A STUDY OF STREAM FLOW TRENDS IN GLACIER NATIONAL PARK, MONTANA

THESIS

Presented to the Graduate Council
of Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

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San Marcos, Texas
August 2004

DEDICATION

I dedicate this thesis and all the hard work put into it to my wonderful daughter, Zoe Walza Cotter. Without her this feat would not have been possible. Thank you, Zoe, for all of your encouragement! I love you!

ACKNOWLEDGEMENTS

I would like to take this time to thank my daughter, Zoe, and all of my family for their support in this journey. It has been a long one and with their help, I have finally been able to say, I'm finished! Thank you, Mom, Pop, Mike, Ivette, Karen, Bryan, and Claudia for all of your encouraging words. I would also like to thank my friends for their help and for reminding me how important this degree is to me. Thank you, Lynnette, Cathleen, and Rock!

Most of all, I would like to thank my committee members for being so patient, yet understanding. Thank you, Dr. Dixon, Dr. Butler, and Dr. Lu. You have made a great team. I couldn't have done it without you! Thank you for staying on top of things and having such a quick turn around time on things submitted. I have truly enjoyed this quest! Thank you, again.

This manuscript was submitted on June 25, 2004.

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CHAPTER I

INTRODUCTION

The retreat of glaciers has become a great interest to scientists in the last several years. Scientists believe that many questions concerning our climate can be answered by evaluating different types of data gathered from these glaciers. Since it is believed that there is a direct correlation between the retreating glaciers and the ever changing climate, research in this area has increased dramatically.

When the climate's temperatures increase, a warming effect of the glaciers is created, causing them to begin melting or retreating. More time and effort from scientists has been directed toward glacial retreat studies to discover how much effect the climate has on these glaciers. Several studies have been conducted to track the glacier changes and to record the changes in volume of these glaciers. The glaciers in Glacier National Park, Montana have been studied for many years and previous research has proven that the glaciers there are definitely in retreat. However, no one has yet designed a study to determine the paths of the glacial melt water, which is a result of this glacial melt.

The amount of and location of the melt water from these glaciers is very important to track. The United States Geological Society (USGS) has been monitoring glaciers and gauging the amount of stream flow in certain areas of the United States. One of those areas of interest is Glacier National Park, Montana, which is where this study has focused. Using the available data of the amount of stream flow in the park that has been provided by the USGS, this study was designed to determine where the stream flow from these melting glaciers is going, as well as to help determine stream flow trends in that area.

The outcome of this study showed the final destinations of the melt water from the retreating glaciers in Glacier National Park. At the conclusion of this research, the methods utilized can be useful to others searching for the same answers. The methods can be used on a global level, as well as on a local level. It is important to know the destination of the water from retreating glaciers.

CHAPTER II

BACKGROUND/LITERATURE REVIEW

The monitoring of glaciers is becoming more common as technology advances and different ways to monitor them are learned. Since monitoring glaciers started in the 1930's, the technology has advanced by leaps and bounds since that time. It is now easier to monitor the glaciers because the data is more readily available. Glaciers all over the world are now being monitored, whereas, several years ago, no one even thought to monitor them. There was no reason to monitor them, at least that is what was thought.

Now, with the climate changing and more information being available, research on the monitoring of glaciers and their retreat is becoming the norm. It is believed that there is a direct correlation between the climate changes and the glaciers retreating. As researchers attempt to prove this theory, one very important factor is being forgotten. Where are the glaciers melting to? What streams are carrying the melt water? Has the melting of the glaciers increased stream flow? And, what stream flow trends can be detected?

Friedman, et. *al* (1999) use Synthetic Aperture Radar to monitor retreating glaciers, specifically the Columbia Glacier in Alaska. Their research has shown that the Columbia Glacier is in a rapid retreat at this time. It is a tidewater glacier that could affect the oil-tanker traffic that goes in and out of the Port of Valdez, Alaska. They use four

ERS-1 and seven RADARSAT SAR images dated from 1992 to 1998 to demonstrate the ability to monitor the long-term retreat of this glacier. The result of using these images was that there was a loss of approximately 17.7 square kilometers from 1992 to 1997. It was also discovered that these images could be used for identifying possible hazardous iceberg conditions within just 6 hours of the time the image was taken. This information can be very valuable in preventing hazardous situations.

Although there are many other glaciers around the world and in the United States that are being monitored, this research will concentrate on the monitoring of the glaciers located in Glacier National Park, Montana. These glaciers have been around since the little ice age and researchers began to monitor them as early as 1901. It is believed that the glaciers began to retreat in 1850 when there were more than 150 glaciers in the park.

According to Fagre (2003), there was a drastic rate of glacial retreat during the period from 1920-1940 when the region had above average summer temperatures in addition to below average annual precipitation. Several of the larger glaciers advanced slightly from 1960-1979 when there was greater precipitation and lower temperatures. With this information, it can be said that glaciers that have long-term reductions in size show that there are long-term increases in average temperatures.

Published reports about the glacial fluctuations in Glacier National Park date back to 1914. The most recent publication was in 1989 with the USGS Bulletin #1902. This publication was done by Paul Carrara (1989), where he summarized most of the glacial history for the park. Between 1930 and 1940, the National Park Service made periodic measurements of the glaciers in the park. Independent research scientists, USGS scientists, and others continued to make measurements during the 1970s for related research purposes. There is now an abundance of data which can be used for a glacier monitoring program which could contribute to broader documentation of climate change.

Every glacier, which has been measured at one time or another, in the park has shown some amount of shrinkage. As some of the smaller glaciers have completely disappeared, the majority of the larger glaciers have decreased to one-third their size since 1850, which is approximately 33 percent shrinkage. For the overall park, there has been a 73 percent reduction of the glacier area in Glacier National Park from 1850-1993. There were 99 square kilometers of glaciers in the first records of glacier data. Now, there are only 27 square kilometers of glaciers which remain (Fagre 2003).

McFarling (2002) informs that there were 150 glaciers in Glacier National Park more than a century ago, whereas, there are only 35 glaciers left. Scientists estimate that within 30 years, all of the glaciers in Glacier National Park will have disappeared. One of the larger glaciers, Boulder Glacier, had already completely melted and disappeared by 1998. Grinnell Glacier, another very large glacier in the park, has shrunk by 90% since 1850.

Four small glaciers out of seventeen that have been rephotographed have not changed at all. These are the ones in the park's shadiest, north-facing recesses. Twelve of those seventeen have shrunk considerably, where one has completely disappeared. Warming left over from the Little Ice Age and global warming is what scientists have come to blame for the melting of these glaciers. Even though these glaciers have melted at considerable rates over the last century, annual temperatures have not warmed that significantly. It was originally believed that the rising temperatures are what were melting the ice. However, additional analysis of temperature data proves that theory wrong (McFarling 2002).

In Key, Fagre, and Menicke (1998), it says that of the 83 perennial ice-and-snow bodies that can be delineated within the Park that exceed 0.1 square kilometers, only 34 of them are considered to be glaciers. There are three additional glaciers which are named, but have areas less than 0.1 square kilometers. Since the mid-19th century, the end of the Little Ice Age in the Western United States, all of these 37 named mountain glaciers have receded dramatically. Only five of the glaciers in Glacier National Park continue to retain an area of 1.0 to 1.5 square kilometers. Two glaciers have shrunk to an area of 0.9 square kilometers. Five additional glaciers are currently between 0.5 and 0.8 square kilometers in size. Total reduction in area for 6 active glaciers since the mid-19th century ranges between 77 and 46 percent. Two glaciers no longer retain characteristics of active glaciers. However, those glaciers still exist as inactive ice masses.

Hall and Fagre (2003) report that Glacier National Park has lost most of its glaciers since its establishment in 1910. By 1980, over two-thirds of the approximately 150 glaciers existing in the park in 1850 had disappeared (Carrara and McGimsey 1981). The glaciers which survived that time period were greatly reduced in area. Between 1910 and 1980, the summer mean temperature increased by 1.66 degrees Celsius. A worldwide pattern has been shown through these events where glacial retreat and climatic change are viewed as evidence of global warming (Hall and Fagre 2003).

Humans consume fifty percent of the freshwater yearly that comes from these mountain glaciers. Water-supply problems have been created for downstream communities with the reduction in the Zongo Glacier in the Bolivian Andes (Liniger, Weingartner, and Grosjean 1998). Some mountain glaciers provide the hydrological base flow for lowland rivers upon which agriculture depends in late summer (Hall and Fagre 2003). There has been a 10-25 centimeter rise globally in sea level during this century. This rise in sea level is being attributed to the worldwide retreat of alpine glaciers (Meier 1984).

Because glaciers respond directly to trends in the climate, they make the perfect barometer of climate change. Temperature, precipitation and cloud cover are the climatic factors that drive ecosystem change. Stream hydrology is one of the aspects of ecosystems which is greatly modified by plant community responses to changed conditions. Glaciers physically reflect their surrounding conditions and do not respond to yearly variability, which provides information that integrates climatic change over time. Their size and mass are changed slowly due to decadal trends in climate, causing the retreat of glaciers to be attributed to real climatic changes and not to temporary deviations of the climate (Hall and Fagre 2003).

The natural resources in Glacier National Park are very likely to be influenced by the rapid melting of the glaciers. Glacial melt water is extremely significant when it comes to stream base flow in the late summer. Temperature-sensitive organisms will decease if they do not shift with the changing stream flow as the summer water temperatures rise in the streams that are no longer fed by the glaciers (Hall and Fagre 2003).

Some of the effects of the receding glaciers will be the change in cold air drainages, the reduction of moisture in glaciated basins during the late summer, and an increase in stream temperatures. This is when the temperature-sensitive aquatic invertebrates will be effected (Fagre, et. *al* 1997). New areas for plant colonization will be created due to the glacial retreat. Sediment transport in streams is altered because of the melting glaciers. Soil moisture changing, fire frequency being altered, the growth of the forest, and the distribution changes in the vegetation are some of the changes that occur in the ecosystem in response to the glaciers melting. Global environmental change is proven by the shrinkage of the glaciers in Glacier National Park as well as glaciers all over the world, providing an important means of tracking that change (Hall and Fagre 2003).

Now that glacier melt and its effects on the ecosystem have been discussed, glacier mass balance and runoff will be introduced. The previous information was directed to Glacier National Park, Montana, which is where this study is going to take place. However, in order to get a better background on runoff, glacial melt, and stream flow, more general information will be provided before returning to how these things are effected in the Park.

General research has been conducted in the United States to provide information on glacier mass balance and runoff. The nation's climate, water resources, and flood hazards can now be better understood through glacier research. This research provides information on routine hydrologic studies which had not been undertaken in glacierized mountainous areas before glacier research programs began. The release of water in non-glacier areas, which adjoin glacier areas, provides 2 to 10 times less than the adjoining glacier area. Glacial runoff rates are decreased with altitude and the outbursting of stored water causes unusual flooding (Mayo 1984).

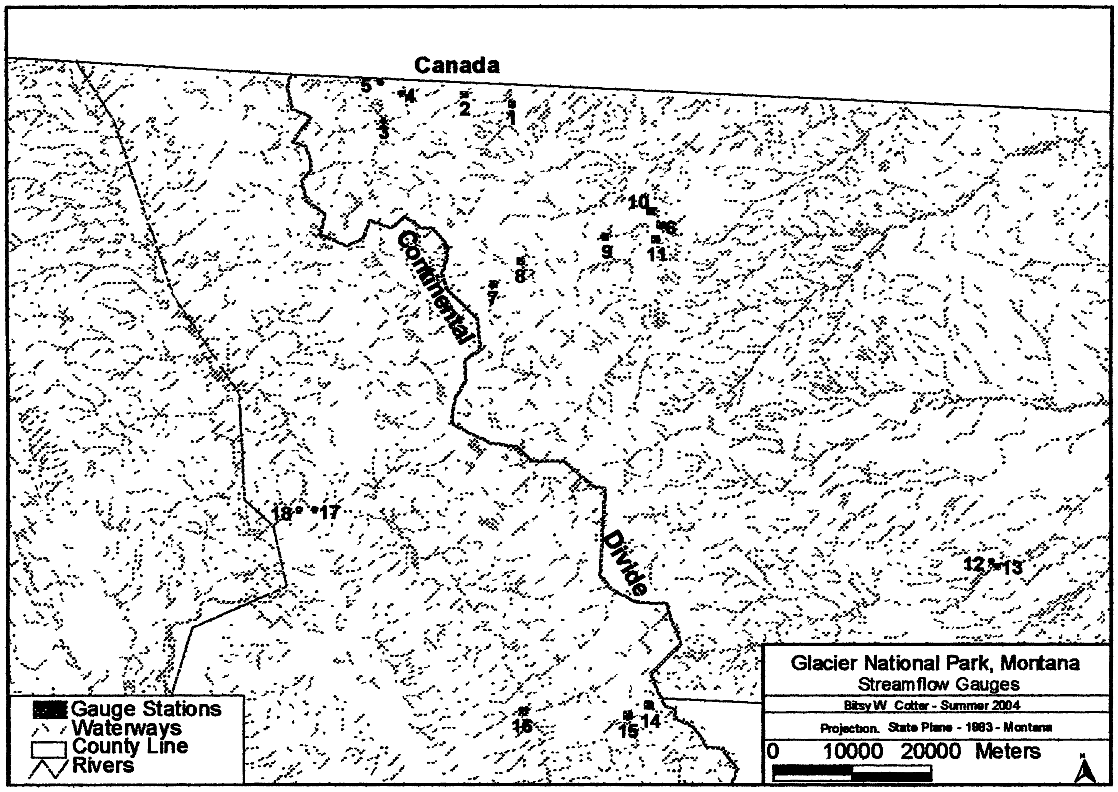
Significant factors in the balance of certain glaciers are the accumulation of mass and reduction of ablation by large landslides (Post 1967; Bull and Marangunic 1968; Reid 1969), ablation by calving (Brown, Meier, and Post 1982), and accumulation of mass by avalanching (Post 1967). Glaciers can also be used as natural calorimeters in volcanic heat-flow studies. The overall balance of a glacier is significantly affected by calving and other local influences, such as glacier geometry and dynamics. All glaciers will not necessarily react similarly or at the same time to the same regional variations in weather and climate (Mayo 1984).

Glaciers produce large amounts of water at high altitudes during hot, dry weather, contributing to the nation economically. Glacier runoff is a valuable source of water for irrigation, municipalities, and power generation (Meier 1960, 1969). Jackson (1961) analyzed the possibility of power generation in Alaska of a potential power site utilizing glacier runoff.

The subject of glacier runoff has become a great interest because the glacier-derived stream flow can be used for irrigation, water supply, and power generation. The water can be hazardous during outburst flooding or volcanic eruptions. Glacier melt water and rain water can pass through snow and through an entire glacier system as if the glacier were a porous medium (Campbell 1973, Colback 1974).

Glacier-derived runoff is not usually measured and is much greater than the runoff from more familiar environments. Anderson (1970) calculated glacier runoff as 47 percent of the Tanana River runoff in Alaska, where only 5 percent of the area is covered by glaciers. Glacier runoff is about twice as much as that of non-glacial basins in maritime regions (Mayo 1984).

Figure 1 - Map of Study Area with labels of stream flow gauges



Gauge Number	Name	Gauge Number	Name
1	Belly River at Intern'l Bndry	10	Swiftcurrent Creek near Babb
2	N Fork Belly River at Intern'l Bndry	11	St Mary River near Babb
3	Waterton River Nr Intern'l Bndry	12	Two Medicine Canal near Browning
4	Street Creek at Intern'l Bndry	13	Two Medicine River near Browning
5	Boundary Creek at Intern'l Bndry	14	Skyland Creek near Essex
6	St Mary River at Swiftcurrent C Nr Babb	15	Bear Creek near Essex
7	Grinnell Creek near Many Glacier	16	Middle Fork Flathead River at Essex
8	Swiftcurrent Creek at Many Glacier	17	Middle Fork Flathead River at W Glacier
9	Swiftcurrent Creek at Sherburne	18	Middle Fork Flathead River near W Glacier

CHAPTER III

METHODS

Table 1 represents the different gauges' locations. The information provided shows the latitude and longitude locations of the gauges, as well as their elevation. In addition, the number of years of record has also been given. This information allows a brief description of the gauge locations and amount of data available in those locations.

Table 1 – Latitude, Longitude, Elevation, and Number of Years of Record

Gauge Number	Latitude	Longitude	Elevation of Gauge	Number of Years of Record
1	48.99722	-113.68060	4,500' above sea level	9
2	48.98889	-113.76390	5,100' above sea level	4
3	48.95555	-113.90000	4,200' above sea level	9
4	48.98889	-113.87780	4,400' above sea level	3
5	48.99722	-113.90560	4,300' above sea level	9
6	48.85000	-113.41390	4,460' above sea level	13
7	48.77056	-113.69810	4,920' above sea level	27
8	48.79917	-113.65580	4,876.78' above sea level	45
9	48.83028	-113.51640	4,730.26' above sea level	6
10	48.85833	-113.42780	4,490' above sea level	7
11	48.83333	-113.41890	4,468.13' above sea level	61
12	48.47805	-112.81310	No data available	14
13	48.49166	-113.26110	3,390' above sea level	41
14	48.29167	-113.38610	4,835.83' above sea level	6
15	48.28056	-113.42500	4,484.14' above sea level	6
16	48.50000	-113.97500	3,721.93' above sea level	20
17	48.27500	-113.60280	3,170' above sea level	9
18	48.49528	-114.00920	3,128.72' above sea level	62

In using the information derived from the above mentioned table, one is able to determine the locations of the gauges that show a trend and where each gauge location is in reference to the others. This information was beneficial after the statistics were run on the data and the results were completed.

