Evaluating the effects of different land uses on evaporation and stream flow: A study across 200 catchments in the United States

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by

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Preface

Time flies so fast that the two-year Master's study period is nearing completion. The moment when I first joined the class seemed to happen yesterday. Studying in a foreign country has given me a wonderful experience. In my life, I cherish water resources, but in nowadays, the world is under a severe water shortage situation. As a hydrologist, we have a long way to go. The shortage and waste of water resources are undoubtedly giving us a warning bell, and everyone is responsible for protecting water resources.

Land use has a great impact on water resources. It is our responsibility to study the impacts of land use and formulate corresponding measurements. I thank my parents for their nurturing and financial support, the school for providing superior learning conditions and facilities, as well as the excellent supervisors for teaching us rich professional knowledge. Through the graduation project, I have a deeper understanding and cognition of my professional knowledge, and reorganize the knowledge system I have learned before, which are very important for my future study and work.

For the topic of this graduation thesis, I indeed want to study the effects of different land use on evaporation and stream flow. Thanks to my supervisor Markus and my committees for their help in a long time. Facing a large amount of data, I used Python, R language, SPSS, QGIS and Excle to process and analyze them. From looking for data to programming, calculation, drawing and analysis day by day, I can apply well what I have learned. Although the process was very hard and tiring and I also did a lot of useless work, I am proud of achieving it at the end. Finally, I would like to thank myself for the hard work in the past two years, and all I have paid for my graduation thesis. I hope in the future, I can make more contributions to the society.

I hope you enjoy reading this thesis!

Xiaopei Guo
Delft, June 2020

Abstract

Studying the effects of different land uses on evaporation and stream flow is a hot and frontier topic in global hydrological research. The occurrence and development of flood disasters are restricted and affected by many factors such as meteorology, hydrology, underlying surfaces and human activities. In recent decades, the changes of evaporation and stream flow caused by land use in the river basin have been more and more important. By calculating the long-term average proportion of all land use types in each catchment during the study period, the effects of six main land use types are evaluated one by one, including forest, grassland, pasture land, cropland, shrub land and wetland.

This thesis mainly uses Budyko framework to analyze large-sample catchments with different land uses in the United States. Totally 200 small catchments (<1000 km^2) located almost evenly in the continental United States are selected as the research samples. Budyko framework is established with long-term mean precipitation, potential evaporation and actual evaporation from 1981 to 2013. The difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation is regarded as the best indicator to evaluate the impacts of different land uses qualitatively. Then, the Budyko framework is divided into five bins according to the dryness index and these watersheds are studied in each bin. Besides, the effects of each land use are quantitatively evaluated by making multiple linear regressions. It also discusses two other methods, Fu's equation and Zhang's equation. The best-fit values of parameter w of the main land types are calculated by nonlinear regression. The best-fit w values in this thesis are compared with previous researches to find out some possible reasons causing the differences.

From the results in this thesis, forest and shrub land coverage evaporate less and lead to more runoff. However, cropland, grassland and pasture land coverage evaporate more and lead to less runoff. It needs to be emphasized that the results show forest land evaporates more than grassland, which is contradictory with what others found. Some physical and hydrometeorological characteristics of the catchments are the possible reasons to explain the results, including mean slopes, precipitation, root systems and so on. Lastly, the evaluation of the impacts of land use in small watersheds on evaporation and stream flow also provides strategic guidance for future land use planning.

Keywords: Land use, catchments, evaporation, stream flow, Budyko framework, qualitatively, quantitatively

Contents

1

Introduction

1.1 Problem statement

Land use is a hot topic and frontier issue in global change research. The impact of land use on catchments is one of the key issues in river basin hydrology research. Stream flow and evaporation in a basin are affected by the rainfall process and underlying surface conditions. They are the basis of the study of hydrological cycle mechanism. Different land uses have different soil retention and infiltration capabilities, resulting in different surface evapotranspiration, which in turn affects runoff processes. The study of land use and land cover is mainly through its role on water balance, which directly or indirectly affects the precipitation - runoff relationship and the process of runoff generation and convergence. The changes of evaporation and stream flow are related to various ecological and environmental problems such as soil erosion, land degradation and water shortage.

In hydrological researches, evaporation and stream flow on catchments are the important hydrological responses, which will profoundly change the hydrological cycle of river systems. Changes in the magnitude and frequency of river flows have a significant impact on freshwater ecosystems and human activities. Meanwhile, human activities can also effect river flows. In addition, changes in stream flow are important for aquatic species because they rely on freshwater for some important conversions during their life cycle, which may affect ecological stability as well as the quality and quantity of water supply [1].

There are numerous international water science programs, such as International Hydrological Programme (IHP), World Climate Research Programme (WCPR), Global Water System Project (GWSP). Relevant international research organizations have studied the water-atmosphere cycle and related environmental issues in the context of global change and human activities through multi-scale and cross-disciplinary integration of macro and micro river basins. The IPCC's climate change assessment in 2001 pointed out that the global temperature increased by 0.74 ℃ in the past century [2]. According to the Fourth National Climate Assessment Report released by the US government in 2018, the effects of climate change, including severe storms, droughts, and wildfires, were increasing in the United States. The cause of longer and stronger climate disasters is global warming. It was reported that natural disasters are becoming more frequent. Without proactive measurements, the situation would only be worsen [3]. On the United States Geological Survey website, by researching the changes in stream flow timing in the western United States in recent decades, annual flow of most western rivers is increasing. The temporal increasing trend is likely attributable to global warming, but the causes of long-term climate trend remain uncertain and complicated. Among them, land use change is an important factor that can substantially influence the variability of stream flow.

Therefore, in the deteriorating environment of the whole world, taking the United States as an example to evaluate the effects of different land uses on evaporation and stream flow is meaningful for water resources planning, management and sustainable development.

1.2 Historical researches

Since the 20th century, some researchers began to study the effects of different land uses on the responses of runoff, mainly focusing on the interaction between forest and water cycle. The comparative experiment of two small watersheds in the Emmenal Mountains of Switzerland in 1900 was the earliest research in this field [4]. In 1909, the United States set up the first experimental watershed to explore the impact of forest cover changes on runoff, and established a hydrological station dedicated to studying the hydrological response of forest. Most of the results at this stage indicated that afforestation will lead to an decrease in runoff.

After the 1950s, the water cycle process was regarded as a complete system, then the concept of hydrological model was proposed. In 1970, the hydrological model was first tried to simulate the effects of land use change on runoff. During this period, some researches about the influence of underlying surface on the mechanism of runoff formation and water balance were paid more attention [5].

In the early 1990s, after the land use and land cover (LULC) was jointly launched by International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme (IHDP), it quickly attracted many scholars. And with the rapid development of Geographic Information System (GIS), Global Positioning System (GPS) and Satellite Remote Sensing Technology (RS), the study of the land use effects on evaporation and runoff entered a new stage.

With the social development and rapid growth of population, agricultural land has been continuously expanded. In 2003, some researchers analyzed the flood peaks and postwar agricultural land use in the Elbe River Basin in the past 100 years and found that the degradation of soil physical properties caused by agricultural mechanization was the main reason for the increase of surface runoff in rainy seasons [6]. What is more, in 2010, the hydrological effects of land use change in the Tocantins River Basin (area 767000 km^2) were studied. The results showed that the increase in agricultural land reduces infiltration and evaporation, thereby increasing the annual average stream flow [7].

The construction of urban lands makes the impervious hardened ground increase. The simulations showed that urbanization leads to an increase in flood peak flow and shortens flood peak lag time [8]. And the discussions of the hydrological effects of urbanization in California expressed that with the increase of urbanization, the daily average flow, minimum flow, and peak flow in dry seasons all have a significant increasing trend [9].

In 1993, on-site measurements of forest and grassland in Amazon Basin were conducted. The results showed that the runoff is larger on grassland compared with the runoff on forest [10]. However, some researchers did research on the impact of land use on runoff in four mesoscale watersheds in New York. The percentages of forest coverage in each watershed were the same, but the impacts on runoff were different [11]. In short, the impacts of land use on runoff vary with different vegetation types.

