

PREDICTING THE EFFECTS OF CLIMATE CHANGE ON THE SEDIMENT YIELD OF WATERSHEDS

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ABSTRACT

The HSPF (Hydrological Simulation Program-Fortran) model has been used to predict the effects of climate change, realised in terms of temperature alterations and changes in precipitation, on the suspended sediment load of a small stream draining an agricultural watershed in Turkey. Three years of flow and sediment load data have been utilised to calibrate the watershed hydrological and sediment transport model and one year of data have been utilised to verify the model predictions. Climate change scenarios likely to occur in the 21st century have been reflected into the input meteorological time series. The modified precipitation, potential evapotranspiration and temperature time series have then been used to produce suspended sediment loads carried by the stream draining the watershed and they have been compared with base simulation results. It has been aimed to develop a tool to couple climate change scenarios and watershed modeling in order to aid watershed management under the changing climate of the 21st century.

Keywords: Climate Change, HSPF, Sediment Load, Watershed Modeling

INTRODUCTION

The suspended sediment load in a stream, which drains a rural watershed, is derived principally from soil erosion occurring on the watershed and due to agricultural activities. The suspended sediment load is a water quality constituent with two facets. Its removal from the soil in excess quantities might be detrimental to the productivity of the soil. On the other hand, the suspended sediment in a stream is a contaminant, by itself and by being a carrier of adsorbed chemicals like metals and organics. The management of suspended sediment in a stream and on a watershed, therefore, concerns not only the improvement of water quality, but also the reduction of erosion. Two beneficial roles of suspended sediment are, however, overlooked frequently. Suspended sediment can be considered as a fertilizer when spread on land adjacent to the stream during floods. It is also an invaluable supply of sediment to coastal areas with beaches.

Due to the continued release of greenhouse gases to the atmosphere, global warming has become a reality of the twenty-first century. While some countries are thought to benefit from a warmer climate, a number of countries, principally the regions around the Mediterranean, might be affected by it quite adversely. The major effect will be felt by the water resources. The water quality of streams will also be affected as the watershed processes as principal suppliers of contaminants to streams will change in response to changes in temperature and in precipitation volumes.

In this study, it is aimed to estimate the effects of the anticipated climate change on the stream suspended sediment loads, exemplified on a stream draining an agricultural watershed. The HSPF model has been used to model the hydrology and water quality processes and to quantify the effects of climate change by creating scenarios.

THE STUDY AREA

The study area is a small watershed (Seydi Suyu Watershed) in north-western Middle Anatolia, Turkey. The 3D view of the watershed is given in Figure 1. Table 1 displays data about the watershed.

Table 1. Data about the Seydi Suyu Watershed

Surface area	414 km ²
Mean elevation	1050 m
Maximum elevation	1362 m
Average land slope	43 m/km
Stream length	40 km
Average stream slope	2.25 m/km
Percentage of forested land	20 %

The watershed is a sparsely settled area with almost no industry. The economy is based, besides mining in the upper reaches, primarily on agriculture with grains and sugar beet as principal crops. The watershed is drained by the Seydi Stream. The stream is dammed (outside of the study area) by two reservoirs, which store water at the rainy winter season. The stored water is released in the summer months and used in irrigation. Ditches on both sides of the stream carry the water to fields located primarily in the more level parts of the watershed for sprinkler irrigation. The delivery of water to the channels is facilitated by a regulator. The soils in the watershed are quite permeable and belong to hydrologic Group A (Göktay, 1991; DSÝ,1983). The natural vegetation is confined to the higher parts of the watershed and is composed of

sparse forests of pine, oak and juniper (EOBM, 1993). The climate is a continental one with milder influences from the Mediterranean coastal areas. The mean precipitation is around 300 mm/year.