Stream flow data from the years 1900 to 2001, which are available through the USGS website, were utilized, manipulated, and evaluated. The annual mean stream flow data in cubic feet per second (ft^3/s) were used to find the destination of the water from the melting glaciers in the Park. The data were manipulated through linear regression and evaluated for stream flow trends. Since stream flow trends exist, the data were quantified through a regression to compare the quantity versus the year.

One method that was used to smooth out the data was the scatter plot, which is a useful summary of a set of bivariate data. It is usually drawn before fitting a regression line. It offers an excellent visual picture of the relationship between the two variables. Each unit equals one point on the scatter plot, where the points are plotted but not joined. The resulting pattern shows the type and strength of the relationship between the two variables (Yale 1997).

Probably the most important part of determining the success of a linear regression is the slope and intercept. The slope quantifies the steepness of the line, whereas the intercept is the y value when x is equal to zero. The value r is a fraction between -1.0 and 1.0 that has no units. When the r value is 0.0, then there is no relationship between x and y. This means that the slope is 0 causing the regression line to be horizontal. When the r value is 1.0 or -1.0, then there is a perfect relationship between x and y. This means that the slope is 1, or -1, causing the regression line to run through all of the points with no scatter. This allows you to predict y perfectly by knowing x (Curvefit.com 1999). A slope of 1 causes the regression line to increase diagonally. A slope of -1 causes the regression line to decrease diagonally.

All of the data have been collected and manipulated. The data were first entered into a spreadsheet using Microsoft Excel and then transferred into SPSS for Windows, Version 11. The data were able to be manipulated using statistics, and in this case, linear regression statistics were used in conjunction with scatter plots.

Before the data were manipulated using linear regression statistics, a scatter plot of each set of data for each stream flow gauge was created. The scatter plots can be found in Appendix B. These scatter plots helped to show any trends in the stream flow amounts for each year the data was collected. Using the scatter plots with the linear regression data overlaid on them, it was easy to determine any trends.

The regression statistics were then run on the data. The regression statistics provided the R squared, the F-score, and the significance of each data set for each stream flow gauge. This information helped to determine which gauges are significant or show a stream flow trend.

In addition to the regression statistics, descriptive statistics were also run. Descriptive statistics showed the number of years there was data collected and used for the study. This information is helpful when determining the accuracy of the data. The more data that is available and used, the more accurate the results will be.

Pearson correlations were also run on the data to determine the correlation between each gauge station. This gave a better understanding of where the highly correlated gauges are and why they are correlated.

CHAPTER IV

RESULTS

Table 2 – Regression Statistics of Stream Flow Gauges

Name of Gauge	R Squared	F-score	Significance
Belly River at Intern'l Bndry	0.022	0.159	0.702
North Fork Belly River at Intern'l Bndry	0.459	1.697	0.322
Waterton River near Intern'l Bndry	0.029	0.209	0.661
Street Creek at Intern'l Bndry	0.883	7.561	0.222
St Mary River at Swiftcurrent C near Babb	0.241	3.498	*0.088
Grinnell Creek near Many Glacier	0.131	3.759	*0.064
St Mary River near Babb	0.026	1.563	0.216
Boundary Creek at Intern'l Bndry	0.040	0.290	0.607
Middle Fork Flathead River at W Glacier	0.103	0.800	0.401
Middle Fork Flathead River near W Glacier	0.002	0.092	0.762
Swiftcurrent Creek at Many Glacier	0.040	1.770	0.190
Swiftcurrent Creek at Sherburne	0.023	0.095	0.773
Swiftcurrent Creek near Babb	0.154	0.910	0.384
Skyland Creek near Essex	0.528	4.483	*0.102
Bear Creek near Essex	0.348	2.136	0.218
Middle Fork Flathead River at Essex	0.112	2.268	0.149
Two Medicine Canal near Browning	0.002	0.027	0.872
Two Medicine River near Browning	0.017	0.679	0.415

The regression statistics for the stream flow gauges can be found in table 2. These statistics show the r^2, the F-score of the data, and the significance of each set of data for each stream flow gauge. The information for this table was obtained through the use of SPSS and compiled for easier readability. Values marked with an * are significant at the 0.10 level.

Descriptive Statistics were also run on the stream flow data. These statistics show the number of years there was data collected and used for the study. Also calculated are the minimum, maximum, and mean of the stream flow data in cubic feet per second. The standard deviation and the coefficient of variation are also given for each stream flow gauge. Table 3 represents these descriptive statistics.

Table 3 – Descriptive Statistics of Stream Flow Gauges

Gauge Number	Years of Data	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
1	9	194.000	322.000	263.220	49.060	0.1864
2	4	24.800	43.800	34.950	7.889	0.2257
3	9	210.000	340.000	274.890	46.320	0.1685
4	3	14.700	20.400	18.467	3.262	0.1766
5	9	58.800	93.900	77.956	12.383	0.1576
6	13	422.000	745.000	559.690	105.590	0.1887
7	27	20.200	33.100	26.056	3.217	0.1235
8	45	88.000	181.000	140.490	22.230	0.1582
9	6	152.000	241.000	201.000	32.240	0.1604
10	7	225.000	399.000	325.140	75.510	0.2322
11	61	435.000	1042.000	746.920	140.560	0.1882
12	14	27.000	57.000	42.650	9.310	0.2183
13	41	165.000	674.000	383.440	109.980	0.2868
14	6	12.500	26.000	18.767	5.500	0.2931
15	6	31.600	58.900	45.667	10.727	0.2349
16	20	556.000	1641.000	1048.050	306.920	0.2928
17	9	1255.000	3021.000	2123.890	547.740	0.2579
18	62	1530.000	4041.000	2878.730	642.010	0.2230

In addition to the descriptive statistics and regression statistics that were run, Pearson correlations were also run. The correlations show how much correlation there is between the gauge stations. Table 4 represents the Pearson Correlations for the stream flow gauges.

Table 5 represents the number of years of common data for the correlation of each set of stream flow gauges. This information gives us an example of which sets of correlations are more accurate versus the other sets. The higher the number of years, the more data there is causing a more accurate set of data.

Table 4 – Pearson Correlations of Stream Flow Gauges

	1	2	3	4	6	7	11	5	17	18	8	9	10	14	15	16	12	13
1	1	942	***.952***	.986		**.812**	***.978***	***.978***		***.937***				**.969**	**.966**	**.926**		**.938**
2	.942	1	.842	.728		***-1.000***		.920		.832				.871	.885	.733		
3	***.952***	.842	1	**.999**		**.871**	***.983***	***.958***		***.977***				***.958***	.941	**.956**		**.938**
4	.986	.728	**.999**	1		***1.000***		.951		.965				.969	.971	.891		
6					1		.917		***1.000***				**.836**					**.784**
7	**.812**	***-1.000***	**.871**	***1.000***		1	***.647***	**.795**		***.649***	***.763***			***1.000***	***1.000***	**.683**	-.273	.559
11	***.978***		***.983***		.917	***.647***	1	***.987***	.857	***.942***	***.922***	***.867***	**.836**					**.784**
5	***.978***	.920	***.958***	.951		**.795**	***.987***	1		***.913***				903	.892	.873		***.971***
17					***1.000***		.857		1	***1.000***						**1.000**		-.218
18	***.937***	.832	***.977***	.965		***.649***	***.942***	***.913***	***1.000***	1	.921			**.888**	***.931***	***.986***	-.461	***.798***
8						***.763***	***.922***			***.921***	1	**1.000**				.842	-.469	***.773***
9							**.867**				**1.000**	1						.482
10					**.836**								1					***1.000***
14	**.969**	871	**.958**	.969		***1.000***		.903		**.888**				1	***.979***	**.914**		
15	**.966**	.885	.941	.971		***1.000***		.892		***.931***				***.979***	1	***.933***		
16	**.926**	.733	**.956**	.891		**.683**	***.816***	.873	**1.000**	***.986***	.842			**.914**	***.933***	1	233	***.928***
12						-.273	**-.559**			-.461	-.469					.233	1	**-.633**
13	**.938**		**.938**		**.784**	***.559***	***.842***	***.971***	-.218	***.798***	***.773***	.482	***1.000***			***.928***	**-.633**	1

Correlations significant at .05 are in bold and italics.

Table 5 – Number of Years of Common Data for Correlations of Stream Flow Gauges

	1	**2**	**3**	**4**	**6**	**7**	**11**	**5**	**17**	**18**	**8**	**9**	**10**	**14**	**15**	**16**	**12**	**13**
1	9	4	9	3	0	7	6	9	0	9	0	0	0	4	4	5	0	5
2	4	4	4	3	0	2	1	4	0	4	0	0	0	4	4	4	0	0
3	9	4	9	3	0	7	6	9	0	9	0	0	0	4	4	5	0	5
4	3	3	3	3	0	2	1	3	0	3	0	0	0	3	3	3	0	0
6	0	0	0	0	13	0	4	0	2	0	0	0	7	0	0	0	0	7
7	7	2	7	2	0	27	26	7	0	27	18	0	0	2	2	10	13	25
11	6	1	6	1	4	26	61	6	3	47	41	6	0	1	1	9	14	38
5	9	4	9	3	0	7	6	9	0	9	0	0	0	4	4	5	0	5
17	0	0	0	0	2	0	3	0	9	3	0	1	0	1	1	3	0	3
18	9	4	9	3	0	27	47	9	3	62	43	0	0	6	6	20	14	25
8	0	0	0	0	0	18	41	0	0	43	45	2	0	0	0	5	14	20
9	0	0	0	0	0	0	6	0	1	0	2	6	0	0	0	0	0	6
10	0	0	0	0	7	0	0	0	0	0	0	0	7	0	0	0	0	2
14	4	4	4	3	0	2	1	4	1	6	0	0	0	6	6	6	0	0
15	4	4	4	3	0	2	1	4	1	6	0	0	0	6	6	6	0	0
16	5	4	5	3	0	10	9	5	3	20	5	0	0	6	6	20	3	8
12	0	0	0	0	0	13	14	0	0	14	14	0	0	0	0	3	14	13
13	5	0	5	0	7	25	38	5	3	25	20	6	2	0	0	8	13	41

Through the use of linear regression analysis and the scatter plots, it can be determined that there are trends in Glacier National Park, Montana. However, only three specific water bodies showed true results of having significant trends. These three water bodies are the St. Mary River at Swiftcurrent C near Babb, Grinnell Creek near Many Glacier, and Skyland Creek near Essex. St. Mary River at Swiftcurrent C showed a significance of 0.088, Grinnell Creek showed a significance of 0.064, and Skyland Creek showed a significance of 0.102. These three water bodies were the only ones that had significance levels which would provide the information necessary to show the trends that are present in the park. Table 6 represents the regression statistics for the stream flow gauge stations that are significant.

The manipulated data for the St. Mary River at Swiftcurrent C stream flow gauge gave a slope of -13.319. This means that there is a negative slope. Grinnell Creek and Skyland Creek's data both gave positive slopes. Grinnell Creek showed a slope of 0.147 and Skyland Creek showed a slope of 2.137. These numbers show that these are the stream flow gauges that have captured the trends in the park and are considered to be significant in this study.

The scatter plots with the regression lines of these water bodies are shown in figures 2, 3, and 4. These figures give a visual representation of the regression statistics, which provide further proof of their significance.

Table 6- Regression Statistics for Significant Stream Flow Gauge Stations

Name of Gauge	Unstandardized Coefficients - B	T	Significance	95% Confidence Interval for B Lower Bound	Upper Bound	Regression Equation
St Mary River at Swiftcurrent C near Babb	-13.319	-1.870	0.088	28.991	2.354	Q = -13.319YR + 25971.736
Grinnell Creek near Many Glacier	0.147	1.939	0.064	-0.009	0.302	Q = .147YR - 261.563
Skyland Creek near Essex	2.137	2.117	0.102	-0.665	4.940	Q = 2.137YR - 4145.456

In order to determine how accurate these data are, it is important to acknowledge the number of years of data that have collected for each stream flow gauge. In this case, St. Mary River at Swiftcurrent C had 13 years of data which had been collected. Grinnell Creek had 27 years of data available and Skyland Creek only had 6 years of available data for this study.