1.3 Goal of the thesis

Based on the historical researches, this thesis focuses on evaluating the effects of different land uses on evaporation and stream flow across a large-sample catchments. Land use refers to both natural and human-impacted lands. Different types of land include agricultural land, forestry land, industrial land, land for transportation and residential land and so on. The hydrological response of watershed is affected by vegetation types, soil characteristics, geology, topography, climate, and the spatial pattern of interactions between these factors [12].The basic consensus now is that these factors and interactions are mainly affected by climate change and land uses. In the context of climate change becoming one of the most pressing global environmental issues, many scholars have studied the impact of climate change on the terrestrial water cycle system, but ignored the changes of evaporation and runoff caused by different land uses on catchments. Studying the influences of different land uses can deepen the understanding of water balance and cycle in different land environments. It also has important theoretical value for the protection and utilization of regional water resources, the operation and management of river basins, and the maintenance of human living environment.

Most studies attributed changes in stream flow to climate change impacts only, such as a shift from snowfall towards rainfall in USA and the increasing trends in annual total precipitation in Canada, without considering possible impacts of land use which can alter the stream flow directly through influencing the runoff production and indirectly through affecting the climatic variables. It is necessary to emphasize that potential changes in water-energy partitioning can be driven by global climate changes altering the supply of water and energy or by land use and management on a regional scale [13]. Some studies have reported conflicting results of climate change and runoff change. For example, in the United States, runoff should have increased after a shift from snowfall to rainfall, but observed flows generally decreased. This may be a contradiction caused by not considering the hydrological impact of land use [14]. Therefore, careful plan of land resource management adapted to the environment is conducive to maintaining human well-being and ecological stability. One of the advantages is that specific land use and management can help mitigate the effect of climate change on water resources. To develop a successful mitigation strategy, it is necessary to understand the relationship between soil vegetation and the atmospheric system as well as to raise awareness of the sensitivity of land surface changes. Based on this purpose, there are three main research questions for this thesis.

What are the influences of different land types on evaporation and stream flow by qualitative evaluation?

What are the influences of different land types on evaporation and stream flow by quantitative evaluation?

How different land uses lead to different effects on evaporation and stream flow?

2

Methodology

2.1 Qualitative evaluation: Budyko framework

In the study of hydrology, the water flow between soil, vegetation and atmosphere is an important process. This thesis aims to understand the relationship between land use and water balance in the small watersheds on spatial and temporal scales, and further quantify the impacts of different land uses. In many studies, the Soil and Water Assessment Tool (SWAT) is widely used. It is a hydrological quality model developed in the United States. The SWAT model is used to predict and evaluate the effects of land use, land management and climate change on water resources, crop growth and so on. However, SWAT is generally used to simulate different physical processes in a single big basin. It requires very detailed internal characteristics of the basin. In this thesis, large sample watersheds are selected to evaluate the general impacts of land use on evaporation and stream flow, so SWAT model is not applicable here. It is very significant to understand the key control factors of the hydrological cycle. The main factors controlling long-term mean actual evaporation (E_A) are long-term mean precipitation (P) and potential evaporation (E_P). Actual evaporation is also related to water balance and energy balance. And it plays a key role in the climate-soil-vegetation interaction [15].

In past studies, there were few hydrological models that considered different kinds of vegetation across space and time. However, with the gradual understanding of the hydrology, it is found that vegetation and other biological processes have more and more important influences on the water balance. In the process of water circulation, when rainfall falls to the ground, it may be intercepted by plant canopy, may infiltrate into the soil, evaporate from the soil surface or be transpired by plants. Precipitation can be surface runoff, or penetrate through the soil as groundwater supply. In addition, the interception of rainfall by vegetation also has various processes. A part of rainfall is intercepted by the leaves of vegetation, flow down through the stem of plant, or evaporate from the wet canopy surface. Especially in the catchments covered by forest, the effects of vegetation are more obvious. Moreover, vegetation also plays an important role in water cycle through the exchange of energy, moisture, carbon dioxide and other substances. The growth of vegetation is affected by water supply and vegetation properties, such as leaf area, photosynthetic capacity, and rooting depth [16]. And different land uses directly change the effective energy of land surface, effective moisture, photosynthetic rate, nutrition level and surface roughness, and they in turn affect the evapotranspiration [17]. Based on these reasons, Budyko framework is a suitable way to evaluate the effects of different land uses on evaporation and stream flow.

Budyko framework is a common method to evaluate the relationship between land cover and evapotranspiration. Budyko described the hydrology of a catchment using a supply-demand framework and a simple bucket model where net drainage is assumed to be negligible [18]. The water balance equation was defined as:

$$\frac{dS}{dt} = P - E_A - Q \tag{1}$$

where P is the daily average precipitation (mm/d), E_A is the daily average actual evaporation (mm/d) calculated by Equation (2), Q is the daily average discharge (mm/d) from 1981 to 2013, and S is the soil water storage (mm), t is the time (day).

During a long period (over 10 years), a catchment is in steady state and the water storage changes can be considered as zero. Water storage only occurs when too much water is available for vegetation, and the excessive water will be stored in the roots. Because the study period is 32 years in this thesis, it can be reasonably assumed that the soil water storage change is zero. Therefore, the water balance equation can be defined as Equation (2).

$$\begin{gathered} 0 = P - E_A - Q \\ E_A = P - Q \end{gathered} \tag{2}$$

In the hydrological cycle, all interactions and feedback between vegetation, soil and atmosphere create the Budyko curve that is plotted by Budyko Equation (3). Under natural conditions (without climate change and human impact), the point of a watershed on the Budyko framework should be distributed on the Budyko curve shown in Figure 2.1 (black curve). However, due to the impacts of climate change and human activities, the point will deviate from the Budyko curve. The impacts of different land uses are the focus in this thesis.

$$\frac{E_A}{P} = \left[\frac{E_P}{P} \tanh\left(\frac{1}{\frac{E_P}{P}} \right) \left(1 - e^{-\frac{E_P}{P}} \right) \right]^{\frac{1}{2}} \tag{3}$$

The plot of Budyko framework describes an relationship between the evaporation index and dryness index, in which the evaporation index is defined as the ratio between E_A and P, and the dryness index is defined as the ratio of E_P to P [19]. Analyzing the evaporation index and dryness index individually is allowed in this method. So it is not necessary to evaluate individual hydrological parameters, like E_A, E_P and P. In addition, the Budyko framework includes two lines, water limit (yellow line) and energy limit (green line) from the Figure 2.1. When E_P / P is smaller than 1, E_P is less than P, which means the maximum E_A is equal to E_P. Potential evaporation is related to local energy, including sunshine duration, wind speed, radiation and temperature. Therefore, the actual evaporation is limited by energy. When E_P / P is larger than 1, E_P is more than P, which means the maximum E_A is equal to P. The amount of rainfall is related to the amount of available water. So in this case, the actual evaporation is limited by the amount of water. One of the advantages of using the Budyko framework is that it can analytically separate the impacts of climate conditions and catchment properties on hydrological partitioning.

The difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation on the Figure 2.1 is regarded as the reference indicator to show the impacts of different land use types on evaporation and stream flow. In this thesis, the impacts of land use refer to changes in precipitation distribution under certain climatic conditions. Climate change is reflected in the ratio of long-term average potential evaporation and precipitation (the dryness index). Therefore, in Figure 2.1, different dryness indexes of different watersheds are only affected by climate. From Budyko Equation (3), the evaporation index in the natural state can be calculated by actual dryness index for each catchment. The difference between evaporation index estimated from data (red dot) and theoretical evaporation index calculated from theoretical Budyko equation (gray dot) is only caused by human activities. Because the topic of this thesis focuses on the effects of different land uses which belong to human activities, the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation, named Δ (E_A / P) is a suitable reference indicator.

