Linear Regression Analysis of the Suspended Sediment Load in Rivers and Streams Using Data of Similar Precipitation Values

by

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ABSTRACT

Sediment provides a method for transportation of a variety of other pollutants such as nutrients and potentially harmful bacteria. In addition, sediment can increase the cost of water treatment processes and reduce storage volume of water reservoirs. This study employs linear regression to predict the annual suspended sediment load, a dependent variable, as a function of the annual river water discharge, an independent variable in four United States Rivers. The available data (annual suspended sediment load and annual river water discharge) for each river was broken down into groups based upon similar precipitation values. Each river was divided into two or three groups, with a total of ten groups for the four rivers. Linear regression was applied to each group. Results of the precipitation approach were compared to those of the traditional approach, the latter did not use any precipitation data and thus there is no individual groupings. The precipitation approach provided higher accuracy for the prediction of the suspended sediment load when compared to the traditional approach. The prediction accuracy is evident from the high correlation coefficient values (between the suspended sediment and river water discharge), and the low percent deviations (percent difference between the observed and predicted suspended sediment). Of the ten river groups, seven resulted in higher correlation coefficients, and five gave lower percent deviations compared to the traditional approach. The mean percent deviation ranged between 20 and 26% in seven groups, which is considered an indication of high accuracy when suspended sediment is predicted by linear regression. All of the ten groups resulted in higher correlation coefficient values greater or equal to 0.80, with four groups exceeding 0.90.

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Chapter 1- Introduction

1.1 Introduction

Sediment is a natural product of river and stream erosion and has a major negative impact on the environment. Sediment is the greatest water pollutant by volume and mass (Botkin and Keller, 2005). The sediment can act as media for the transportation of other potentially harmful substances such as bacteria, organic matter, heavy metals, phosphorus, nitrogen and pesticides. Agriculture practices can account for many of these sources, fertilizer being composed primarily of derivatives of phosphorus and nitrogen, and livestock and manure tied to bacteria and organic matter. Nitrogen commonly reacts in a natural environment to form nitrate (NO_3^-) and poses a health risk to young children/infants and livestock. The Environmental Protection Agency has set the Maximum Contaminant Level (MCL) for nitrate at 10 mg/L, in excessive amounts it can cause methemoglobinemia, which is the condition where nitrate binds to the red blood cells and interferes with the uptake of oxygen. Also, excessive concentrations of nitrates and phosphorus in water can lead to eutrophication in surface water bodies. Eutrophication results in high levels of aquatic growth, typically in the form of algal blooms. The relatively short live of algae causes a rapid buildup of organic matter that ultimately settles into the water where it is decomposed. The decomposers break down the algae and consume the available dissolved oxygen in the water. This will cause a drop in the available oxygen and is detrimental to the aquatic life.

The direct effect upon fish by high concentrations of suspended sediment can cause a variety of issues; irritation of their gills that can lead to death, higher susceptibility for infection and disease , suffocation of fish eggs, and increase temperature of the water body (DFO, 2000). Certain fish species cannot tolerate fluxes in water temperature, resulting in shock and then death. This excessive sedimentation can disrupt the photosynthesis processes of submerged aquatic plants by blocking the sunlight and as a result limit the amount of available food for certain fish species.

Excessive sedimentation can negatively impact functionality of a wide array of man-made structures. Water reservoirs are adversely impacted by sedimentation, which reduces their water storage capacity. The two most common uses of these reservoirs are drinking water sources and hydro-electric power generation. The increased sediments can cause abrasion to pumps at drinking water treatment plants and electric generating turbines, which can result in higher repair and maintenance costs and loss of productivity at these facilities. Excess sedimentation can cause navigable waterways (rivers) to be impassable by ships, this is typically corrected by dredging. In the fiscal year of 2011 the U.S. Corps of Engineers spent approximately 220 million (US) dollars in dredging projects in the United States (USACE, 2011).

Anthropogenic impacts on land cover from agriculture, forestry and some surface mining practices are major factors for accelerated and excessive sedimentation. Traditional tilling practices disturb the ground surface and remove ground cover vegetation, which increases the potential for larger quantities of sediments to be carried away during precipitation event(s). This same process can occur when there is deforestation. Also, mining practices can expose bedrock and leave loose debris that can be transported during precipitation events.

In the United States, excessive or accelerated erosion and following sedimentation results in almost $27 billion dollars a year in lost productivity on cropland and an additional estimated $17 billion dollar for off-site environmental costs, such as increased water treatment costs (USACE, 2008). All of the previous issues support the fact that erosion control is critically required. A wide variety of professionals from local to federal governments need scientific information on sediment prediction in order to achieve successful erosion control and the mitigation of the resulting sediment pollution.

These natural processes and available suspended sediment are impacted by the following variables, the characteristics of the watershed such as types of soils, land use (i.e. forest cover), precipitation characteristics related to rain fall intensity, runoff and snow and ice melt, topography features such as type of bed and bank materials and sinuosity and finally any anthropogenic impacts to surface cover, topography, dam construction and channelization (Bhowmik et al., 1980).

There are three types of sediment loads found in streams. These include the dissolved load, suspended load, and bed load. The dissolved load is transported as chemical ions. Suspended sediments are those materials, typically of a size range from clay to silt that are suspended in the water. Bed load are those materials that are frequently in contact with the bed of the river, for example coarser materials such as gravels or larger. This work focuses on the suspended sediment since the majority of sediments transported in a natural stream are in the form of a suspended load (USGS, 2016).

1.2 Problem Statement

As indicated in section 1.1. an excess sediment concentration in rivers and streams causes serious environmental problems. Suspended sediment load prediction, therefore, is important in the design of effective sediment control strategies and mitigation of the sediment pollution. In short, the awareness and knowledge of the prediction of the suspended sediment load in rivers and streams, the focus of this study, is very critical for the protection of the environment.

1.3 Objectives

The objective of this research is to build a predictive suspended sediment load model using linear regression based upon the water discharge of the river or stream in question. Linear regression is used to predict the suspended sediment load, a dependent variable, as a function of river water-discharge, an independent variable. The suspended sediment load and water-discharge data were divided into groups of equal or similar ranges of precipitation as the amount of precipitation directly affects the water discharge and the resulting suspended sediment in a stream or river. The purpose of this grouping, therefore, is to ensure high correlation coefficients between the suspended sediment load and water-discharge, and minimal deviations (differences) between the observed (measured) and predicted suspended sediment loads.

This study will test the hypothesis that utilizing the precipitation approach, grouping the data using similar precipitation, will improve prediction of suspended sediment load when compared to the traditional approach.

1.4 Scope

Four American rivers were investigated in this study, Feather River, CA, Sacramento River, CA, Maumee, OH, and Delaware, DE, primarily due to their robust suspended sediment data and various regional locations. In each river, the suspended sediment load is predicted using linear regression analysis as explained above. All of the rivers in this study will be thoroughly examined for regional geology, topography, precipitation, land use, and gauge station data. The river-water discharge and suspended sediment load used in this study were obtained from the portal of the United States Geological Survey (USGS, 2018).

1.5 Approach

There is a wide variety of approaches used to predict suspended sediment load based on river water-discharge. There are physical methods that normally examine one reach of a river, a reach being a section of a river. This method is not readily applied for rivers that transverse vast distances due to morphology that can change significantly from one reach to another, such as sinuosity, depth, width, vegetation cover along banks, roughness (Manning's n), and other parameters. Another more recent approach is to use Geographical Information Systems (GIS) by way of one of the geospatial tools, such as Hydro-Tools. Various computer models based on GIS can simulate the run-off based on parameters that examine land cover, slope and properties of the soil to name a few. The statistical approach of linear regression analysis is another method used to predict the suspended sediment load based on river water-discharge. This approach is employed in this study. This is a common approach in the study of sediment discharge typically over long period of time, (Amin and Jacobs, 2007). It has been suggested that sediment should be collected daily or weekly over a period of 10 to 20 years to provide a robust base for statistical analysis (Bhowmik et al., 1980). In conjunction with the linear regression analysis approach, is the utilization of precipitation data to homogenize the observed suspended sediment data so as to develop more accurate linear regression equations for a single river. This is the approach taken in this study.

Chapter 2 - Literature Review and Description of Rivers

2.1 Introduction

The processes of erosion of surface sediments are classified in three different types. These are: sheet, rill, and gully erosion. All of these overland erosional processes are sources of sediment for streams in addition to erosion of stream bed and bank materials. Erosion of stream banks can lead to wider rivers and erosion of stream bed can lead to a deeper river channel. The latter process will continue until the channel reaches equilibrium between erosion and deposition, meaning the channel has achieved a stable slope (Piest and Bowie., 1974). Bank erosion on the other hand is related directly to channel erosion, as the channel deepens, commonly the banks become unstable and materials collapse into the channel. The material that forms the bank will play a role in the rate of erosion, i.e. lithified sediments will be more resistant to erosion compared to unlithified sediments.

There are numerous studies that have utilized a form of regression analysis to quantify the suspended sediment load in streams and rivers as a function of stream or river water discharge. One of the earliest studies that started to examine this phenomenon and attempted to develop an empirical explanation was conducted by Luna Leopold and Thomas Maddock, Jr. in 1953. In this study, the authors examined the suspended sediment load in twenty rivers located in South Dakota, Wyoming, Utah, Kansas, and Nebraska using data collected over a period of 30 days (Leopold and Maddock, 1953). Their regression equations yielded slope values ranging from 1.09 to 1.58 for the rivers. The steeper the slope means the higher suspended sediment load based on water discharge. This various span of sampling locations and the short, limited duration (30 days) of the collected data supports that the relationship between the suspended sediment load and water discharge is not limited to one stream or one geographical region. Leopold and Maddock (1953) utilized and developed a unique linear regression equation for each stream or river to explain this relationship. Their work is very similar to the one utilized in this research. Although they did not have the luxury of statistical software in 1953, they continued to apply this and similar methodology to streams throughout the United States while working for the United States Geological Survey.

2. 2 Previous Studies

Brown and Ritter (1986) built upon the foundational research of Leopold and Maddock Jr. They continued to examine the relationship between the suspended sediment load and water discharge and the related variables that impact both. In particular they examined the slope values of the linear regression equations. Their research work had a more robust data set of twelve years for twenty-two locations along the Eel River in California. The authors used linear regression to calculate the suspended sediment load as a function of water discharge and obtained linear regression equations that were used to predict the suspended sediment load. This relationship held true for the twelve years of data and the thirty days of data that was collected and utilized by Leopold and Maddock Jr. (1953). This study once again supports that the linear regression approach can be used on a wide range of collected data sets.

In an unrelated study from those performed by Leopold and Maddock, Jr. (1953) and Brown and Ritter (1986), Bhowmik, et al. (1980), collected and analyzed data from a water survey on the Kankakee River and tributaries in the State of Illinois. The authors utilized the same methodology but had a large data set with the earliest discharge information recorded in 1916 for a single tributary. The data sets for other tributaries were as short as twelve months, which the authors cited as being a limiting factor and suggested that the data should span for a longer period ranging from 10 to 20 years. Once the data was compiled, linear regression equations were developed for the tributaries. The study resulted in good correlation coefficients between the suspended sediment load and water discharge ranging from 0.61 to 0.95.

In 2004, James Rankl explored this same relationship, using the same approach employed in this current research. In the Rankl work, approximately 10 years of data was used for Fifteenmile, Dugout, Dead Horse, Coal Creeks, and the Belle Fourche River (Rankl, 2004). The limitation of this study is that it focused on five streams in the State of Wyoming and not a larger geographical area. As in the other previous studies, Rankl also examined the slope of the five linear regression equations, which ranged from 1.07 to 1.29. These values compare very well to those obtained by Leopold and Maddock in 1953 for streams in the western U.S. As indicated above, Leopold and Maddock slope values ranged from 1.09 to 1.58. The fact that Rankl study was conducted 50 years after that of Leopold and Maddock (1953) clearly shows that the relationship between the suspended sediment load and water discharge is well defined and not purely random. The range of the correlation coefficients obtained by Rankl was 0.94 to 0.98, indicating a strong relationship between the suspended sediment loads and stream water discharge and, therefore, accurate predictive results of the linear regression equations for each of the five streams.

Another study (Amin and Jacobs, 2007) utilized the same technique of linear regression analysis coupled with an additional method to account for sediment sources and sinks. Linear Regression was applied to daily, monthly and annual date sets obtained from

Rio Puerco, an ephemeral stream in central New Mexico. The results showed that the monthly correlation coefficient was the highest at 0.93 (Amin and Jacobs, 2007).

Several other researchers have noted that there are numerous variables that have effects on water discharge and the suspended sediment load in rivers and streams, and hence the accuracy of the linear regression approach, e.g., a change in the sediment source can reduce the correlation factor (Araujo et al., 2012). Due to other natural processes the daily peak water discharge may not match the daily peak suspended sediment load. This can produce outliers due to large differences between the two variables (Bhowmik et al., 1980). Finally, there is a limitation on the quality and number of sediment samples collected and water discharge measured by the United States Geological Survey or other agencies (Araujo et al., 2012).

Another group of authors, Boukhrissa et al. (2013), examined the El Kebir River in Algeria for the relationship between suspended sediment load and water discharge. They compared linear regression analysis to another common approach, sediment rating curves coupled with artificial neural networks (ANNs). Linear regression analysis was applied to the water discharge and suspended sediment load for the El Kebir River. A best fit linear line was obtained and a linear regression equation was generated with a correlation value of 0.93 for the El Kebir River. This high correlation value again supports the validity of the linear regression approach. The ANNs and sediment rating curves approach provided an even higher correlation value of 0.99. The linear regression approach predicted lower suspended sediment loads at extreme discharge events in comparison to ANNs. This could be due to the limited availability of the suspended sediment data.

The concept of ANNs is based on the biological processes that have been documented between neurons. This breaks down into pathways that lead to nodes (neurons) and can represent a linear or more complex non-linear relationship that has been applied to the El Kebir watershed (Cigizoglu, 2004 and Zaheer, 2003).

Numerous researchers have used the ANNs approach that has been applied to the water resources field based on the work of Nagy et al. (2002), Merritt et al. (2003) and Jain (2001). For example, Jain's 2001 research concluded that a single ANN approach provided better results than the sediment rating curve approach when the two approaches are used to describe the complex process of sediment transport.

All of the reviewed studies listed in this section made note of the physical variables that impact water discharge in streams and rivers and suspended sediment loading, namely climate, topography (gradient), geology of location (i.e. available sediment), and anthropogenic impacts.

2.3 Overview of Streams and Rivers

As noted in the above section and other studies, there is key information that must be collected and explored for each watershed. The following sections in Chapter 2, will address the basic information that is needed to explain any anomalies that may be appear in the "Results Section" of Chapter 4.

2.3.1 Overview of Sacramento River

The Sacramento River lies between several mountain ranges, Sierras and the Cascade Range on the east and bordered on the west by Klamath (CNRA, 2014). The

Sacramento River Basin is the second largest river basin in the United States at 27,000-square miles, which terminates into the Pacific Ocean (Domagalski et al., 2000). In addition, it is estimated that on average there is 27 billion cubic meters of runoff annually in this watershed (Domagalski and Brown, 1998). The Feather River is a major tributary of the Sacramento River. As a result, the Feather River is a sub-watershed of the Sacramento River basin, with some overlap of geological and land use features.

Given the large size of the watershed (Figure 2.1) there is a wide variety of different land uses, which range from annual grasslands, pockets of oak forests, a wide array of agriculture, and wetlands. Further up into the mountain ranges that border the basin, there is a large mix of conifers such as cedar, pine and fir (SRWP, 2010). Based upon previous USGS reports and maps, the major crops are fruits, nuts, tomatoes, beets, corn and wheat, all of which requires irrigation that is typically diverted from tributaries in the watershed. Also, there are significant urban areas, one of the largest being Sacramento with a population of over 2.4 million based on the 2000 census.

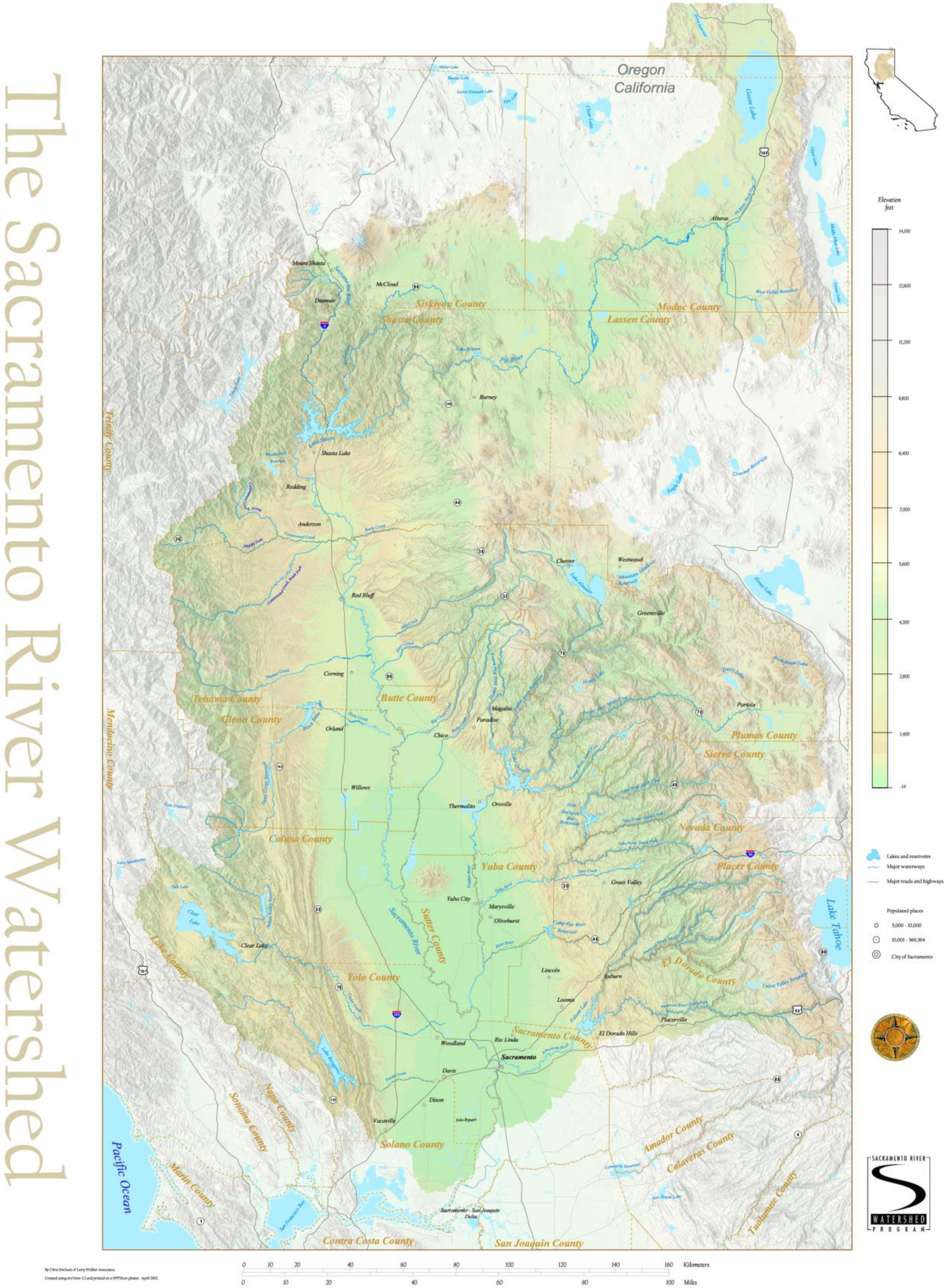

Figure 2.1 Sacramento River Watershed Map (Erichson, 2002)

The mountains surrounding the Sacramento River basin provide a steeped topographic, which causes increased water velocities during precipitation events. The three mountain ranges that surround the river are Sierras, Cascade and Klamath, which have a complex geology that won't be documented in detail here. They are generally comprised of intrusive rocks: granitic, gabbroic and ultramafic rocks (Hotz, 1971). As common for most basins or valleys, it is made up of sediment that is carried by streams and rivers from the surrounding mountains. These loose or unconsolidated material provide a source for suspended sediment in the associated streams and rivers.

There is distinct variation in precipitation for this river basin. As previously noted, one of the primary sources of water comes from the adjacent mountain ranges in the form of snowpack. The highest precipitation month is January with an average of over 3.5 inches and the lowest is August with only trace amounts of precipitation. Most of the precipitation occurs during the months between November and April. The dry months occur from May to October with little to no significant precipitation during those months. The precipitation data used in this study was obtained from the National Oceanic & Atmospheric Administration at the Sacramento Executive Airport and from the USGS gauging station in the same city.

2.3.2 Overview of Feather River

The Feather River lies within Plumas, Butte, Lassen, Shasta and Sierra Counties in California and falls within the framework of a Mediterranean climate (Koczot al et., 2004). The overall size of the Feather River Basin is 3,2000 square miles and in addition (Figure 2.2), the Feather River is a primary tributary of the Sacramento River (SRWP, 2010).

Fortunately, the United States Geological Survey conducted a related investigation of this watershed, which has offered additional information than typically available.