Figure 2 – Significant Scatter Plot with Regression Line

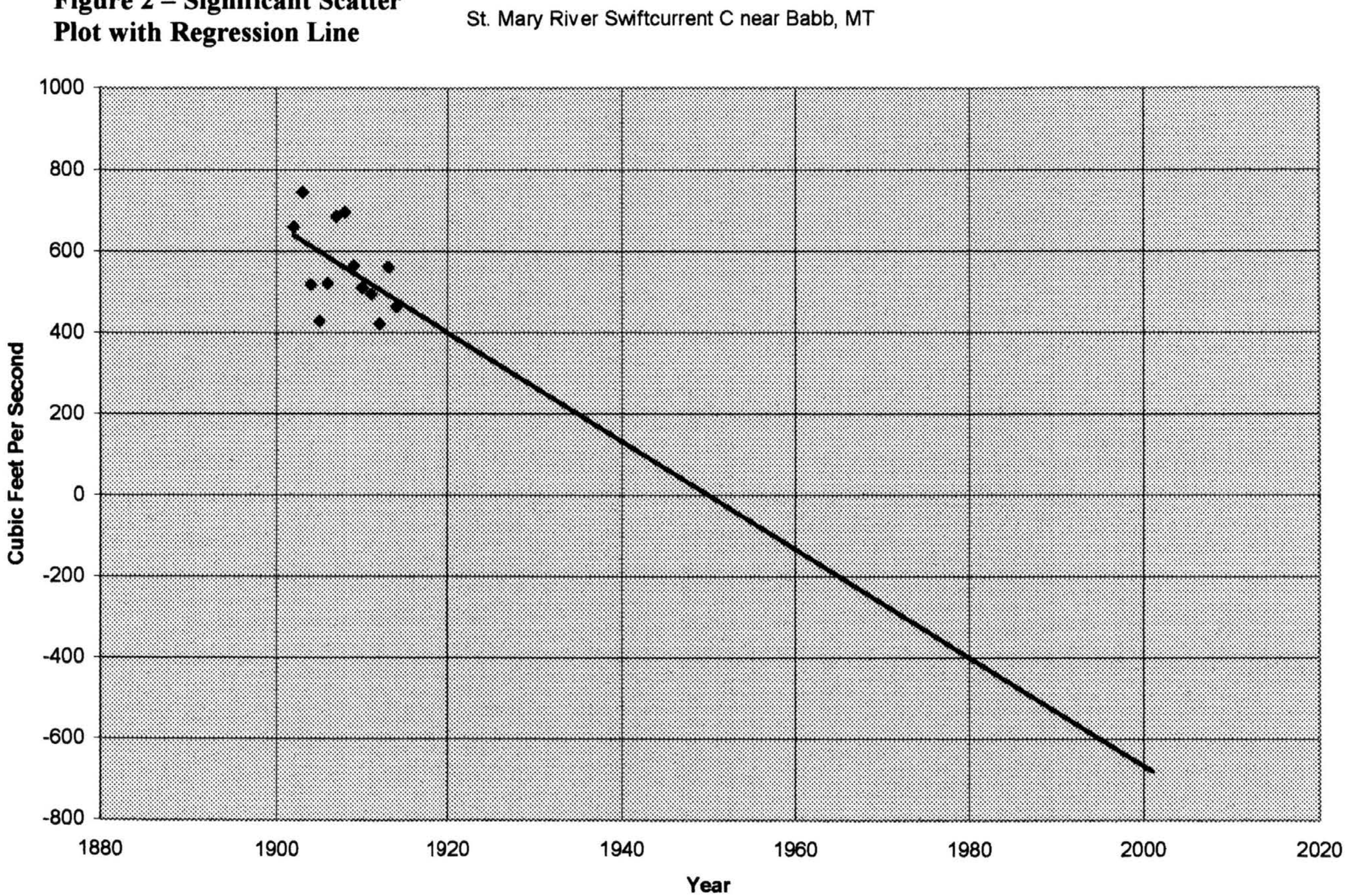


Figure 3 – Significant Scatter Plot with Regression Line

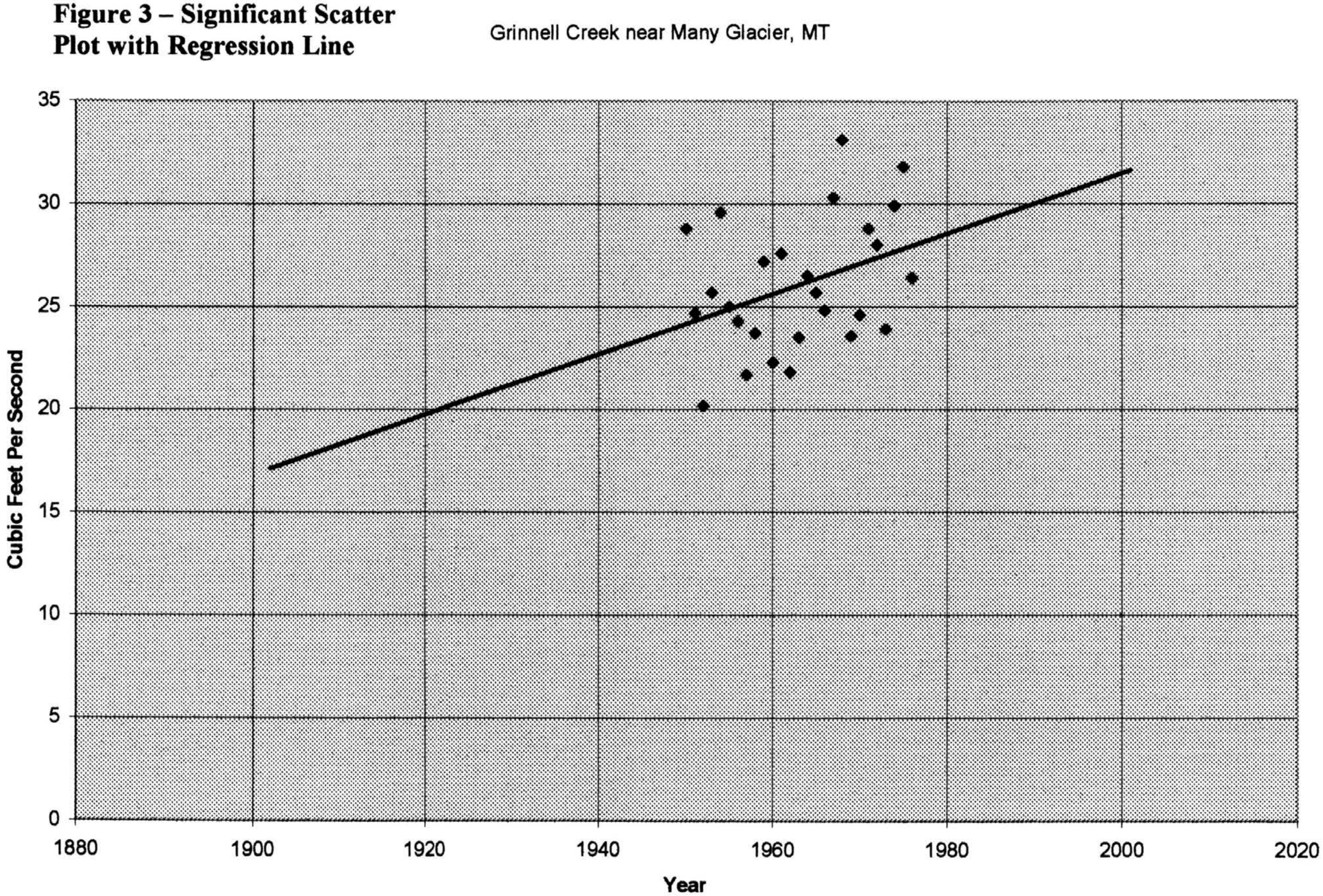
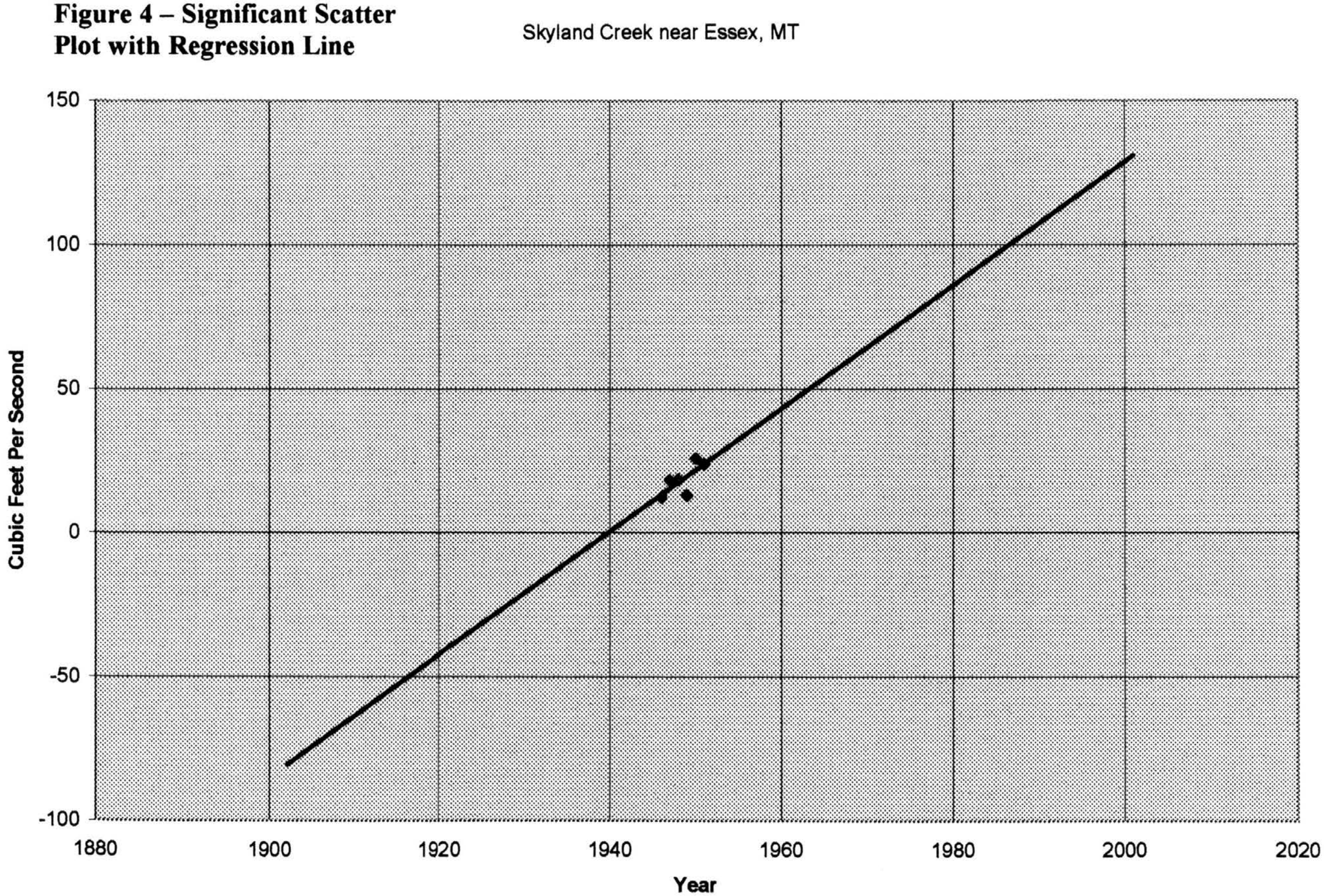


Figure 4 – Significant Scatter Plot with Regression Line



CHAPTER V

CONCLUSION

This study was done to try to determine if there were any trends in the stream flow gauges in Glacier National Park, Montana over a period of 101 years. To do this, data was collected from the USGS website. Different types of statistics were manipulated and documented using this data. Through this process, it has been determined that there are three stream flow gauges which proved to show a trend. These stream flow gauges were located at St. Mary River at Swiftcurrent C, Grinnell Creek, and Skyland Creek. Once that had been determined, more statistics were run on those particular sets of data and scatter plots were produced. After the scatter plots were produced and examined and the gauges were located on the map, it was determined that the results in this study have proven to be significant.

In looking at the map in figure 1, you will notice that the gauges at St. Mary River at Swiftcurrent C and at Grinnell Creek are both in the north central section of the park and on the east side of the Continental Divide, whereas Skyland Creek is more on the south side of the park and on the west side of the Continental Divide. Although St. Mary River at Swiftcurrent C and Grinnell Creek are both in the north central section of the park and on the east side of the Continental Divide, they are not very close to one another. This information tells us the there may not be a spatial pattern to these trends. It would appear that these trends are homogenous.

In conclusion, it can be said that through the use of regression analysis and scatter plot analysis, there is a stream flow trend in Glacier National Park, Montana. This trend has helped us to determine where the glacial melt from the glaciers in the park are flowing. The increasing amount of stream flow in and around the park only proves that the melting glaciers are running into the local streams and then dispersing outward from the park. This information can now assist in the areas of irrigation, fisheries, and power generation. This water feeds the local river systems, which can be very important during a dry period or drought. These results can be beneficial to various entities, including the park service, local residents, farmers, and tourists.

APPENDIX A – RAW DATA

	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914
Belly River at International Boundary													
North Fork Belly River at International Boundary													
Waterton River near International Boundary													
Street Creek at International Boundary													
St Mary River at Swiftcurrent C near Babb	660	745	519	429	522	686	696	565	511	495	422	562	464
Grinnell Creek near Many Glacier													
St Mary River near Babb										812	653	828	735
Boundary Creek at International Boundary													
Middle Fork Flathead River at West Glacier										2309	2098		
Middle Fork Flathead River near West Glacier													
Swiftcurrent Creek at Many Glacier													
Swiftcurrent Creek at Sherburne													
Swiftcurrent Creek near Babb		392	264	225	249	378	369	399					
Skyland Creek near Essex													
Bear Creek near Essex													
Middle Fork Flathead River at Essex													
Two Medicine Canal near Browning													
Two Medicine River near Browning							571	609	358	424	338	409	307

	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1930	1931	1932
Belly River at International Boundary													
North Fork Belly River at International Boundary													
Waterton River near International Boundary													
Street Creek at International Boundary													
St Mary River at Swiftcurrent C near Babb													
Grinnell Creek near Many Glacier													
St Mary River near Babb	636	925	772	767	553	727	877	713	705	678			
Boundary Creek at International Boundary													
Middle Fork Flathead River at West Glacier							3021				1870	1500	2562
Middle Fork Flathead River near West Glacier													
Swiftcurrent Creek at Many Glacier				175	123								
Swiftcurrent Creek at Sherburne			206	196	152	229	241	182					
Swiftcurrent Creek near Babb													
Skyland Creek near Essex													
Bear Creek near Essex													
Middle Fork Flathead River at Essex													
Two Medicine Canal near Browning													
Two Medicine River near Browning	281	555	496	415	230	362	346	325	361				

	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
Belly River at International Boundary									242	198	309	322	194
North Fork Belly River at International Boundary									34.1	24.8	37.1	43.8	
Waterton River near International Boundary									244	228	328	322	210
Street Creek at International Boundary									14.7		20.4	20.3	
St Mary River at Swiftcurrent C near Babb													
Grinnell Creek near Many Glacier											28.8	24.7	20.2
St Mary River near Babb												1042	650
Boundary Creek at International Boundary									70.1	65.7	86.1	93	58.8
Middle Fork Flathead River at West Glacier					1255	1997	2503						
Middle Fork Flathead River near West Glacier	1784	1743	2370	3317	1530	2455	3098	3302	2979	2527	3994	3705	2537
Swiftcurrent Creek at Many Glacier													
Swiftcurrent Creek at Sherburne													
Swiftcurrent Creek near Babb													
Skyland Creek near Essex							12.5	18.4	18.6	13.1	26	24	
Bear Creek near Essex							35.4	48	44.9	31.6	58.9	55.2	
Middle Fork Flathead River at Essex	587	556	857	1376	568	877	1104	1239	1104	933	1641	1390	959
Two Medicine Canal near Browning													
Two Medicine River near Browning													279

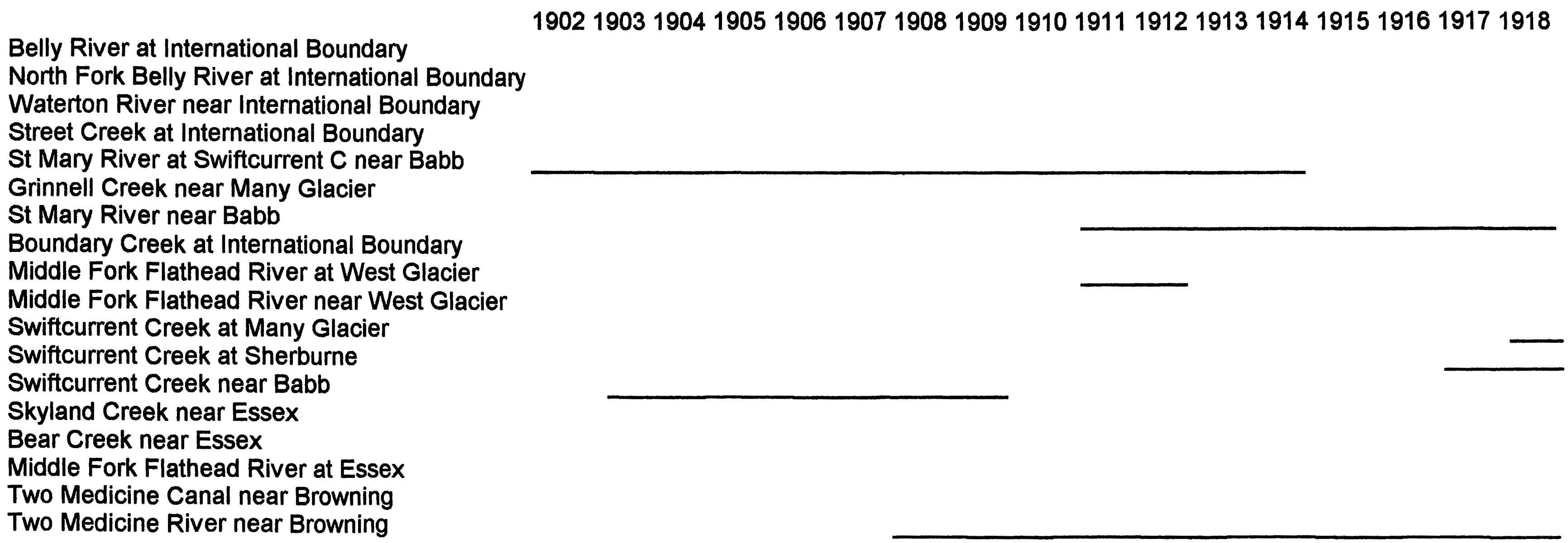
	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
Belly River at International Boundary	293	316	243	252									
North Fork Belly River at International Boundary													
Waterton River near International Boundary	275	340	252	275									
Street Creek at International Boundary													
St Mary River at Swiftcurrent C near Babb													
Grinnell Creek near Many Glacier	25.7	29.6	25	24.3	21.7	23.7	27.2	22.3	27.6	21.8	23.5	26.5	25.7
St Mary River near Babb	889	1039	755	837	700	673	968	632	758	658	715	925	826
Boundary Creek at International Boundary	85.3	93.9	71.1	77.6									
Middle Fork Flathead River at West Glacier													
Middle Fork Flathead River near West Glacier	3184	3826	2861	3290	2673	2569	4041	2775	2897	2883	2408	3646	3449
Swiftcurrent Creek at Many Glacier							181	126	145	130	136	159	146
Swiftcurrent Creek at Sherburne													
Swiftcurrent Creek near Babb													
Skyland Creek near Essex													
Bear Creek near Essex													
Middle Fork Flathead River at Essex					1080	959	1623	1032	1069	1169	838		
Two Medicine Canal near Browning									46	50.5	48.5	27.2	30.9
Two Medicine River near Browning	461	519	350	455	319	312	456	268	270	296	229	466	429