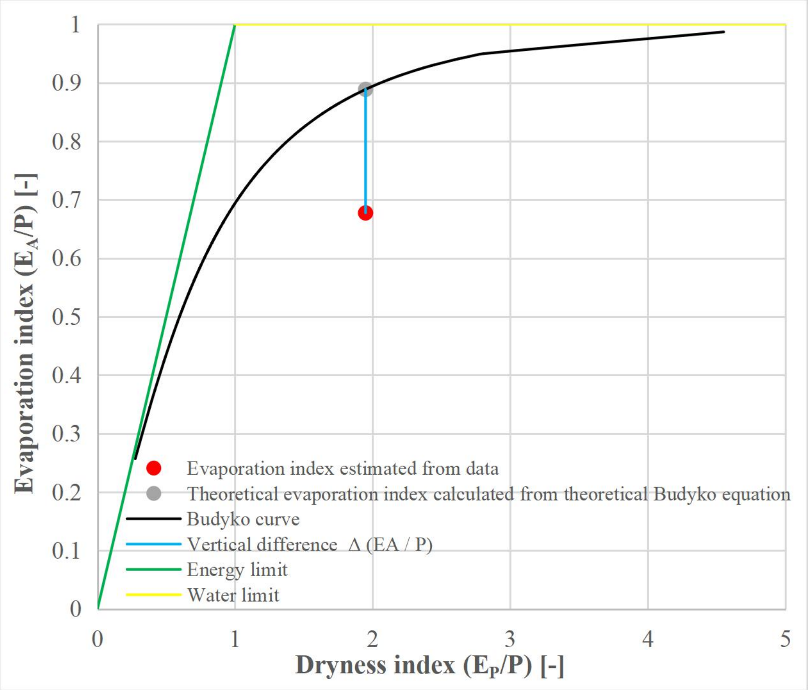


Figure 2.1 The black curve shows the long-term daily average evaporation index as described by Budyko curve. For a given dryness index (E_P / P) value, the gray dot is the evaporation index (E_A / P) calculated by the curve, and the red dot is the evaporation index (E_A / P) estimated from data. The blue line is the vertical difference between two points [20]. It is represented as Δ (E_A / P) in following figures.

2.2 Quantitative evaluation

2.2.1 Multiple linear regression

To quantify the effects of land use on the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation, regression analysis is widely used among multiple statistical analysis methods. The main process is to build a best-fit regression equation based on the known data. A very important problem in the process is to select the appropriate dependent and independent variables. In this thesis, backward multiple linear regression is used firstly. There are one dependent variable and multiple independent variables. And independent variables are continuously removed from the regression equation. At first, all independent variables are introduced into the regression equation, and then the variable that is the least significant is eliminated until only one independent variable remains. The method is implemented by SPSS (Statistical Product and Service Solutions) software.

Suppose that there are n independent variables X_1, X_2, X_3, ... , X_n, and Y is the dependent variable. Now the experiments are conducted i times, and there are i data sets, Y_i, X_{i1}, X_{i2}, ... , X_{in}, (i = 1, 2, ..., i). The first multiple linear regression equation can be show below.

$$Y = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_n X_n + C \qquad (4)$$

Where C is the constant, and β is the coefficient of each independent variable. In Equation (4), obviously any m ($m \leq n$) independent variables among the n independent variables can establish a regression equation with the dependent variable Y. In order to find the optimal regression equation, it is necessary to compare the advantages and disadvantages of all regression subsets under a certain criterion. In this thesis, R^2, adjusted R^2 and p value are selected to be the metrics. The following paragraphs are brief introduction of them.

Firstly, R^2 is the coefficient of determination of a regression equation. The value of R^2 is between 0 and 1. The closer the value is to 1, the stronger the ability of the independent variables is to explain the dependent variable. There are two general regulations when using R^2 as the selection criterion. The first one is that if there is a nonlinear relationship between variables, it is uncertain that the larger R^2 is, the better the fitting is. The second one is that when the number of independent variables increases, even if the linear relationship between some independent variables and dependent variable is not significant, R^2 will also increases.

Secondly, when the number of independent variables involved in a regression equation is large, the fitting of the regression model may seem good. But the length of the interval of estimation and prediction will be large, and the regression model even has no practical significance. The reason for this phenomenon is that some false components are actually hidden in the model. In order to overcome the shortcomings caused by the change of R^2, R^2 needs to be revised. The adjusted coefficient of determination is called adjusted R^2.

Thirdly, p value is widely used in statistical hypothesis testing, specifically in null hypothesis significance testing. In this thesis, 0.01 and 0.05 are chosen as the threshold values. If the p value is bigger than the chosen significance level, it suggests that the known data is sufficiently inconsistent with the null hypothesis.

It is noticed that the backward multiple linear regression has two disadvantages. The first one is the large amount of calculation. Especially when there are many independent variables, the variables that have no significant effect on the dependent variable will be more. The second disadvantage is that with the removal of independent variables one by one, some relatively important variables may be missed in the final optimal regression equation. Hence, the reliability of the results in Chapter 4.2 should be analyzed when using this method.

2.2.2 Fu's equation

This thesis aims to investigate the link between vegetation types and long-term water balance in catchment areas. The Budyko framework is a method to qualitatively evaluate the effects of different land uses on evaporation and stream flow. In addition, in order to assess whether long-term stream flow can be explained by land cover attributes, some widely used water balance formulas or models that relate long-term annual stream flow to long-term annual rainfall and long-term potential evaporation estimates are introduced, including Fu's equation and Zhang's equation.

Firstly, the model developed by Fu in 1981 provides a useful framework for evaluating average annual water balance at the catchment scale. The model has some degree of empiricism, especially when it comes to the parameter estimation [21]. Some improvements were made by Fu's equation. Under certain precipitation, the increase rate of actual evaporation is determined by the balance between the remaining water supply and evaporation capacity. Both the evaporation capacity and the water supply of the underlying surface have an effect on the actual evaporation. The evaporation complementation hypothesis emphasizes the negative feedback of the atmosphere when the water supply on the evaporation surface changes. That is, by changing the atmospheric temperature and humidity to change the potential evaporation, the effect of the underlying surface moisture on the actual evaporation is mitigated.

One analytical equation has been proposed for the Budyko curve, among which the one-parameter function proposed by Fu (Equation (5)) is widely used [22]:

$$\frac{E_A}{P} = 1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w}\right]^{\frac{1}{w}} \tag{5}$$

Where E_A is the long-term mean actual evaporation. E_P is he long-term mean potential evaporation and P is the he long-term mean precipitation. The parameter w is empirical, which determines the shape of the plotted curve and reflects the impact of land cove types on water and energy balances.

When using Fu's equation, the w value for each land cover type needs to be determined. Different land cover types have different best-fit w values. In other studies, some researchers directly used the empirical w values derived by previous studies. However, there are only some simulated results about forest and grassland. Like the shrub land and pasture land that are also important in this thesis, their empirical w values cannot be found from literature. Therefore, under the premise of known Equation (5), nonlinear regression is introduced to calculate the best-fit w values of different land cover types.

2.2.3 Zhang's equation

Zhang and Dawes [23] considered the depth and distribution of plant roots and then developed Zhang's equation. Different vegetation types have different root depth and distribution which are affected by a number of factors such as physical and chemical barriers, as well as nutrient distribution. When the porosity, pore sizes of soils and root channels are unfavorable to water and oxygen supply, plant growth will be severely limited. The available water supply for plants depends more on the rooting depth than soil hydraulic properties. Therefore, it is expected that rooting depth will contribute to the differences in actual evaporation between different vegetation types. Zhang's equation is a ‘top-down’ approach, related to actual evaporation and plant-available water content.

This method considers the effects of different land uses on evaporation and stream flow from different aspects and set the parameter w in the equations. The w values of different land uses represent specific effects on evaporation. In past studies, some conclusions had been presented by the equation for different land types. It is also meaningful to discuss and compare them.