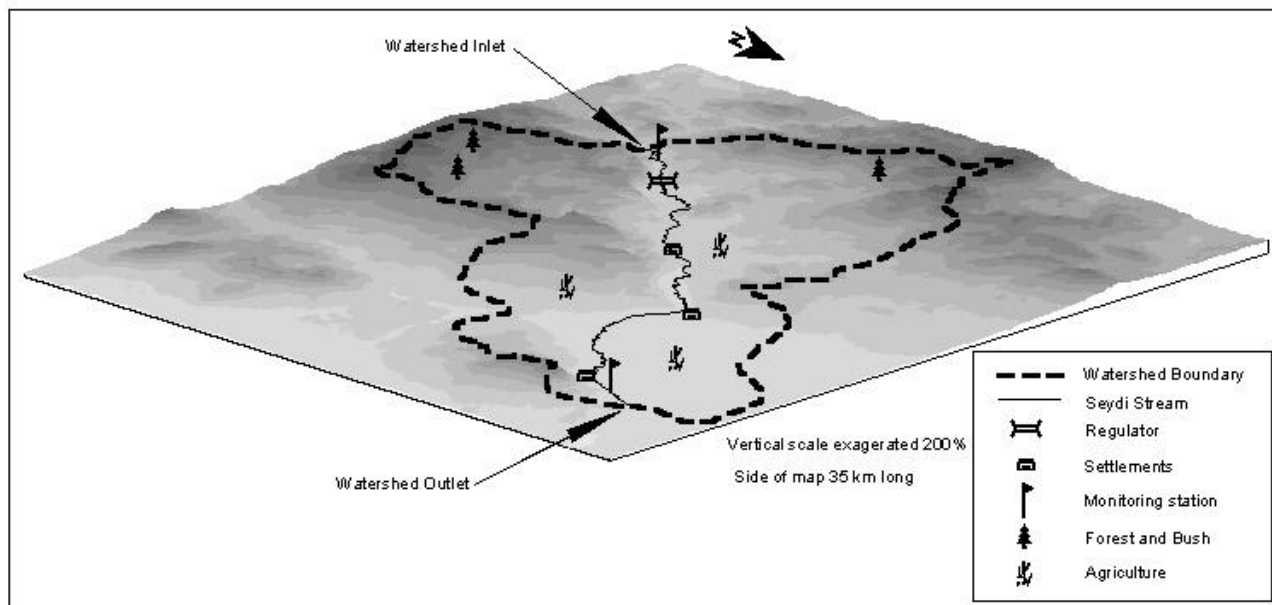


Figure 1. The Seydi Suyu Watershed

The watershed has been monitored in the past for flow and intermittently for water quality. Till 1987 a state agency (EIE, Electrical Power Resources Survey and Development Agency) has been recording daily flow at a station close to the watershed outlet. Another state agency, DSÝ (State Hydraulic Works), monitors the water released from the reservoirs and the water volumes allocated to agriculture. Water quality has been monitored by DSÝ before the construction of the reservoirs in 1987.

The stream has been monitored by the Anadolu University, Environmental Engineering Department for three years at two stations (shown in Figure 1) beginning in water year 1999 in order to obtain data to be used in the calibration and verification steps. Flow and several water quality constituents including suspended sediment have been measured at these stations at monthly intervals (Albek et. al., 2001).

METHOD

The watershed has been modeled using HSPF (Hydrological Simulation Program-FORTRAN). HSPF is a comprehensive simulation model developed by the United States Environmental Protection Agency (USEPA). The model can simulate the hydrological and water quality processes occurring on a watershed on a continuous basis utilising meteorological and hydrological time series as the driving forces behind watershed processes. The model is a lumped parameter model and the watershed is divided into segments of homogenous characteristics like topography, climatic conditions and land use. While the majority of parameters can be quantified based on observations, theory, experimentation or empirical equations, a number of parameters are only assigned proper values by calibration. The model is described in (Bicknel et al. 1993; Donigian et. al, 1976; Donigian et al., 1976) and a detailed description of the model will not be given here. Only the most important aspect of the modeling study carried out will be described briefly.

HSPF has a modular structure and depending on the particular processes to be modeled, the corresponding modules are used. In this study, the modules used have been those simulating the hydrology of the land areas, the stream hydraulics and the sediment transport over the land and in the stream. The watershed has been segmented into four sub-basins based on several criteria including topography, vegetation and land use. The stream has been divided into three reaches based on the obstacles, talveg slope and relation to watershed. Parameters related to the physical characteristics of the watershed and the stream like slopes, areas etc. have been obtained using digitized maps and information from related agencies and literature (DSÝ, 1983; EOBM, 1993; Göktay, 1991). Data gathered at the field during the 1999-2001 survey has also been used, principally for establishing the hydraulic characteristics of the stream, the bed sediment properties and recession parameters for the different water storage zones belonging to the land segments of the watershed.

