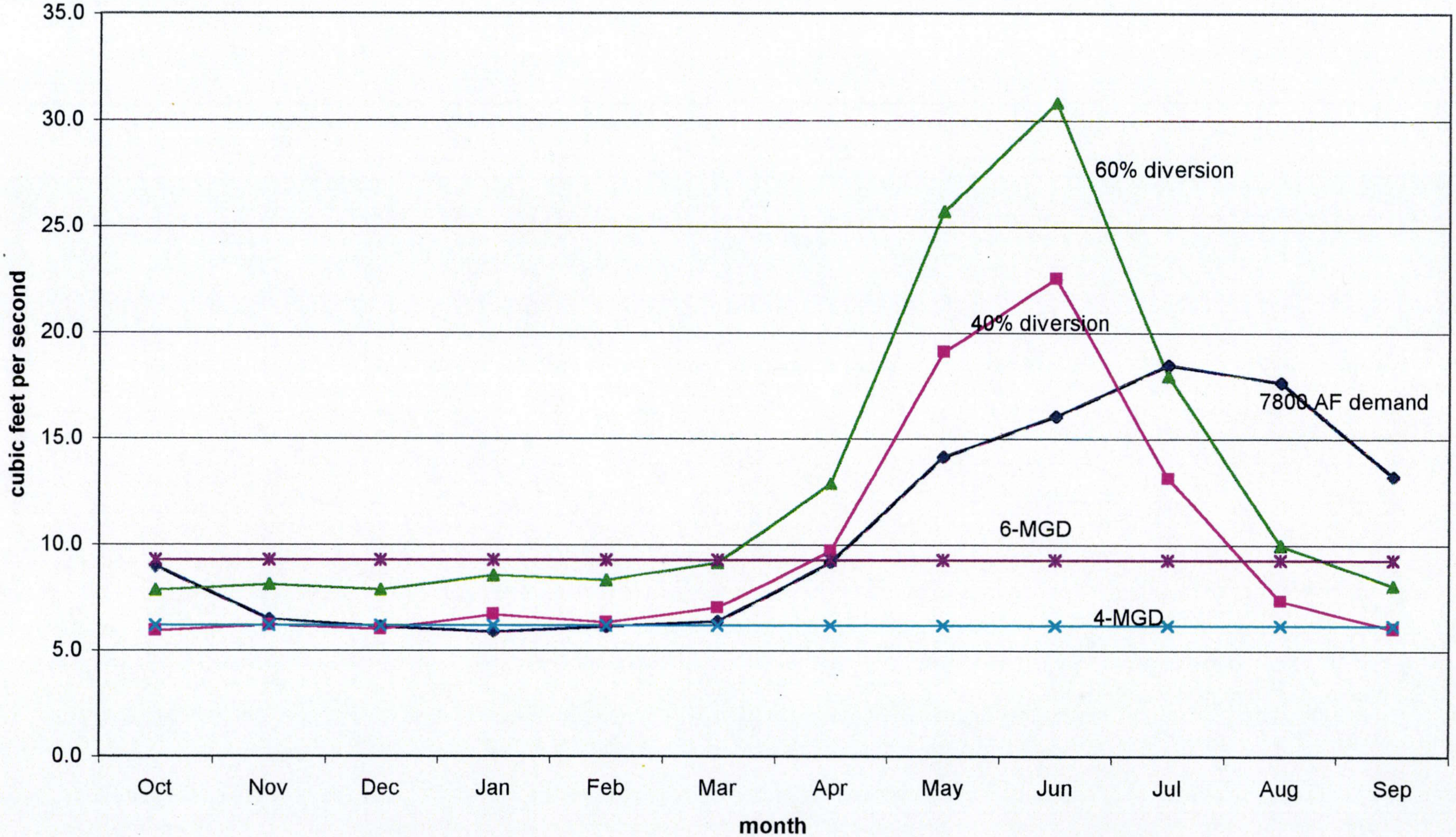


Figure 15. Galena Creek and Montana Method base flows plotted vs. natural flow (cfs)