Using hydrologic data including mean annual actual evaporation, precipitation and potential evaporation by Priestley and Taylor equation from over 250 watersheds worldwide across a wide range of climatic zones and biomes, the following Formula (6) is described and estimated [23].

$$\frac{E_A}{P} = \frac{1 + \mathrm{w} * \frac{E_P}{P}}{1 + w * \frac{E_P}{P} + \frac{P}{E_P}} \tag{6}$$

Where w is the plant-available water coefficient and it represents the relative differences in the way plants use to transpire soil water. Therefore, under the premise of known Equation (6), nonlinear regression is introduced to calculate the best-fit w values of different land cover types.

Through the SPSS software, nonlinear regression can be made. The iterative method and least square method are used to fit the known complex equation. After fitting the nonlinear regression, the solution is optimal under the given independent variables. That is, the sum of the squares of the distances of the scattered points from the curve is the smallest. The R^2 at this time is generally the highest in the curve fitting process.

3

Data and study area

3.1 Study areas

A full understanding of the characteristics of watershed is a basis of hydrology. Large samples of watersheds provide multiple spatial and temporal scales and changing environments [24]. Although modeling a single watershed can promote a deeper understanding of the internal hydrological mechanisms, using large sample data sets is helpful to find the difference and similarity between the watersheds and obtain some conclusions that are impossible to gain with small sample data sets. An individual catchment can be considered as a continuum of catchment attributes. The catchment attributes change spatially along several gradients (such as climate changes and land use cove changes), so these changes can be studied on different gradients.

The United States has a vast territory, complex and diverse topography and climate, as well as complete physical and hydrological data sets. And there are many land uses and climate types, such as the drought in California, forest in the southeast and so on. The study links land cover changes to the hydrological response on small to medium (<1000 km^2) catchments. Because the characteristics of small watersheds are more obvious, the changes in catchments are relatively stable and the numbers of land use types are less. More importantly, they are less disturbed by other factors compared with large catchments, which is conducive to the study of large-sample small catchments. Newman presented a community data set of daily forcing and hydrologic response data for 671 small to medium sized basins across the contiguous United States (with median basin size 336 km^2) in CAMEL. These catchments span a wide range of hydroclimatic conditions only with a few man-made disturbances. A lot of basic data, including daily precipitation, discharge, potential evaporation, mean slopes, elevation and so on can be found. Moreover, the United States Geological Survey (USGS) developed an updated version of their Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) in 2011 [25].

For the processes of choosing 200 catchments from the 671 catchments, firstly, 534 catchments whose areas are all smaller than 1000 km^2 were selected. Next, considering the problem of missing forcing or stream flow data in the study period from 1981 to 2013, 306 watersheds with continuous and complete daily data were selected as the sample sets. After checking long term (from 1981 to 2013) water balance and making Budyko framework, 200 catchments that meet the requirement of water balance and with scattered distribution on Budyko framework were chosen in the final (see Appendix E, Figures E.1 - E.6). They are distributed almost evenly across the continental United States, except Alaska and Hawaii. Besides, the total catchments represent different hydrological systems with various climatic conditions from arid to temperate to wet (see Appendix B, range of E_P / P).

3.2 Forcing and stream flow data

A large sample of watershed attributes were also provided including mean slopes and mean elevation referred in next chapters as well as hydrometeorological time series, which together form a freely available CAMEL data set (https://doi.org/10.5065/D6MW2F4D) [26]. The United States Geological Survey (USGS) developed a database which contains geospatial information for over 9000 streams. A digital elevation model (DEM) was applied to the geospatial fabric data set to create elevation contour polygon shapefiles for each basin. A basin spatial configurations were provided [27], including entire watersheds (lumped), elevation bands, hydrologic response units (HRUs), or grids. Daily stream flow data was compiled from the United States Geological Survey National Water Information System. The daymet data set was selected as the primary gridded meteorological data set, such as daily precipitation. Based on the spatial convolution of a truncated Gaussian weighting filter with the set of station locations, the gridded daymet data set can be converted to area daymet data set [28].

Regarding the calculation of daily potential evaporation, ten random selections of the initial parameter set for each watershed were made and the SCE global search algorithm was applied. It is an algorithm for objective calibration by minimizing the RMSE of daily simulated runoff relative to observed runoff, and selected the optimal parameter set with the smallest RMSE from 10 models for evaluation [25]. The difference of daily potential evaporation values in each basin obtained by ten models is very small. In order to ensure the accuracy of the data and to exclude the particularity of a certain model, the potential evaporation data set used in this thesis is the average value of the ten results.

From Appendix A, the areas of 200 catchments range from 25 km^2 to 997 km^2, and the median area is 321 km^2. More than half of the catchments are below 500 km^2 from the Figure E.7 in Appendix E. There are many watersheds with slopes of 0.1 or close to 1 from Figure E.8. The extreme slopes have a great influence on stream flow. This means that in addition to considering the effects of land use, mean slope is an important factor that cannot be ignored. Moreover, these catchments have mean elevations ranging from nearly the sea level (13 m) to high alpine elevation (3360 m) with a median elevation of 424 m. The topography of the United States is high in the west and north, and low in the east and south. From the normal distribution for mean elevation (Figure E.9), there are a few catchments with more than two kilometers elevations. The reference [29] studied that the watershed elevation correlates well with temperature. The combination of elevations with precipitation can explain the variation of the evapotranspiration. From Appendix B, daymet-estimated annual mean temperatures for all catchments between 1981 and 2013 range from -0.4 to 22.8℃ and the annual mean precipitation are between 243 and 2690 mm/y. Annual mean observed runoff ranges from 10 to 2042 mm/y with potential evaporation ranging from 716 to 1723 mm/y. Obviously, this implies that daymet precipitation is not enough to balance the observed runoff in some basins.

It can be seen that the physical and hydrological characteristics of the 200 watersheds have a large span, which is conducive to the analysis of various types of large samples. Meanwhile, there are many different types of climates in the United States. For some special climates in US, the high mountain ranges in the west include the Rocky Mountains and Sierra Nevada. Due to the high altitude, some regions have formed an alpine climate. The west of the mountain spreads from south to north with a narrow Mediterranean climate and temperate marine climate. The southwest of US connecting to Mexico is controlled by the subtropical high pressure zone all year round and it belongs to the tropical desert climate.

3.3 Land use data

Over the past 200 years, the LULC (land use and land cover) in the United States was changing at a rapidly increasing rate. The complex changes are related to the sustainability of the natural climate system, ecosystems, natural resources, economic development and human migration. For example, the reduction of forests and wetlands has changed the regulation of water flow. Changes in agricultural land have affected the maintenance of soil fertility. And rapid urban expansion has also threatened the ecological environment on which humans depend. In order to relate different land uses with hydrology, the areas of each land use in all catchments during the study period should be known. Some researchers of the US Geological Survey used a wide range of historical data sources for modeling, and they obtained annual LULC maps from 1938 to 1991 with a resolution of 250 m [30]. Each map contains 14 LULC categories. There are three land types with the area of zero ('blank' in the Table 3.1). It assumes that before 1992, there was no mechanically disturbed land use.

This period from 1992 to 2005 is considered as the historical baseline for the landscape modeling, so the years after 2005 are regarded as the future projection time frames. Four scenarios (A1B, A2, B1, and B2 scenarios) are simulated from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) between 2006 and 2100 [31]. There is no big difference between the four scenarios. Annual land cover maps of A1B scenario from 2006 to 2013 are selected for the following research. These maps in this period are produced at 250-meter spatial resolution (250-m pixels), with 17 LULC classes (like Figure 3.1). Totally, in this thesis, the annual LULC maps from 1981 to 2013 are used, including the modeling maps from 1981 to 1991 by backcasting, historical LULC maps from 1992 to 2005, and conterminous US land cover projections between 2006 and 2013.