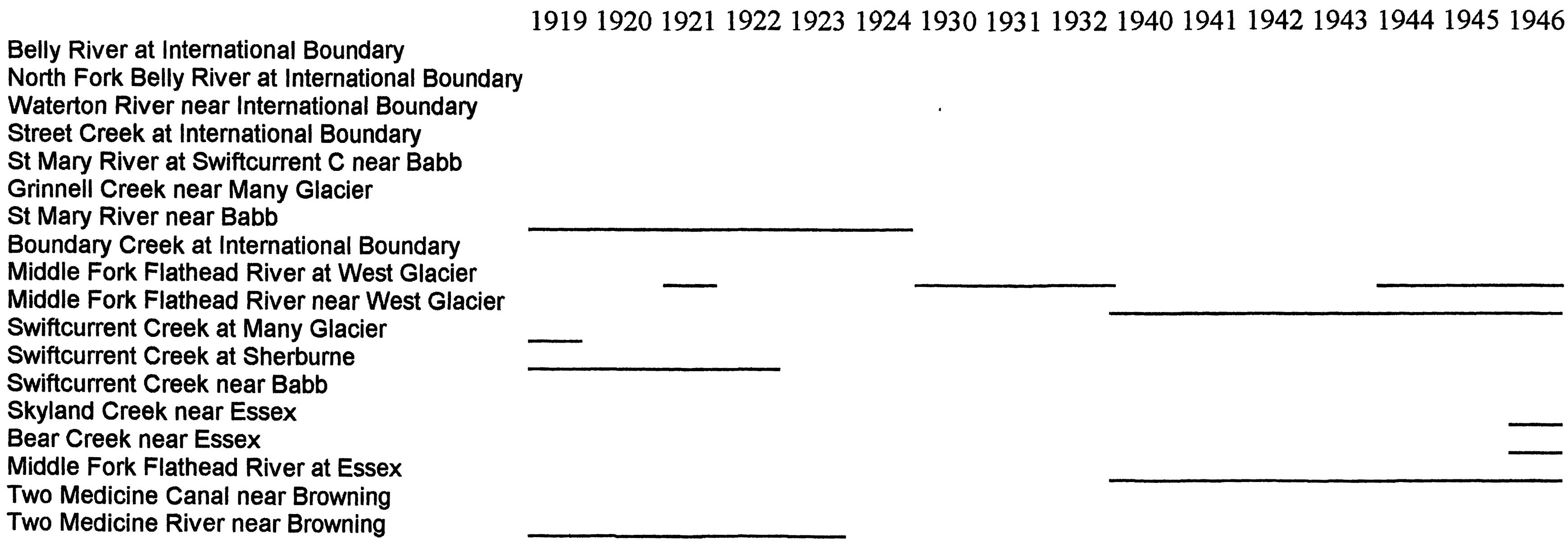
	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Belly River at International Boundary													
North Fork Belly River at International Boundary													
Waterton River near International Boundary													
Street Creek at International Boundary													
St Mary River at Swiftcurrent C near Babb													
Grinnell Creek near Many Glacier	24.8	30.3	33.1	23.6	24.6	28.8	28	23.9	29.9	31.8	26.4		
St Mary River near Babb	734	831	782	708	755	907	959	563	928	1035	779	449	857
Boundary Creek at International Boundary													
Middle Fork Flathead River at West Glacier													
Middle Fork Flathead River near West Glacier	2753	3326	3036	2612	2886	3718	3678	2222	3924	3668	3094	1676	2931
Swiftcurrent Creek at Many Glacier	132	151	156	126	134	164	160	121	164	178	137	102	153
Swiftcurrent Creek at Sherburne													
Swiftcurrent Creek near Babb													
Skyland Creek near Essex													
Bear Creek near Essex													
Middle Fork Flathead River at Essex													
Two Medicine Canal near Browning	39.2	35.5	46.6	46.9	46.9	53.4				29	57.3		
Two Medicine River near Browning	289	453	299	289	430	422	497	165	377	674	330		

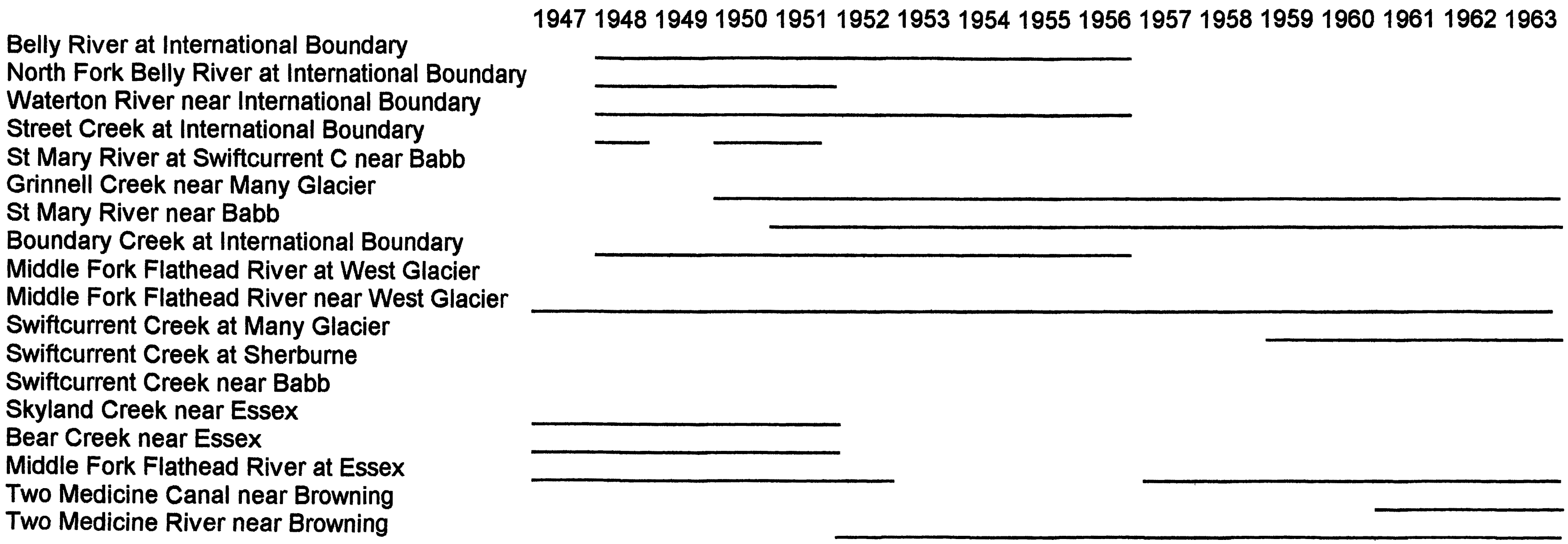
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Belly River at International Boundary													
North Fork Belly River at International Boundary													
Waterton River near International Boundary													
Street Creek at International Boundary													
St Mary River at Swiftcurrent C near Babb													
Grinnell Creek near Many Glacier													
St Mary River near Babb	627	730	744	709	593	592	764	687	612	547	874	809	944
Boundary Creek at International Boundary													
Middle Fork Flathead River at West Glacier													
Middle Fork Flathead River near West Glacier	2544	2790	2863	3186	2493	2420	3122	2519	2145	1942	3406	3595	3556
Swiftcurrent Creek at Many Glacier	115	150	143	145	129	131	146	136	115	109	162	152	161
Swiftcurrent Creek at Sherburne													
Swiftcurrent Creek near Babb													
Skyland Creek near Essex													
Bear Creek near Essex													
Middle Fork Flathead River at Essex													
Two Medicine Canal near Browning			39.2										
Two Medicine River near Browning													

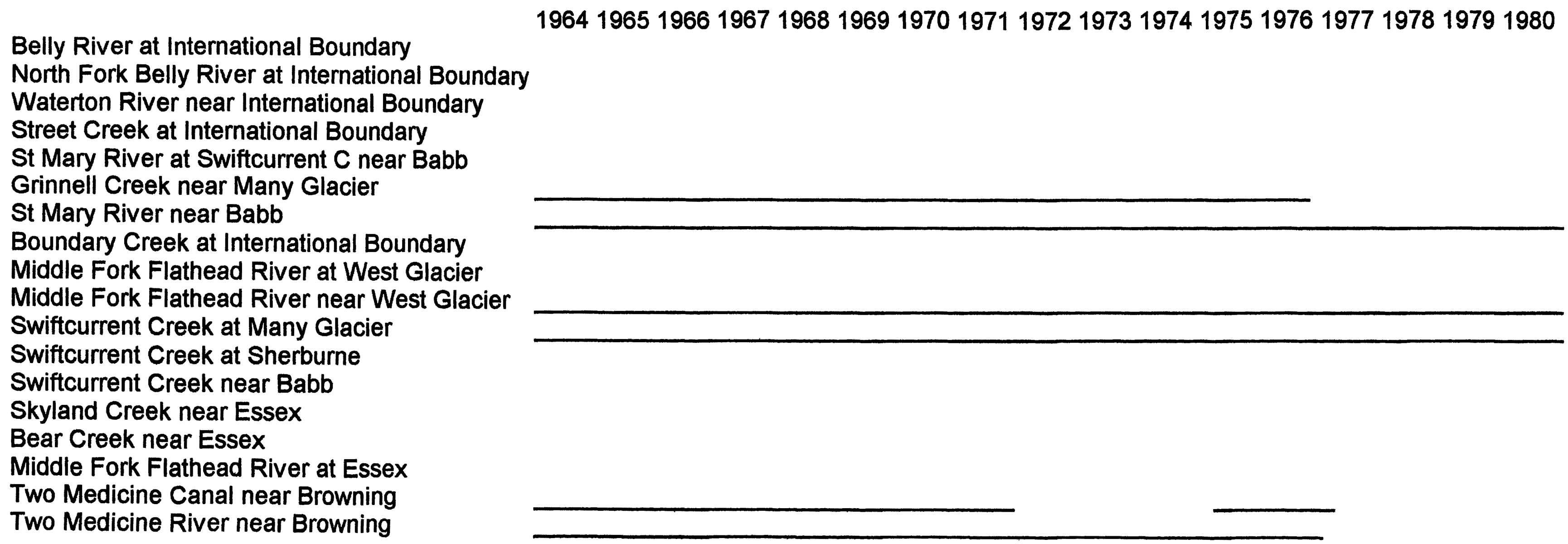
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Belly River at International Boundary										
North Fork Belly River at International Boundary										
Waterton River near International Boundary										
Street Creek at International Boundary										
St Mary River at Swiftcurrent C near Babb										
Grinnell Creek near Many Glacier										
St Mary River near Babb	531	603	590					826	610	435
Boundary Creek at International Boundary										
Middle Fork Flathead River at West Glacier										
Middle Fork Flathead River near West Glacier	1917	2479	2130	3555	3338	3740	2248	3071	2440	1615
Swiftcurrent Creek at Many Glacier	108	115	114	179	146	164	122	168	125	87.9
Swiftcurrent Creek at Sherburne										
Swiftcurrent Creek near Babb										
Skyland Creek near Essex										
Bear Creek near Essex										
Middle Fork Flathead River at Essex										
Two Medicine Canal near Browning										
Two Medicine River near Browning										

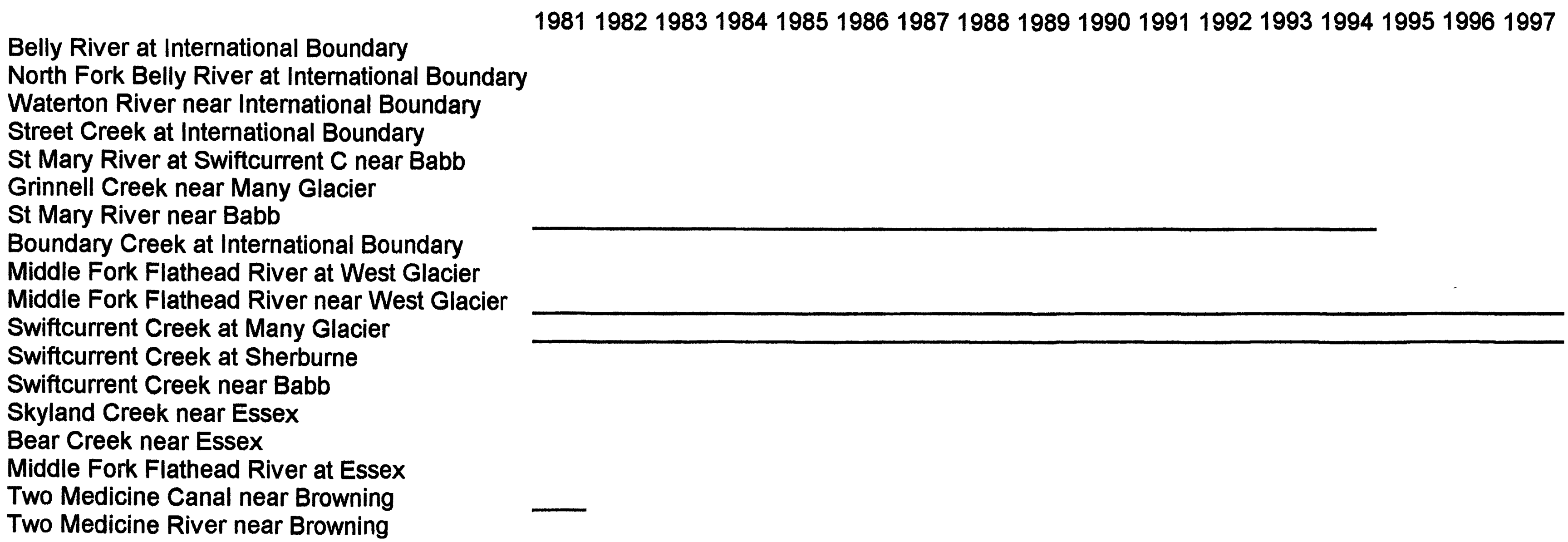
APPENDIX B – YEARS OF COVERAGE




1919 1920 1921 1922 1923 1924 1930 1931 1932 1940 1941 1942 1943 1944 1945 1946
Belly River at International Boundary
North Fork Belly River at International Boundary
Waterton River near International Boundary
Street Creek at International Boundary
St Mary River at Swiftcurrent C near Babb
Grinnell Creek near Many Glacier
St Mary River near Babb
Boundary Creek at International Boundary
Middle Fork Flathead River at West Glacier
Middle Fork Flathead River near West Glacier
Swiftcurrent Creek at Many Glacier
Swiftcurrent Creek at Sherburne
Swiftcurrent Creek near Babb
Skyland Creek near Essex
Bear Creek near Essex
Middle Fork Flathead River at Essex
Two Medicine Canal near Browning
Two Medicine River near Browning


1947 1948 1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960 1961 1962 1963
Belly River at International Boundary
North Fork Belly River at International Boundary
Waterton River near International Boundary
Street Creek at International Boundary
St Mary River at Swiftcurrent C near Babb
Grinnell Creek near Many Glacier
St Mary River near Babb
Boundary Creek at International Boundary
Middle Fork Flathead River at West Glacier
Middle Fork Flathead River near West Glacier
Swiftcurrent Creek at Many Glacier
Swiftcurrent Creek at Sherburne
Swiftcurrent Creek near Babb
Skyland Creek near Essex
Bear Creek near Essex
Middle Fork Flathead River at Essex
Two Medicine Canal near Browning
Two Medicine River near Browning

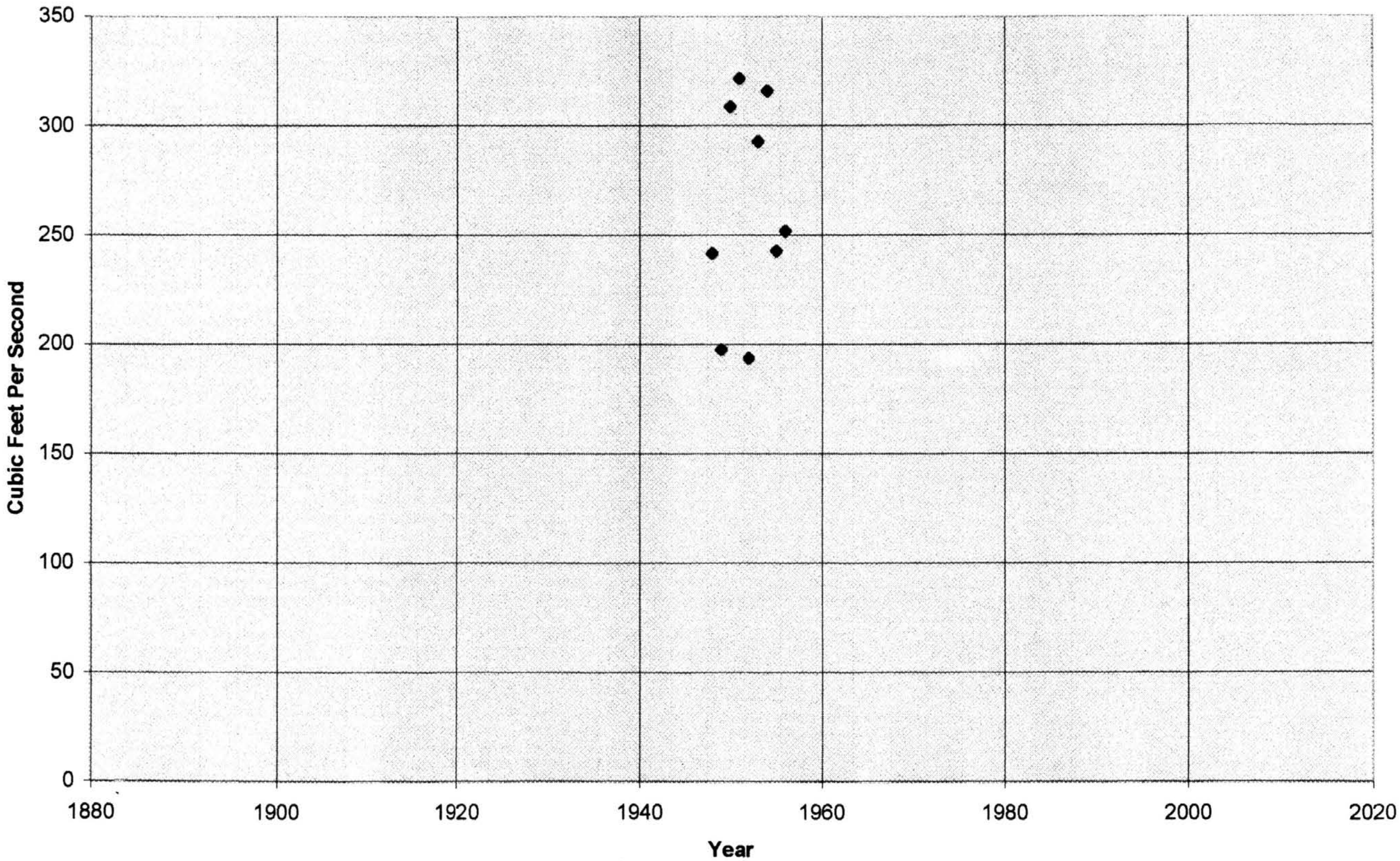

1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980
Belly River at International Boundary
North Fork Belly River at International Boundary
Waterton River near International Boundary
Street Creek at International Boundary
St Mary River at Swiftcurrent C near Babb
Grinnell Creek near Many Glacier
St Mary River near Babb
Boundary Creek at International Boundary
Middle Fork Flathead River at West Glacier
Middle Fork Flathead River near West Glacier
Swiftcurrent Creek at Many Glacier
Swiftcurrent Creek at Sherburne
Swiftcurrent Creek near Babb
Skyland Creek near Essex
Bear Creek near Essex
Middle Fork Flathead River at Essex
Two Medicine Canal near Browning
Two Medicine River near Browning