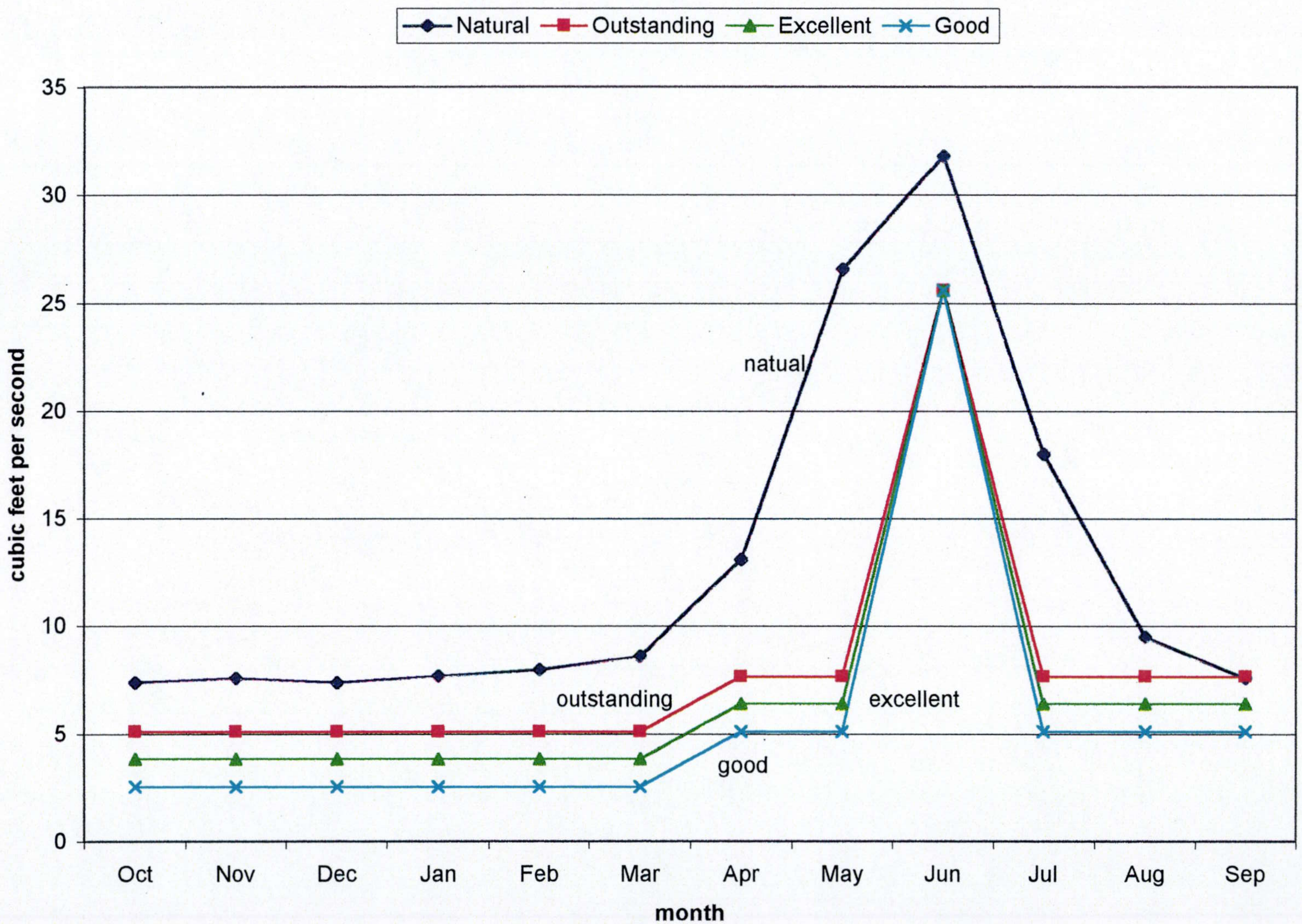


Figure 16. Total Creeks and Montana Method base flows plotted vs. natural flow (cfs)