Table 3.1 LULC classes for land cover maps from 1981 to 2013

Period	Classes	Category	Period	Classes	Category
1981-1991	1	Open water	1992-2013	1	Open water
	2	Urban developed		2	Urban developed
	3	Blank		3	Mechanically disturbed forest
	4	Blank		4	Mechanically disturbed other public lands
	5	Blank		5	Mechanically disturbed private
	6	Mining		6	Mining
	7	Barren		7	Barren
	8	Deciduous forest		8	Deciduous forest
	9	Evergreen forest		9	Evergreen forest
	10	Mixed forest		10	Mixed forest
	11	Grassland		11	Grassland

	12	Shrub land		12	Shrub land
	13	Cropland		13	Cropland
	14	Hay/pasture		14	Hay/pasture
	15	Herbaceous wetland		15	Herbaceous wetland
	16	Woody wetland		16	Woody wetland
	17	Perennial ice/snow		17	Perennial ice/snow

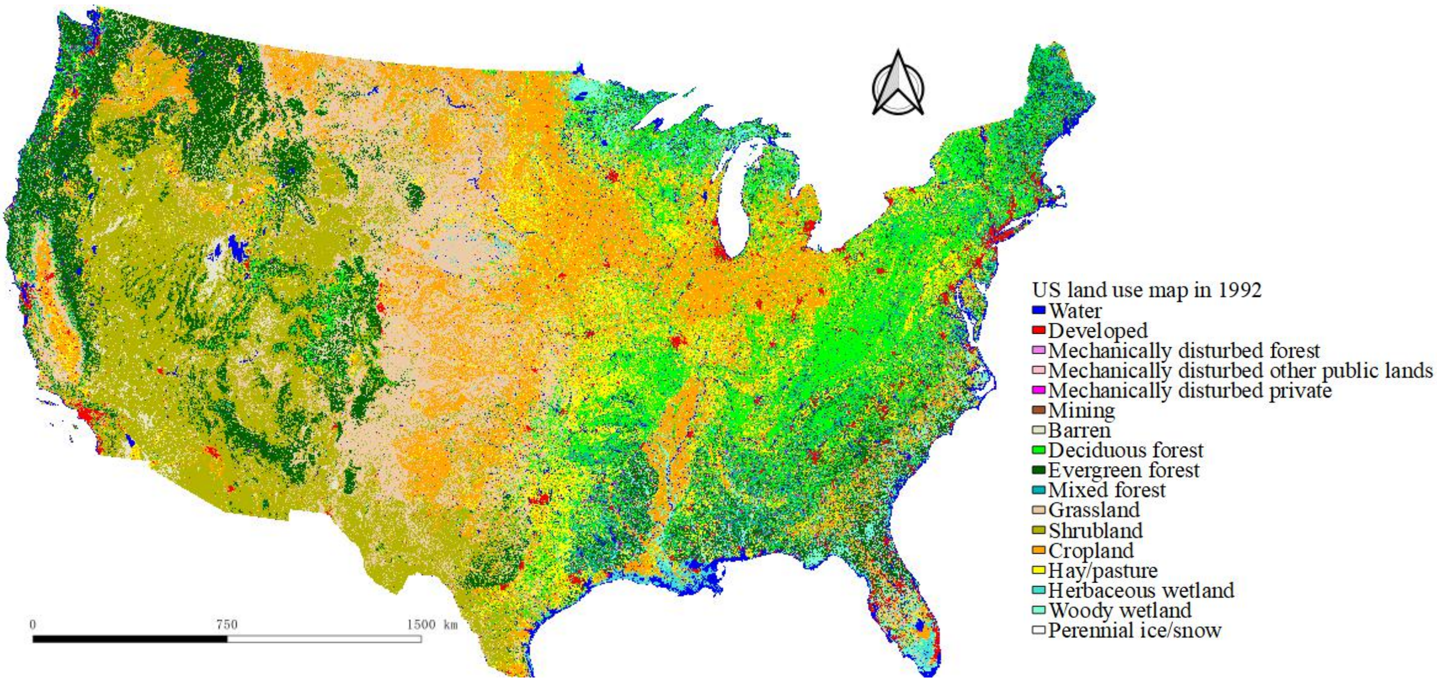


Figure 3.1 Land use map of the United States in 1992

Table 3.2 Introduction and distribution in US of each land use type

Land use category	Introduction	Distribution in US
Open water	It refers to the area occupied by open water bodies, including rivers, lakes, canals, channels, reservoirs, ponds。	Only a few water bodies are in southeastern coast.
Urban developed	The urban developed areas mainly include residential areas, commercial or industrial or transportation areas, and leisure areas. In general, the focus of urban development is on residential areas that are achieved by expanding uninhabited areas or transforming abandoned areas.	The urban developed areas are mostly in the eastern United States, and there are also several parts in the west. But from the entire map, the urban lands occupy a quite small area.
Mechanically disturbed forest	It is also called national forest. The value was initially established in 1992.	It covers a small area in the western border of US, and is almost invisible on the map.
Mechanically disturbed other public lands	In modern states, a part of land is held by central or local governments, called public land, state land, or crown land.	It covers a small area in the northwest of US, and is also almost invisible on the map.

Mechanically disturbed private	In US, some forest lands in the United States are owned and managed by some private owners, called private land. It supplies fish and wildlife habitat, domestically produced forest products, including the timber and fuel wood. Private land contributes to national energy security, housing, and infrastructure.	It covers a small area in the northern US, and is also almost invisible on the map.
Mining	It refers to mining land outside of urban and rural settlements.	It covers a small area in the northeastern and southwestern US, and is also almost invisible on the map.
Barren	Barren lands have thin soil, sand, or rocks. They also include deserts, dry salt flats, beaches, sand dunes, exposed rock, strip mines, quarries, and gravel pits.	There are a few barren lands in the west of US.
Deciduous forest	There are temperate, tropical and subtropical deciduous forests. Deciduous trees have flat leaves which fall seasonally. Deciduous forest is also called broad-leaf forest because of the wide leaves.	In northeastern US, there is a large area of deciduous forest.
Evergreen forest	Evergreen trees occur across a wide range of climatic zones, including coniferous and holly in cold climates, eucalyptus, live oak, acacias and banksia in temperate zones, and rainforest trees in tropical zones.	This kind of forests exist in the west of US, especially in the northwest, and some evergreen forests are also located in the southeast.
Mixed forest	It is a vegetation transition between coniferous forest and broad-leaved deciduous forest, especially in the northern hemisphere. If there are two or more dominant tree species, it can also be expressed as mixed forest.	There are sporadic mixed forests on the border between the east and west of US.
Grassland	Grassland is suitable for the development of animal husbandry. There are wild grasses with some trees.	Grassland is mainly concentrated in the central region. There is also a lot of grassland in California.
Shrub land	It is a kind of plant community dominated by shrubs, including grasses, herbs, and geophyte.	There are a lot of shrub lands in the western and southern US.

Cropland	It is an aggregation of row crops, small grains, fallow, orchards, vineyards or other classes.	The croplands are mainly located in the central and northern US. There is also a large area of cropland in California.
Hay/pasture	Hay land is covered by grass, legumes, or other herbaceous plants that have been cut and dried to be stored as animal fodder. Pasture land is used for grazing.	Most hay/pasture lands are concentrated in the eastern US. There are also some scattered hay/pasture lands in the west.
Herbaceous wetland	The land is mainly covered by herbaceous marsh.	The herbaceous wetland is located near the southern water bodies. However, due to the small area, it is not obvious on the map.
Woody wetland	Swamp is a kind of wetland whose surface is submerged or infiltrated by shallow water. In woody wetland, wet woody plants grow a lot, including forested swamp and shrub swamp.	Beside large rivers, woody wetlands are in the southeast and a few parts of the north. But due to the small area, it is not obvious on the map.
Perennial ice/snow	Those ecosystems are dominated by a perennial cover of either snow or ice.	The perennial ice/snow only exists a little in the west of central US.