Meteorological data has been obtained from the State Meteorological Agency (DMÝ). The solar radiation time series has been generated artificially by using the equations presented in Brown and Barnwell (1987) as there were extensive gaps in the measured data. The potential evapotranspiration has been computed by using the Priestly-Taylor equation (Dingman, 1994). The meteorological data belonged to a station outside the watershed, but close to it. Comparisons with some data taken inside the watershed have shown negligible disagreement.

The model distinguishes three soil particle types, namely sand, silt and clay for the watershed soils. Based on literature (Göktay, 1991) the fractions of these have been supplied to the program. The stream bed sediment particle size distribution has been determined by particle size analysis on samples collected from the stream bed during the survey mentioned above.

Calibration and verification have been carried out by comparing the stream flow and suspended sediment load carried by the stream at the watershed outlet by measured flows and computed suspended sediment loads. The stream suspended sediment loads have been computed using measured flows and suspended sediment concentrations during the 1999-2001 survey. As the stream is a regulated stream, it has been assumed that the conditions have not changed appreciably between 1991-1994 water years and the survey period. Also there has been no change in the vegetation and land use of the watershed. The suspended sediment loads have been obtained by regression analysis using the Bradu-Mundlak smearing estimator technique (USGS, 2000) for bias correction.

Comparisons have shown a good agreement for the hydrological part of the model. There has been good agreement for yearly flows with some discrepancies in daily flows due to uncertainties in the data and a few observed disagreements between precipitation records and stream flow values. Sediment simulation also has produced a good agreement in yearly loads.

The estimation of the effects of climate change by HSPF has been facilitated by two stages. First, the base conditions reflecting the contemporary conditions in the watershed (namely the prevailing hydrology and water quality regarding suspended sediment) have been simulated. Nine scenarios have been prepared to estimate the quantitative effects of climate change on the watershed suspended sediment output. Three of them are based on temperature changes and the rest on precipitation changes.

The temperature scenarios are based on the anticipated temperature increase of a few degrees during the twenty-first century (Mays, 1996; Yazar and Magnin, 1997; Szilagyi et. al., 2002) Climate models predict increases in annual mean temperatures. Variations will be encountered in different parts of the world, depending on location, topography, proximity to oceans, etc. How different regions will respond to the climate change in terms of temperature increase is for the most part unknown. Moreover, how the temperature increase will be distributed among the seasons is also very uncertain. In reflecting the increase into the meteorological time series, it has therefore been assumed that the future temperatures will show the same seasonal distribution prevailing now. The three temperature scenarios are based on temperature increases of +1, +2 and +3 degrees Celsius (designated as T1, T2 and T3) over the contemporary temperatures. The temperature increase will be accompanied by changes in other meteorological time series. As the dewpoint temperature and potential evapotranspiration are temperature-dependent, they have been modified accordingly. Likely changes in other meteorological time series have been not taken into account as the relationships to temperature are not well established.

While temperature increases are a fact, it is highly uncertain how the precipitation patterns and volumes will change. Some regions will receive more precipitation than now and some will experience prolonged and more severe droughts. Many specialists foresee that the Mediterranean countries will be exposed to droughts (Hayward, 2001). To be able to capture the greater variability in precipitation forecasts, six scenarios have been prepared. Some are based on precipitation increases (likely to occur due to increased water vapor in the atmosphere) and some on decreases due to shifting frontal systems. Seasonal variations (winter-summer) have also been reflected into precipitation time series. The precipitation scenarios are the following (P1=10% precipitation increase over whole year, P2= 20% precipitation increase over whole year, P3= 10% precipitation increase in winter, P4=10% precipitation increase in winter, 10 % precipitation decrease in summer, P5= 10% precipitation decrease in summer, P6 = 10% precipitation decrease in winter, 20% precipitation decrease in summer). In comparing the scenarios with each other and the base conditions (which are the simulations covering the water years 1991-1994), the averages of the total annual suspended sediment loads have been used.