1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Belly River at International Boundary
North Fork Belly River at International Boundary
Waterton River near International Boundary
Street Creek at International Boundary
St Mary River at Swiftcurrent C near Babb
Grinnell Creek near Many Glacier
St Mary River near Babb
Boundary Creek at International Boundary
Middle Fork Flathead River at West Glacier
Middle Fork Flathead River near West Glacier
Swiftcurrent Creek at Many Glacier
Swiftcurrent Creek at Sherburne
Swiftcurrent Creek near Babb
Skyland Creek near Essex
Bear Creek near Essex
Middle Fork Flathead River at Essex
Two Medicine Canal near Browning
Two Medicine River near Browning

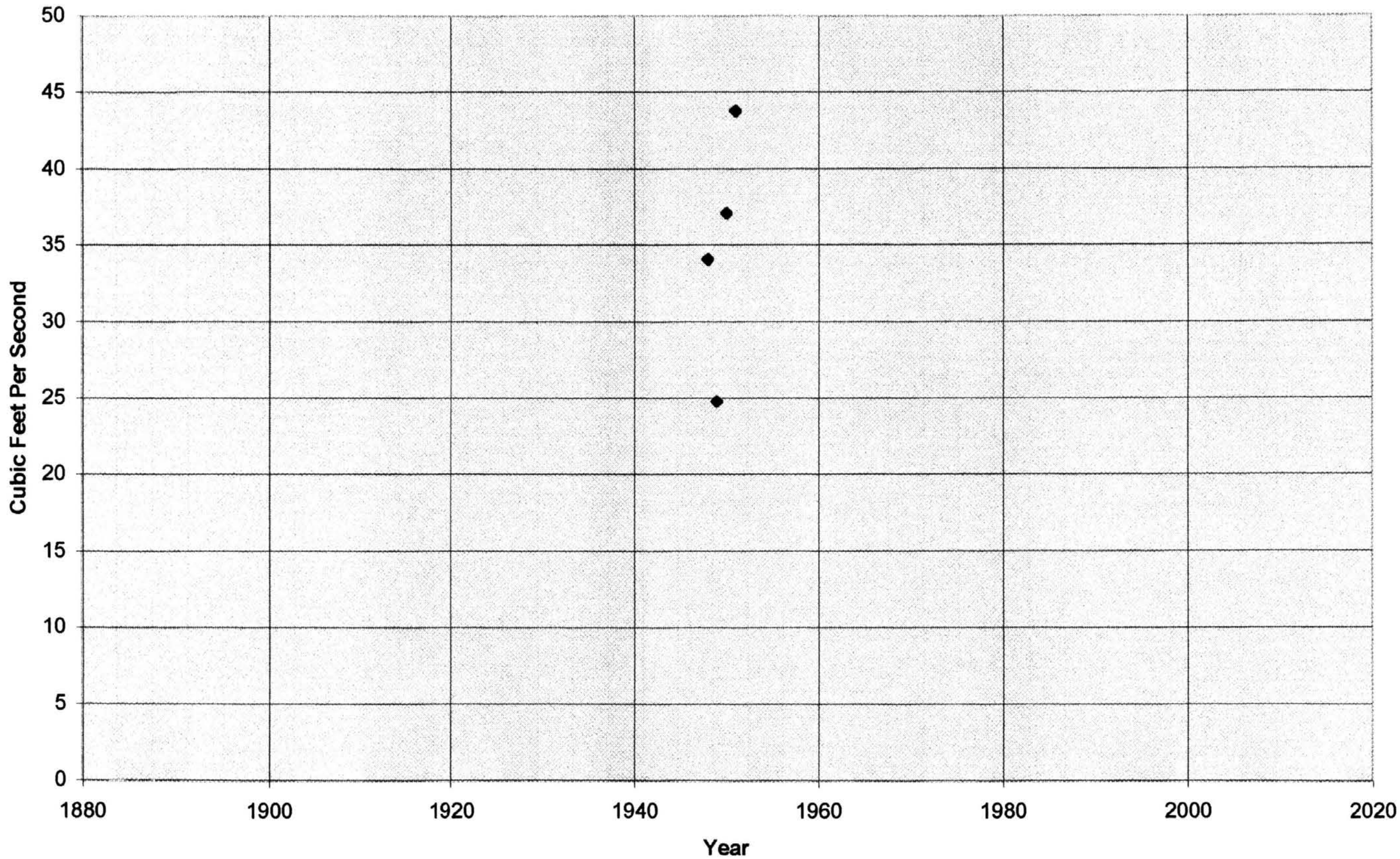
	1998	1999	2000	2001
Belly River at International Boundary				
North Fork Belly River at International Boundary				
Waterton River near International Boundary				
Street Creek at International Boundary				
St Mary River at Swiftcurrent C near Babb				
Grinnell Creek near Many Glacier				
St Mary River near Babb				
Boundary Creek at International Boundary				
Middle Fork Flathead River at West Glacier				
Middle Fork Flathead River near West Glacier				
Swiftcurrent Creek at Many Glacier				
Swiftcurrent Creek at Sherburne				
Swiftcurrent Creek near Babb				
Skyland Creek near Essex				
Bear Creek near Essex				
Middle Fork Flathead River at Essex				
Two Medicine Canal near Browning				
Two Medicine River near Browning				