Before 1992, there was almost no any mechanically disturbed land use type. After that, the influence of human intervention gradually increased. In order to know the areas of all land use types in each catchment, R language as a program is introduced to extract these specific areas of all land use types from annual land use maps between 1981 and 2013. R code, a free software programming language and operating environment, is mainly used for statistical analysis, graphics, and data mining. The Appendix C shows long-term mean percentages of 17 LULC categories in 200 catchments.

There are 17 LULC categories totally. It would be too complicated when analyzing them one by one. In order to simplify and focus on the evaluation of the impacts of some main land uses on evaporation and stream flow, the land use types are combined to 7 main LULC categories (the first column in Table 3.3). They are forest land, shrub land, grassland, pasture land, cropland, wetland and human-impacted land. From Appendix D, the percentages of human-impacted land are very small, so it can be ignored in Chapter 4.

Table 3.3 Combined LULC classes from land cover maps

Category	Secondary Category
Forest land	Deciduous Forest
	Evergreen Forest
	Mixed Forest
	Mechanically Disturbed National Forest
Shrub land	Shrub land

Grassland	Grassland
Hay/Pasture	Hay/Pasture
Cropland	Cropland
Wetland	Herbaceous Wetland
	Woody Wetland
Human-impacted land	Mechanically Disturbed Other Public Lands
	Mechanically Disturbed Private
	Developed
	Mining
	Open Water
	Barren

4

Results

The catchments with different land uses have different evaporation and stream flow. With a given long-term mean daily precipitation, the long-term mean daily evaporation and long-term mean daily runoff are inversely proportional based on the Equation (2). One catchment is covered by various land use types. In this chapter, the effects of six main land uses are evaluated, including forest land, grassland, pasture land, cropland, shrub land and wetland. Those methods referred in Chapter 2 are used to qualitatively and quantitatively evaluate the influences of different land types. In addition, the possible reasons causing such results are also discussed. As we all know, there are many kinds of reasons causing these results. What are the main reasons is a problem to be solved in this chapter. Expect different land types, some factors like precipitation, slopes, root depth, percolation rate will be considered to explain the results.

From Table 4.1, forest (deciduous forest, evergreen forest and mixed forest) and shrub have long root depth. However, the root depth of grass, crop and pasture is relatively short. Root depth is one of the important factors in the following analysis.

Table 4.1 Root depth of 7 vegetation types [32]

Root depth	Unit (m)
Deciduous forest	2
Evergreen forest	2.4
Mixed forest	2.4
Shrub	2.8
Grass	1.5
Crop	1.5
Pasture	1.5

4.1 Qualitative evaluation on the influences of each land use

In order to ignore the influence of climate, all catchments are divided into five bins on the Budyko framework according to the dryness index using the almost same step. Different literature uses different division methods. For example, Peter and Boris [22] defined that when the dryness index of a catchment is less than 1, it is in wet region, and when the dryness index is larger than 1, it is in dry region. For another example, arid, semi-arid, sub-humid, and humid regions are defined by the dryness index ranges of 5-12, 2-5, 0.75-2, 0.375-0.75 respectively [33]. In order to ensure that the number of bins and the number of catchments in each bin are reasonable, the division method used in this thesis is shown in Figure 4.1 (black lines). In each bin, these catchments have almost the same dryness index. The five bins are separately from 0 to 0.5 (wet region), from 0.5 to 1.0 (semi-wet region), from 1.0 to 1.5 (semi-dry region), from 1.5 to 2.0 (dry region), from 2.0 to 5.0 (very dry region). The differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation from Figure 2.1 of the catchments in each bin are effected by the different land uses. The following qualitative evaluation about the influences of land use on evaporation and stream flow will be done in five bins separately.

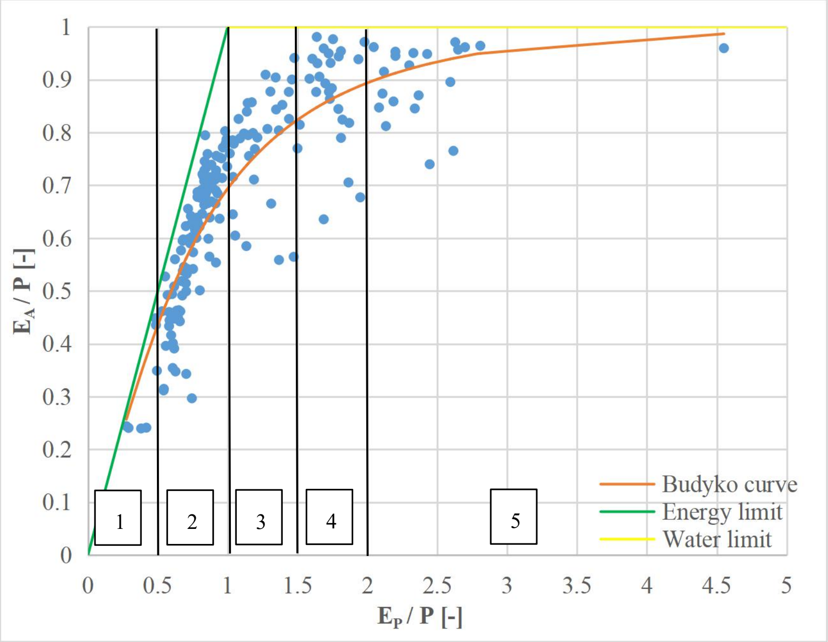


Figure 4.1 Divided five bins of 200 catchments by black lines on Budyko framework

4.1.1 Forest land

The first Budyko framework shows 200 catchments with different percentages of forest coverage using different maker sizes (Figure 4.2). Different marker sizes represent the different ranges of percentage of forest coverage. The points with larger marker size show the percentages of forest coverage on the catchments are bigger. Here, the percentage of forest is the sum of percentage of deciduous forest, evergreen forest, mixed forest and mechanically disturbed forest from Table 3.3 in Chapter 3. Among these points, the biggest blue points represent those catchments which are covered by more than 90% forest and the second biggest pink points show the catchments with 80% to 90% forest coverage. Obviously, most blue and pink dots are concentrated in the lower left corner. It means those catchments with large percentage (>80%) of forest are in lower dryness index and lower evaporation index. However, in relatively dry regions (dryness index > 1), the red dots are almost above the Budyko curve. It explains that the catchments with less than 10% percentage of forest coverage have higher evaporation and lower stream flow for a given precipitation. In most studies, large percentage of forest coverage will lead to larger evaporation. The contents in Figure 4.2 are opposite to the role of forests in regulating floods. The reasons causing this phenomenon are introduced in the next paragraphs.