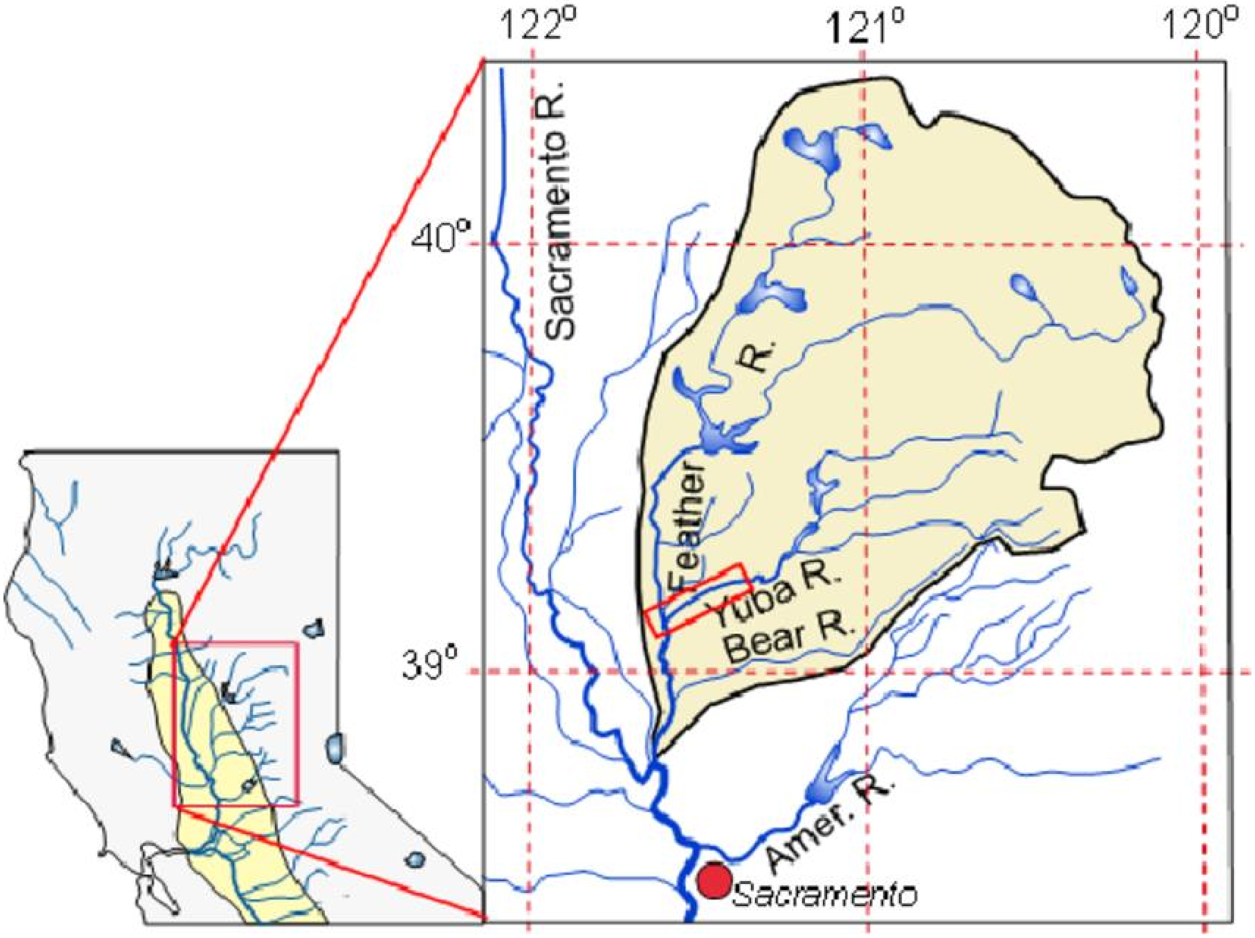

Figure 2.2 Feather River Watershed Map (Ghoshal, 2010)

Most of the watershed is composed of United States Forestry Service or other public land, and privately-owned ranch lands (SRWP, 2010). In addition, there is active timbering along the North Fork of the river and several National Forests, such as Tahoe National Forest (Koczot al et., 2004).

The soil ranges predominately from sand to silt in this basin as reported by the Feather River Watershed Management Strategy Plan (2004). High-permeability sandy soils allow greater infiltration rates compared to silt or clay soils.

The geology of this basin varies greatly, a transition from granitic bedrock to the north and Basin and Range Province to the south (Koczot al et., 2005). The rocks in the north and west sections are volcanic in nature (Durrell, 1987) and typically these rocks exhibit high permeability (Koczot al et., 2005). High permeability will affect the overland hydrological processes by allowing greater infiltration and lower run-off. Lower run off would cause a lower degree of peak flow on hydrographs.

The overall climate of the basin is Mediterranean in nature with warm, dry summers and cooler, wet winters and springs according to Koczot et al. (2012), as supported by Table 2.3. Most of the precipitation occurs between November and March with the water flow coming from snowmelt, which occurs between April and July (Koczot et al., 2005). As a result, stream flow would be directly impacted by the quantity of snow pack and the number of days exceeding freezing. Snow pack is measured by the California Department of Water Resources (DWR) and ends on April 1st of each year (DWR, 2000).

2.3.3 Overview of Maumee River

The Maumee River is located in the northwestern part of Ohio and has a drainage area of 6,609 mi^2 (Figure 2.3). It is the largest stream discharging into Lake Erie in the United States and Canada (Cumming, 1983). It is fed by tributaries with headwaters that begin in Indiana and Michigan. Of particular interest to many state and federal agencies, as well as private citizens is the amount of sediment deposited in Lake Erie. As was recognized by Baker in 1993, the Maumee River "discharges more tons of suspended sediment per year to the Great Lakes than any other stream".

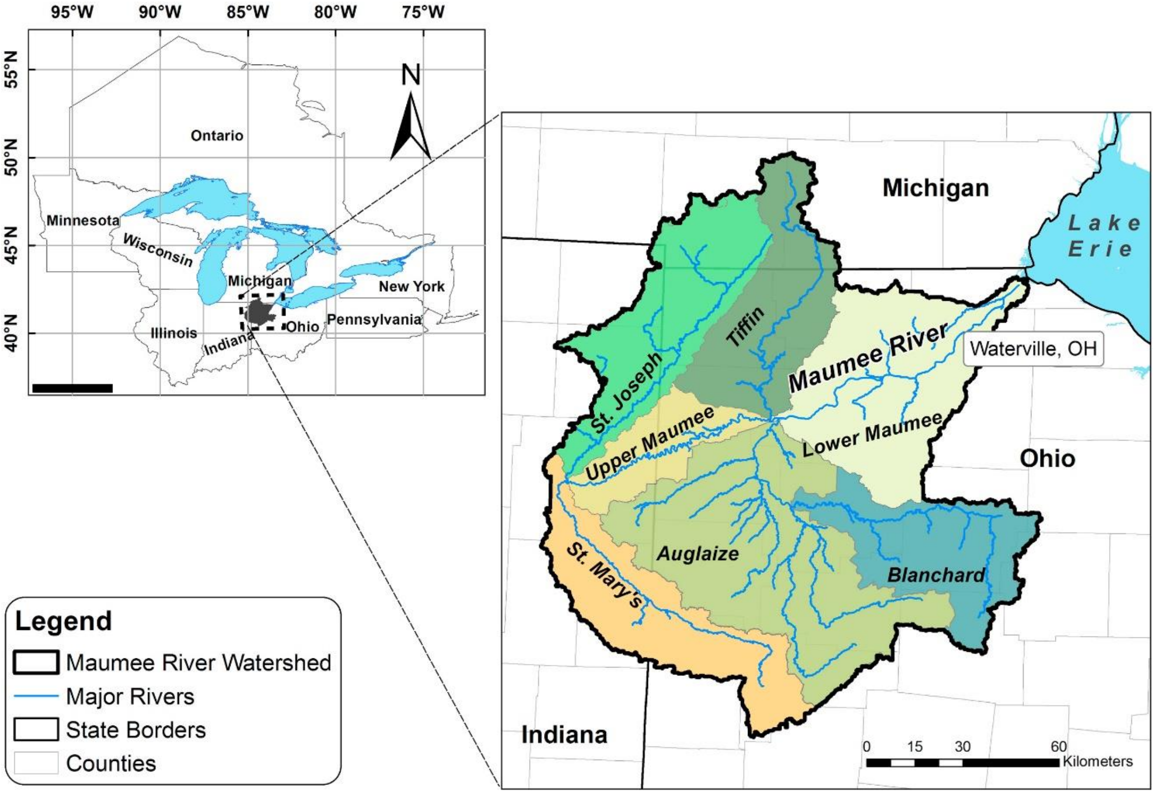

Figure 2.3 Maumee River Watershed Map (Cousino, 2015)

The overall land use of the Maumee River Basin is primarily agricultural with several major cities within the river basin, including Toledo, Ohio and Fort Wayne, Indiana. Approximately, 70 percent of the total basin area is agricultural cropland, which provides a major source of sediments for the Maumee River Basin (USDA, 1998). Not only are there elevated suspended sediments, but other studies have shown that there are higher levels of both fertilizers and pesticides (Baker, 1993). The soil types in this river basin are predominantly finer texture matrix with low drainage rates that allows a greater probability for their transport (Logan, 1977). Likewise, another study showed that higher infiltration rates were linked to soils that are formed from till and lacustrine deposits that are poorly drained (Beasely, 1985).

The river basin is primarily dominated by Pleistocene glacial deposits consisting of poorly sorted till with clast sizes ranging from clay to large boulders (Casey et al., 1997). There are other types of minor glacial deposits that include poorly sorted stratified sand and gravel and a mixture of clay, silt and very fine sand. The range of thickness of these sediments varies greatly from less than one foot along the shoreline of Lake Erie to over 200 feet westward from where the Maumee River deposits into the lake (Meyers et al., 2000).

The overall size of the Maumee River Basin allots for a wide range of precipitation, which is the most important variable factor for sediment transport (Guy, 1969). The Maumee River Basin experiences all four seasons, winter, spring, summer and fall with snow falling mainly within the winter period. The potential for intense precipitation events in the form of thunderstorms occurs in late spring and through the summer months, whereas low intensity and steady rain occurs in the early spring and fall months (IDNR, 1996).

The average monthly precipitation data for the Maumee River at Toledo, Ohio between 1951 and 1981 were published by the National Oceanic and Atmospheric Administration. The data shows that April, May, June, and August are the highest precipitation months. Based on the data, the average annual precipitation for this period is 33.21 inches (average annual = sum of average monthly values). Due to these temporal variations of precipitation the river flow rates are on average lowest in September and October (Casey et al., 1997). The National Oceanic and Atmospheric Administration's (NOAA) weather station located at Toledo Express Airport is utilized for precipitation data for this study. The data used is from the period of 1951 through 1981, which corresponds with the time period during which the water discharge and suspended sediment data were collected and later used in this study for the linear regression analysis of this river.

2.3.4 Overview of Delaware River

The Delaware River is ranked as the longest un-dammed river in the United States east of the Mississippi River (DRBC, 2013). Its watershed spans Pennsylvania, New Jersey, New York and Delaware; the largest portion of the watershed is in Pennsylvania (PACD, 2009). The Delaware River Basin covers 13,000 square miles and is fed by over 200 tributaries of various magnitudes (DRBC, 2013).

The watershed includes a variety of land uses. Most of the land cover is deciduous forests, followed by residential, pasture land and row crops (PACD, 2009). Due to anthropogenic modifications, most of the soil in the urbanized areas is classified as Urban Land (PACD, 2011).

The large size of the watershed contains different geological features. A large area of this region is primarily composed of carbonate formations, namely limestone and dolomite (PACD, 2009). The USGS gauging station from which the suspended sediment loads and river water discharge were obtained is located in Mercer County, which have low hills that are formed primarily of gneisses and schists (Widmer, 1977).

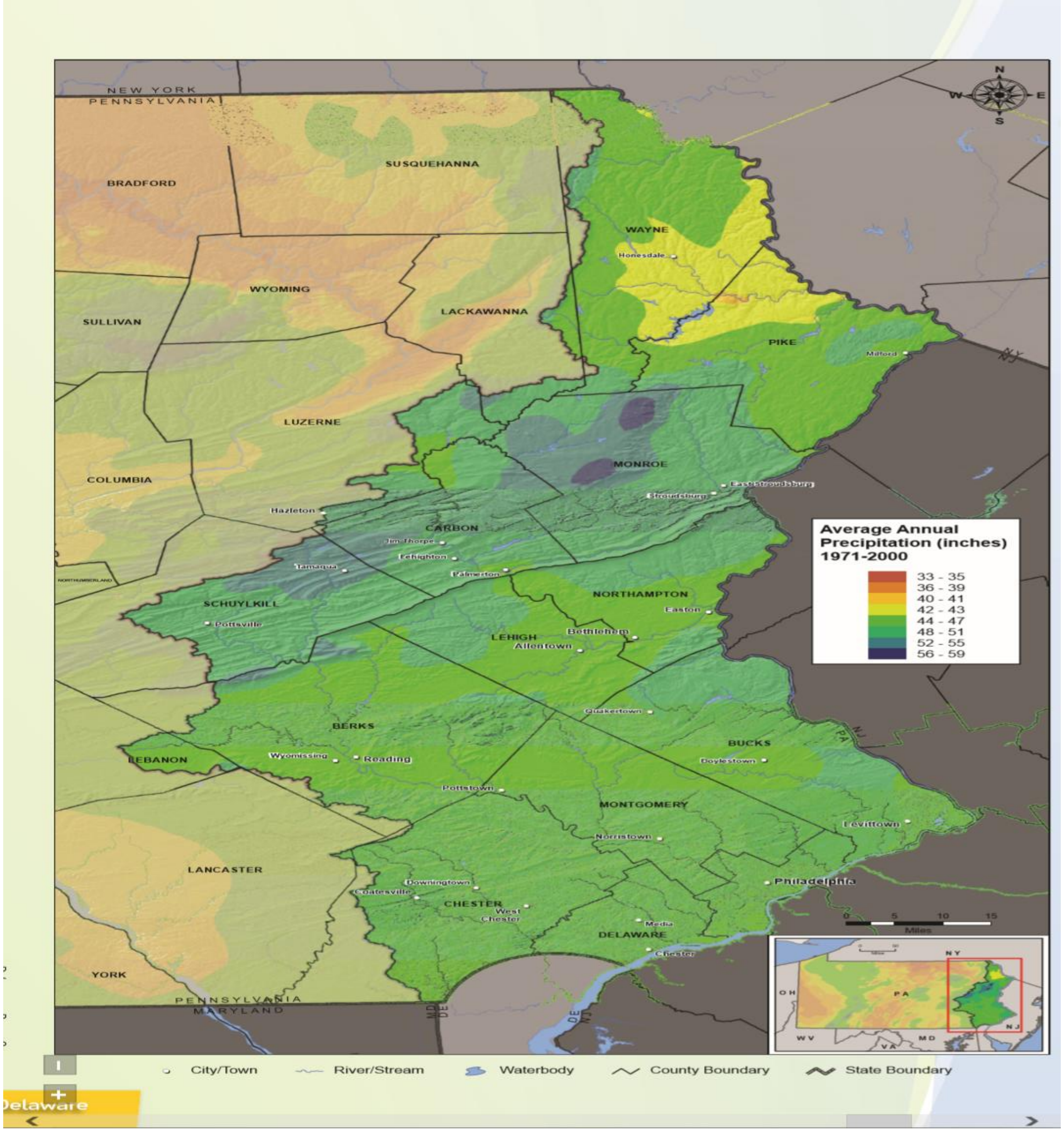

Figure 2.4 Climate Map of the Delaware Watershed (PACD, 2009)

The weather in the Delaware River Basin has distinct variations due to elevation changes and nearness of the Atlantic Ocean, though it is classified as having a humid continental climate pattern (PACD, 2009). Precipitation varies as indicated by the Pennsylvania Association of Conservation Districts (PACAD, 2009) map (see Figure 2.4), from 33 inches to 50 inches annually.

The large size of the Delaware River Basin is significant and offers challenges to select appropriate data sets for precipitation, river water discharge and suspended sediment. All the precipitation data used in this study were obtained from the Mercer County Airport in Trenton, New Jersey and from the USGS gauging station located in Trenton. Monthly precipitation averages from 1961-1990 show that August experienced the highest average that exceeded 4 inches and the lowest precipitation month is February with less than 3 inches.

Chapter 3 – Linear Regression Analysis

3.1 Linear Regression Analysis

There are various approaches to predict the suspended sediment load in rivers and streams. The approaches can be classified into three general categories: the first, statistical equations and the second and third are based on physical equations (Neibling and Foster, 1977). The second category uses the universal soil loss equation, which is based on rainfall to predict sediment yield. The third category uses the modified universal soil loss equation, which utilizes runoff to predict the sediment yield (Meyer and Wishchmeier, 1969). The first category is employed in this study.

Linear regression analysis was applied to annual suspended sediment load and annual water discharge for four different rivers throughout the continental United States. The available data was broken down into groups based upon similar precipitation values for each of the four rivers.

Linear regression was used to predict the suspended sediment load as a function of water discharge, the former is a dependent variable and the later independent variable. The regression equation has the form:

$$Y = a\,X^{m} \tag{1}$$

where: Y = suspended sediment load, X = water discharge, a = constant, and m = slope of regression line.

Equation (1) in the logarithmic form is as noted below:

$$\log Y = m \log X + \log a \quad (2)$$

Which is in the form $y = mx + b$, where m = slope of regression line and b = log a is the intercept.

Figure 3.1 is an example for application of linear regression to the annual sediment load (Y-ton/year) and annual water discharge (X-ft^3/year) of the first group of the Feather River. The linear regression equation in this case is:

$$\log Y = 1.0691 \log X - 1.7002 \quad (3)$$

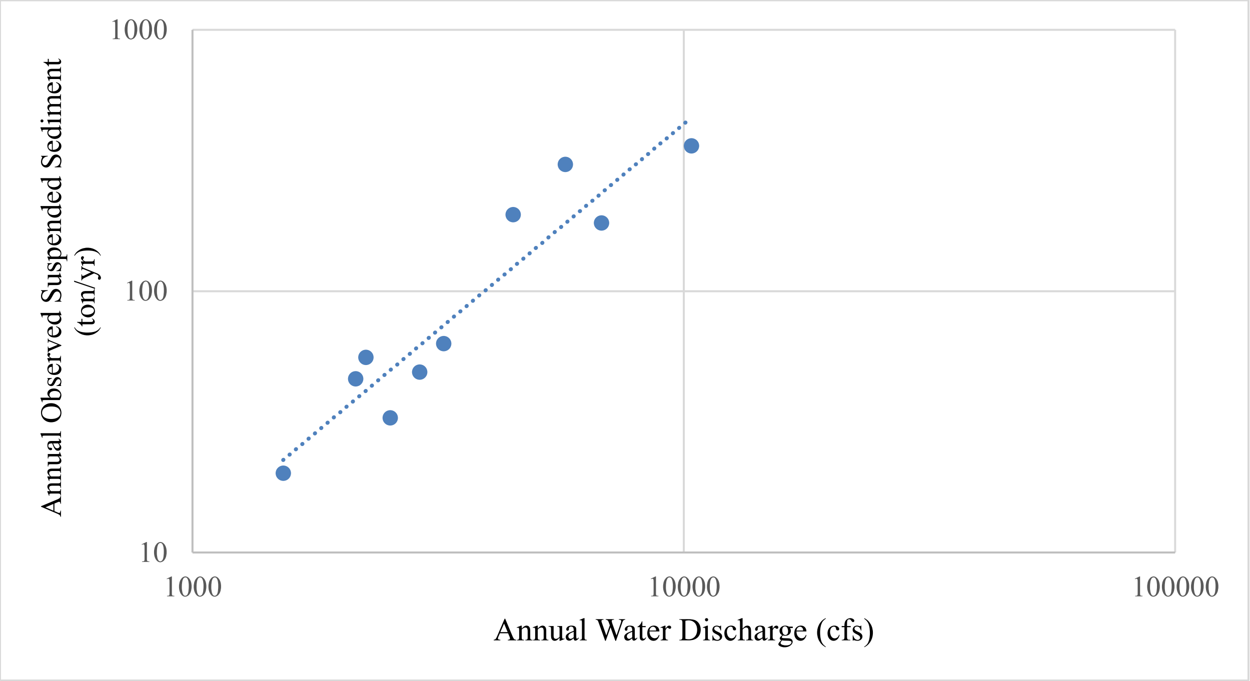

Figure 3.1 Feather River-Group #1: Regression Relationship of the Annual Observed Suspended Sediment Load and Annual Water Discharge

The resulting correlation coefficient value is 0.94, which supports a high degree of accuracy of the predicted suspended sediment load.

The regression analysis utilized in this study transforms originally engineering units (equation 1) to a logarithmic identity (equation 2), which must be retransformed back to engineering units for final results. The retransformation can cause a “bias correction problem”. There are a wide variety of statistical approaches to correct bias in this step. Three of the common corrections are: (1) the Quasi-Maximum Likelihood Estimator (QMLE), (2) the Minimum Variance Unbiased Estimator (MVUE), and (3) the Smearing Estimator (SM) as reported by Helsel and Hirsch (2002). Of the above three, two are recommended by professionals at the USGS, Minimum Variance Unbiased Estimator and Smearing Estimator (Cohn and Gilroy, 1991). The primary difference between MVUE and SM, is the distribution of the errors. In the former method the errors are assumed to have a normal distribution and the latter does not have a normal error distribution (Cohn and Gilroy, 1991). The Smearing Estimator was developed by Duan (1983), which is a nonparametric method that is based on the equation:

$$Y_{SE} = Y\,[10^{res}/n] \tag{3}$$

Y_{SE} is the predicted sediment load using the smearing estimator, Y is the predicted sediment load, n is the number of predicted sediment loads, and res are the residuals. Residuals are the difference between the logarithm of the observed sediment load and logarithm of the predicted sediment load, as displayed by equation 4.

$$\text{res} = [(\text{log observed sediment load}) - (\text{log predicted sediment load})] \tag{4}$$

Table 3.1 provides an example for the correction of the bias by the smearing estimator using the annual suspended sediment and water discharge of the Feather River.