APPENDIX C – SCATTER PLOTS

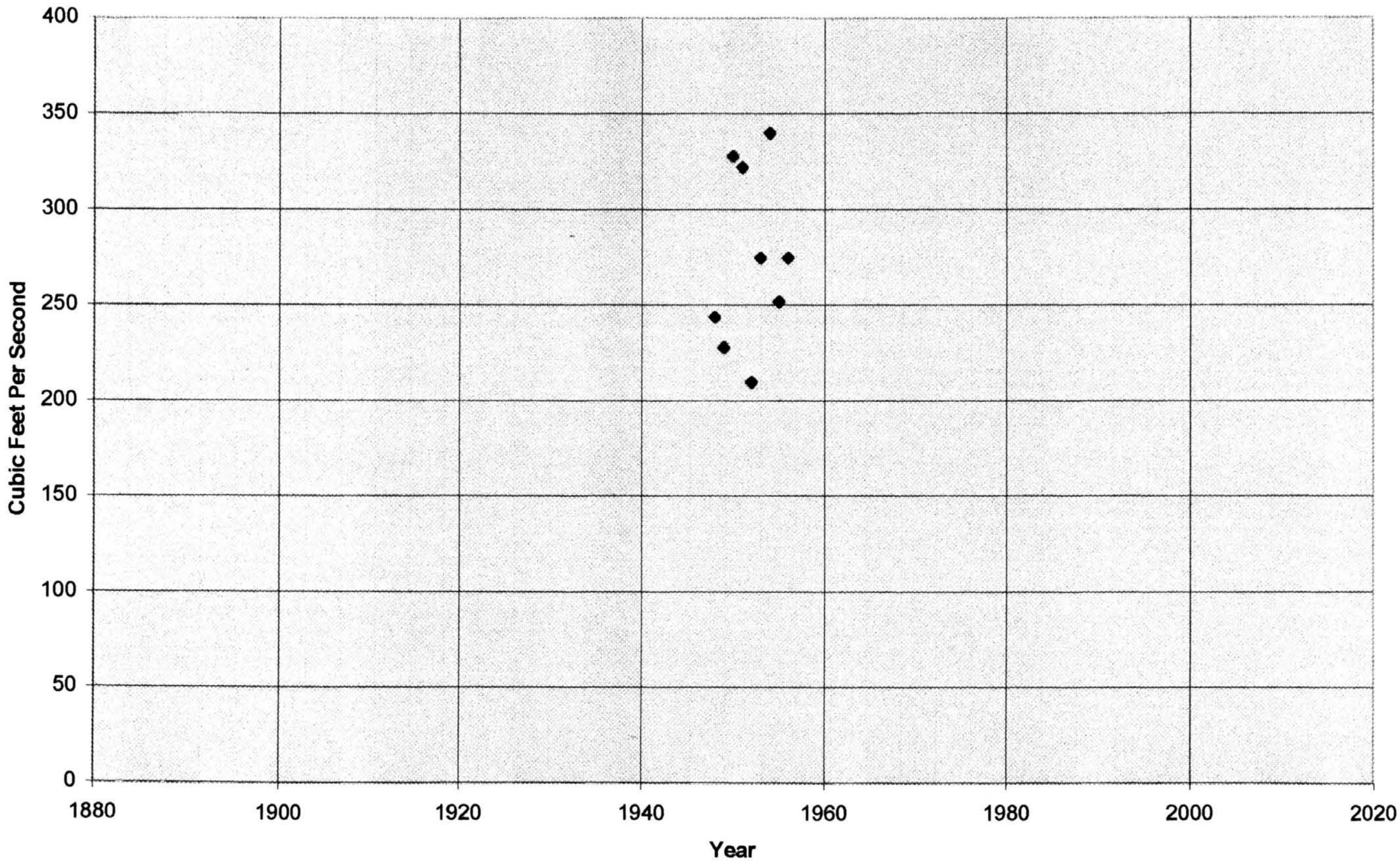
Belly River at International Boundary

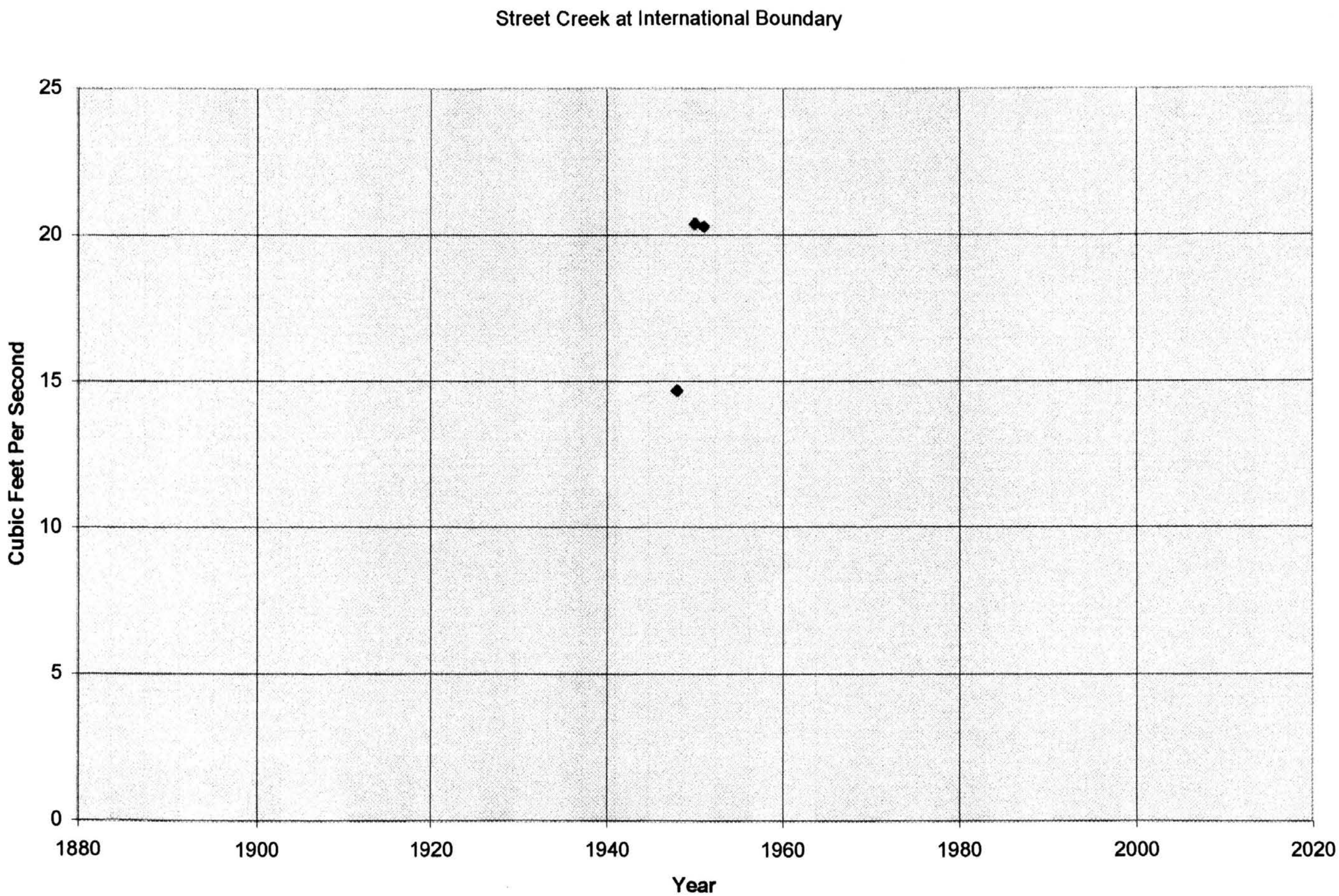


North Fork Belly River at International Boundary

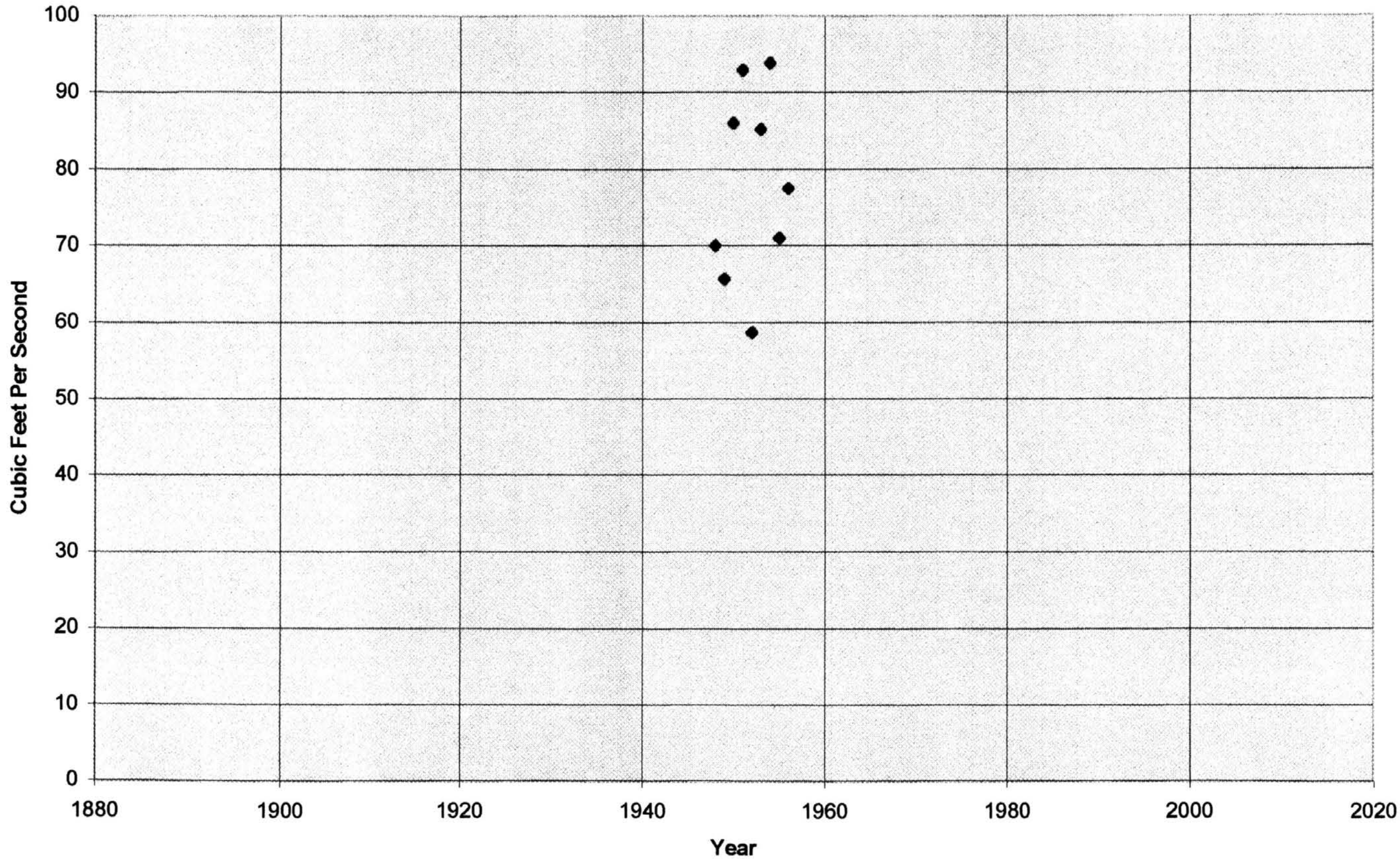


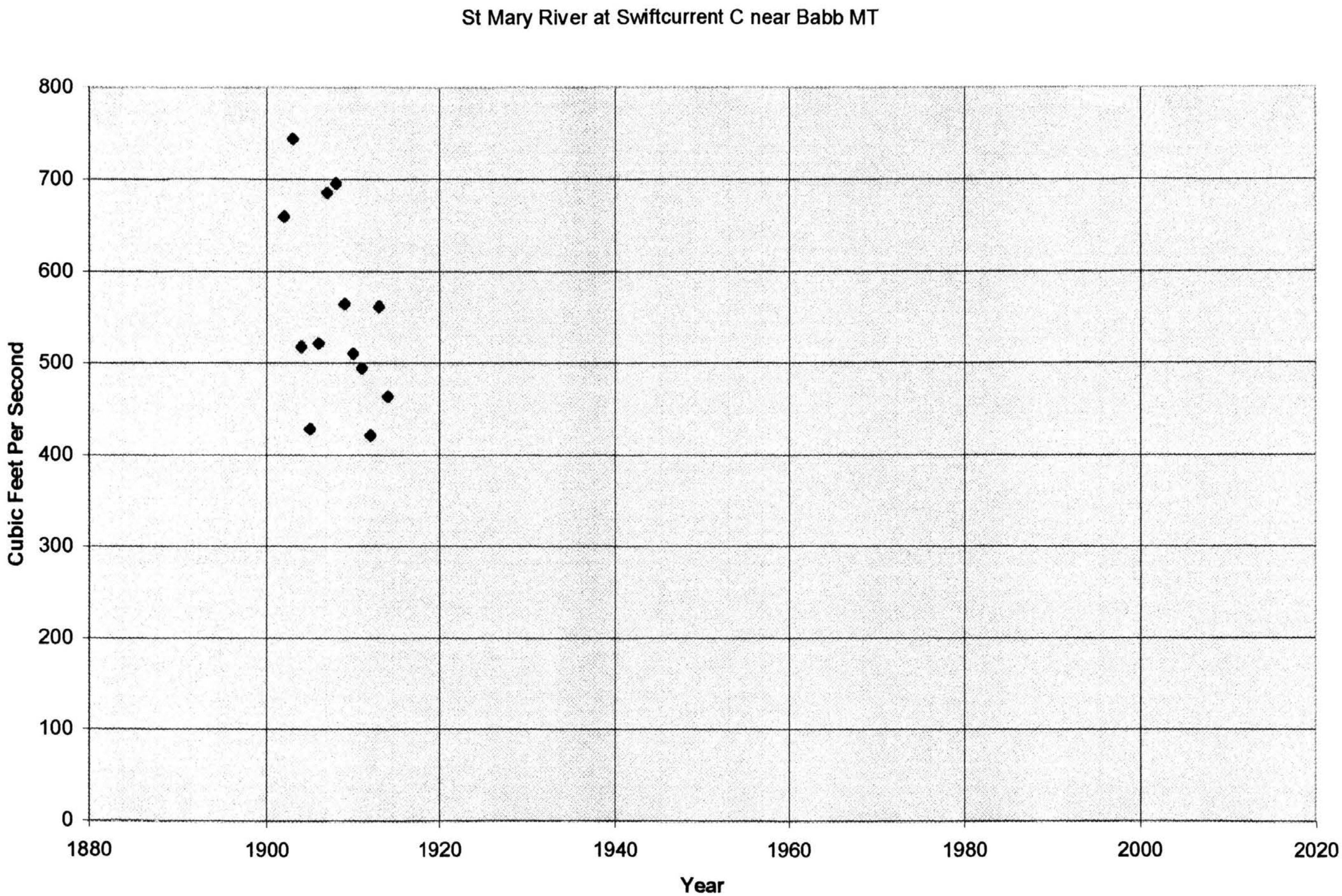
Waterton River near International Boundary

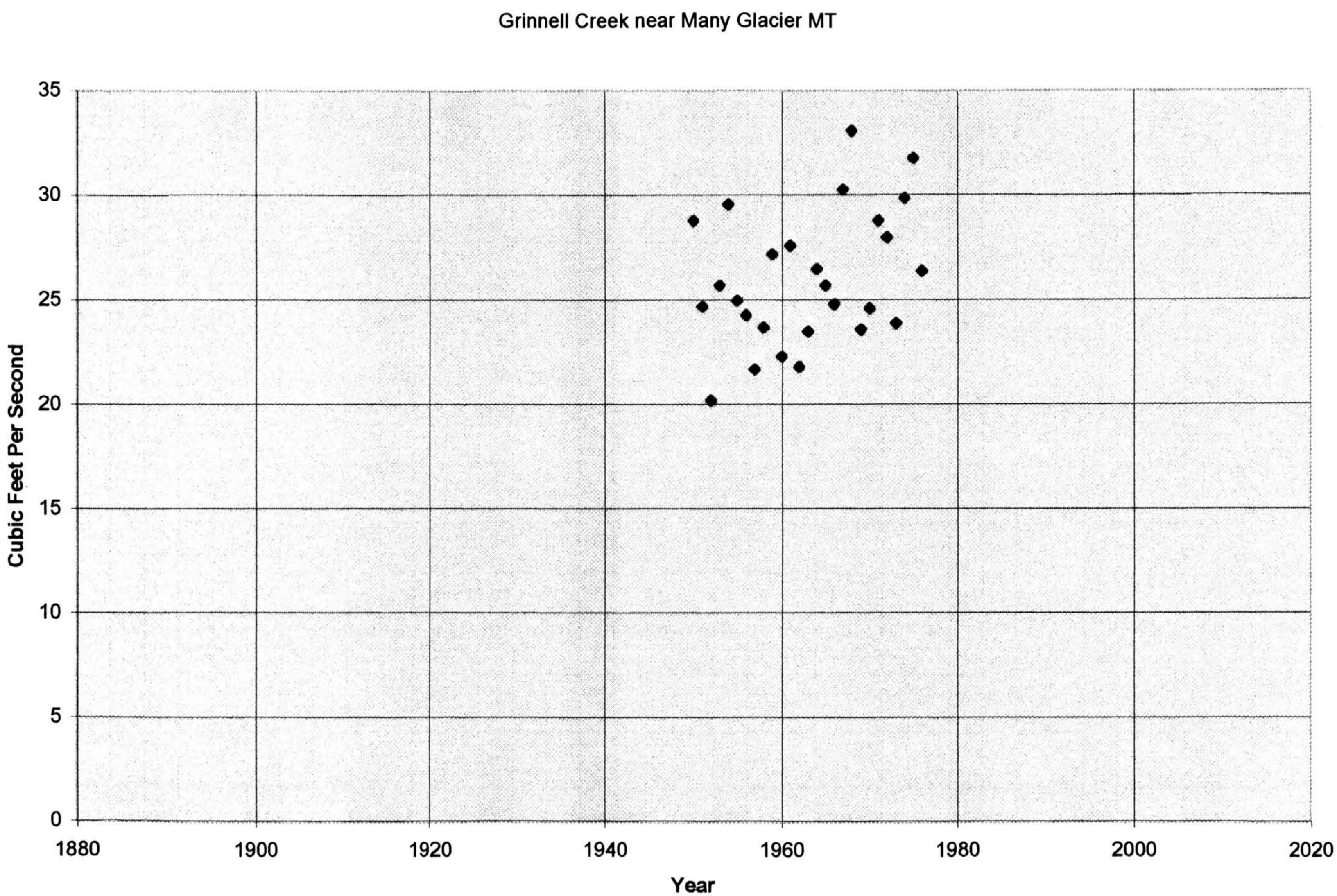


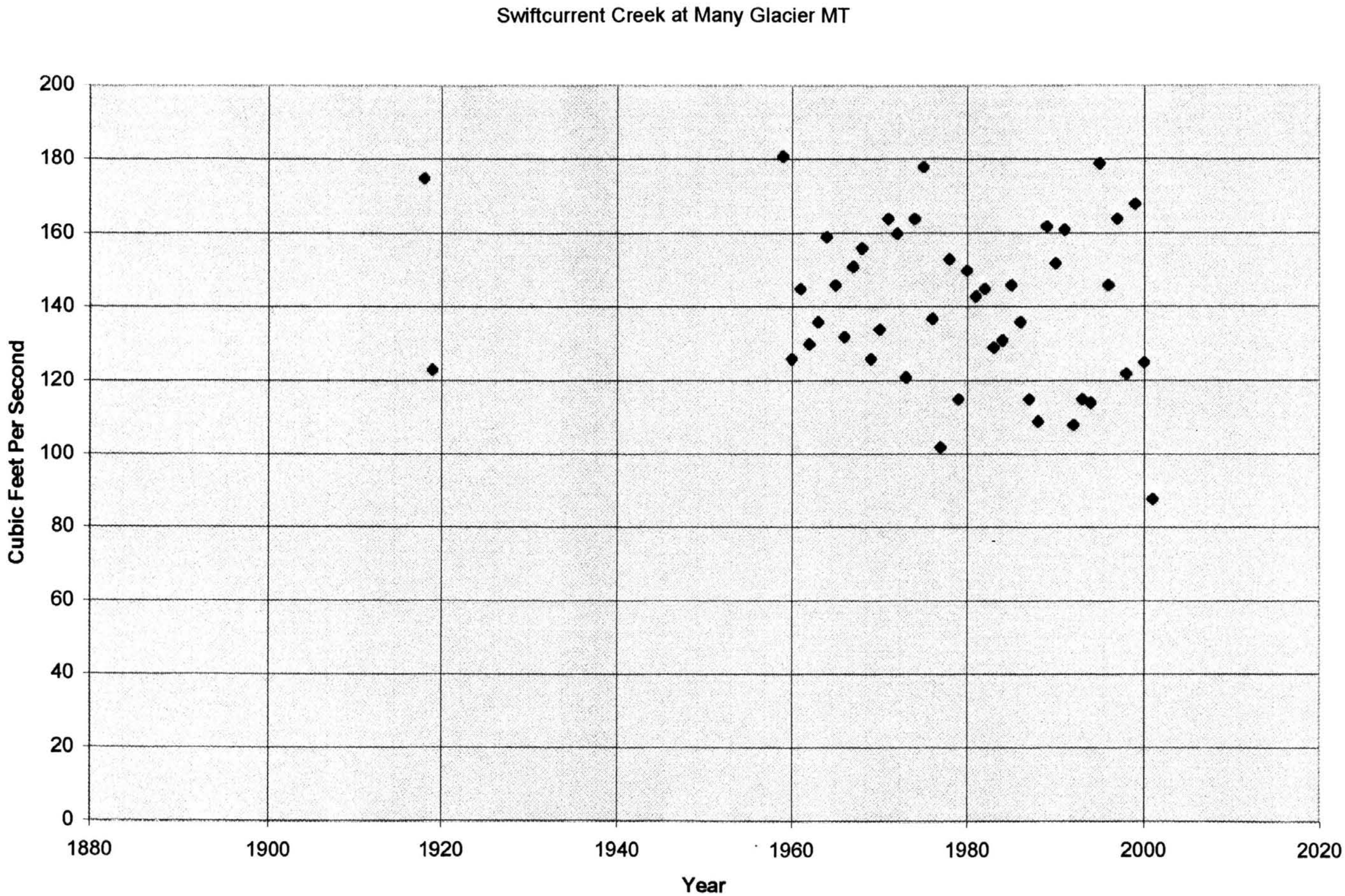

Street Creek at International Boundary
Cubic Feet Per Second
25
20
15
10
5
0
1880
1900
1920
1940
1960
1980
2000
2020
Year

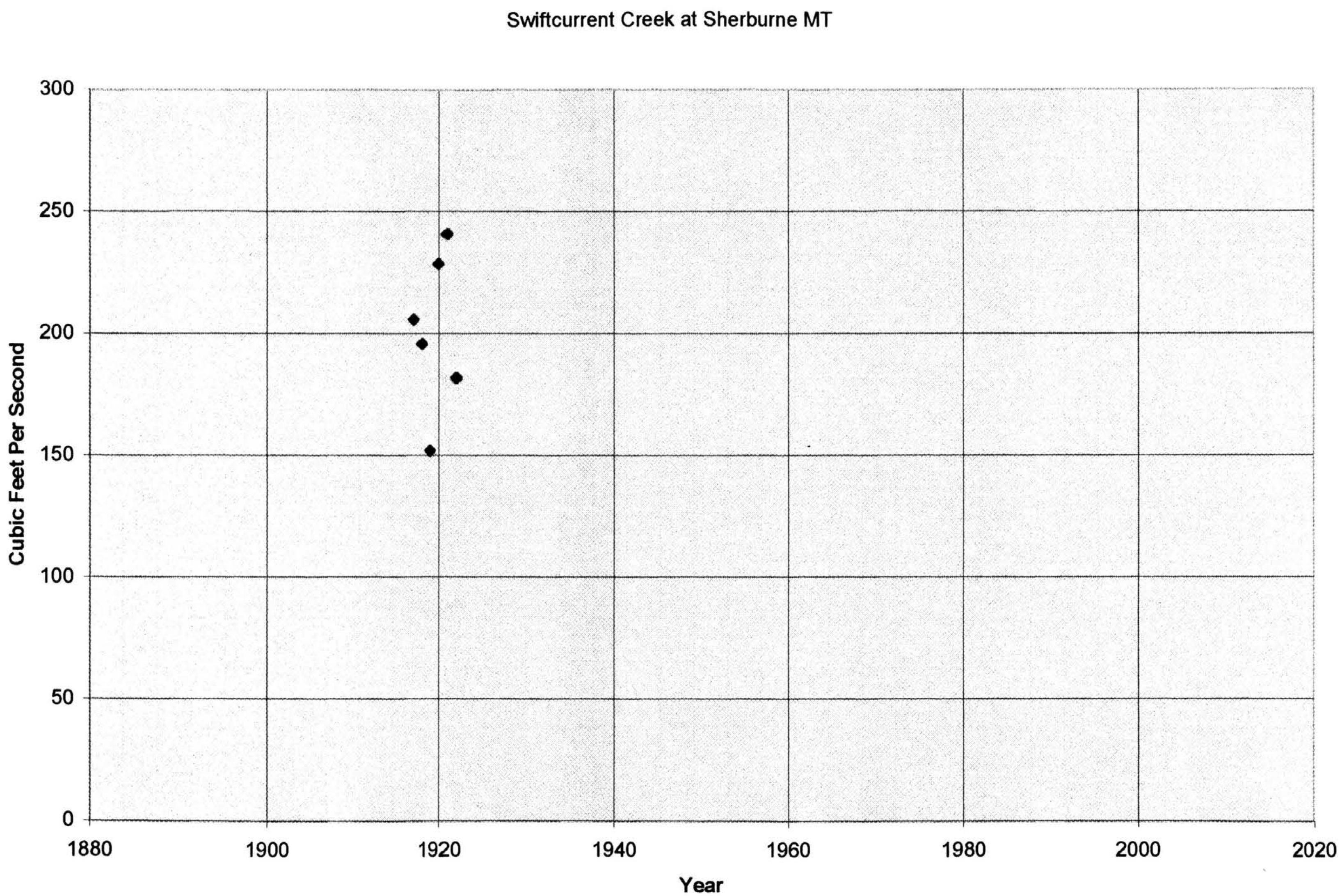
Boundary Creek at International Boundary