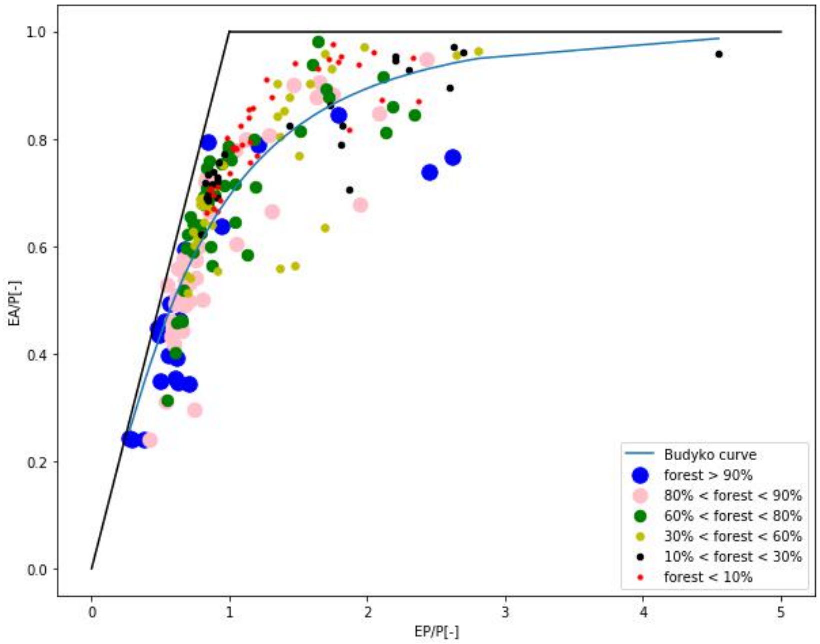
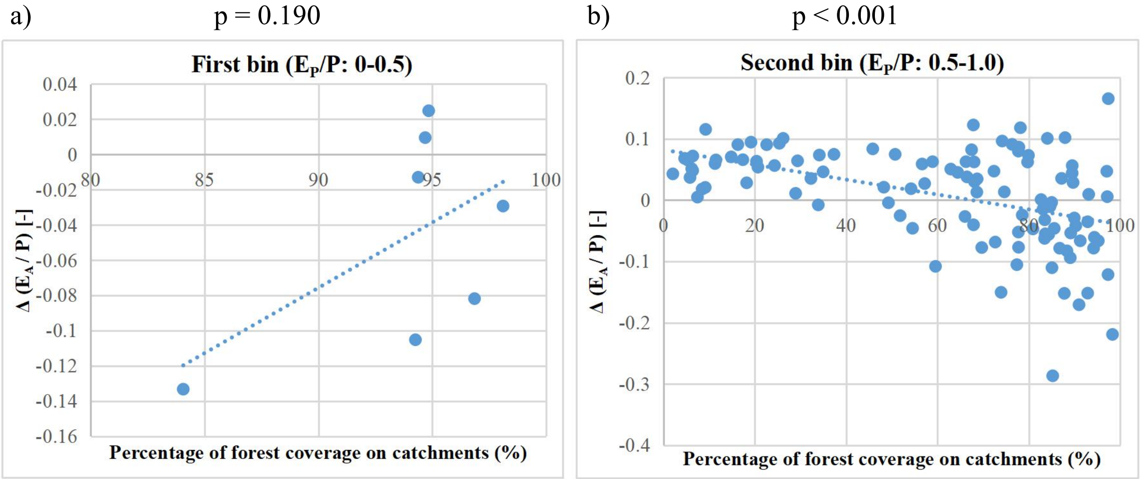


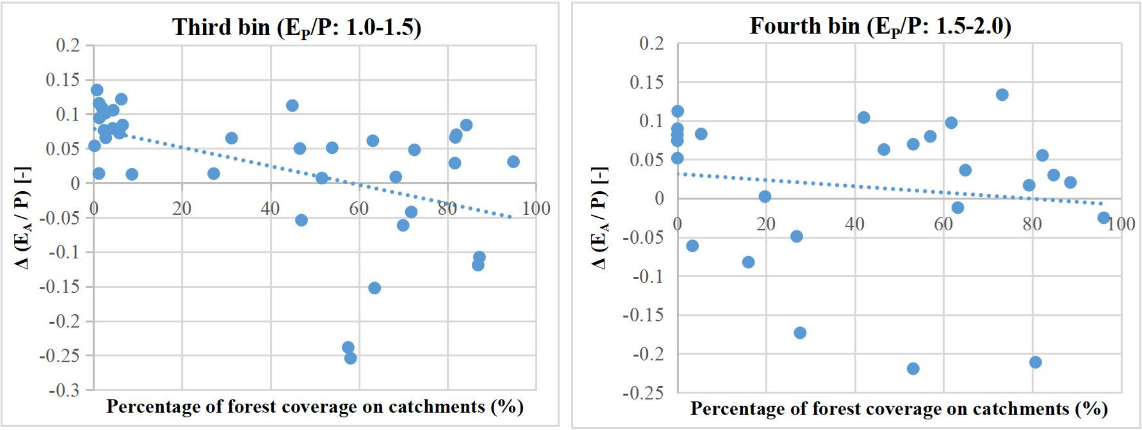
Figure 4.2 The Budyko framework of all catchments with different percentages of forest coverage

The relationship of forest coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in five bins are shown as the two-dimensional Figures 4.3. The x-axis represents the percentages of forest coverage on those catchments which are in each bin from 0 to 100%, and the y-axis represents Δ (E_A / P) as the Figure 2.1 shows. When one point is above the Budyko curve, Δ (E_A / P) is positive. On the contrary, when one point is below the Budyko curve, Δ (E_A / P) is negative. The p values of the Figures 4.3 are 0.190, <0.001, 0.002, 0.138 and 0.003 separately. Regarded 0.05 as the threshold value, there is no significance in Figure 4.3 (a) and (d). For the other figures, there are slightly decreasing trends between the percentage of forest coverage and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. It means more forest coverage causes less evaporation on catchments. Obviously, in the range of small percentages of forest coverage, most points have positive Δ (E_A / P). It conforms to the contents shown in Figure 4.2 (red dots).

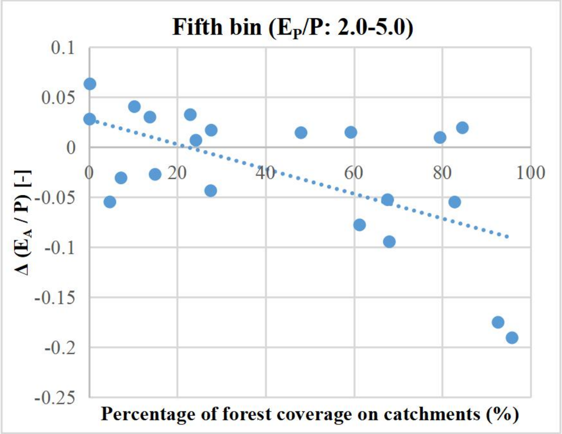

a) p = 0.190

b) p < 0.001

c) p = 0.002 d) p = 0.138



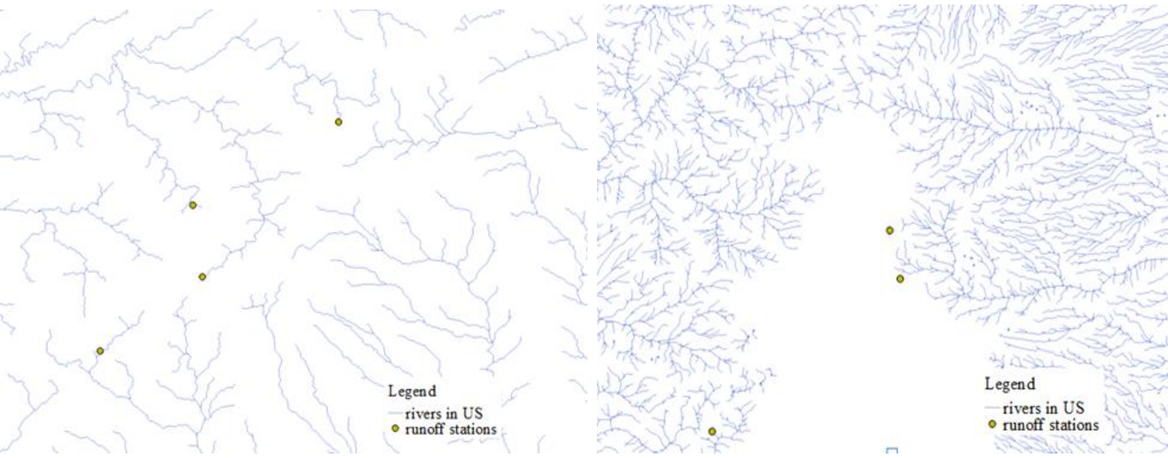
e) p = 0.003



Figures 4.3 Relationship of forest coverage percentages and differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in five bins

It is emphasized that the results are contradictory with what others found. There are many factors affecting the evaporation and stream flow on forest lands. The key controls are rainfall interception, net radiation, advection turbulent transport, leaf area, and plant available water capacity [29]. When the storage capacity of the forest is occupied a lot by the previous rainstorm, the soil moisture content has been almost saturated. The infiltration capacity of the soil is greatly restricted, and it is easy to form full flow. Therefore, for small rainstorms or short-duration rainstorms, the peak-shaving effect of the forest is more obvious, while for long-duration continuous rainstorms, the forest storage capacity is very limited. Different catchments have different physical and hydrological characteristics. The reasons causing different Δ (E_A / P) are specific on different catchments.