Table 3.1 Example for the Correction of the Bias by the Smearing Estimator Using the Annual Sediment Load and Water Discharge of the Feather River

1	2	3	4	5	6	7	8	9	10
Groups	Year	Precipitation Values (in)	Annual Stream Flow (cubic ft/year)	Uncorrected Predicted Suspended	Observed Suspended Sediment Load	Residual	Transformed Residual	Corrected Predicted Suspended	Absolute Percent Deviation
#1	1975	14.0 – 22.0	4494	124	196.2	0.2007	1.5874376	101	48%
	1989		2528	50	32.7	-0.1834	0.6554934	41	25%
	1986		6801	238	182.4	-0.1147	0.7678167	195	7%
	1988		2150	39	46.2	0.07759	1.1956017	32	32%
	1972		3247	74	62.9	-0.0708	0.8496559	61	4%
	1987		2253	42	55.7	0.12675	1.3389082	34	39%
	1980		5741	182	305.6	0.22543	1.6804670	149	51%
	1974		10370	462	359.7	-0.1087	0.7784977	378	5%
	1990		2902	62	49	-0.1023	0.7901731	51	4%
	1991		1530	23	20.1	-0.0509	0.889483	19	8%
#2	1992	22.1 – 35.0	1587	36	21.9	-0.2156	0.6086378	29	35%
	1979		2934	87	85.1	-0.0079	0.9820223	71	17%
	1970		7418	327	768.1	0.37145	2.3520498	267	65%
	1978		3111	94	124.9	0.12237	1.3254628	77	38%
	1993		4401	155	114.5	-0.1309	0.7398335	127	11%
	1969		6371	263	458.6	0.24198	1.7457253	215	53%
	1981		2384	64	74.8	0.06504	1.1615568	53	30%
	1982		10080	506	320.9	-0.1981	0.6337531	415	29%
	1983		11880	640	349.4	-0.2632	0.5455228	524	50%
	1973		4793	175	180.6	0.01404	1.0328683	143	21%
	1984		4401	145	115	-0.1014	0.792	118	3%

(Column 7) Residual = [log observed suspended sediment load (column 6)] – [log predicted suspended sediment load (column 5)]

(Column 8) Power Residual = 10 $^{\text{Residual}}$

(Column 9) Corrected Predicted Suspended Sediment Load using the smearing estimator method, where the predicted values, which are listed in (column 5) are multiplied by the mean (0.818793) of the power residual

(Column 10) Percent Deviation = [(observed sediment – corrected sediment)/observed sediment] x 100%

The linear regression equation (equation 3) for Group #1 of the Feather River was used to predict the suspended sediment load. The resulting corrected predicted suspended sediment load is graphed in comparison to the observed suspended sediment load (Figure 3.2). The trend of the predicted suspended sediment loads is directly impacted by the correlation value. The higher the correlation, the more closely the predicted sediment load will follow the observed load. The high correlation value (0.94) is reflected in Figure 3.2.

Figure 3.2 Feather River: Predicted vs. Observed Suspended Sediment Load – Group #1

Chapter 4 – Results and Discussion

4.1 Sacramento River Results and Discussion

The following statistical results are based on 21 years of data from 1957 until 1979, with no records available for years 1959 and 1966. This data was collected at the USGS gauging station located at Sacramento, CA. For the available dates noted, there were complete records of suspended sediment load and water discharge at this location. The suspended sediment load and river water discharge data were broken down by similar precipitation values that were collected from the NOAA weather station located in Sacramento, CA.

The data was broken down into three groups based upon similar precipitation values, as noted in Table 4.1, and excluded two extreme outliers. Linear regression was applied to each group. The resulting correlation coefficient values for the three groups are 0.93, 0.92, and 0.87, respectively. The regression equations of the three groups are:

Group #1: $\log Y = 2.0290 \log X - 5.0385$

Group #2: $\log Y = 1.0324 \log X - 0.7441$

Group #3: $\log Y = 1.5461 \log X - 2.9114$

Figures 4.1 through 4.3 show the regression relationships of the three groups.

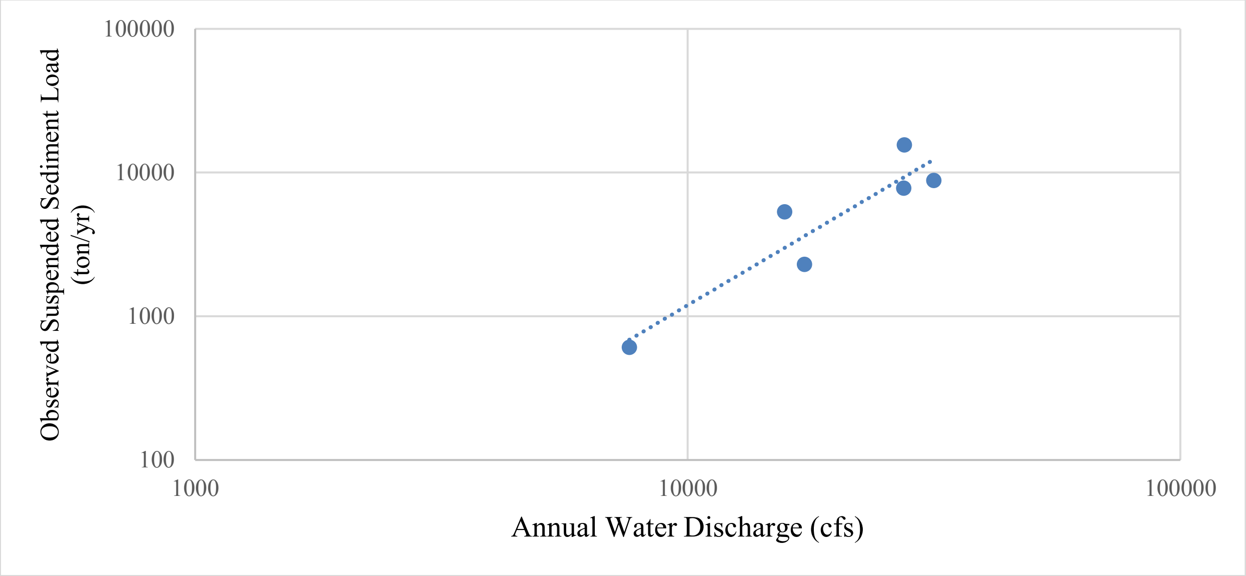

Figure 4.1 Sacramento River - Group #1: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

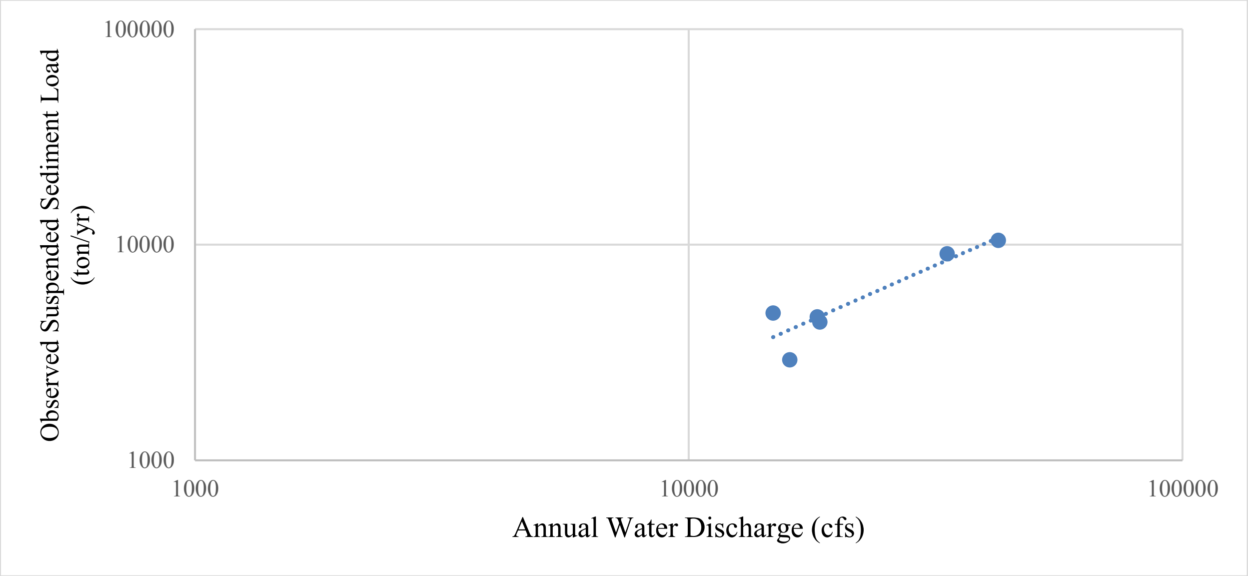

Figure 4.2 Sacramento River - Group #2: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

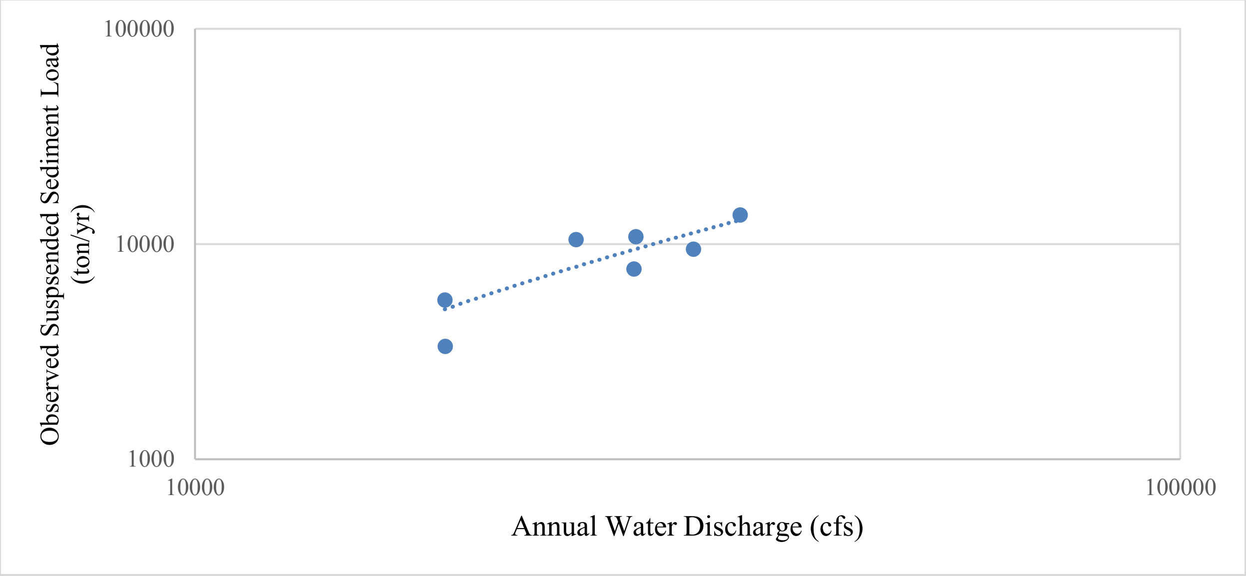

Figure 4.3 Sacramento River - Group #3: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

Figures 4.1 (Group #1) and 4.3 (Group #3) data sets exclude two years, 1973 and 1976 from the linear regression analysis due to being outliers. These noted outliers would negatively impact the correlation coefficient values if included in the linear regression analysis. The three regression equations were used to predict the suspended sediment load. The predicted values closely mirror the observed suspended sediment loads with a few exceptions (Figures 4.4 through 4.6).

Figure 4.4 Sacramento River: Observed vs. Predicted Suspended Sediment Load – Group #1

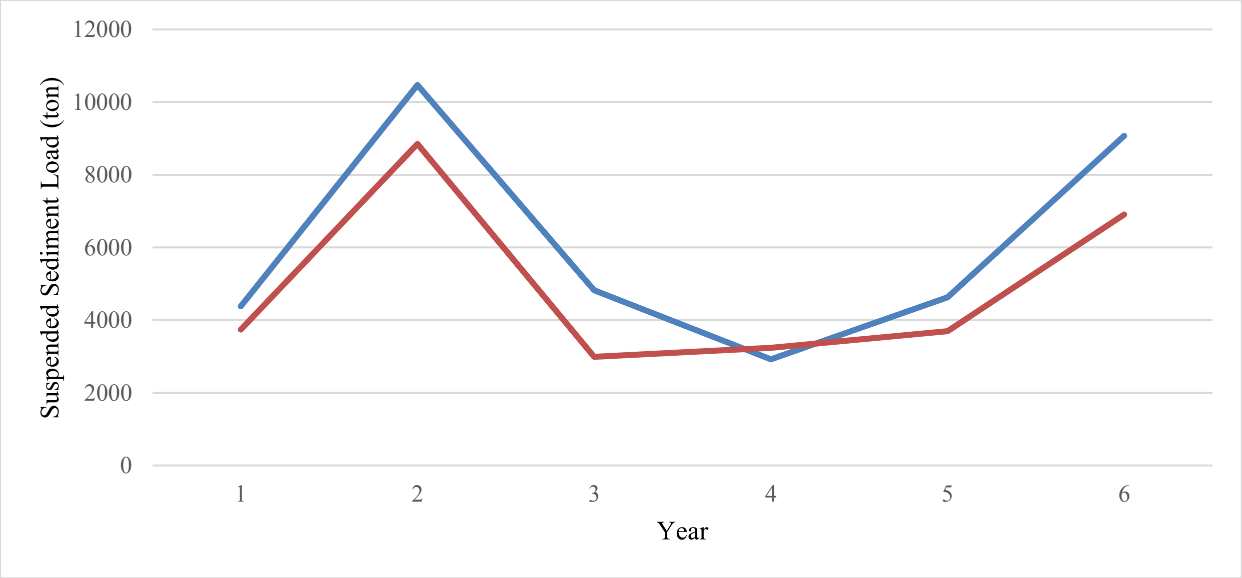

Figure 4.5 Sacramento River: Observed vs. Predicted Suspended Sediment Load – Group #2

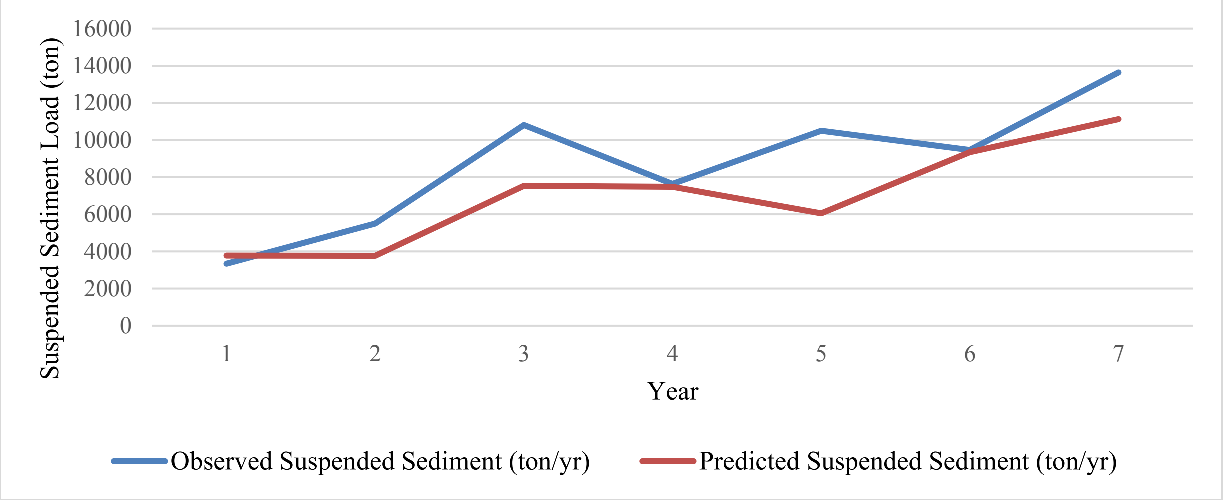

Figure 4.6 Sacramento River: Observed vs. Predicted Suspended Sediment Load – Group #3

There are a few anomalies between observed and predicted suspended sediment primarily in Group #1, year 5 (1965). As indicated in the discussion of the Maumee River, these anomalies can be caused by the complex hydrologic changes that take place during the entire year, such as changes in the intensity and duration of precipitation over the watershed.

Table 4.1 Sacramento River: Linear Regression Data of the River Groups

Group(s)	Annual Precipitation (in)	Corrected Predicted Suspended Sediment Load (ton/yr)	Observed Suspended Sediment Load (ton/year)	Absolute Percent Deviation	Mean of Absolute Values of Deviation
Group #1	9.0 – 13.9	9953	8805	13%	27%
		554	609	9%	
		7485	7781	4%	
		2422	5324	55%	
		7529	15570	52%	
		2916	2294	27%	
Group #2	14.0 – 20.0	3688	4377	16%	21%
		8698	10470	17%	
		2943	4821	39%	
		3189	2921	9%	
		3642	4626	21%	
		6805	9073	25%	
Group #3	20.1 – 25.0	3738	3341	12%	20%
		3732	5498	32%	
		7442	10810	31%	
		7389	7644	3%	
		5994	10490	43%	
		9165	9463	3%	
		10847	13640	20%	

Group #1: (Precipitation Range: 9 - 13.9 inches)

Listed in Table 4.1 are the absolute percent deviation values (column 5), which show the accuracy of the suspended sediment load prediction. The lower the deviation, the higher the accuracy. Group #1 consists of 6 data points, of which 4 points resulted in percent deviations ranging from 1% to 27%, with an average of 13%, and 2 points with percent deviations ranging from 52% to 56%, with an average of 54%. The average percent deviation of the entire data set (6 points) is 27%, as shown in Table 4.1. Therefore, most of the data points (4 out of 6 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.93) obtained for Group #1.

Group #2: (Precipitation Range 14.0 – 20.0 inches)

Group #2 consists of 6 data points, of which 5 points resulted in percent deviations ranging from 19% to 25%, with an average of 18%, and 1 point with percent deviation at 39%. The average percent deviation of the entire data set (6 points) is 21%, as shown in Table 4.1. Once again, most of the data points (5 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.92) obtained for Group #2.

Group #3: (Precipitation Range 20.1 – 25.0 inches)

Group #3 consists of 7 data points, of which 4 points resulted in percent deviations ranging from 3% to 20%, with an average of 10%, and 3 points with percent deviations ranging from 31% to 43%, with an average of 35%. The average percent deviation of the entire data set (7 points) is 20%, as shown in Table 4.1. Therefore, most of the data points (4 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.87) obtained for Group #3.

From Table 4.1, it can be seen that group #1 shows the highest percent deviations (52 and 55) despite having the highest correlation coefficient value of the three groups. This indicates that the high correlation coefficient of this group is mainly due to the other four data points.

Complete Data Set: (Traditional)

The regression relationship for the complete data set is shown in Figure 4.7, the regression equation in this case is: $\log Y = 1.702 \log X - 3.6433$

and the correlation coefficient is 0.89.

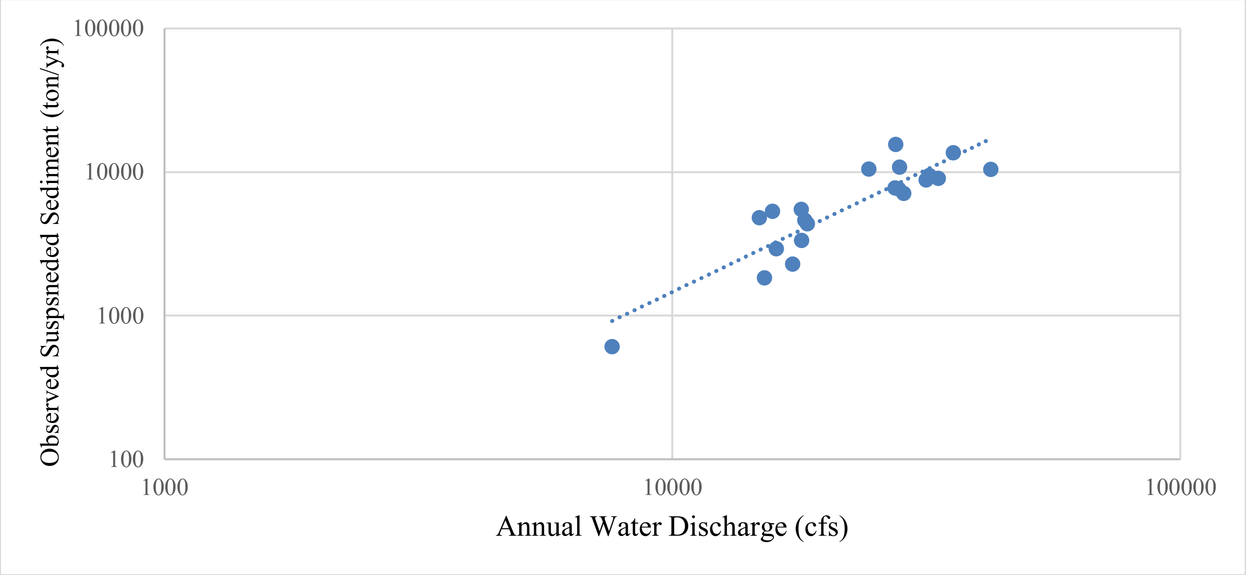

Figure 4.7 Sacramento River - Complete Data Set: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

The regression equation was used to predict the suspended sediment load without grouping the data based on precipitation values (Figure 4.8).

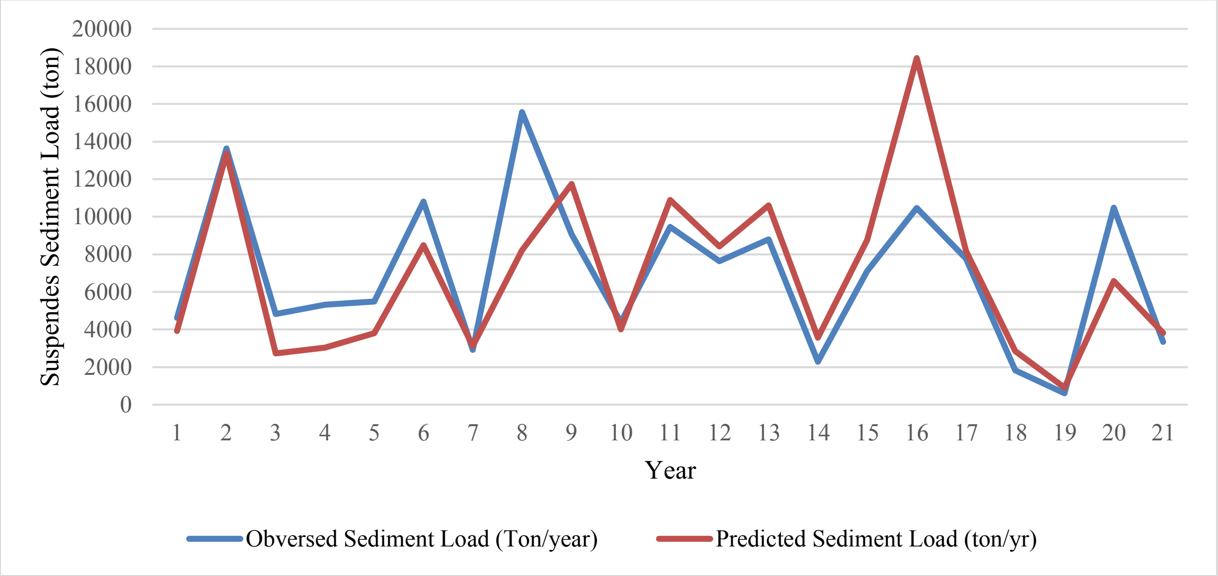

Figure 4.8 Sacramento River - Complete Data Set: Observed vs. Predicted Suspended Sediment Load

The complete data set resulted in percent deviations ranging from 1% to 56%, with an average of 27% and a correlation coefficient value of 0.89. This value (0.89) is higher than that of Group #3 (0.87) and lower than those of Group #1 (0.93) and group #2 (0.92). The average percent deviation of the complete data set (27%) is higher than those of group #2 (21%), group #3 (20%), but equal to group #1 (27%). Therefore, two groups (#1 and #2) resulted in better correlation coefficients than the complete data set, and two groups (#2 and #3) resulted in better percent deviations than the complete data set. As indicated earlier, the accuracy of the prediction requires a high correlation coefficient value and a low percent deviation. In short, the proposed approach has improved the accuracy of prediction in the Sacramento River.