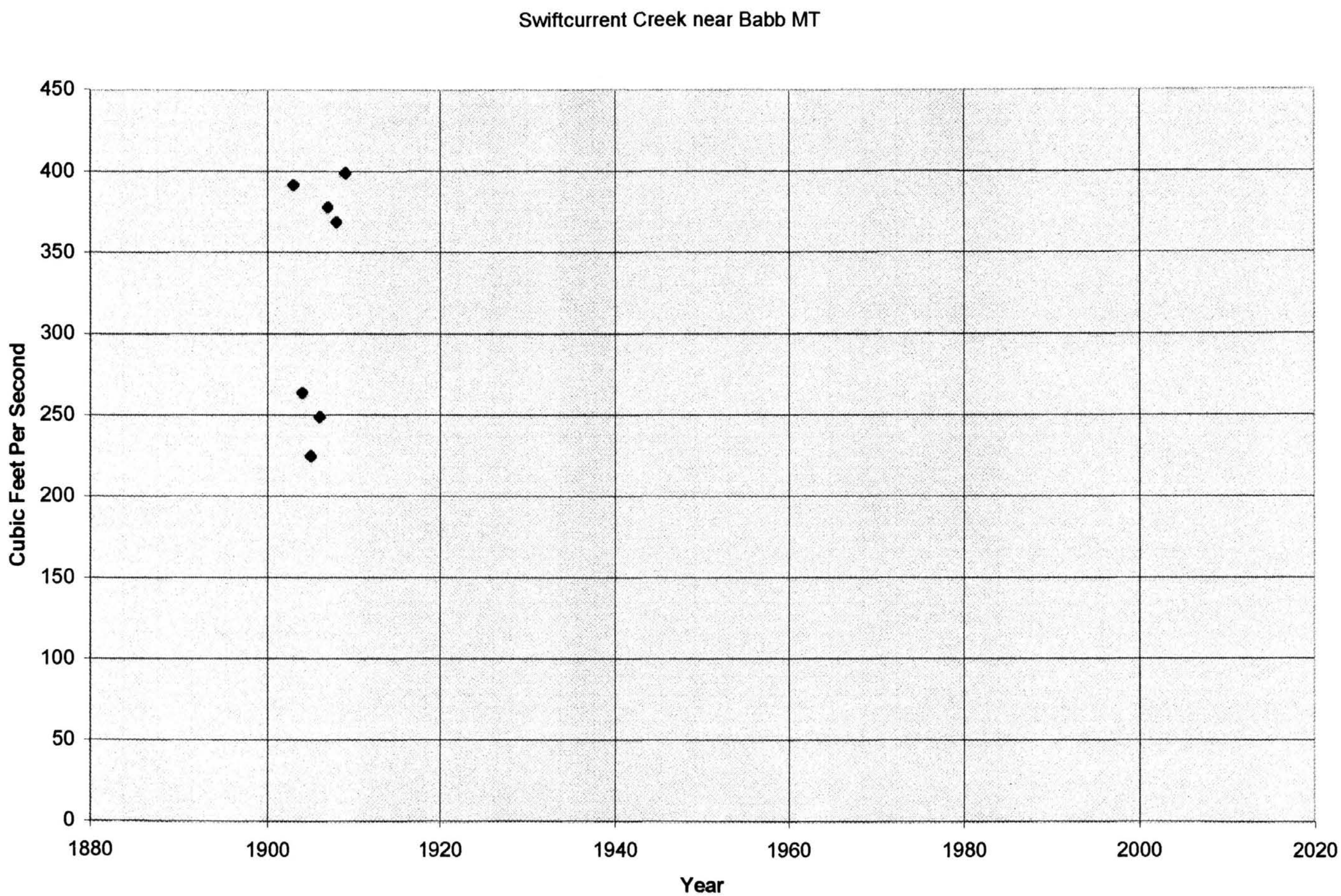



St Mary River at Swiftcurrent C near Babb MT
Cubic Feet Per Second
800
700
600
500
400
300
200
100
0
1880
1900
1920
1940
1960
1980
2000
2020
Year

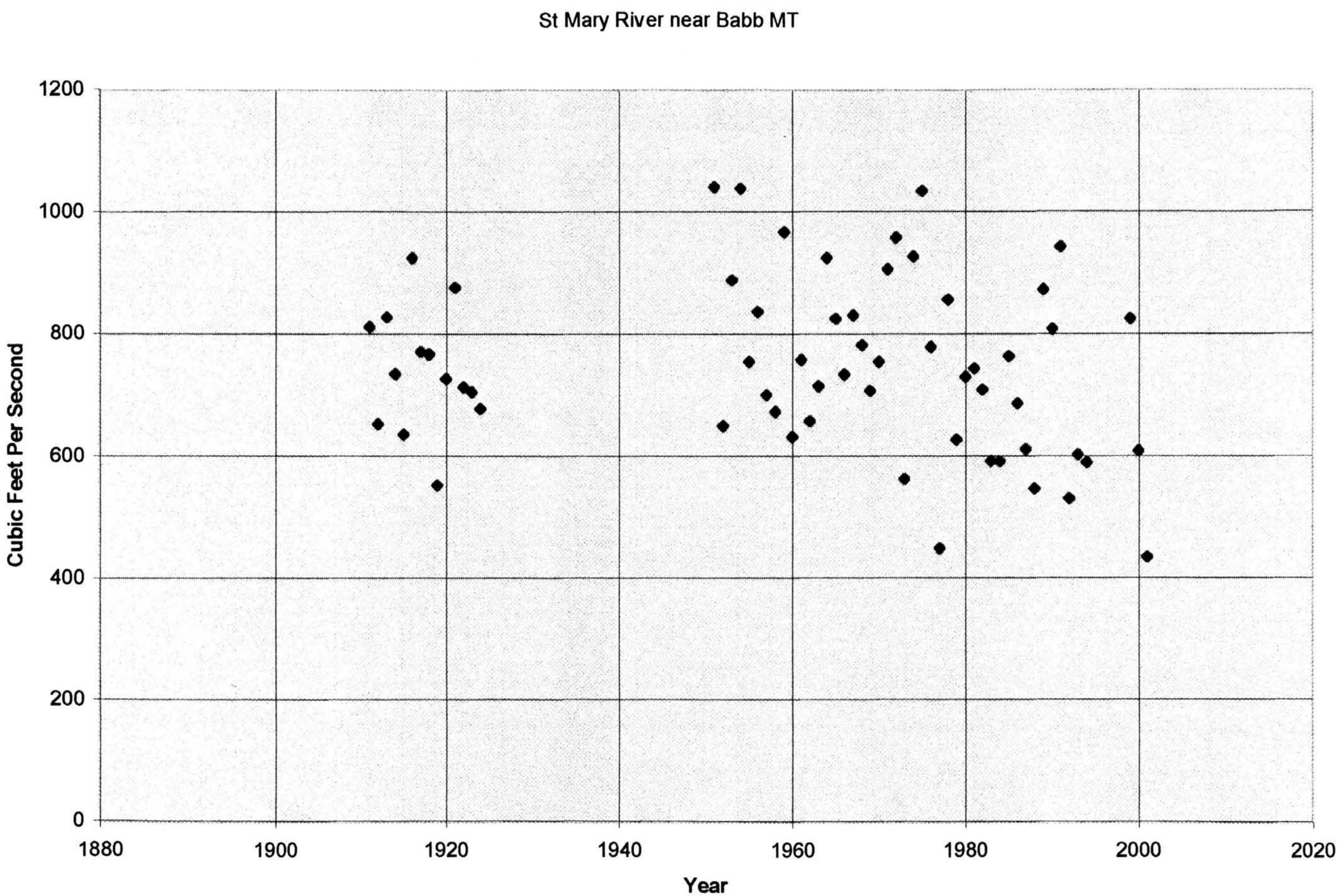

Grinnell Creek near Many Glacier MT
Cubic Feet Per Second
0
5
10
15
20
25
30
35
1880
1900
1920
1940
1960
1980
2000
2020
Year


Swiftcurrent Creek at Many Glacier MT
Cubic Feet Per Second
200
180
160
140
120
100
80
60
40
20
0
1880
1900
1920
1940
1960
1980
2000
2020
Year


Swiftcurrent Creek at Sherburne MT
300
250
200
150
100
50
0
Cubic Feet Per Second
1880
1900
1920
1940
1960
1980
2000
2020
Year

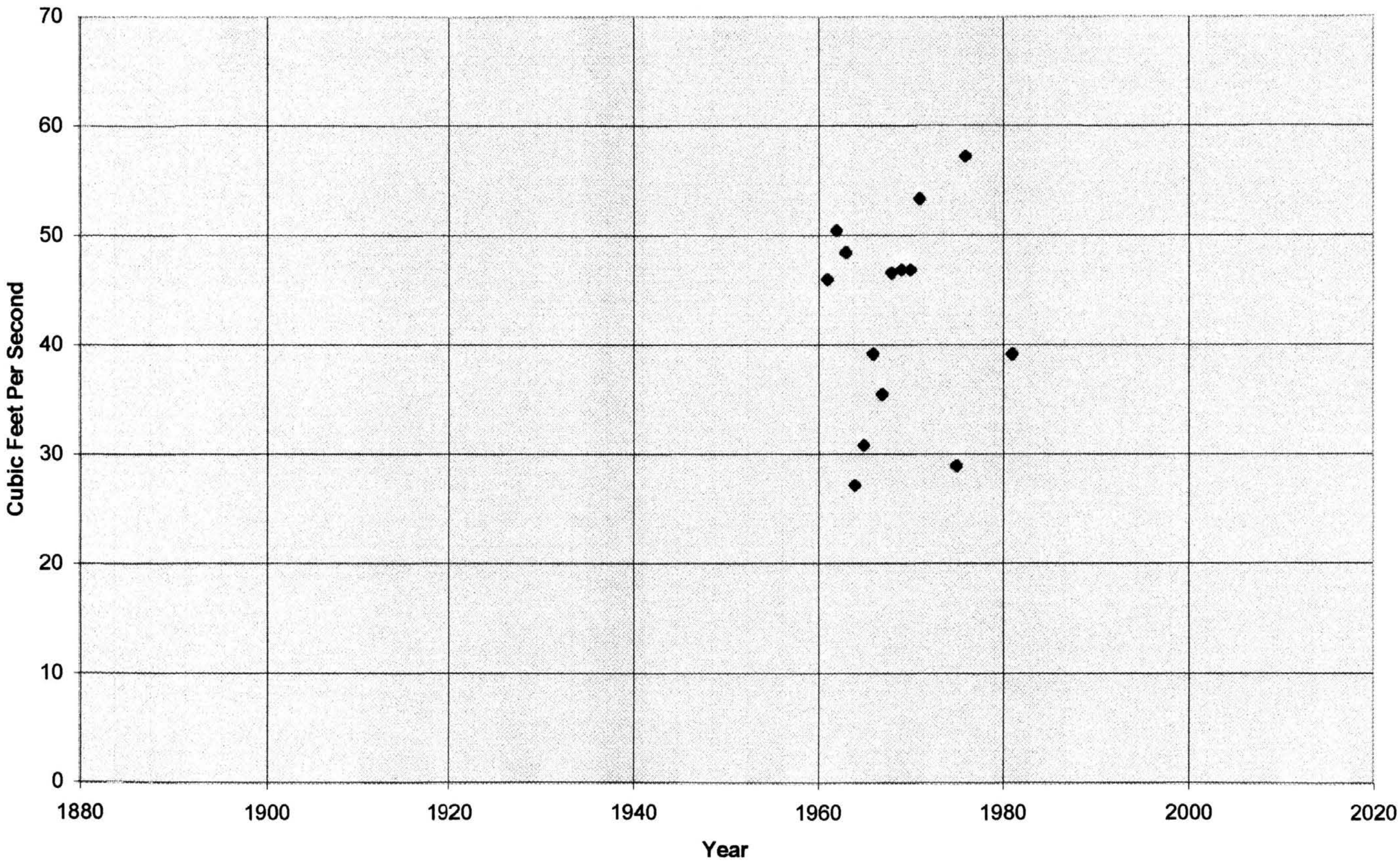


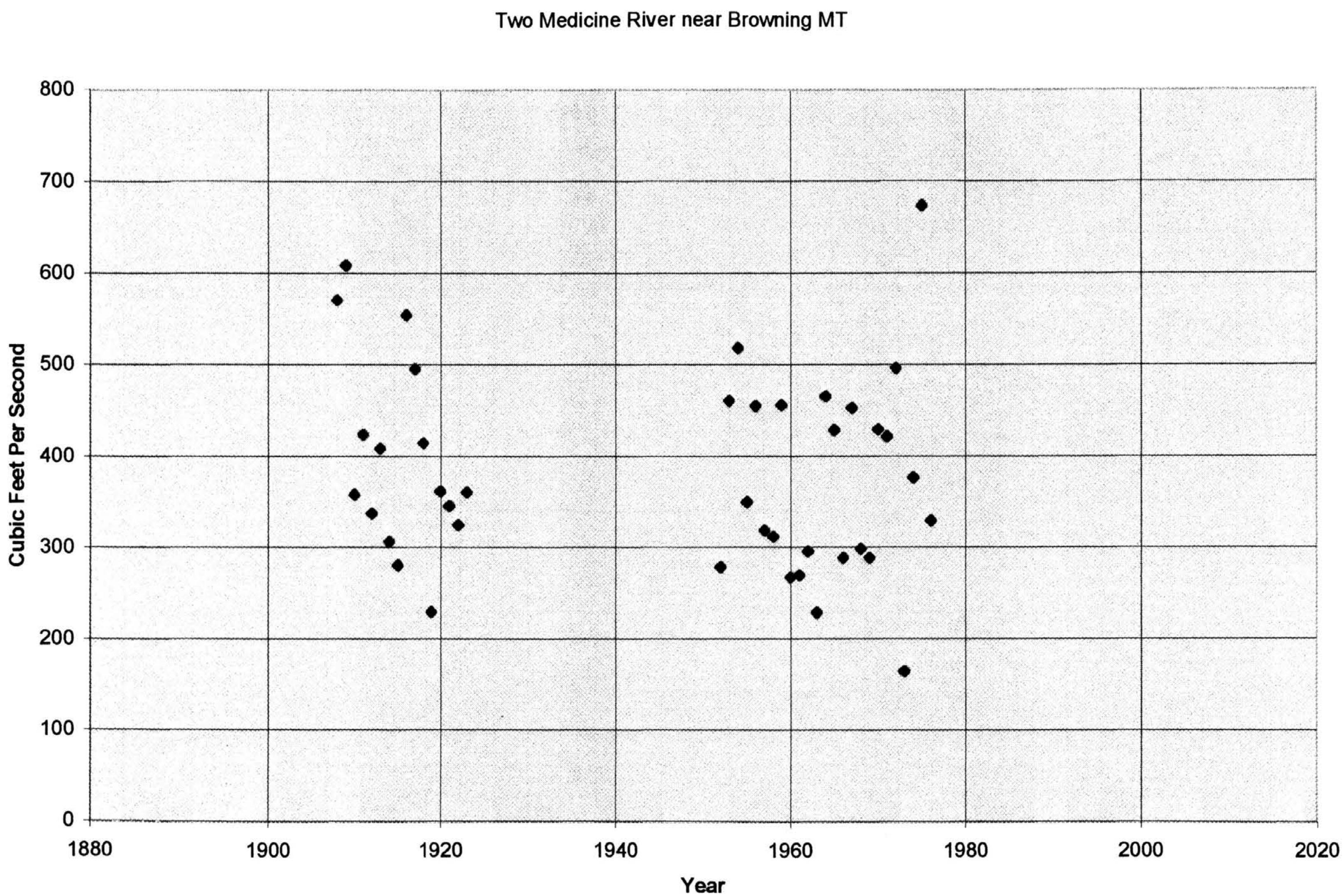
Swiftcurrent Creek near Babb MT
Cubic Feet Per Second
0
50
100
150
200
250
300
350
400
450
1880
1900
1920
1940
1960
1980
2000
2020
Year

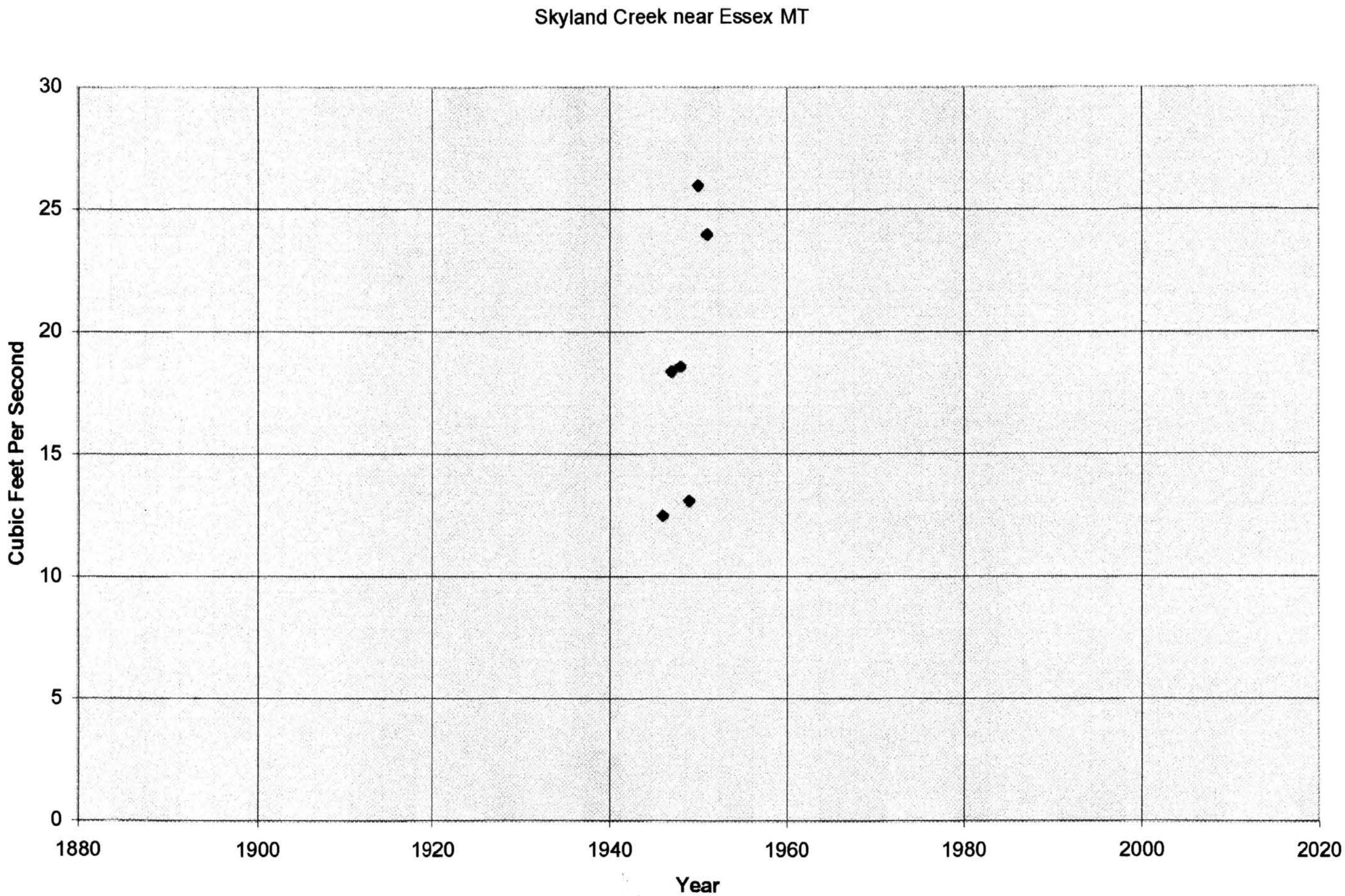


St Mary River near Babb MT
Cubic Feet Per Second
1200
1000
800
600
400
200
0
1880
1900
1920
1940
1960
1980
2000
2020
Year