RESULTS

Figure 2 displays the percentage changes with respect to base conditions of the suspended sediment load carried by the stream at the watershed outlet. The loads decrease with increasing temperature. This is an expected result as increasing temperatures increase the evaporation from interception and surface detention storages, thus reducing the surface runoff carrying the sediment. The percentages decrease in an almost linear fashion. The reduction in suspended sediment loads will be beneficial as the useful lives of reservoirs on the water course will increase. From the viewpoint of erosion control a temperature increase seems to be beneficial, but it must be taken into account that other influences (like soil property changes, vegetation coverage) have not been considered.

With regard to water quality, the suspended sediment concentrations are more indicative. Figure 2 also shows the concentrations in the stream at the watershed outlet. These concentrations are based on yearly suspended sediment loads and yearly flows and thus represent a yearly average concentration. The concentrations show a decrease similar to the loads but the numerical values are smaller. Temperature decrease both reduces sediment loads and flows. These two effects are working in different directions in determining the concentration. But as loads are exponentially related to flows, their effect overwhelms those of the flows and decreases are encountered, though smaller. The stream receives considerable water from the outside of the watershed from the above-mentioned reservoirs. The relatively clear water from

the reservoirs tends to dilute the sediment loads from the watershed. The climate change will also affect the reservoirs and the upper watershed feeding them. The above concentrations do not take into account these upstream effects. In order to see the upstream effects, it has been assumed that the upper watershed is subject to the same conditions and the flows from the reservoirs have been modified accordingly. Thus, in the case of temperature scenarios, the water entering the watershed from above has been reduced in proportion to the decrease of water yield experienced in the watershed as simulated by HSPF. This reduction has produced a completely different picture. Due to the reduction in dilution water quantities, the concentrations have risen sharply. Thus it is likely that the temperature decrease will reduce water quality with respect to suspended solids concentrations and associated contaminants.