4.2 Feather River Results and Discussion

The following statistical results are based on 25 years of data (1969 through 1993) obtained from the USGS gauging station located at Gridley, CA. This is an uninterrupted record of suspended sediment load and water discharge data for the period of noted years. Following removal of outliers, the data were grouped into two groups based on similar precipitation values that were collected from the NOAA weather station located in Sacramento, CA. The outliers fall in precipitation values ranging from less than 14.0 inches and greater than 35.0 inches.

Linear regression was applied to each group. Two unique linear regression equations were developed for each group with correlation coefficient values of 0.94 and 0.89, respectively. The regression equations of the two groups are:

Group #1: $\log Y = 1.0691 \log X - 1.7002$

Group #2: $\log Y = 1.7169 \log X - 4.1340$

The regression relationships of the two groups are shown in Figures 4.9 and 4.10.

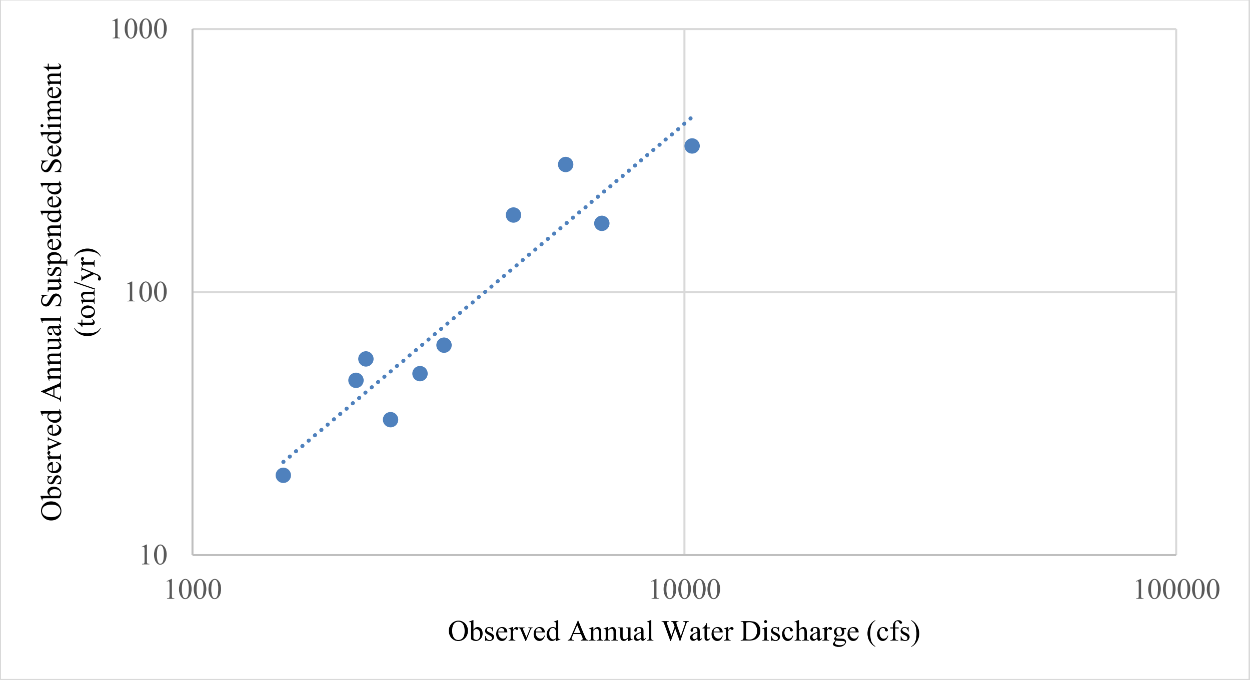

Figure 4.9 Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

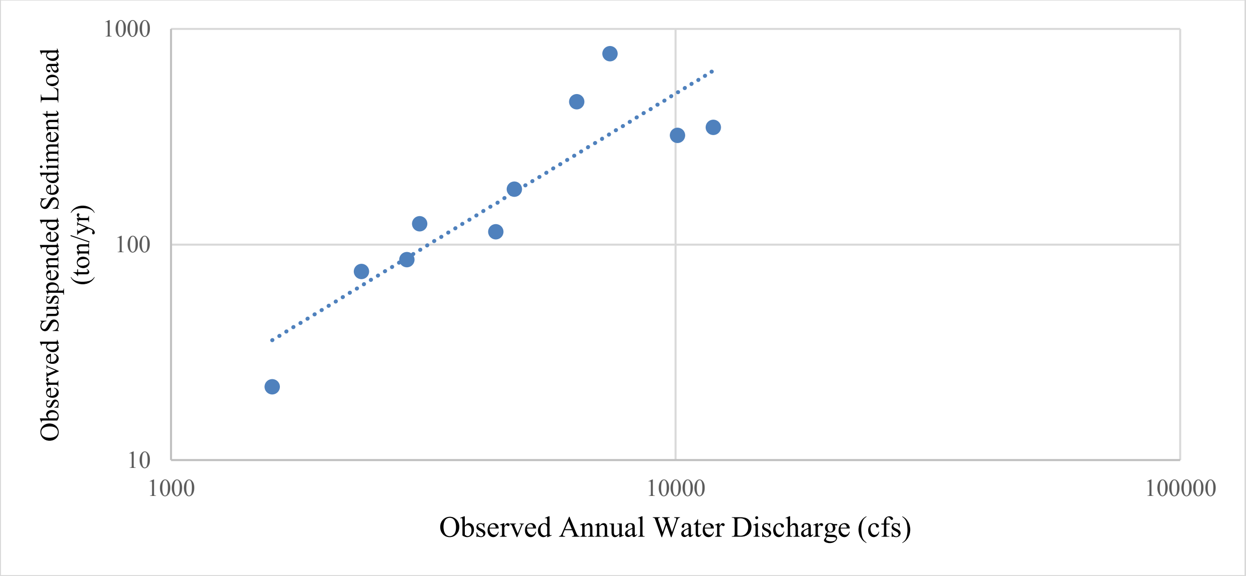

Figure 4.10 Feather River-Group #2: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

The two linear regression equations were used to predict the suspend sediment load for each group. The predicted suspended sediment load for Group #1 and #2 closely mirrored the observed data (Figures 4.11 and 4.12) with a few exceptions.

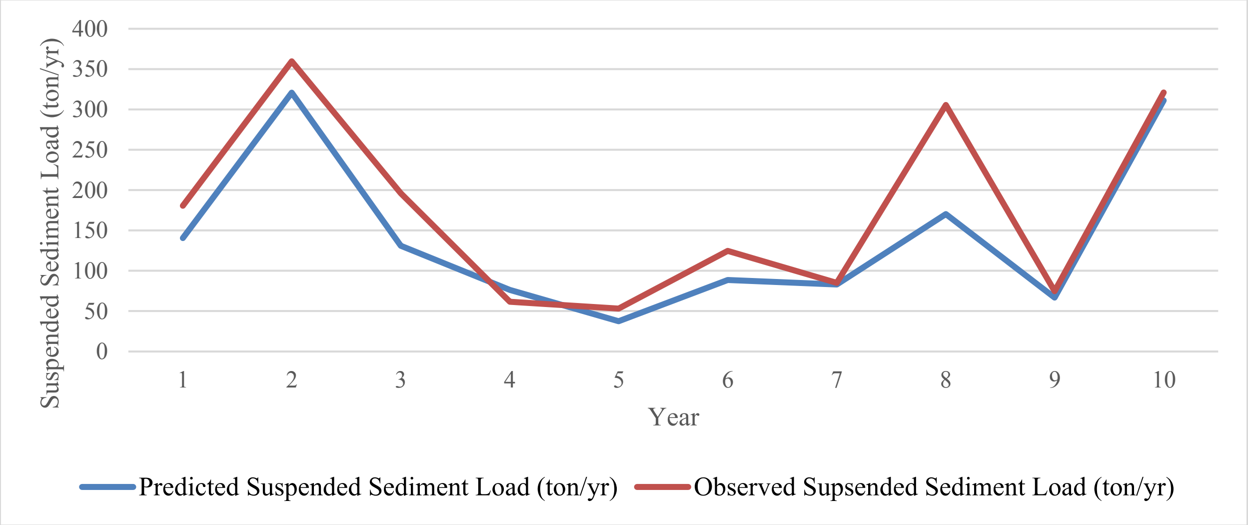

Figure 4.11 Feather River: Observed vs. Predicted Suspended Sediment Load – Group #1

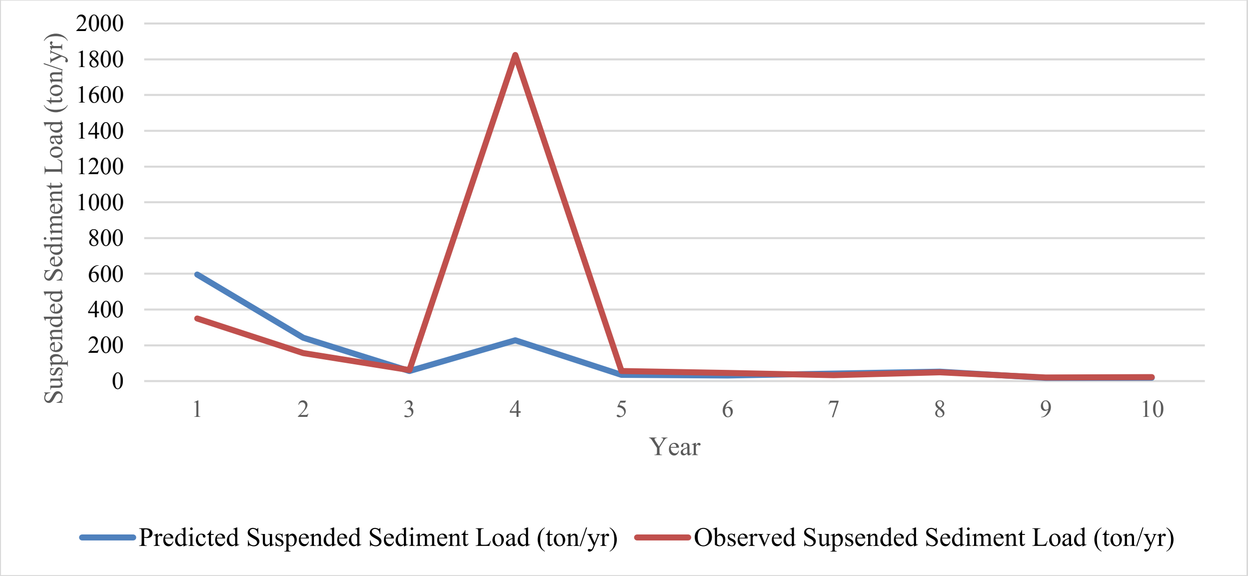

Figure 4.12 Feather River: Observed vs. Predicted Suspended Sediment Load – Group #2

As explained earlier, the anomalies between the observed and predicted suspended sediment loads are caused by the vast hydrologic variations that take place during the entire year and affect the water discharge and suspended sediment.

Table 4.2 Feather River: Data of Linear Regression of River Groups

Group(s)	Observed Annual Precipitation (in)	Corrected Predicted Suspended Sediment Load (ton/yr)	Observed Sediment Suspended Load (ton/year)	Absolute Percent Deviation	Mean of Absolute Values of Deviation
Group #1	14.0 – 22.0	141	181	48%	22%
		321	360	25%	
		131	196	7%	
		76	62	32%	
		38	53	4%	
		89	125	39%	
		83	85	51%	
		170	306	5%	
		67	75	4%	
		311	321	8%	
Group #2	22.1 – 35.0	596	349	35%	35%
		243	156	17%	
		56	61	65%	
		229	1824	38%	
		34	56	11%	
		32	46	53%	
		42	33	30%	
		53	49	29%	
		18	20	50%	
		19	22	21%	

Group #1: (Precipitation Range 14.0 – 22.0 inches)

Listed in Table 4.2 are the absolute percent deviation values (column 5), which show the accuracy of the suspended sediment load prediction. The lower the deviation, the higher the accuracy. Group #1 consists of 10 data points, of which 6 points resulted in percent deviations ranging from 4% to 25%, with an average of 9%, and 4 points with percent deviations ranging from 32% to 51%, with an average of 43%. The average percent deviation of the entire data set (10 points) is 22%, as shown in Table 4.2. Therefore, most of the data points (6 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.94) obtained for group #1.

<u>Group #2:</u> (Precipitation Range 22.1 – 35.0 inches)

Group #2 consists of 10 data points, of which 5 points resulted in percent deviations ranging from 11% to 30%, with an average of 22%, and 5 points with percent deviations ranging from 35% to 65%, with an average of 48%. The average percent deviation of the entire data set (10 points) is 35%, as shown in Table 4.2. In this group, 50% of the data points (5 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.89) obtained for Group #2.

In Group #1, the mean percent deviation decreased significantly when the sole outlier was removed from the data. The mean percent deviation decreased from 22% down to 18%. Also, in Group #2 when one outlier was removed from the data, the mean percent deviation value went from 35% down to 31%. This proves that the outliers have a significant statistical impact upon the percent deviations of the two groups.

<u>Complete Data Set</u>**:** (Traditional)

The regression relationship for the complete data set is shown in Figure 4.13, the regression equation in this case: $\log Y = 1.5434 \log X - 3.4633$

and the correlation coefficient is 0.85.

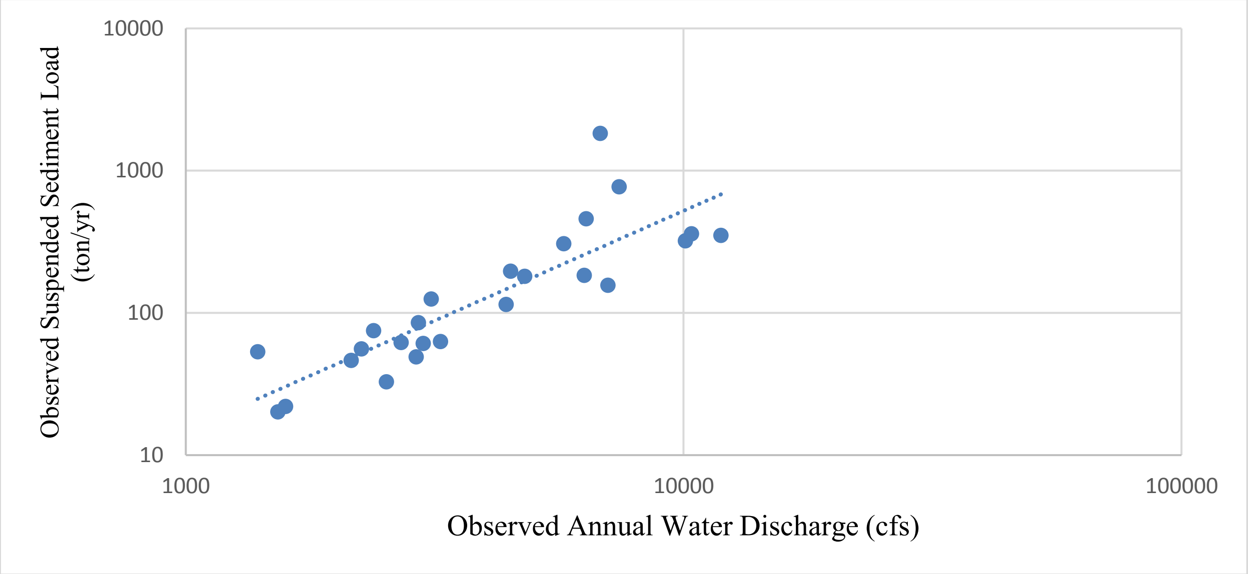

Figure 4.13 Feather River-Complete Data Set: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

The regression equation of the complete data set was used to predict the suspended sediment load. The predicted sediment load is shown in Figure 4.14 along with the observed loads.

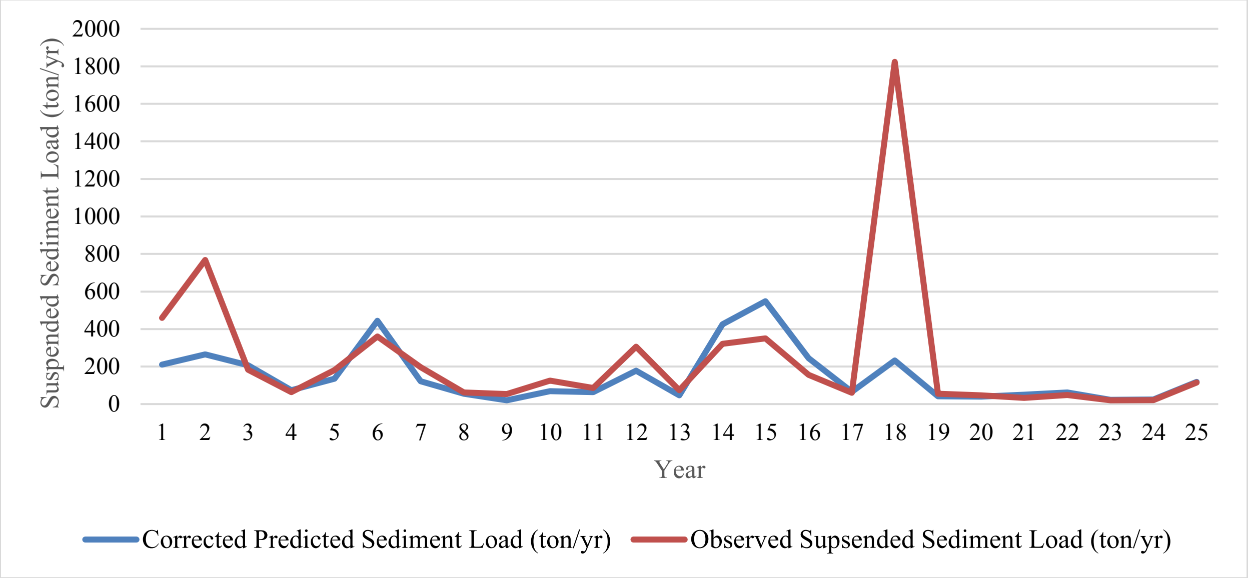

Figure 4.14 Feather River: Observed vs. Predicted Suspended Sediment Load - Complete Data Set

The complete data set resulted in percent deviations ranging from 3% to 87%, with an average of 34%. The correlation coefficient in this instance is 0.85. Comparation of the complete data set with the two groups shows that Group #1 has the highest correlation coefficient (0.94) and the lowest percent deviation (22%). Group #2 generated higher correlation coefficient value (0.89) and slightly higher percent deviation than the complete data set. Therefore, the proposed approach improved the prediction of the suspended sediment load in at least one group.

4.3 Maumee River Results and Discussion

The following statistical results are based on 44 years, from 1955 through 1983 and 1988 through 2002, of annual discharge and sediment data recorded at the Waterville, Ohio USGS gauging station. The whole of the observed data was grouped based on similar precipitation values that was collected from the National Oceanic and Atmospheric Administration’s (NOAA) weather station located at Toledo Express Airport. The annual water discharge and suspended sediment load were broken down into ten-percent precipitation intervals for each group with the outliers removed from the linear regression as noted.

The data was divided into three groups. Linear regression analysis was applied to each group and the resulting correlation coefficient values for the three groups are 0.87, 0.85, and 0.93, respectively. The regression equations of the three groups are:

Group #1: $\log Y = 1.8113 \log X - 3.2006,$

Group #2: $\log Y = 1.1653 \log X - 0.8220,$

Group #3: $\log Y = 1.3581 \log X - 1.5621.$

Figures 4.15 through 4.17 show the regression relationships of the three groups.