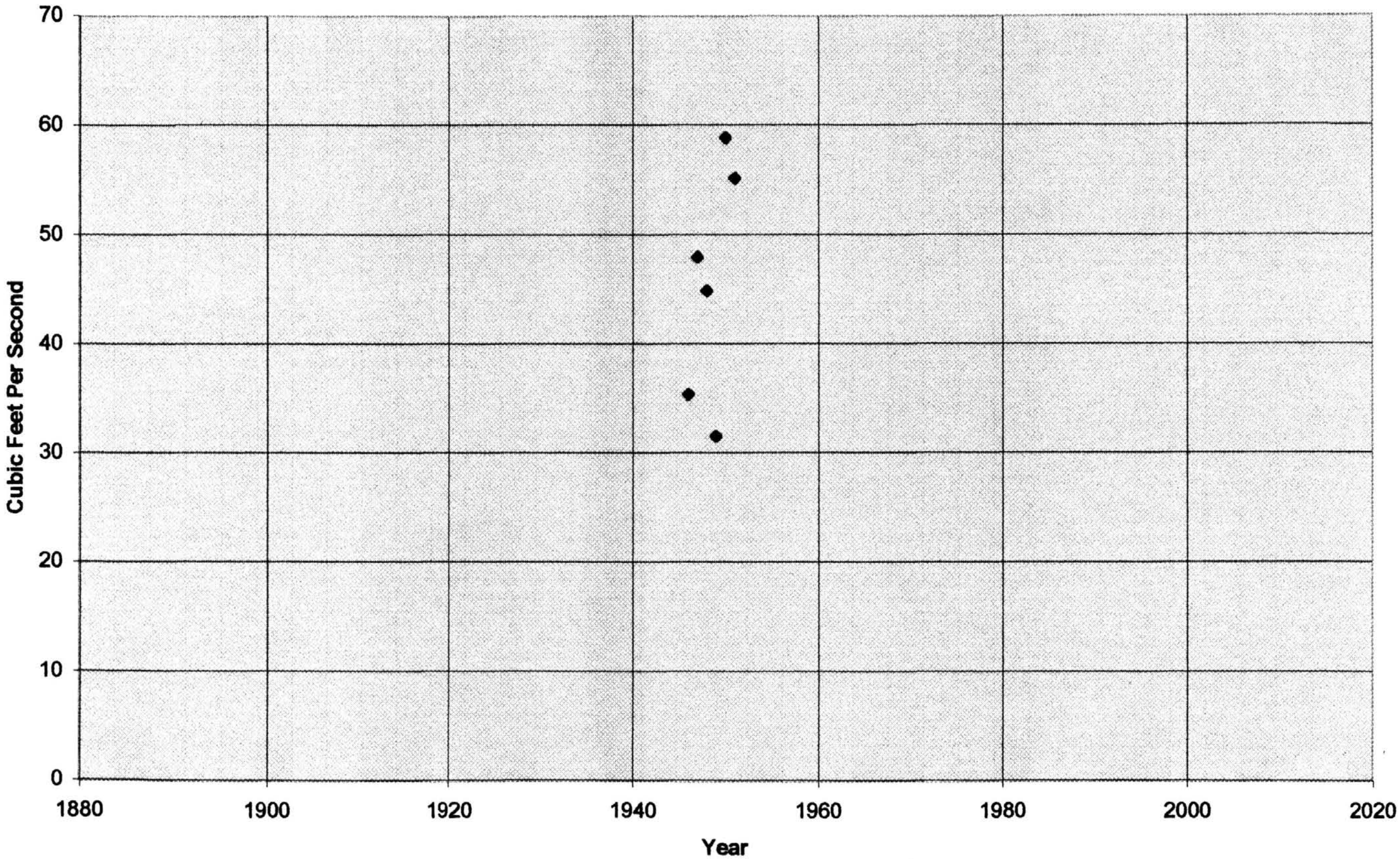
Two Medicine Canal near Browning MT

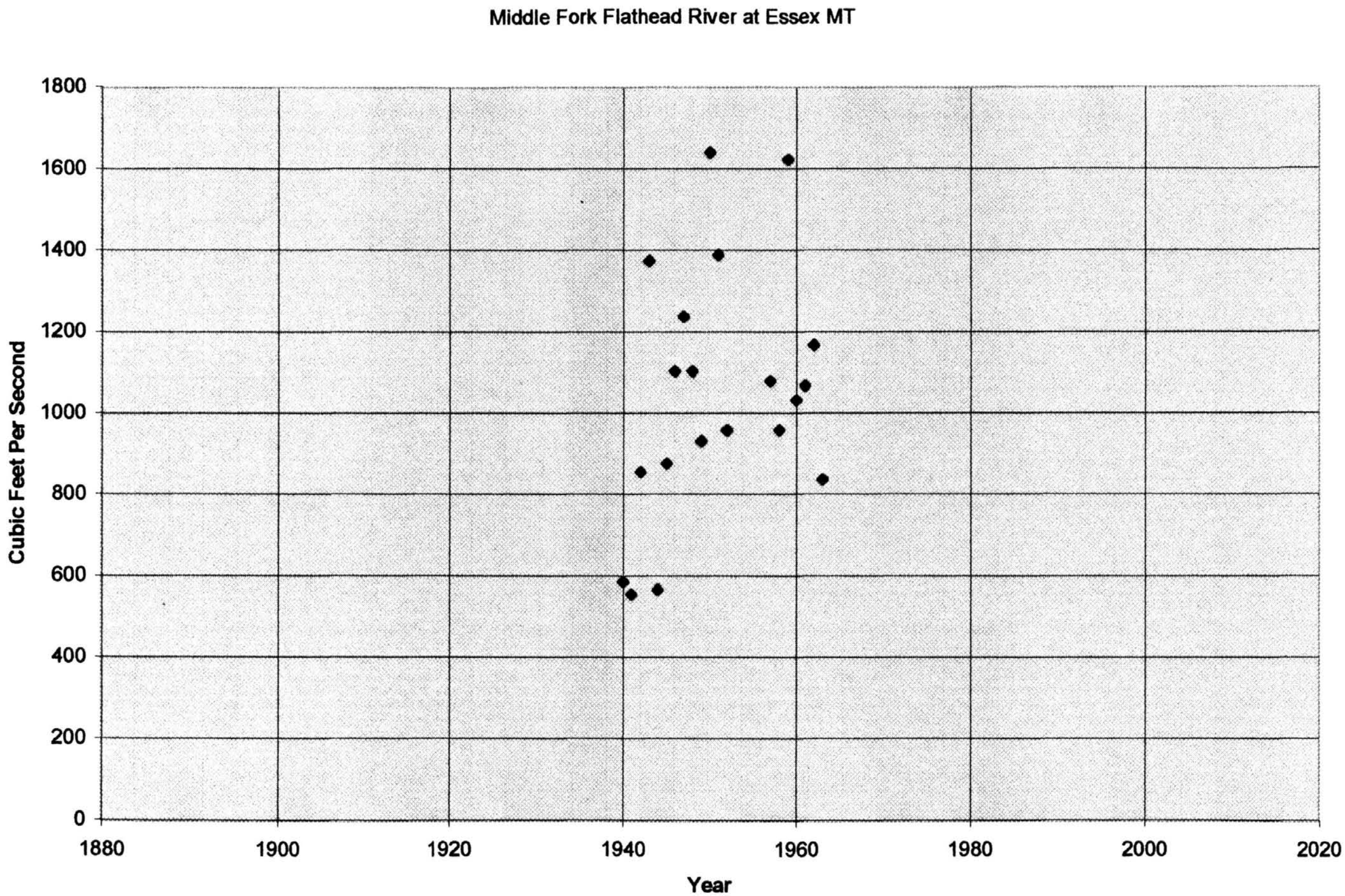


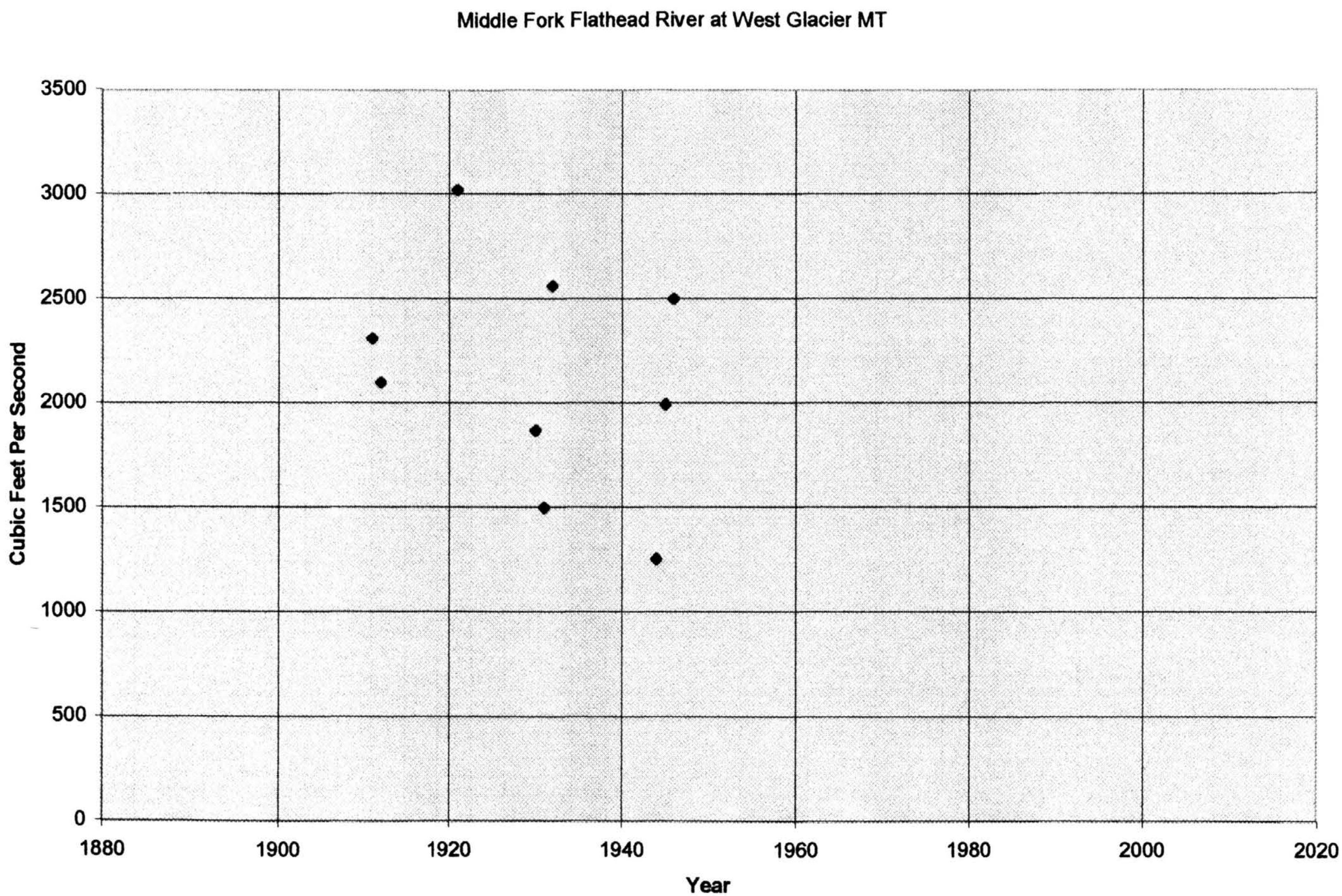

Two Medicine River near Browning MT
Cubic Feet Per Second
800
700
600
500
400
300
200
100
0
1880
1900
1920
1940
1960
1980
2000
2020
Year


Skyland Creek near Essex MT
Cubic Feet Per Second
30
25
20
15
10
5
0
1880
1900
1920
1940
1960
1980
2000
2020
Year

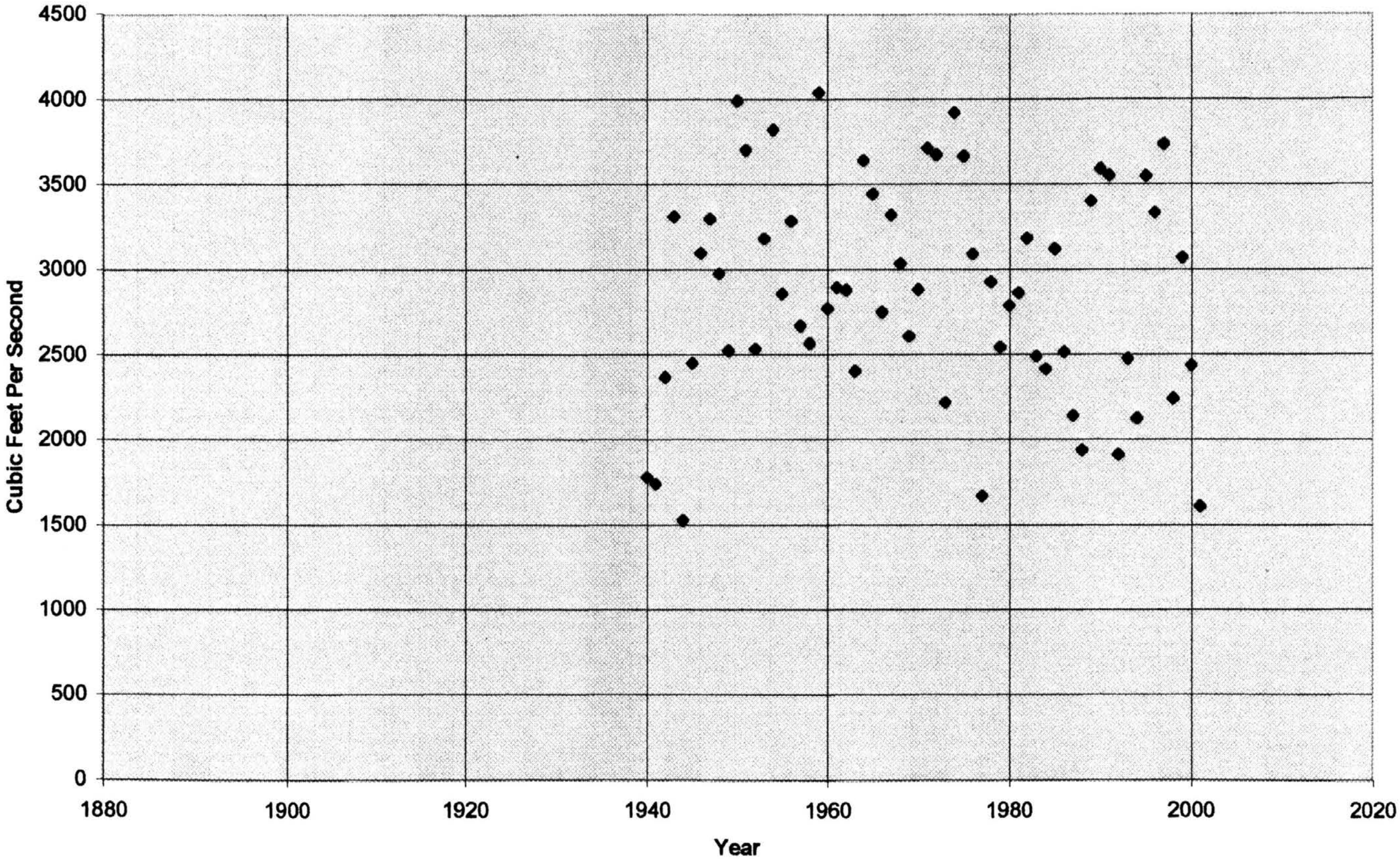
Bear Creek near Essex MT




Middle Fork Flathead River at Essex MT
Cubic Feet Per Second
1800
1600
1400
1200
1000
800
600
400
200
0
1880
1900
1920
1940
1960
1980
2000
2020
Year


Middle Fork Flathead River at West Glacier MT
3500
3000
2500
2000
1500
1000
500
0
Cubic Feet Per Second
1880
1900
1920
1940
1960
1980
2000
2020
Year

Middle Fork Flathead River near West Glacier MT



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VITA

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This thesis was typed by Bitsy Walza Cotter.