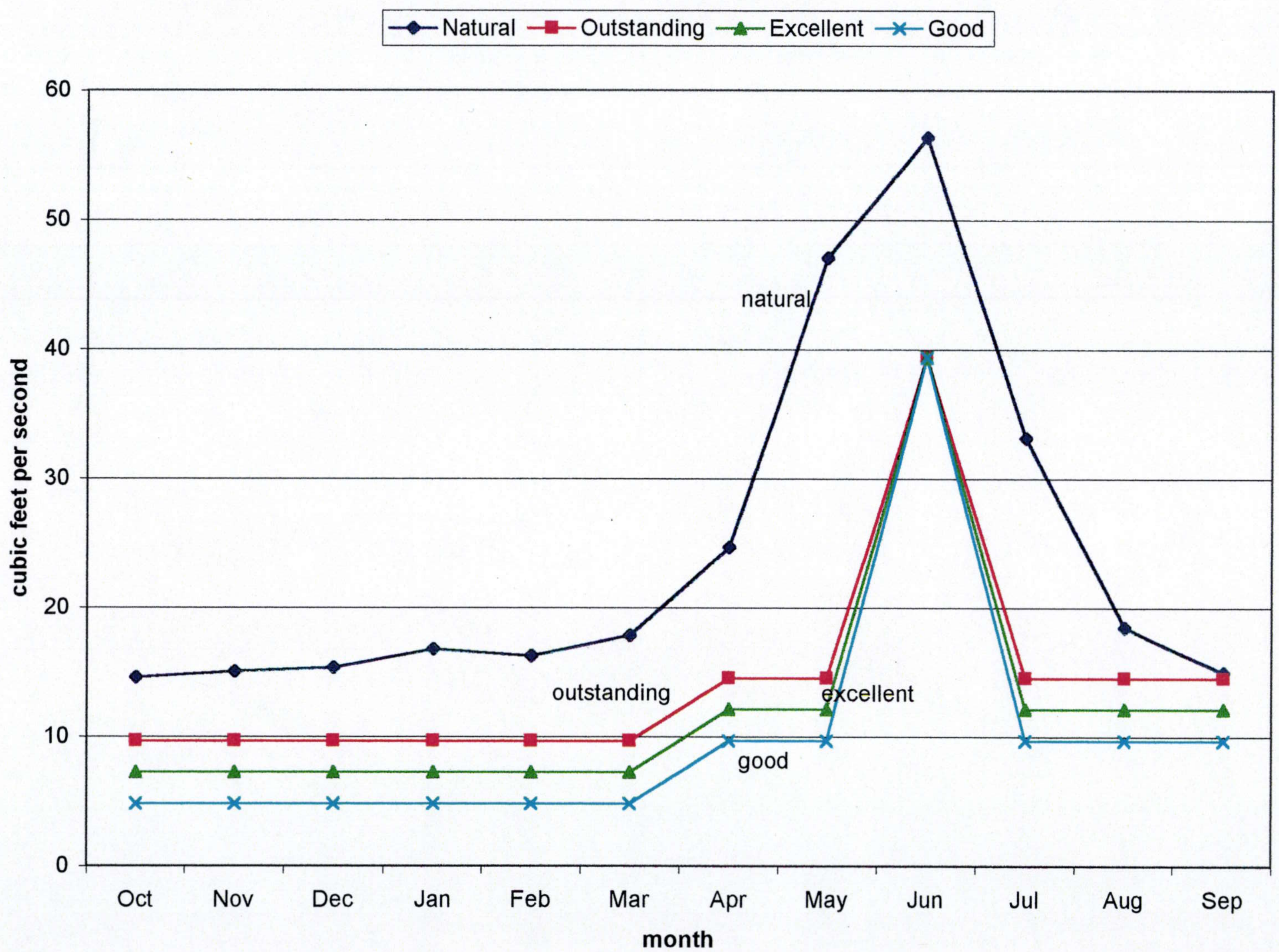
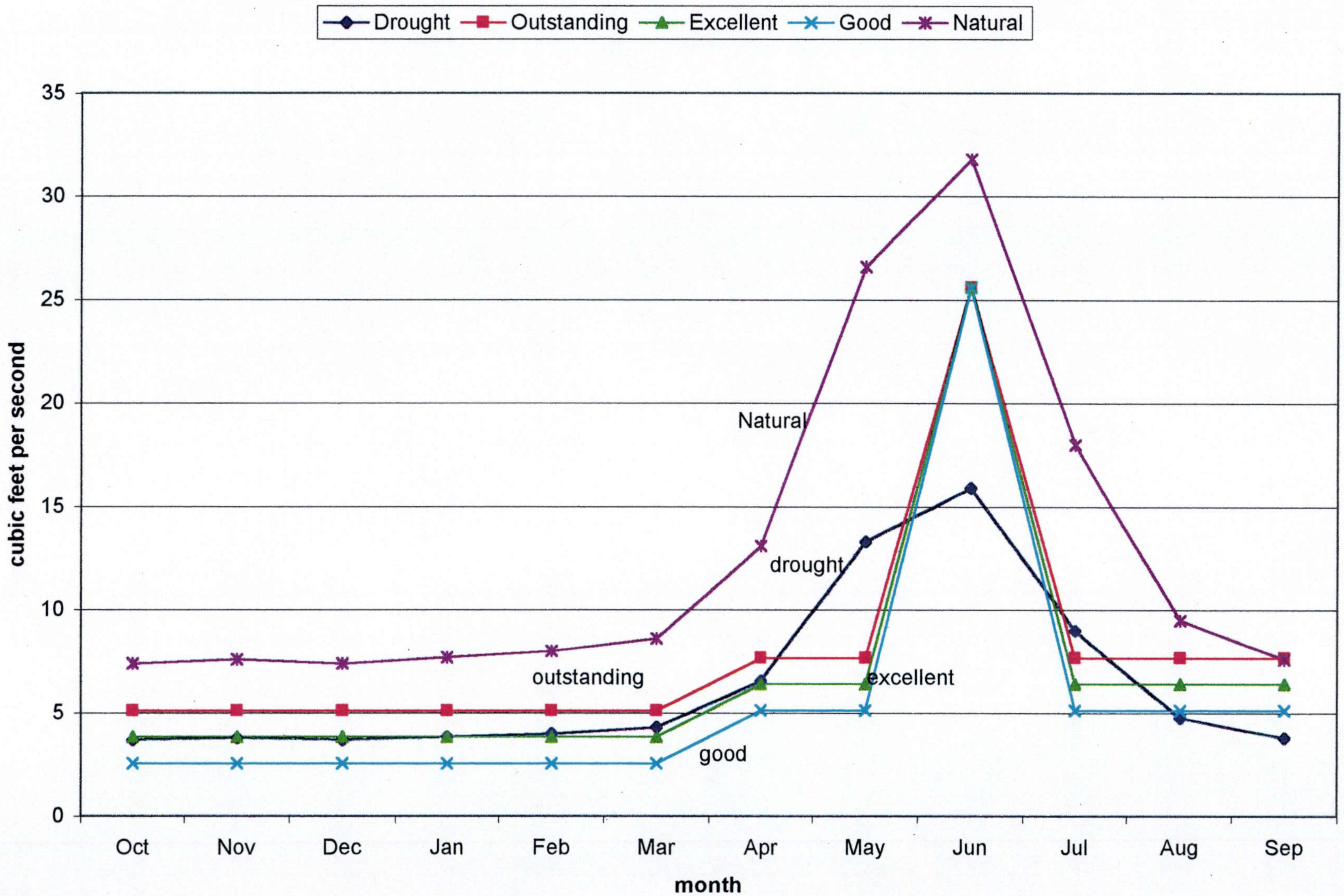


Figure 17. Galena Creek and Montana Method base flow plotted vs. drought conditions (cfs)



Appendices

Appendix 1	Measured Streamflow records
Appendix 2	Hydrographs for monthly flows from measured record
Appendix 3	Regression statistics and graphs for creeks
Appendix 4	Synthetic monthly records for creeks
Appendix 5	Comparison plots of monthly actual and synthetic frequency exceedance curves for Galena Creek
Appendix 6	Minimum and maximum flow frequency duration curves for Galena, Whites, Thomas and Hunter creeks
Appendix 7	Backup data for frequency duration curves
Appendix 8	Low-flow and high-flow frequency duration curves for 3-, 7-, 15-, 30-, 90-, 120- and 183-day durations