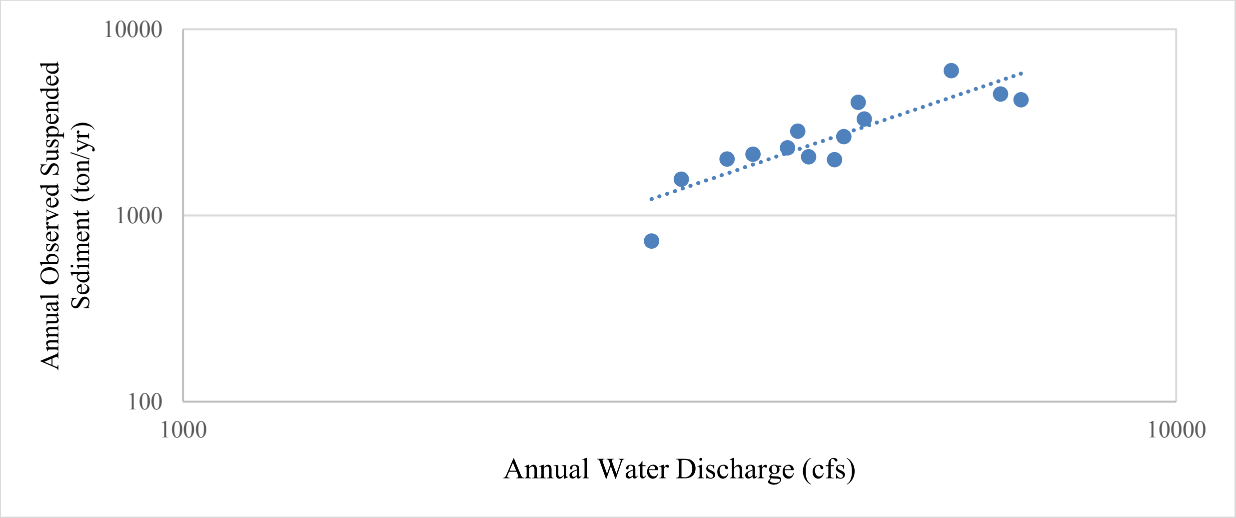

Figure 4.15 Maumee River-Group #1: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

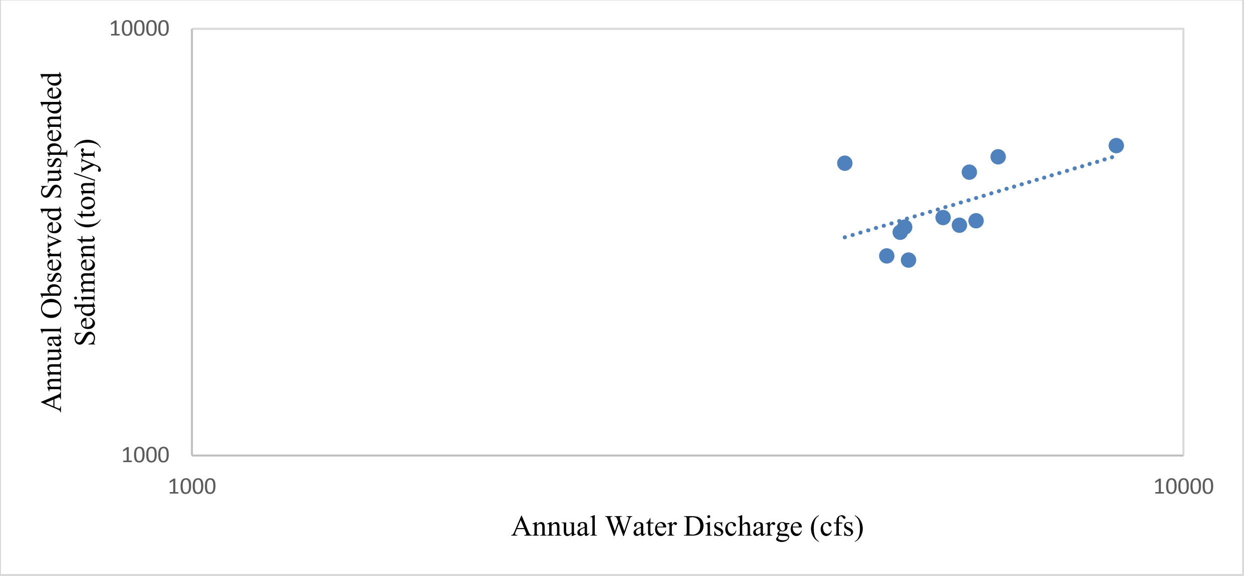

Figure 4.16 Maumee River-Group #2: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

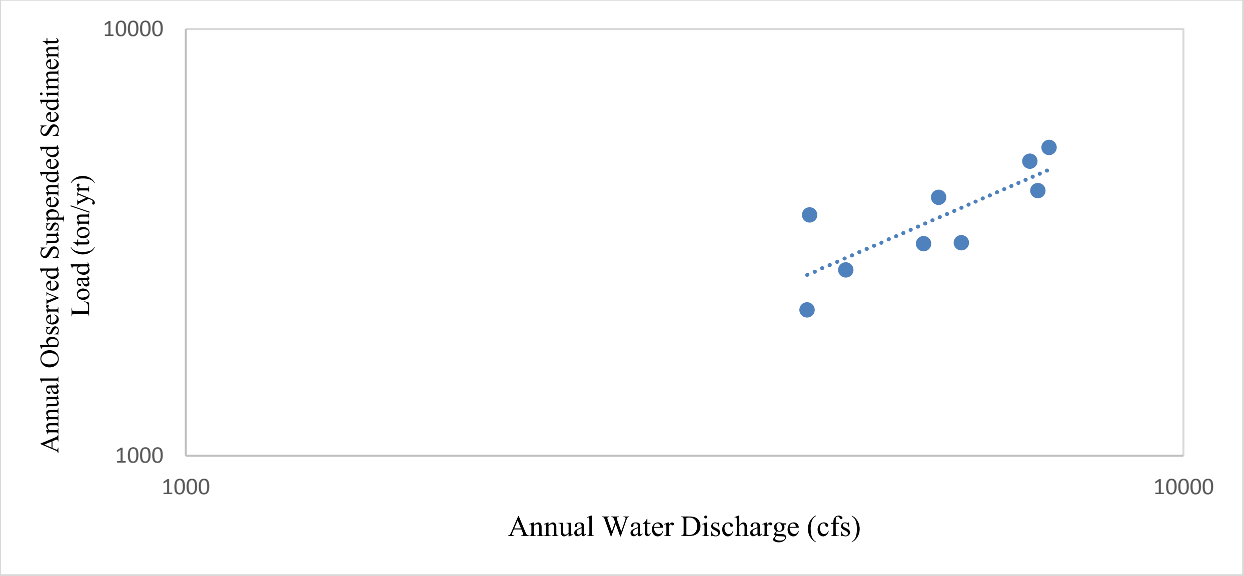

Figure 4.17 Maumee River-Group #3: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

Figures 4.16 and 4.17 excluded the years 1956 and 1989 from the linear regression analysis due to being outliers that negatively impact the correlation coefficient value, respectfully.

The three equations were used to predict the suspended sediment load. The predicted values closely mirror the observed suspended sediment loads with a few exceptions (Figures 4.18 through 4.20).

Figure 4.18 Maumee River: Observed vs. Predicted Suspended Sediment Load - Group #1

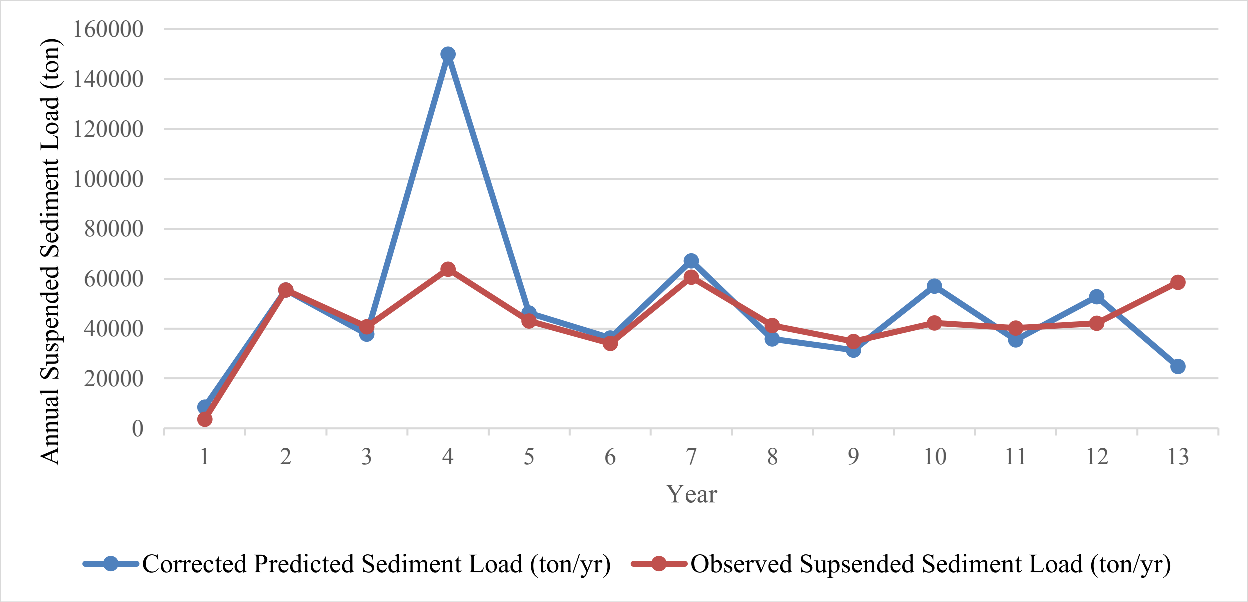

Figure 4.19 Maumee River: Observed vs. Predicted Suspended Sediment Load - Group #2

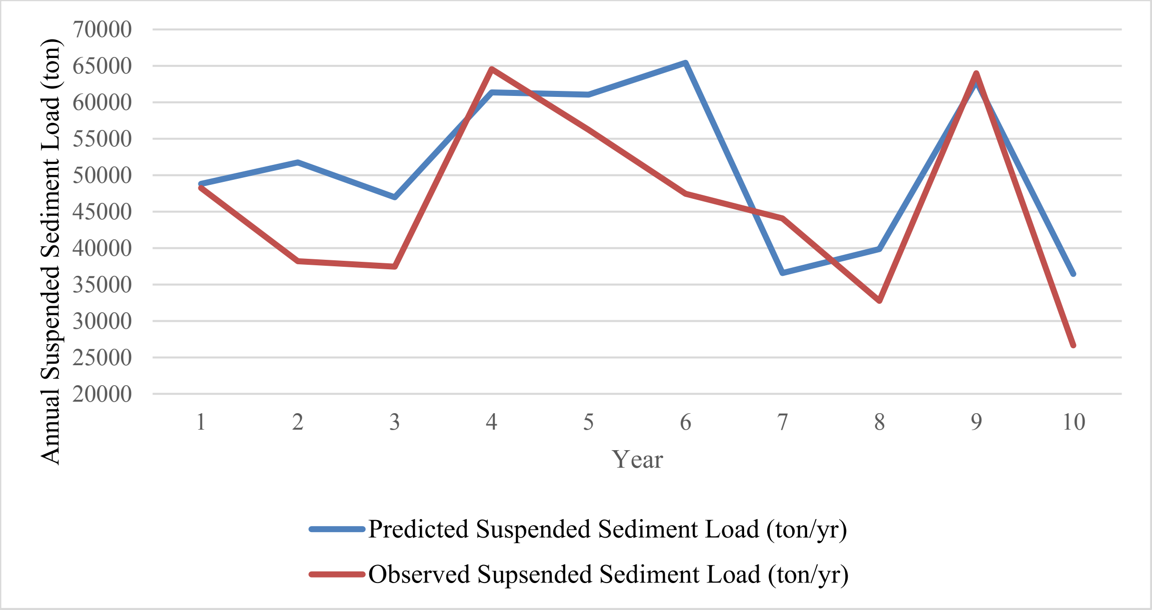

Figure 4.20 Maumee River: Observed vs. Predicted Suspended Sediment Load - Group #3

The anomalies at year 2 (1969) and year 6 (1989) for Group #3, between observed and predicted suspended sediment can be attributed to a variety of processes, such as the intensity of precipitation and its distribution over the watershed. In short, the differences between the observed and predicted suspended sediment can be significant due to complex natural physical processes that affect both water discharge and suspended sediment.

Table 4.3 Maumee River: Data of Linear Regression of River Groups

Group(s)	Annual Precipitation (in)	Corrected Predicted Suspended Sediment Load (ton/yr)	Observed Suspended Sediment Load (ton/yr)	Absolute Percent Deviation	Mean of Absolute Values of Deviation
#1	26.0 - 30.0	1538	1565	2%	24%
		2402	2306	4%	
		3314	3292	1%	
		2508	2835	12%	
		2623	2063	27%	
		1356	727	86%	
		4774	5985	20%	
		3231	4039	20%	
		2925	1988	47%	
		2076	2130	3%	
		3043	2646	15%	
		1862	2011	7%	
		6399	4169	54%	
		5870	4493	31%	
#2	30.1 - 34.0	4572	4613	1%	21%
		6800	5322	28%	
		4258	3609	18%	
		3877	2871	35%	
		4940	5016	2%	
		3836	3429	12%	
		3654	2935	25%	
		4655	3548	31%	
		3789	3338	14%	
		4448	3463	28%	
		3261	4846	33%	
#3	34.1 - 38.1	4149	4031	3%	21%
		4452	3154	41%	
		3957	3136	26%	
		5661	4179	35%	
		5522	4902	13%	
		2769	3667	24%	
		3099	2724	14%	
		5866	5272	11%	
		2747	2196	25%	

Group #1: (Precipitation Range 26.0 – 30.0 inches)

Listed in Table 4.3 are the absolute percent deviation values (column 5), which show the accuracy of the suspended sediment load prediction. The lower the deviation, the higher the accuracy. Group #1 consists of 14 data points, of which 10 points resulted in percent deviations ranging from 1% to 27%, with an average of 11%, and 4 points with percent deviations ranging from 31% to 86%, with an average of 55%. The average percent deviation of the entire data set (14 points) is 24%, as shown in Table 4.3. Therefore, most of the data points (10 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.87) obtained for Group #1.

Group #2: (Precipitation Range 30.1 – 34.0 inches)

Group #2 consists of 11 data points, of which 8 points resulted in percent deviations ranging from 1% to 28%, with an average of 16%, and 3 points with percent deviations ranging from 31% to 35%, with an average of 33%. The average percent deviation of the entire data set (13 points) is 21%, as shown in Table 4.3. Once again, most of the data points (9 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.85) obtained for Group #2.

Group #3: (Precipitation Range 34.1 – 38.1 inches)

Group #3 consists of 9 data points, of which 7 points resulted in percent deviations ranging from 3% to 26%, with an average of 17%, and 2 points with percent deviations ranging from 35% to 41%, with an average of 38%. The average percent deviation of the entire data set (10 points) is 21%, as shown in Table 4.3. Therefore, most of the data points (7 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.93) obtained for group #3.

Table 4.3 shows in some instances large variation between the observed and predicted annual suspended sediment load. It should be noted that these annual variations are caused by vast hydrologic changes in precipitation and river water discharge that take place throughout the entire year period. For example, the high intensity storms can generate hundreds if not thousands of tons of suspended sediment in one year. The variations depend on the factors discussed in Chapter 1, section 1.1 of this thesis.

In Group #1, the percent deviation decreased significantly when the sole outlier was removed from the data points to compute the mean of the percent deviations with the value of the latter changing from 24% down to 19%. Also, in Group #2 when one outlier was removed the mean of the percent deviation value went from 21% down to 19%. This proves that the outliers have a significant statistical impact upon the percent deviation for each of these two groups. The 3rd group did not show evidence of any outliers.

Complete Data Set**:** (Traditional Approach)

The regression relationship for the complete data set is shown in Figure 4.21, the regression equation in this case is: $\log Y = 1.3881 \log X - 1.6358$

and the correlation coefficient is 0.88.

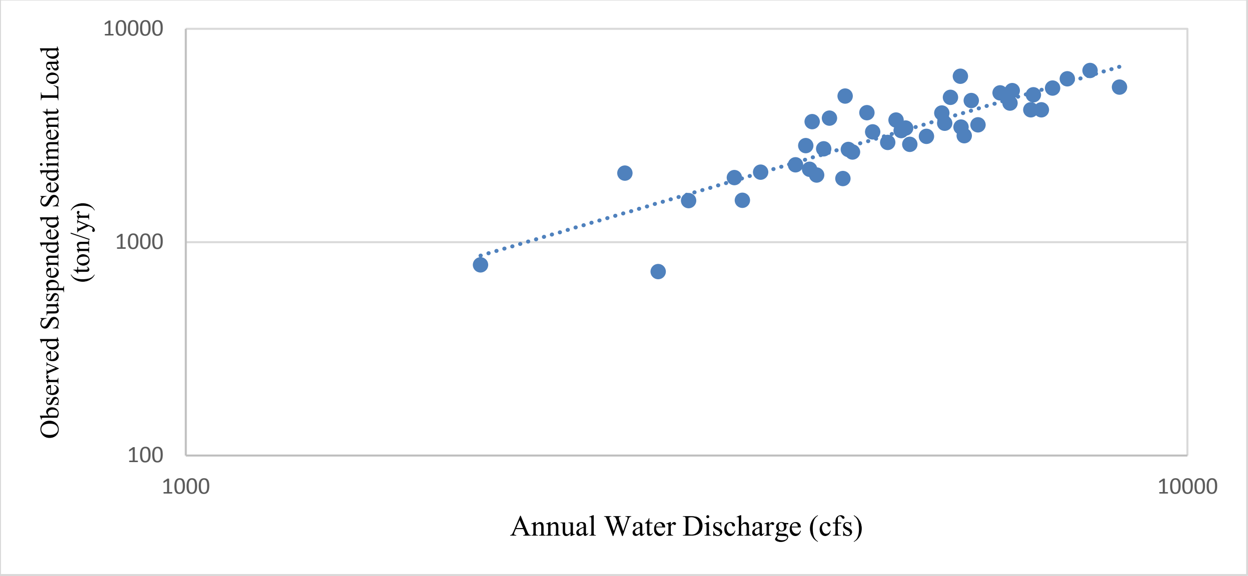

Figure 4.21 Maumee River-Complete Data Set: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

Figure 4.22 shows the observed and predicted suspended sediment load of the complete data set of the Maumee River.

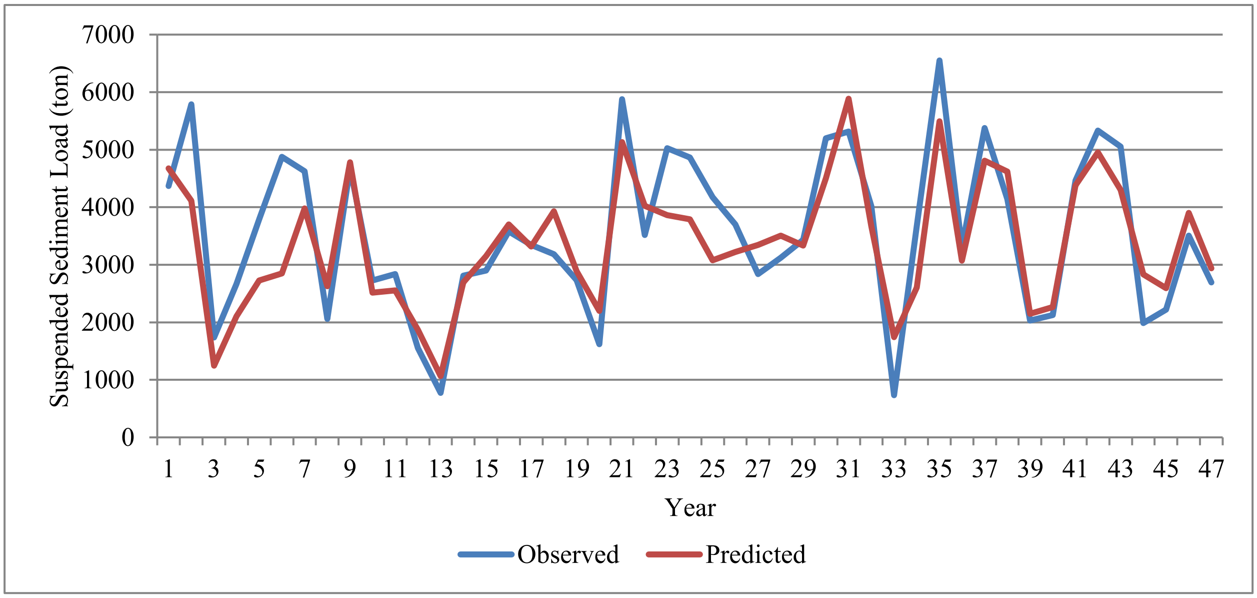

Figure 4.22 Maumee River: Observed vs. Predicted Suspended Sediment Load – Complete Data Set

The complete data set resulted in percent deviations ranging from 1% to 115%, with an average of 18%. The correlation coefficient in this case is 0.88. Comparation of the complete data set with the three groups shows that Group #3 has the highest correlation coefficient (0.93). The average percent deviation of the complete data set (18%) is slightly lower than first group (24%) and the second and third groups (21%). Therefore, the propose approach that groups the data based on similar precipitation values has improved the prediction of the suspended sediment load at least in one group (group #3).

4.4 Delaware River Results and Discussion

The statistical data for this river is based on 20 years of record covering the period from1950 through 1969. Observed suspended sediment load and water discharge were collected at the USGS station located in Trenton, NJ. The NOAA weather station in Trenton, NJ was utilized for the recorded precipitation data for the same time span. The annual water discharge and suspended sediment load were broken down into three groups based on similar precipitation values obtained from NOAA station. Precipitation of the three groups ranged from 10.0 – 13.9, 14.0 – 17.0, and 17.1 – 23.1 inches, respectively, as indicated in Table 4.4.

Following removal of the outliers, linear regression was applied to each of the three groups and unique linear regression equations were generated. Linear regression resulted in the following correlation coefficients for the three groups: 0.80, 0.88, and 0.89, respectively. The regression equations of the three groups are:

Group #1: $\log Y = 1.0546 \log X - 1.1081,$

Group #2: $\log Y = 3.5347 \log X - 11.249,$

Group #3: $\log Y = -2.5348 \log X - 13.652.$

Figures 4.23 through 4.25 show the regression relationships of the three groups.

The equation for Group #3 yielded a negative slope (Figure 4.25) indicating a negative (inverse) correlation between river water discharge and suspended sediment (i.e., as water discharge increases, the suspended sediment load decreases). Therefore, this equation is incorrect and was excluded from the analysis (not used to predict the suspended sediment load).