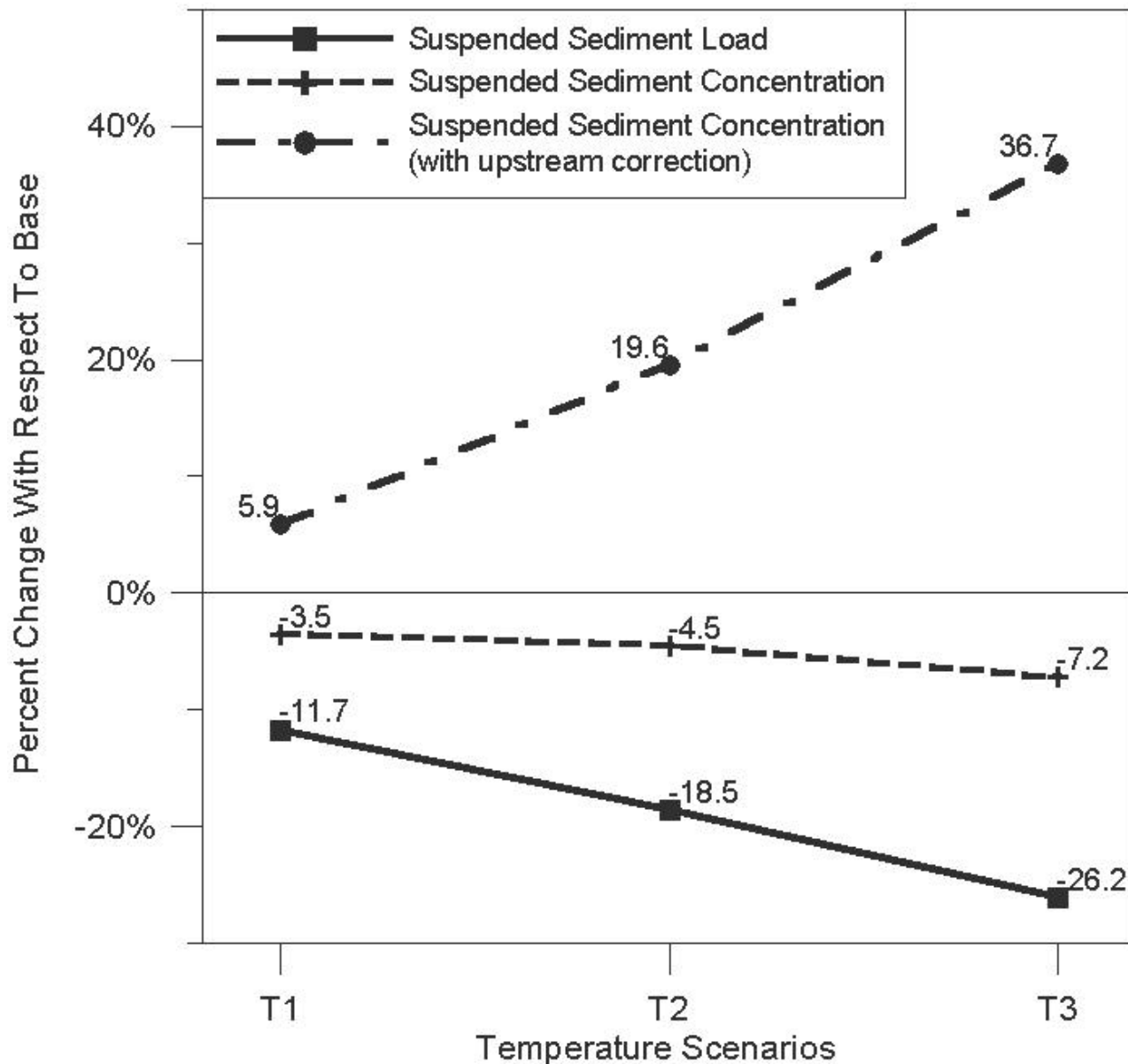


Figure 2. Suspended sediment loads and concentrations in the stream for the temperature scenarios

Precipitation scenarios have produced higher percentage changes. Figure 3 displays the percent changes in stream suspended sediment loads over the base conditions. The first four scenarios (P1, P2, P3 and P4), which foresee precipitation increases of varying degrees, predict increases in sediment loads. It is also observable from this figure that the summer precipitation decrease (P4) does not appreciably alter the results when P3 and P4 are compared. In summer, due to increased evapotranspiration by the more luxuriant vegetation, the surface runoff and the corresponding sediment loads are quite low. As expected, precipitation decreases result in lower suspended sediment loads compared to base conditions (P5 and P6). The concentrations with and without upstream correction show a similar picture. The concentrations rise with increased precipitation. The upstream correction, in contrast to temperature scenarios, produces smaller concentrations as the diluting water volumes increase (for P1 to P4). For the scenarios with precipitation decrease, the concentrations still decrease but the decreases are smaller for concentrations with upstream correction. It is observable from these values that precipitation increase will burden the stream with higher loads and higher concentrations. Erosion control will also suffer from increased precipitation. The water resources will however surely benefit, though with a loss in quality for surface water sources. Precipitation decreases seem to be beneficial with respect to water quality. However, sustainability of irrigated agriculture will suffer from losses of invaluable water volumes.

CONCLUSIONS

This study has been an attempt in predicting the effects of climate change on suspended sediment loads from a watershed and on suspended sediment concentration in a stream. Results have shown that there will be changes which have to be taken seriously by watershed managers. The procedure followed in this study can be considered as a precursor to more refined and detailed studies. Two aspects need to be mentioned. The climate change scenarios must be refined to be more representative of the future conditions. However, due to the uncertainties inherent in climatic conditions, it is clear that this is quite difficult, if not impossible. One way to improve the scenarios is to use a more detailed seasonal distribution of climatic parameters. This, however, must be approached with care, as the uncertainties might as well lead to more unreliable results.

Parameter evolution due to changes in watershed processes (e.g. a change in infiltration capacity due to alterations in soil properties resulting from prolonged droughts) is another concern. Some researchers have calibrated HSPF with varying parameter values for different years (Jacomino and Fields, 1997). This approach might be followed and the model parameter changed as more knowledge about the watershed processes is accumulated in time and under the influence of the changing climate. A continuous simulation with periodic parameter evolution breaks might be attempted to get more refined predictions for the future.