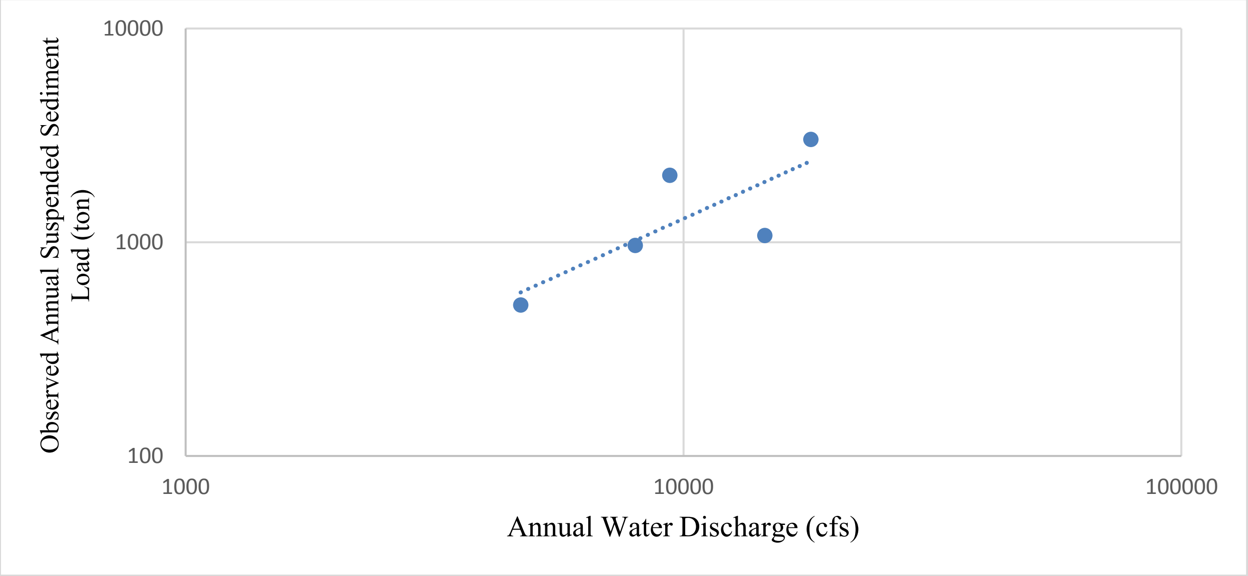

Figure 4.23 Delaware River-Group #1: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge.

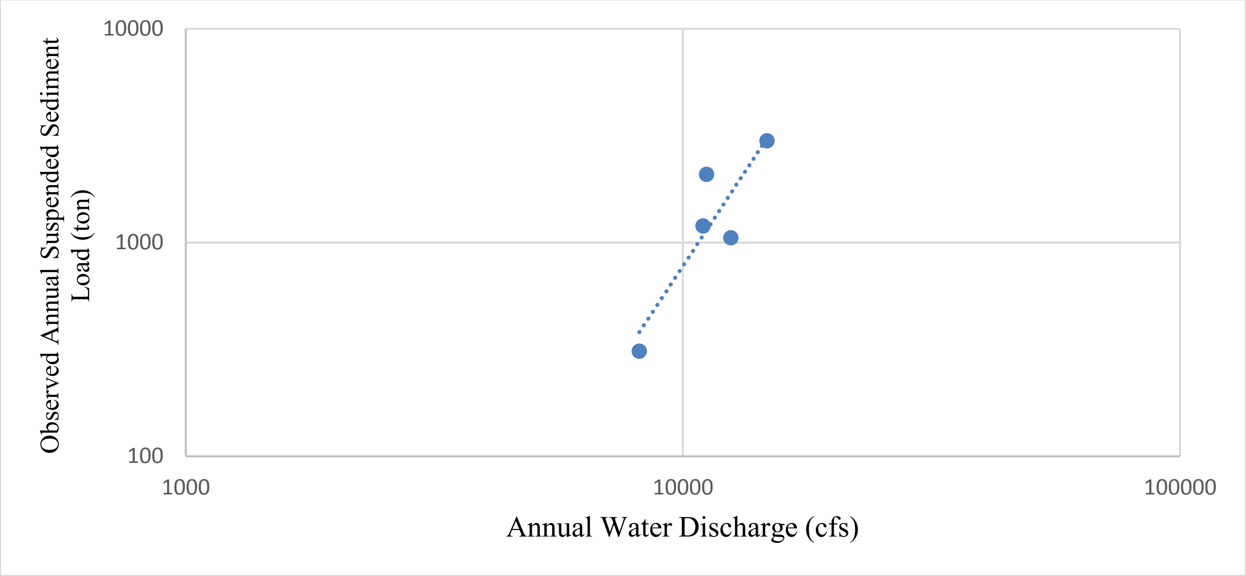

Figure 4.24 Delaware River-Group #2: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

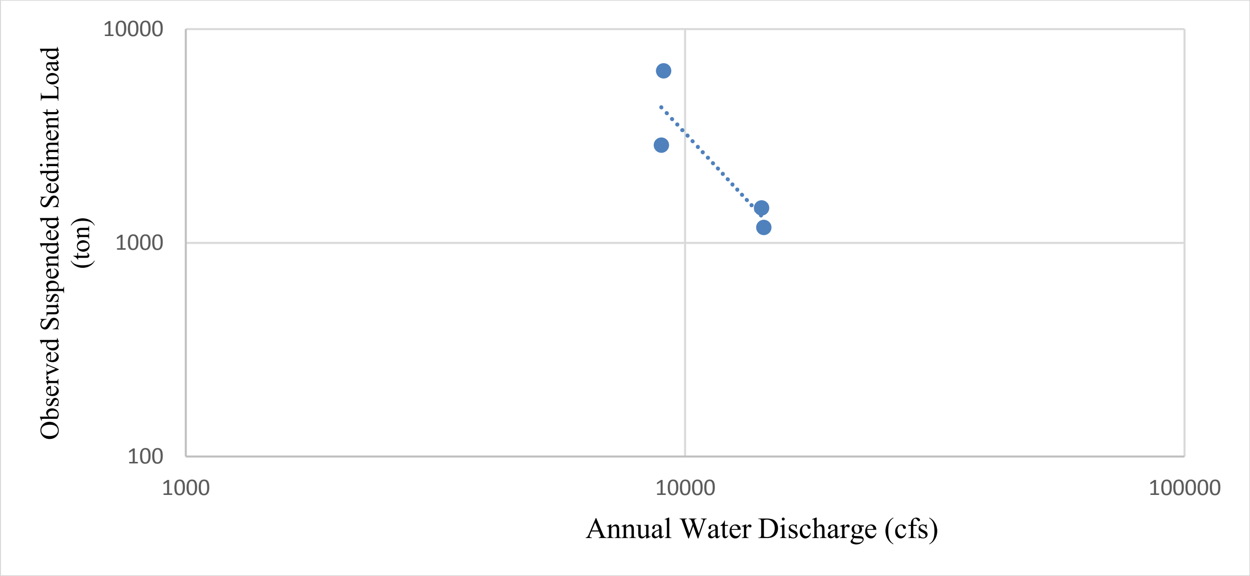

Figure 4.25 Delaware River-Group #3: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

The equations for Group #1 and Group #2 were used to predict the suspended sediment load. The predicted values closely mirror the observed suspended sediment loads with a few exceptions (Figures 4.26 and 4.27).

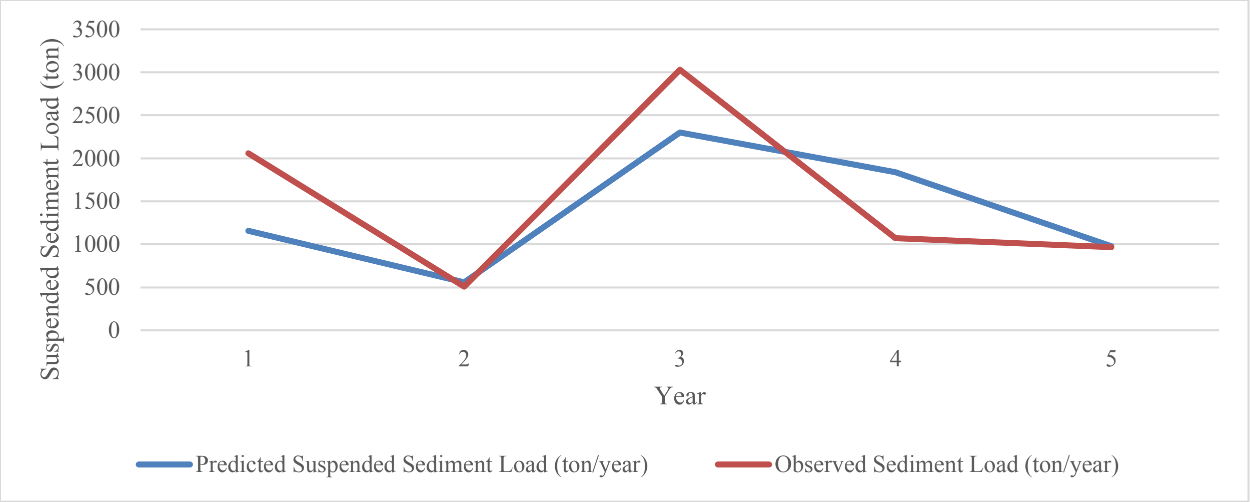

Figure 4.26 Delaware River: Observed vs. Predicted Suspended Sediment Load - Group #1

Figure 4.27 Delaware River: Observed vs. Predicted Suspended Sediment Load - Group #2

Figures 4.26 and 4.27 show that the predicted suspended sediment follow the same trend of the observed suspended sediment with some anomalies, year 4 (1953) in Group #1 and year 4 (1956) in Group #2. As explained earlier, these anomalies are caused by the complex hydrologic variations that occur during the entire year and directly impact the river water discharge and the resulting suspended sediment load.

Table 4.4 Delaware River: Data of Linear Regression of River Groups

Group(s)	Annual Precipitation (in)	Corrected Predicted Suspended Sediment Load (ton/yr)	Observed Sediment Suspended Load (ton/year)	Absolute Percent Deviation	Mean of Absolute Values of Deviation
Group #1	10.0 – 13.9	1156	2058	44%	30%
		559	508	10%	
		2300	3030	24%	
		1838	1073	71%	
		977	966	1%	
Group #2	14.0 – 17.0	1628	1053	55%	30%
		365	310	18%	
		2953	2996	1%	
		1093	2087	48%	
		1032	1195	14%	

Group #1: (Precipitation Range 10.0 – 13.9 inches)

Listed in Table 4.4 are the absolute percent deviation values (column 5), which show the accuracy of the suspended sediment load prediction. The lower the deviation, the higher the accuracy. Group #1 consists of 5 data points, of which 3 points resulted in percent deviations ranging from 1% to 24%, with an average of 12%, and 2 points with percent deviations ranging from 44% to 71%, with an average of 58%. The average percent deviation of the entire data set (5 points) is 30%, as shown in Table 4.4. Therefore, over 50% of the data points (3 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.80) obtained for Group #1.

Group #2: (Precipitation Ranges 14.0 – 17.0 inches)

Group #2 consists of 5 data points, of which 3 points resulted in percent deviations ranging from 1% to 18%, with an average of 11%, and 2 points with percent deviations ranging from 48% to 55%, with an average of 52%. The average percent deviation of the entire data set (5 points) is 30%, as shown in Table 4.4. Once again, over 50% of the data points (5 points) yielded a small percent deviation indicating high accuracy of the prediction. The high accuracy of the prediction is also supported by the high value of the correlation coefficient (0.88) obtained for Group #2.

In Group #1, the mean percent deviation decreased significantly when the sole outlier was removed from the data points. The value of the mean percent deviation decreased from 30% down to 20%. Also, in Group #2 when one outlier was removed the mean of the percent deviations went from 30% down to 20%. This proves that the outliers have a significant statistical impact upon the percent deviation for each of these two groups.

Complete Data Set**:** (Traditional)

The regression relationship for the complete data set is shown in Figure 4.28, the regression equation in this case is: $\log Y = 0.8078 \log X - 0.0328$

and the correlation coefficient is 0.36.

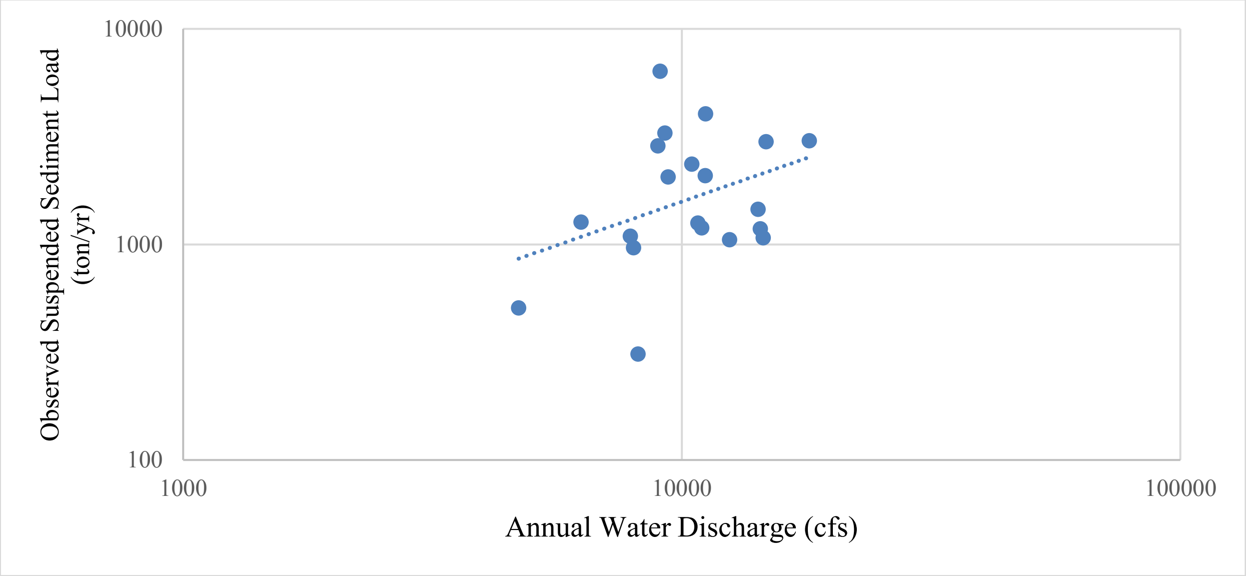

Figure 4.28 Delaware River – Complete Data Set: Regression Relationship of the Annual Suspended Sediment Load and Annual Water Discharge

This regression equation was used to predict the suspended sediment load. The predicted values were compared to the observed values in Figure 4.29.

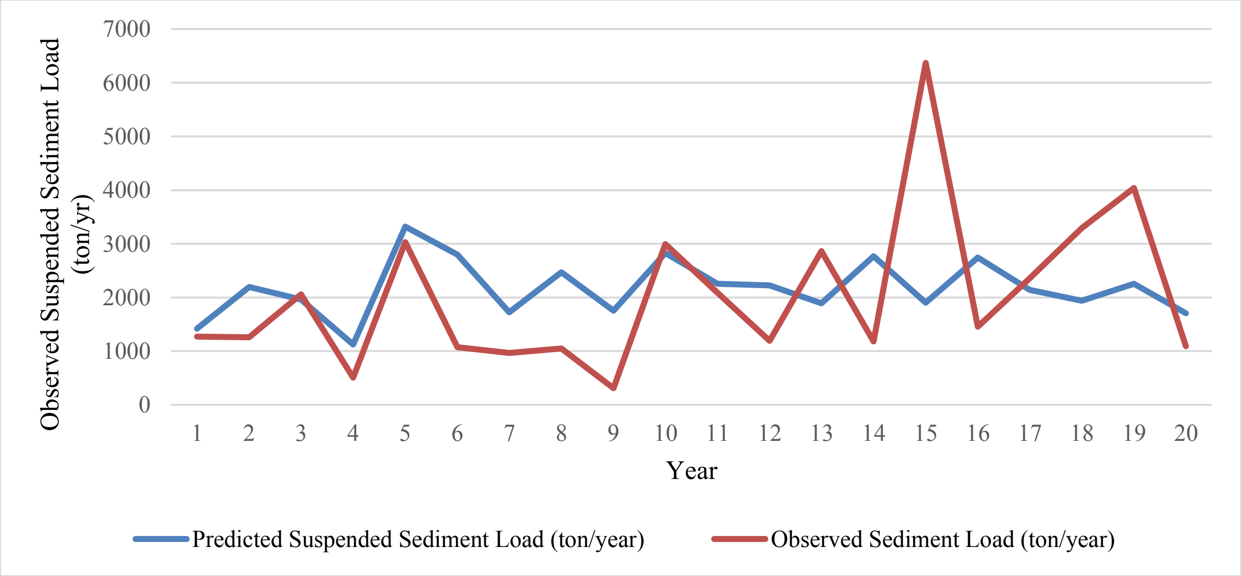

Figure 4.29 Delaware River: Observed vs. Predicted Suspended Sediment Load – Complete Data Set

The complete data set resulted in percent deviations ranging from 5% to 465%, with an average of 82%. The correlation coefficient in this case is 0.36. This extremely low value of the correlation coefficient indicates little or no correlation between water discharge and suspended sediment. The low correlation coefficient was caused by the remarkably high percent deviations that characterized the complete data set. The effects of the high percent deviations and low correlation coefficient are reflected in the differences between the observed and predicted suspended sediment (Figure 4.29).

Comparison of the complete data set with the two groups clearly shows the superiority of the proposed approach as the two groups have resulted in significantly higher correlation coefficients (0.80 and 0.88) and much lower percent deviations (30%). Therefore, the proposed approach has significantly improved the prediction of the suspended sediment load in the two groups.

Table 4.5 shows the summary of all correlation coefficient values and percent deviations for all four rivers. This table also compares these values to the precipitation approach and the traditional approach.

Table 4.5 All Rivers: Summary of Correlation Coefficient Values and Absolute Deviation for Precipitation Approach and Traditional Approach

	Maumee River		**Sacramento River**		**Feather River**		**Delaware River**	
Identifier	Correlation Coefficient Values	Absolute Percent Deviation	Correlation Coefficient Values	Average Percent Deviation	Correlation Cofficient Values	Average Percent Deviation	Correlation Cofficient Values	Average Percent Deviation
Group #1	0.87	24%	0.93	27%	0.94	22%	0.80	30%
Group #2	0.85	21%	0.92	21%	0.89	35%	0.88	30%
Group #3	0.93	21%	0.87	20%	NA	NA	NA	NA
Traditional	0.88	18%	0.89	27%	0.85	34%	0.36	82%

Chapter 5 – Conclusions and Future Recommendations

5.1 Conclusions

The objective of this study is to improve the accuracy of predicting suspended sediment loads in rivers and streams as a function of river or stream water discharge using linear regression analysis. To achieve this objective, this study proposed a new approach in which the suspended sediment load and water discharge data were grouped based on similar precipitation values, as precipitation directly impacts the water discharge and the resulting suspended sediment loads, and then linear regression was applied to each group. The traditional linear regression approach does not involve such grouping based on precipitation. In the traditional approach, therefore, all the data are treated as one group.

Compared to the traditional approach, the proposed approach has reasonably improved the accuracy of the prediction of the suspended sediment load using linear regression, as indicated by the increased correlation coefficient values (between the suspended sediment load and the water discharge) and decreased percent deviations (percent difference between the observed and predicted suspended sediment).

Most of the grouped data resulted in low values of percent deviations ranging from 1% to 30% (the lower the percent deviation, the higher the prediction accuracy). A few grouped data yielded higher percent deviations (lower accuracy) ranging from 30% to 86%. All of the grouped data resulted in higher correlation coefficient values greater or equal to 0.80.

5.2 Future Recommendations

Linear regression in this study was applied to four U.S. rivers using annual suspended sediment loads and annual water discharge values. Future studies are recommended to use monthly sediment loads and monthly water discharge values. This may further improve the accuracy of the sediment prediction.

Average monthly precipitation values were used in this study to group the data. Future studies can use daily precipitation values, which may improve the accuracy of the prediction.

Finally, the accuracy of the prediction may also increase by accounting for the effects of sediment sources and sinks and employing the proposed approach with monthly or daily (suspended sediment and water discharge) data.

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Appendix A – Maumee River Grouped Calculations and Data

Group(s) (1)	Year (2)	Annual Observed Precipitation (in) Toledo Airport (NOAA) (3)	Precipitation Percentiles (4)	Average Annual Observed Discharge (cfs) (5)	Average Annual Observed Suspended Sediment Load (ton/day) (6)	Unique Linear Regression Equations for Groups (7)	Log Average Annual Water Discharge (cfs) (8)	Log Average Annual Observed Suspended Sediment Load (ton/day) (9)	Log Predicted Suspended Sediment Load (ton/day) (10)	Uncorrected Predicted Suspended Sediment (ton/yr) (11)	Residual (12)	Transformed Residual (13)	Mean of Residuals (14)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (15)	Observed and Predicted Sediment Load Difference (ton) (16)	Percent Deviation (17)	Absolute Percent of Deviation (18)	Mean of Absolute Values of Deviation (19)
Outliers	1963	22.0	54%	1969	783	Outliers	3.294245716	2.893928127	Outliers									
	1971	23.2	57%	3594	1573		3.555578073	3.196728723										
	1964	24.3	59%	2744	2110		3.438384107	3.324282455										
	1955	24.4	60%	4393	3810		3.642761203	3.580924976										
Group #1	1962	26.4	65%	3176	1565	y=1.8113x-3.2006	3.501880494	3.194514342	3.142356138	1388	0.052158	1.127608143	1.108132	1538	27	2%	2%	24%
	1960	27.2	67%	4062	2306		3.608739919	3.362859303	3.335910615	2167	0.026949	1.064017296	1.108132	2402	-96	-4%	4%	24%
	1991	27.3	67%	4852	3292		3.685920792	3.517459827	3.475708331	2990	0.041751	1.100909186	1.108132	3314	-22	-1%	1%	24%
	1961	27.6	68%	4160	2835		3.619093331	3.452553063	3.35466375	2262.891597	0.097889	1.252821834	1.108132	2508	327	12%	12%	24%
	1958	28.3	69%	4265	2063		3.629919036	3.314499228	3.374272349	2367.403847	-0.05977	0.871418707	1.108132	2623	-560	-27%	27%	24%
	1988	28.6	70%	2963	727		3.471731651	2.861713588	3.08774754	1223.904525	-0.22603	0.594245699	1.108132	1356	-629	-86%	86%	24%
	1974	28.6	70%	5936	5985		3.773493892	3.777064155	3.634329487	4308.533629	0.142735	1.389103699	1.108132	4774	1211	20%	20%	24%
	1976	28.8	70%	4785	4039		3.679881942	3.606273853	3.464770162	2915.883456	0.141504	1.38517196	1.108132	3231	808	20%	20%	24%
	1999	28.8	71%	4529	1988		3.656002321	3.29841638	3.421517003	2639.471661	-0.1231	0.753181036	1.108132	2925	-937	-47%	47%	24%
	1995	28.9	71%	3748	2130		3.573799582	3.328379603	3.272623183	1873.36837	0.055756	1.136989411	1.108132	2076	54	3%	3%	24%
	2002	29.1	71%	4629	2646		3.665487181	3.42258984	3.438696931	2745.977223	-0.01611	0.963591387	1.108132	3043	-397	-15%	15%	24%
	1994	29.2	71%	3530	2011		3.547774705	3.303412071	3.225484324	1680.67726	0.077928	1.196541447	1.108132	1862	149	7%	7%	24%
	1993	29.9	73%	6978	4169		3.843730965	3.620031895	3.761549897	5774.972189	-0.14152	0.721908238	1.108132	6399	-2230	-54%	54%	24%
	1996	30.0	73%	6653	4493		3.823017523	3.652536419	3.72403164	5297.020336	-0.0715	0.848212715	1.108132	5870	-1377	-31%	31%	24%
Group #2	1957	31.0	76%	6085	4613	y=1.1653x-0.822	3.784260583	3.663983455	3.587798857	3870.783284	0.076185	1.191748455	1.18108	4572	41	1%	1%	21%
	1982	31.5	77%	8555	5322		3.932220014	3.72607487	3.760215982	5757.261848	-0.03414	0.924397768	1.18108	6800	-1478	-28%	28%	21%
	1967	31.7	78%	5725	3609		3.757775491	3.557386882	3.55693578	3605.253272	0.000451	1.001039241	1.18108	4258	-649	-18%	18%	21%
	1978	31.7	78%	5282	2871		3.722798397	3.458033192	3.516176972	3282.290168	-0.05814	0.874694147	1.18108	3877	-1006	-35%	35%	21%
	1998	31.9	78%	6503	5016		3.813113754	3.700357528	3.621421458	4182.360435	0.078936	1.199322745	1.18108	4940	76	2%	2%	21%
	1980	31.9	78%	5234	3429		3.718833718	3.535167485	3.511556932	3247.558118	0.023611	1.055870249	1.18108	3836	-407	-12%	12%	21%
	1966	32.1	79%	5021	2935		3.700790221	3.467608106	3.490530845	3094.075059	-0.02292	0.948587201	1.18108	3654	-719	-25%	25%	21%
	1973	32.7	80%	6180	3548		3.790988475	3.549983611	3.59563887	3941.294343	-0.04566	0.900211882	1.18108	4655	-1107	-31%	31%	21%
	1968	33.1	81%	5179	3338		3.714245911	3.523486332	3.50621076	3207.825682	0.017276	1.040580234	1.18108	3789	-451	-14%	14%	21%
	2001	33.4	82%	5944	3463		3.774078801	3.539452492	3.575934027	3766.465784	-0.03648	0.919429566	1.18108	4448	-985	-28%	28%	21%
	1956	33.8	83%	4554	4846		3.658393026	3.68538341	3.441125394	2761.375031	0.244258	1.7549228	1.18108	3261	1585	33%	33%	21%
Group #3	1983	35.7	87%	5685	4031	y=1.3581x-1.5621	3.754730469	3.605412798	3.53719945	3445.0811	0.068213	1.170074051	1.204313	4149	-118	-3%	3%	21%
	1969	35.8	88%	5988	3154		3.777281792	3.498861689	3.567826401	3696.803794	-0.06896	0.853169434	1.204313	4452	-1298	-41%	41%	21%
	1979	36.2	89%	5490	3136		3.739572344	3.496376054	3.516613201	3285.588736	-0.02024	0.954471254	1.204313	3957	-821	-26%	26%	21%
	1992	37.0	91%	7147	4179		3.854123782	3.621072371	3.672185508	4700.948663	-0.05111	0.888969504	1.204313	5661	-1482	-35%	35%	21%
	1959	37.2	91%	7017	4902		3.846151477	3.690373307	3.66135832	4585.200386	0.029015	1.069091771	1.204313	5522	-620	-13%	13%	21%
	1989	37.4	92%	4221	3667		3.625415352	3.56431091	3.36157659	2299.199147	0.202734	1.594903166	1.204313	2769	898	24%	24%	21%
	1970	37.8	93%	4586	2724		3.66143405	3.435207103	3.410493584	2573.318747	0.024714	1.058555223	1.204313	3099	-375	-14%	14%	21%
	1997	38.1	93%	7336	5272		3.865459323	3.721975402	3.687580306	4870.575795	0.034395	1.082418224	1.204313	5866	-594	-11%	11%	21%
	2000	38.1	93%	4196	2196		3.62283548	3.341632336	3.358072865	2280.724694	-0.01644	0.962851854	1.204313	2747	-551	-25%	25%	21%
Outliers	1981	38.4	94%	6684	5124	Outliers	3.825036441	3.709609121	Outliers									
	1972	38.4	94%	7586	5837		3.880012838	3.766189693										
	1990	38.4	94%	7994	6370		3.902764144	3.804139432										
	1975	38.6	94%	5798	4780		3.763278211	3.679427897										
	1977	38.8	95%	5118	3741		3.709100282	3.572987708										
	1965	40.9	100%	4334	2735		3.636888907	3.436957331										

(4) = [percipitation value/max percipitation] * 100

(7) = Linear Regression analysis of columns (9) & (8)

(8) = Log (5)

(9) = Log (6)

(10) = Generated from Unique Linear Regression [variable x = (8)]

(11) = $10^{(10)}$

(12) = log observed suspended sediment - log predicted suspended sediment

(13) = $10^{(12)}$

(14) = (13/number of 13)

(15) = (10) * (14)

(16) = (6) - (15)

(17) = [(16)/(6) * 100]

(18) = Absolute Value (17)

(19) = (18)/(number of 18)

Appendix B – Maumee River Complete Calculations and Data

Year (1)	Average Annual Observed Discharge (cfs) (2)	Average Annual Observed Supsended Sediment Load (ton/day) (3)	Unique Linear Regression Equations for Whole Data Set (4)	Log Average Annual Water Discharge (cfs) (5)	Log Average Annual Observed Suspended Sediment Load (ton/day) (6)	Log Predicted Suspended Sediment Load (ton/day) (7)	Uncorrected Predicted Suspended Sediment (ton/yr) (8)	Residual (9)	Transformed Residual (10)	Mean of Residuals (11)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (12)	Observed and Predicted Sediment Load Difference (ton) (13)	Percent Deviation (14)	Absolute Percent of Deviation (15)	Mean of Absolute Values of Deviation (16)
1955	4393	3810	y=1.3881x-1.6358	3.6427612	3.580925	3.4207168	2635	0.1602081	1.44613271	1.0256508	2702.1928	1107.8072	29%	29%	18.00%
1956	4554	4846		3.658393	3.6853834	3.4424154	2770	0.2429681	1.74971796	1.0256508	2840.6313	2005.3687	41%	41%	18.00%
1957	6085	4613		3.7842606	3.6639835	3.6171321	4141	0.0468513	1.11391317	1.0256508	4247.4828	365.51724	8%	8%	18.00%
1958	4265	2063		3.629919	3.3144992	3.4028906	2529	-0.088391	0.8158468	1.0256508	2593.5231	-530.5231	-26%	26%	18.00%
1959	7017	4902		3.8461515	3.6903733	3.7030429	5047	-0.01267	0.97124868	1.0256508	5176.5734	-274.5734	-6%	6%	18.00%
1960	4062	2306		3.6087399	3.3628593	3.3734919	2363	-0.010633	0.97581485	1.0256508	2423.7699	-117.7699	-5%	5%	18.00%
1961	4160	2835		3.6190933	3.4525531	3.3878635	2443	0.0646896	1.16061883	1.0256508	2505.3186	329.6814	12%	12%	18.00%
1962	3176	1565		3.5018805	3.1945143	3.2251603	1679	-0.030646	0.93186721	1.0256508	1722.5023	-157.5023	-10%	10%	18.00%
1963	1969	783.3		3.2942457	2.8939281	2.9369425	865	-0.043014	0.90570267	1.0256508	887.03752	-103.7375	-13%	13%	18.00%
1964	2744	2110		3.4383841	3.3242825	3.137021	1371	0.1872615	1.539081	1.0256508	1406.1139	703.88614	33%	33%	18.00%
1965	4334	2735		3.6368889	3.4369573	3.4125655	2586	0.0243918	1.05777145	1.0256508	2651.948	83.052016	3%	3%	18.00%
1966	5021	2935		3.7007902	3.4676081	3.5012669	3172	-0.033659	0.92542494	1.0256508	3252.8678	-317.8678	-11%	11%	18.00%
1967	5725	3609		3.7577755	3.5573869	3.5803682	3805	-0.022981	0.94845935	1.0256508	3902.7225	-293.7225	-8%	8%	18.00%
1968	5179	3338		3.7142459	3.5234863	3.5199447	3311	0.0035416	1.00818814	1.0256508	3395.8168	-57.81685	-2%	2%	18.00%
1969	5988	3154		3.7772818	3.4988617	3.6074449	4050	-0.108583	0.77878367	1.0256508	4153.7884	-999.7884	-32%	32%	18.00%
1970	4586	2724		3.6614341	3.4352071	3.4466366	2797	-0.01143	0.97402588	1.0256508	2868.3762	-144.3762	-5%	5%	18.00%
1971	3594	1573		3.5555781	3.1967287	3.2996979	1994	-0.102969	0.78891606	1.0256508	2045.0194	-472.0194	-30%	30%	18.00%
1972	7586	5837		3.8800128	3.7661897	3.7500458	5624	0.0161439	1.03787218	1.0256508	5768.2667	68.733319	1%	1%	18.00%
1973	6180	3548		3.7909885	3.5499836	3.6264711	4231	-0.076487	0.83851823	1.0256508	4339.809	-791.809	-22%	22%	18.00%
1974	5936	5985		3.7734939	3.7770642	3.6021869	4001	0.1748773	1.49581293	1.0256508	4103.8018	1881.1982	31%	31%	18.00%
1975	5798	4780		3.7632782	3.6794279	3.5880065	3873	0.0914214	1.23430194	1.0256508	3971.9703	808.02968	17%	17%	18.00%
1976	4785	4039		3.6798819	3.6062739	3.4722441	2966	0.1340297	1.36153788	1.0256508	3042.5914	996.4086	25%	25%	18.00%
1977	5118	3741		3.7091003	3.5729877	3.5128021	3257	0.0601856	1.14864442	1.0256508	3340.4241	400.57588	11%	11%	18.00%
1978	5282	2871		3.7227984	3.4580332	3.5318165	3403	-0.073783	0.84375574	1.0256508	3489.924	-618.924	-22%	22%	18.00%
1979	5490	3136		3.7395723	3.4963761	3.5551004	3590	-0.058724	0.87352569	1.0256508	3682.1365	-546.1365	-17%	17%	18.00%
1980	5234	3429		3.7188337	3.5351675	3.5263131	3360	0.0088544	1.02059727	1.0256508	3445.9787	-16.97874	0%	0%	18.00%
1981	6684	5124		3.8250364	3.7096091	3.6737331	4718	0.035876	1.08611556	1.0256508	4838.7434	285.25658	6%	6%	18.00%
1982	8555	5322		3.93222	3.7260749	3.8225146	6645	-0.09644	0.80086676	1.0256508	6815.7572	-1493.757	-28%	28%	18.00%
1983	5685	4031		3.7547305	3.6054128	3.5761414	3768	0.0292714	1.06972325	1.0256508	3864.9232	166.07675	4%	4%	18.00%
1988	2963	727.3		3.4717317	2.8617136	3.1833107	1525	-0.321597	0.47687316	1.0256508	1564.2646	-836.9646	-115%	115%	18.00%
1989	4221	3667		3.6254154	3.5643109	3.3966391	2493	0.1676719	1.47120049	1.0256508	2556.4574	1110.5426	30%	30%	18.00%
1990	7994	6370		3.9027641	3.8041394	3.7816269	6048	0.0225125	1.05320406	1.0256508	6203.3519	166.64811	3%	3%	18.00%
1991	4852	3292		3.6859208	3.5174598	3.4806267	3024	0.0368332	1.08851188	1.0256508	3101.8883	190.11165	6%	6%	18.00%
1992	7147	4179		3.8541238	3.6210724	3.7141092	5177	-0.093037	0.80716654	1.0256508	5310.1738	-1131.174	-27%	27%	18.00%
1993	6978	4169		3.843731	3.6200319	3.699683	5008	-0.079651	0.83243234	1.0256508	5136.6794	-967.6794	-23%	23%	18.00%
1994	3530	2011		3.5477747	3.3034121	3.2888661	1945	0.014546	1.03406063	1.0256508	1994.6448	16.355158	1%	1%	18.00%
1995	3748	2130		3.5737996	3.3283796	3.3249912	2113	0.0033884	1.0078326	1.0256508	2167.6577	-37.65773	-2%	2%	18.00%
1996	6653	4493		3.8230175	3.6525364	3.6709306	4687	-0.018394	0.95853019	1.0256508	4807.62	-314.62	-7%	7%	18.00%
1997	7336	5272		3.8654593	3.7219754	3.7298441	5368	-0.007869	0.98204483	1.0256508	5506.0937	-234.0937	-4%	4%	18.00%
1998	6503	5016		3.8131138	3.7003575	3.6571832	4541	0.0431743	1.10452189	1.0256508	4657.8201	358.17989	7%	7%	18.00%
1999	4529	1988		3.6560023	3.2984164	3.4390968	2749	-0.14068	0.72330182	1.0256508	2819.0081	-831.0081	-42%	42%	18.00%
2000	4196	2196		3.6228355	3.3416323	3.3930579	2472	-0.051426	0.88833016	1.0256508	2535.4639	-339.4639	-15%	15%	18.00%
2001	5944	3463		3.7740788	3.5394525	3.6029988	4009	-0.063546	0.86388057	1.0256508	4111.4811	-648.4811	-19%	19%	18.00%
2002	4629	2646		3.6654872	3.4225898	3.4522628	2833	-0.029673	0.93395744	1.0256508	2905.7769	-259.7769	-10%	10%	18.00%

(4) = Linear Regression analysis of columns (6) & (5)
(5) = Log (2)
(6) = Log (3)
(7) = Generated from Unique Linear Regression [variable x = (5)]
(8) = Log (5)
(9) = (6) - (7)
(10) = $10^{(9)}$
(11) = ((10)/number of (10))
(12) = (11) * (8)
(13) = (3) - (12)
(17) = [((13)/(3)) * 100]
(18) = Absolute Value (14)
(19) = (15)/(number of (15))

Appendix C – Sacramento River Grouped Calculations and Data

Groups (1)	Year (2)	Annual Observed Precipitation (in) Toledo Airport (NOAA) (3)	Precipitation Percentiles (4)	Average Annual Observed Discharge (cfs) (5)	Average Annual Observed Suspended Sediment Load (ton/day) (6)	Unique Linear Regression Equations for Groups (7)	Log Average Annual Water Discharge (cfs) (8)	Log Average Annual Observed Suspended Sediment Load (ton/day) (9)	Log Predicted Suspended Sediment Load (ton/day) (10)	Uncorrected Predicted Suspended Sediment (ton/yr) (11)	Residual (12)	Transformed Residual (13)	Mean of Residuals (14)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (15)	Observed and Predicted Sediment Load Difference (ton) (16)	Percent Deviation (17)	Absolute Percent of Deviation (18)	Mean of Absolute Values of Deviation (19)
	1976	6.3	24%	15180	1834		4.18127	3.2633993	Outlier(s)									
Group #1	1971	9.8	37%	31590	8805	y=2.029x-5.0385	4.49955	3.9447294	4.0910862	12333.4958	-4.09109	8.108E-05	0.807005	9953	-1148.199	13%	13%	27%
	1977	11.7	44%	7608	608.7		3.88127	2.7844033	2.8365979	686.432524	-2.8366	0.001456807	0.807005	554	54.745192	-9%	9%	27%
	1975	13.2	50%	27450	7781		4.43854	3.8910354	3.9673024	9274.75456	-3.9673	0.00010782	0.807005	7485	296.22224	-4%	4%	27%
	1961	13.2	50%	15740	5324		4.19700	3.726238	3.4772226	3000.7001	0.249015	1.774252614	0.807005	2422	2902.4186	-55%	55%	27%
	1965	13.8	52%	27530	15570		4.43981	4.1922886	3.9698668	9329.68118	0.222422	1.668867317	0.807005	7529	8040.8962	-52%	52%	27%
	1972	13.9	53%	17250	2294		4.23679	3.3605934	3.5579451	3613.64165	-0.19735	0.634816682	0.807005	2916	-622.2286	27%	27%	27%
Group #2	1968	14.9	56%	18440	4377	y=1.0324x-0.7441	4.26576	3.6411765	3.6598716	4569.53039	-0.0187	0.957866481	0.807005	3688	689.36393	16%	16%	21%
	1974	15.2	57%	42340	10470		4.62675	4.0199467	4.0325576	10778.4815	-0.01261	0.971379872	0.807005	8698	1771.7063	17%	17%	21%
	1960	15.2	57%	14820	4821		4.17085	3.6831371	3.5618837	3646.5627	0.121253	1.322066942	0.807005	2943	1878.2039	39%	39%	21%
	1964	16.7	63%	16020	2921		4.20466	3.4655316	3.5967936	3951.78745	-0.13126	0.739159188	0.807005	3189	-268.1141	-9%	9%	21%
	1957	17.0	64%	18220	4626		4.26055	3.6652056	3.6544901	4513.25778	0.010715	1.02498023	0.807005	3642	983.77623	21%	21%	21%
	1967	19.6	74%	33380	9073		4.52349	3.9577509	3.9259473	8432.32408	0.031804	1.075978569	0.807005	6805	2268.0683	25%	25%	21%
Group #3	1979	20.3	77%	17950	3341	y=1.5461x-2.9114	4.25406	3.5238765	3.6658091	4632.43198	-0.14193	0.721219441	0.807005	3738	-397.398	-12%	12%	20%
	1962	21.6	81%	17930	5498		4.25358	3.7402047	3.6650605	4624.45423	0.075144	1.188897051	0.807005	3732	1766.0401	32%	32%	20%
	1963	21.6	82%	28020	10810		4.44747	4.0338257	3.9648305	9222.1138	0.068995	1.172182455	0.807005	7442	3367.7036	31%	31%	20%
	1970	23.1	87%	27890	7644		4.44545	3.8833207	3.9617079	9156.04562	-0.07839	0.834858226	0.807005	7389	255.02101	3%	3%	20%
	1978	23.7	90%	24360	10490		4.38668	4.0207755	3.8708417	7427.48441	0.149934	1.412322049	0.807005	5994	4495.9794	43%	43%	20%
	1969	23.9	90%	32060	9463		4.50596	3.9760288	4.0552702	11357.1718	-0.07924	0.833218003	0.807005	9165	297.70012	3%	3%	20%
	1958	24.4	92%	35750	13640		4.55328	4.1348144	4.1284201	13440.6445	0.006394	1.014832286	0.807005	10847	2793.3262	20%	20%	20%
	1973	26.5	100%	28520	7118		4.45515	3.852358	Outlier(s)									

(4) = [percipitation value/max percipitation] * 100

(7) = Linear Regression analysis of columns (9) & (8)

(8) = Log (5)

(9) = Log (6)

(10) = Generated from Unique Linear Regression [variable x = (8)]

(11) = $10^{(10)}$

(12) = log observed suspended sediment - log predicted suspended sediment

(13) = $10^{(12)}$

(14) = (13/number of 13)

(15) = (10) * (14)

(16) = (6) - (15)

(17) = [(16)/(6) * 100]

(18) = Absolute Value (17)

(19) = (18)/(number of 18)

Appendix D – Sacramento River Complete Calculations and Data

Year (1)	Average Annual Observed Discharge (cfs) (2)	Average Annual Observed Suspended Sediment Load (ton/day) (3)	Unique Linear Regression Equations for Whole Data Set (4)	Log Average Annual Water Discharge (cfs) (5)	Log Average Annual Observed Suspended Sediment Load (ton/day) (6)	Log Predicted Suspended Sediment Load (ton/day) (7)	Uncorrected Predicted Suspended Sediment (ton/yr) (8)	Residual (9)	Transformed Residual (10)	Mean of Residuals (11)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (12)	Observed and Predicted Sediment Load Difference (ton) (13)	Percent Deviation (14)	Absolute Percent of Deviation (15)	Mean of Absolute Values of Deviation (16)
1957	18220	4626	y=1.702x-3.6433	4.181271772	3.263399331	3.473224555	2973	-3.4732	0.00033634	0.95948339	2852.7388	-1018.739	-56%	56%	27%
1958	35750	13640		4.499549626	3.94472936	4.014933463	10350	-4.0149	9.662E-05	0.95948339	9930.4956	-1125.496	-13%	13%	27%
1960	14820	4821		3.881270504	2.784403302	2.962622398	918	-2.9626	0.00108988	0.95948339	880.3591	-271.6591	-45%	45%	27%
1961	15740	5324		4.438542349	3.891035415	3.911099078	8149	-3.9111	0.00012272	0.95948339	7818.7358	-37.73577	0%	0%	27%
1962	17930	5498		4.197004728	3.726238047	3.500002047	3162	0.22624	1.68358869	0.95948339	3034.1672	2289.8328	43%	43%	27%
1963	28020	10810		4.439806211	4.192288613	3.913250172	8189	0.27904	1.90124656	0.95948339	7857.5586	7712.4414	50%	50%	27%
1964	16020	2921		4.236789099	3.360593414	3.567715047	3696	-0.2071	0.62069517	0.95948339	3546.1125	-1252.112	-55%	55%	27%
1965	27530	15570		4.265760917	3.641176547	3.61702508	4140	0.02415	1.05718615	0.95948339	3972.4875	404.5125	9%	9%	27%
1967	33380	9073		4.626750854	4.019946682	4.231429953	17038	-0.2115	0.6144927	0.95948339	16348.105	-5878.105	-56%	56%	27%
1968	18440	4377		4.170848204	3.683137131	3.455483643	2854	0.22765	1.68909272	0.95948339	2738.5527	2082.4473	43%	43%	27%
1969	32060	9463		4.204662512	3.465531557	3.513035595	3259	-0.0475	0.89638785	0.95948339	3126.6053	-205.6053	-7%	7%	27%
1970	27890	7644		4.260548373	3.665205628	3.60815333	4057	0.05705	1.14038711	0.95948339	3892.1609	733.83906	16%	16%	27%
1971	31590	8805		4.523486332	3.957750911	4.055673738	11368	-0.0979	0.7981365	0.95948339	10907.148	-1834.148	-20%	20%	27%
1972	17250	2294		4.254064453	3.523876476	3.597117699	3955	-0.0732	0.84480948	0.95948339	3794.5053	-453.5053	-14%	14%	27%
1973	28520	7118		4.25358029	3.740204736	3.596293653	3947	0.14391	1.3928716	0.95948339	3787.3122	1710.6878	31%	31%	27%
1974	42340	10470		4.447468131	4.033825694	3.926290759	8439	0.10753	1.28095813	0.95948339	8097.076	2712.924	25%	25%	27%
1975	27450	7781		4.445448514	3.883320678	3.922853371	8372	-0.0395	0.9129927	0.95948339	8033.2416	-389.2416	-5%	5%	27%
1976	15180	1834		4.386677284	4.020775488	3.822824737	6650	0.19795	1.57743238	0.95948339	6380.6099	4109.3901	39%	39%	27%
1977	7608	608.7		4.505963518	3.97602884	4.025849908	10613	-0.0498	0.89161822	0.95948339	10183.273	-720.2725	-8%	8%	27%
1978	24360	10490		4.553276046	4.13481437	4.106375831	12775	0.02844	1.06767369	0.95948339	12257.821	1382.1786	10%	10%	27%
1979	17950	3341		4.455149521	3.852357984	3.939364485	8697	-0.087	0.81845254	0.95948339	8344.5312	-1226.531	-17%	17%	27%