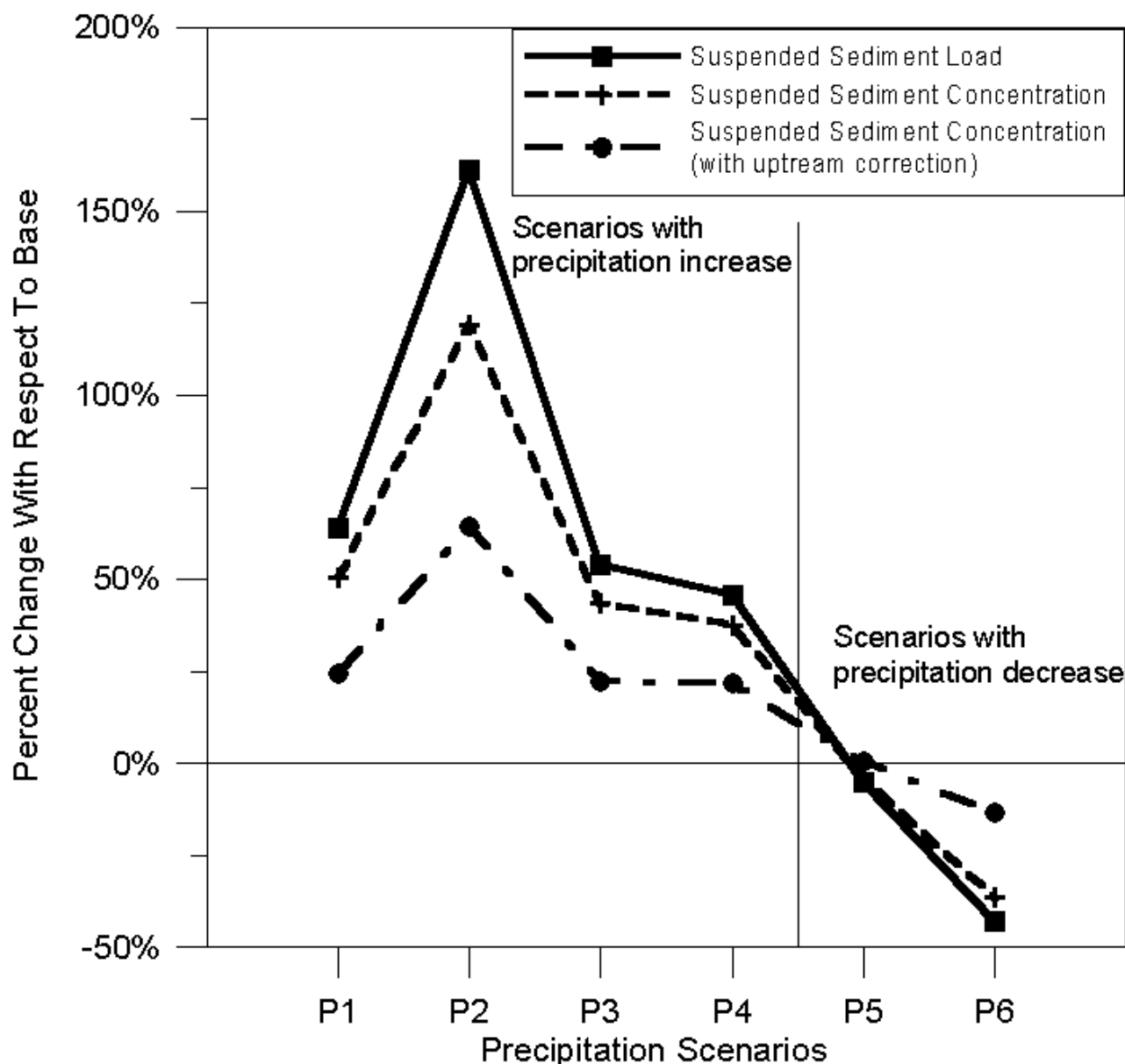


Figure 3. Suspended sediment loads and concentrations in the stream for the precipitation scenarios

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