(4) = Linear Regression analysis of columns (6) & (5)
(5) = Log (2)
(6) = Log (3)
(7) = Generated from Unique Linear Regression [variable x = (5)]
(8) = Log (5)
(9) = (6) - (7)
(10) = $10^{(9)}$
(11) = ((10)/number of (10))
(12) = (11) * (8)
(13) = (3) - (12)
(14) = [((13)/(3)) * 100]
(15) = Absolute Value (14)
(16) = Average of (15)

Appendix E – Delaware River Grouped Calculations and Data

Groups (1)	Year (2)	Annual Observed Precipitation (in) Toledo Airport (NOAA) (3)	Precipitation Percentiles (4)	Average Annual Observed Discharge (cfs) (5)	Average Annual Observed Suspended Sediment Load (ton/day) (6)	Unique Linear Regression Equations for Groups (7)	Log Average Annual Water Discharge (cfs) (8)	Log Average Annual Observed Suspended Sediment Load (ton/day) (9)	Log Predicted Suspended Sediment Load (ton/day) (10)	Uncorrected Predicted Suspended Sediment (ton/yr) (11)	Residual (12)	Transformed Residual (13)	Mean of Residuals (14)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (15)	Observed and Predicted Sediment Load Difference (ton) (16)	Percent Deviation (17)	Absolute Percent of Deviation (18)	Mean of Absolute Values of Deviation (19)
Outliers	1967	6.3	24	6277	1271	Outliers	3.798	3.104145551	Outliers									
	1962	9.8	37	10780	1258		4.033	3.099680641										
Group #1	1968	11.7	44	9386	2058	y=1.0546x-1.1081	3.972	3.31344537	3.081277988	1205.80752	0.232167	1.70674	0.958901	1156	902	44%	44%	30.06%
	1966	13.2	50	4708	508.1		3.673	2.705949195	2.765273325	582.4696815	-0.05932	0.87232	0.958901	559	-50	-10%	10%	30.06%
	1953	13.2	50	18020	3030		4.256	3.481442629	3.380018998	2398.937857	0.101424	1.263059	0.958901	2300	730	24%	24%	30.06%
	1957	13.8	52	14570	1073		4.163	3.030599722	3.282684443	1917.27515	-0.25208	0.559648	0.958901	1838	-765	-71%	71%	30.06%
	1963	13.9	53	8004	966.3		3.903	2.98511198	3.008327647	1019.360138	-0.02322	0.947948	0.958901	977	-11	-1%	1%	30.06%
Group #2	1959	14.9	56	12480	1053	y=3.5347x-11.249	4.096	3.022428371	3.229889695	1697.812375	-0.20746	0.62021	0.958901	1628	-575	-55%	55%	29.87%
	1965	15.2	57	8175	310.4		3.912	2.491921713	2.58047049	380.6014951	-0.08855	0.815551	0.958901	365	-55	-18%	18%	29.87%
	1952	15.2	57	14770	2996		4.169	3.476541809	3.488509237	3079.705841	-0.01197	0.97282	0.958901	2953	43	1%	1%	29.87%
	1956	16.7	63	11150	2087		4.047	3.319522449	3.056902474	1139.993759	0.26262	1.830712	0.958901	1093	994	48%	48%	29.87%
	1950	17.0	64	10970	1195		4.040	3.077367905	3.031918366	1076.262892	0.04545	1.110324	0.958901	1032	163	14%	14%	29.87%
Group #3	1958	19.6	74	8957	2861	y=-2.5348x+13.652	3.952	3.456517858	3.634058307	4305.844154	-0.17754	0.664446	0.958901	4129	-1268	-44%	44%	24.71%
	1954	21.6	81	14380	1180		4.158	3.071882007	3.112912776	1296.91877	-0.04103	0.909849	0.958901	1244	-64	-5%	5%	24.71%
	1955	21.6	82	9051	6369		3.957	3.804071249	3.622565547	4193.392821	0.181506	1.518818	0.958901	4021	2348	37%	37%	24.71%
	1961	23.1	87	14230	1456		4.153	3.163161375	3.124456219	1331.852773	0.038705	1.093214	0.958901	1277	179	12%	12%	24.71%
Outliers	1969	23.7	90	10480	2359	Outliers	4.020	3.372727941	Outliers									
	1960	23.9	90	9248	3291		3.966	3.517327882										
	1951	24.4	92	11160	4039		4.048	3.606273853										
	1964	26.5	100	7883	1092		3.897	3.038222638										

(4) = [percipitation value/max percipitation] * 100
(7) = Linear Regression analysis of columns (9) & (8)
(8) = Log (5)
(9) = Log (6)
(10) = Generated from Unique Linear Regression [variable x = (8)]
(11) = $10^{(10)}$
(12) = log observed suspended sediment - log predicted suspended sediment
(13) = $10^{(12)}$
(14) = (13/number of 13)
(15) = (10) * (14)
(16) = (6) - (15)
(17) = [(16)/(6) * 100]
(18) = Absolute Value (17)
(19) = (18)/(number of 18)

Appendix F – Delaware River Complete Calculations and Data

Year (1)	Average Annual Observed Discharge (cfs) (2)	Average Annual Observed Supsended Sediment Load (ton/day) (3)	Unique Linear Regression Equations for Whole Data Set (4)	Log Average Annual Water Discharge (cfs) (5)	Log Average Annual Observed Suspended Sediment Load (ton/day) (6)	Log Predicted Suspended Sediment Load (ton/day) (7)	Uncorrected Predicted Suspended Sediment (ton/yr) (8)	Residual (9)	Transformed Residual (10)	Mean of Residuals (11)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (12)	Observed and Predicted Sediment Load Difference (ton) (13)	Percent Deviation (14)	Absolute Percent of Deviation (15)	Mean of Absolute Values of Deviation (16)
1950	10970	1195	y=0.8078x-0.0328	3.798	3.104145551	3.03502417	1083.98724	0.06912	1.17252303	1.3072628	1417.0562	-146.0562	-11%	11%	82%
1951	11160	4039		4.033	3.099680641	3.22474944	1677.83572	-0.1251	0.74977543	1.3072628	2193.3722	-935.3722	-74%	74%	82%
1952	14770	2996		3.972	3.31344537	3.17616979	1500.27125	0.13728	1.37175194	1.3072628	1961.2488	96.751197	5%	5%	82%
1953	18020	3030		3.673	2.705949195	2.93411729	859.245542	-0.2282	0.59133272	1.3072628	1123.2597	-615.1597	-121%	121%	82%
1954	14380	1180		4.256	3.481442629	3.40499872	2540.9652	0.07644	1.19246025	1.3072628	3321.7093	-291.7093	-10%	10%	82%
1955	9051	6369		4.163	3.030599722	3.33044263	2140.14218	-0.2998	0.50136856	1.3072628	2797.7283	-1724.728	-161%	161%	82%
1956	11150	2087		3.903	2.98511198	3.12029146	1319.14173	-0.1352	0.73252174	1.3072628	1724.4649	-758.1649	-78%	78%	82%
1957	14570	1073		4.096	3.022428371	3.27612214	1888.52241	-0.2537	0.55757877	1.3072628	2468.7951	-1415.795	-134%	134%	82%
1958	8957	2861		3.912	2.491921713	3.12770761	1341.86126	-0.6358	0.23132049	1.3072628	1754.1653	-1443.765	-465%	465%	82%
1959	12480	1053		4.169	3.476541809	3.33522556	2163.84209	0.14132	1.38457423	1.3072628	2828.7103	167.28973	6%	6%	82%
1960	9248	3291		4.047	3.319522449	3.23658864	1724.20396	0.08293	1.21041365	1.3072628	2253.9877	-166.9877	-8%	8%	82%
1961	14230	1456		4.040	3.077367905	3.23087891	1701.68399	-0.1535	0.70224554	1.3072628	2224.5482	-1029.548	-86%	86%	82%
1962	10780	1258		3.952	3.456517858	3.15975693	1444.63099	0.29676	1.98043654	1.3072628	1888.5124	972.48764	34%	34%	82%
1963	8004	966.3		4.158	3.071882007	3.32583763	2117.56928	-0.254	0.55724269	1.3072628	2768.2196	-1588.22	-135%	135%	82%
1964	7883	1092		3.957	3.804071249	3.16341949	1456.86559	0.64065	4.37171421	1.3072628	1904.5062	4464.4938	70%	70%	82%
1965	8175	310.4		4.153	3.163161375	3.32215892	2099.70807	-0.159	0.69342973	1.3072628	2744.8703	-1288.87	-89%	89%	82%
1966	4708	508.1		4.020	3.372727941	3.21484784	1640.01509	0.15788	1.4384014	1.3072628	2143.9307	215.06928	9%	9%	82%
1967	6277	1271		3.966	3.517327882	3.17097343	1482.42739	0.34635	2.22000756	1.3072628	1937.9222	1353.0778	41%	41%	82%
1968	9386	2058		4.048	3.606273853	3.23690314	1725.45301	0.36937	2.34083454	1.3072628	2255.6205	1783.3795	44%	44%	82%
1969	10480	2359		3.897	3.038222638	3.11494742	1303.009	-0.0767	0.83806021	1.3072628	1703.3752	-611.3752	-56%	56%	82%

(4) = Linear Regression analysis of columns (6) & (5)
(5) = Log (2)
(6) = Log (3)
(7) = Generated from Unique Linear Regression [variable x = (5)]
(8) = Log (5)
(9) = (6) - (7)
(10) = $10^{(9)}$
(11) = ((10)/number of (10))
(12) = (11) * (8)
(13) = (3) - (12)
(17) = [((13)/(3)) * 100]
(18) = Absolute Value (14)
(19) = (15)/(number of (15))

Appendix G – Feather River Grouped Calculations and Data

Groups (1)	Year (2)	Annual Observed Precipitation (in) Toledo Airport (NOAA) (3)	Precipitation Percentiles (4)	Average Annual Observed Discharge (cfs) (5)	Average Annual Observed Suspended Sediment Load (ton/day) (6)	Unique Linear Regression Equations for Groups (7)	Log Average Annual Water Discharge (cfs) (8)	Log Average Annual Observed Suspended Sediment Load (ton/day) (9)	Log Predicted Suspended Sediment Load (ton/day) (10)	Uncorrected Predicted Suspended Sediment (ton/yr) (11)	Residual (12)	Transformed Residual (13)	Mean of Residuals (14)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (15)	Observed and Predicted Sediment Load Difference (ton) (16)	Percent Deviation (17)	Absolute Percent of Deviation (18)	Mean of Absolute Values of Deviation (19)
Outliers	1976	7.41	16	2706	61.7	Outliers	3.432327792	1.790285164	Outliers									
	1977	13.02	28	1394	53.2		3.144262774	1.725911632										
	1985	13.09	28	2998	60.7		3.476831629	1.783188691										
	1971	13.26	29	6319	182.8		3.800648355	2.261976191										
Group #1	1975	14.15	31	4494	196.2	y=1.0691x-1.7002	3.652633068	2.292699003	2.092002348	124	0.200697	1.58743757	0.818793	101	95	48%	48%	22.20%
	1989	15.04	33	2528	32.7		3.40277707	1.514547753	1.697979439	50	-0.18343	0.655493386	0.818793	41	-8	-25%	25%	22.20%
	1986	16.54	36	6801	182.4		3.832572775	2.261024834	2.375767266	238	-0.11474	0.767816725	0.818793	195	-12	-7%	7%	22.20%
	1988	16.85	36	2150	46.2		3.33243846	1.664641976	1.587055451	39	0.077587	1.195601701	0.818793	32	15	32%	32%	22.20%
	1972	17.03	37	3247	62.9		3.511482289	1.798650645	1.869407569	74	-0.07076	0.849655898	0.818793	61	2	4%	4%	22.20%
	1987	19.40	42	2253	55.7		3.352761192	1.745855195	1.619104399	42	0.126751	1.338908183	0.818793	34	22	39%	39%	22.20%
	1980	19.69	43	5741	305.6		3.758987547	2.48515335	2.259723361	182	0.22543	1.680467000	0.818793	149	157	51%	51%	22.20%
	1974	19.77	43	10370	359.7		4.015778756	2.555940438	2.664683099	462	-0.10874	0.778497709	0.818793	378	-19	-5%	5%	22.20%
	1990	21.22	46	2902	49		3.462697408	1.69019608	1.792473813	62	-0.10228	0.790173148	0.818793	51	-2	-4%	4%	22.20%
	1991	21.22	46	1530	20.1		3.184691431	1.303196057	1.354058386	23	-0.05086	0.889483039	0.818793	19	2	8%	8%	22.20%
Group #2	1992	24.30	53	1587	21.9	y=1.7169x-4.134	3.200576927	1.340444115	1.556085178	36	-0.21564	0.608637822	0.818793	29	-8	-35%	35%	34.79%
	1979	24.36	53	2934	85.1		3.46746011	1.92992956	1.937808195	87	-0.00788	0.982022335	0.818793	71	14	17%	17%	34.79%
	1970	26.00	56	7418	768.1		3.870286829	2.885417765	2.513971252	327	0.371447	2.352049804	0.818793	267	501	65%	65%	34.79%
	1978	27.32	59	3111	124.9		3.492900011	2.096562438	1.974194886	94	0.122368	1.325462827	0.818793	77	48	38%	38%	34.79%
	1993	28.35	61	4401	114.5		3.643551369	2.058805487	2.189671522	155	-0.13087	0.739833452	0.818793	127	-12	-11%	11%	34.79%
	1969	28.54	62	6371	458.6		3.804207605	2.66143405	2.419458138	263	0.241976	1.745725328	0.818793	215	244	53%	53%	34.79%
	1981	29.59	64	2384	74.8		3.377306251	1.873901598	1.808861131	64	0.06504	1.161556841	0.818793	53	22	30%	30%	34.79%
	1982	29.60	64	10080	320.9		4.003460532	2.506369717	2.704449599	506	-0.19808	0.633753131	0.818793	415	-94	-29%	29%	34.79%
	1983	29.60	64	11880	349.4		4.074816441	2.543322901	2.806509955	640	-0.26319	0.545522849	0.818793	524	-175	-50%	50%	34.79%
	1973	34.86	75	4793	180.6		3.680607429	2.256717746	2.242672806	175	0.014045	1.03286828	0.818793	143	37	21%	21%	34.79%
Outlier	1984	46.26	100	4401	114.5	Outlier	3.643551369	2.058805487	Outlier									

(4) = [percipitation value/max percipitation] * 100

(7) = Linear Regression analysis of columns (9) & (8)

(8) = Log (5)

(9) = Log (6)

(10) = Generated from Unique Linear Regression [variable x = (8)]

(11) = $10^{(10)}$

(12) = log observed suspended sediment - log predicted suspended sediment

(13) = $10^{(12)}$

(14) = (13/number of 13)

(15) = (10) * (14)

(16) = (6) - (15)

(17) = [(16)/(6) * 100]

(18) = Absolute Value (17)

(19) = (18)/(number of 18)

Appendix H – Feather River Complete Calculations and Data

Year (1)	Average Annual Observed Discharge (cfs) (2)	Average Annual Observed Suspended Sediment Load (ton/day) (3)	Unique Linear Regression Equations for Whole Data Set (4)	Log Average Annual Water Discharge (cfs) (5)	Log Average Annual Observed Suspended Sediment Load (ton/day) (6)	Log Predicted Suspended Sediment Load (ton/day) (7)	Uncorrected Predicted Suspended Sediment (ton/yr) (8)	Residual (9)	Transformed Residual (10)	Mean of Residuals (11)	Corrected Predicted Annual Suspended Sediment Load (ton/day) (12)	Observed and Predicted Sediment Load Difference (ton) (13)	Percent Deviation (14)	Absolute Percent of Deviation (15)	Mean of Absolute Values of Deviation (16)
1969	6371	458.6	y=1.5434x-3.4633	3.8042076	2.6614341	2.408114	256	0.25332	1.79192584	0.8187927	209.55014	249.04986	54%	54%	34%
1970	7418	768.1		3.8702868	2.8854178	2.5101007	324	0.37532	2.37310565	0.8187927	265.01755	503.08245	65%	65%	34%
1971	6319	182.8		3.8006484	2.2619762	2.4026207	253	-0.14064	0.72336172	0.8187927	206.91626	-24.11626	-13%	13%	34%
1972	3247	62.9		3.5114823	1.7986506	1.9563218	90	-0.15767	0.69555084	0.8187927	74.044994	-11.14499	-18%	18%	34%
1973	4793	180.6		3.6806074	2.2567177	2.2173495	165	0.03937	1.09488433	0.8187927	135.05897	45.541026	25%	25%	34%
1974	10370	359.7		4.0157788	2.5559404	2.7346529	543	-0.17871	0.66265504	0.8187927	444.45406	-84.75406	-24%	24%	34%
1975	4494	196.2		3.6526331	2.292699	2.1741739	149	0.11853	1.3137875	0.8187927	122.27786	73.922143	38%	38%	34%
1976	2706	61.7		3.4323278	1.7902852	1.8341547	68	-0.04387	0.90392094	0.8187927	55.889298	5.810702	9%	9%	34%
1977	1394	53.2		3.1442628	1.7259116	1.3895552	25	0.33636	2.16948408	0.8187927	20.0784	33.1216	62%	62%	34%
1978	3111	124.9		3.4929	2.0965624	1.9276419	85	0.16892	1.47543663	0.8187927	69.313179	55.586821	45%	45%	34%
1979	2934	85.1		3.4674601	1.9299296	1.8883779	77	0.04155	1.10040265	0.8187927	63.321599	21.778401	26%	26%	34%
1980	5741	305.6		3.7589875	2.4851533	2.3383214	218	0.14683	1.40227106	0.8187927	178.44128	127.15872	42%	42%	34%
1981	2384	74.8		3.3773063	1.8739016	1.7492345	56	0.12467	1.33249973	0.8187927	45.963004	28.836996	39%	39%	34%
1982	10080	320.9		4.0034605	2.5063697	2.715641	520	-0.20927	0.6176305	0.8187927	425.41708	-104.5171	-33%	33%	34%
1983	11880	349.4		4.0748164	2.5433229	2.8257717	670	-0.28245	0.52185663	0.8187927	548.20834	-198.8083	-57%	57%	34%
1984	7043	156		3.8477577	2.1931246	2.4753292	299	-0.2822	0.52215012	0.8187927	244.62631	-88.62631	-57%	57%	34%
1985	2998	60.7		3.4768316	1.7831887	1.9028419	80	-0.11965	0.75918349	0.8187927	65.46601	-4.76601	-8%	8%	34%
1986	6801	1824		3.8325728	3.2610248	2.4518928	283	0.80913	6.44365105	0.8187927	231.77509	1592.2249	87%	87%	34%
1987	2253	55.7		3.3527612	1.7458552	1.7113516	51	0.0345	1.08268862	0.8187927	42.123608	13.576392	24%	24%	34%
1988	2150	46.2		3.3324385	1.664642	1.6799855	48	-0.01534	0.965287	0.8187927	39.188574	7.0114261	15%	15%	34%
1989	2528	32.7		3.4027771	1.5145478	1.7885461	61	-0.274	0.53211025	0.8187927	50.317618	-17.61762	-54%	54%	34%
1990	2902	49		3.4626974	1.6901961	1.8810272	76	-0.19083	0.64441984	0.8187927	62.258854	-13.25885	-27%	27%	34%
1991	1530	20.1		3.1846914	1.3031961	1.4519528	28	-0.14876	0.7099754	0.8187927	23.180708	-3.080708	-15%	15%	34%
1992	1587	21.9		3.2005769	1.3404441	1.4764704	30	-0.13603	0.73109479	0.8187927	24.526996	-2.626996	-12%	12%	34%
1993	4401	114.5		3.6435514	2.0588055	2.1601572	145	-0.10135	0.79185982	0.8187927	118.39439	-3.89439	-3%	3%	34%

(4) = Linear Regression analysis of columns (6) & (5)

(5) = Log (2)

(6) = Log (3)

(7) = Generated from Unique Linear Regression [variable x = (5)]

(8) = Log (5)

(9) = (6) - (7)

(10) = $10^{(9)}$

(11) = ((10)/number of (10))

(12) = (11) * (8)

(13) = (3) - (12)

(17) = [((13)/(3)) * 100]

(18) = Absolute Value (14)

(19) = (15)/(number of (15))