What is more, runoff includes surface runoff and underground runoff. The forest land is highly permeable, which allows water to penetrate deep into the soil and increases groundwater recharge. In particular, the forest root systems increase the permeability of soils. Therefore, the forest land can retain moisture to prevent excessive evaporation. What is more, when forest is distributed in the upstream, it has the greatest effect on regulating runoff. While when forest is distributed in the downstream, it is easy to form a large flood peak flow, because it is not conducive to exerting the regulating effect on runoff. The Figures 4.4 show the locations of some gauges measuring stream flow. Most catchments which have large percentage of forest coverage are located in downstream, so the forest there is ineffective to control the generation of runoff.



Figures 4.4 Locations of some gauges measuring stream flow in the catchments with large percentage of forest coverage

Deciduous forest

The forest land use is divided into deciduous forest, evergreen forest, mixed forest and mechanically disturbed national forests. Different kinds of forest have different characteristics like leaf area and living environment, which cause different influences on evaporation and stream flow. The effects of mechanically disturbed national forest will not be evaluated specifically in this chapter because its percentages on all catchments are too small. The largest percentage of mechanically disturbed national forest coverage is only 2.4%. From the Budyko framework of all catchments with different percentages of deciduous forest coverage (Figure 4.5), those catchments with large percentage (>60%) of deciduous forest coverage are obviously distributed in humid and sub-humid regions (the dryness index < 1) and have lower evaporation because the energy limit.

From the Figures 4.6, the relationship of the deciduous forest coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments has a slightly decreasing tend. There is almost no deciduous forest coverage when the dryness index is less than 0.5 and larger than 1.5. So the figures of the deciduous forest coverage percentages and Δ (E_A / P) of the catchments in the first, fourth and fifth bins will not be shown. The p value of the Figure 4.6 (a) is 0.017 which is below 0.05. The decreasing trend has significance. So the deciduous forest coverage on the catchments in semi-humid ranges (the second bin) leads to lower evaporation and stream flow with a given precipitation. However, the p value of the Figure 4.6 (b) is 0.388. It means there is no significance for the relationship of the deciduous forest coverage percentages and Δ (E_A / P) of the catchments in the third bin. This is because in the third bin, the percentages of deciduous forest coverage are less than half of the area, the evaporation and stream flow are more likely affected by other kinds of land use.

Generally speaking, deciduous forests are dominated by broad-leafed trees. The transpiration of large leaf should have been more. Because when the resistance of water passing through the canopy is small, the transpiration will be more. The reference [34] reviewed some studies on water use of trees by different technologies, and found that water use of trees increased with the increase of leaf area. However, there are some contradictory results in Figures 4.6. This is mainly because deciduous forests in the study catchments grow in wet regions, their evaporation is limited by the available energy. Moreover, the mean slopes of these catchments with more than 60% deciduous forest coverage are close to 1 from the Table 4.1, which are quite slant. Surface runoff is easy to generate on steep terrain. It explains why the stream flow of these catchments are larger.

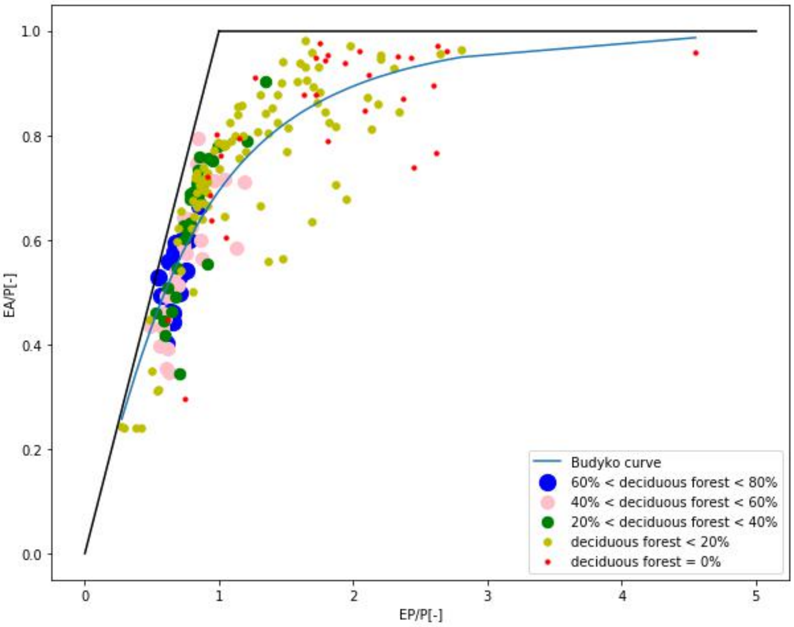
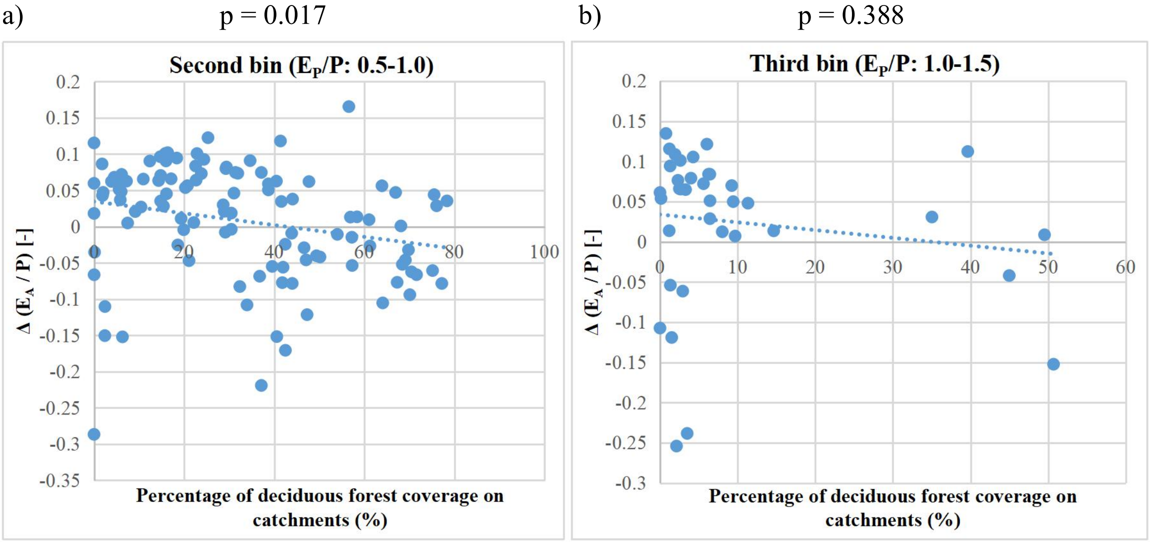


Figure 4.5 The Budyko framework of all catchments with different percentages of deciduous forest coverage



a) p = 0.017

b) p = 0.388

Figures 4.6 Relationship of deciduous forest coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second and third bins

There are a lot of deciduous forest in northeastern America, including cone-bearing seed plants (conifers), such as pine and hemlock (From National Park Service Website). The locations of these catchments with large percentage of deciduous forest are Pennsyivania and some states around it from the Figure 4.7. The physical and hydrometeorological characteristics of them are also important factors affecting the evaporation and runoff. In general, deciduous broad-leaved forests grow in a warm season of 4-6 months with abundant rainfall and a relatively warm winter that lasts 3-4 months. The mean elevation of all 200 catchments is 713 meters from Appendix A, which is bigger than the mean elevations of most catchments with large percentage of deciduous forest in Table 4.1. Besides, the regions where deciduous forest grows are moderate, with the maximum temperature 20℃ and the minimum temperature -0.3℃. The range of their average temperature is from 5.4℃ to 14.7℃, which is slightly cool in the division of temperature grades. And the average annual rainfall is from 1000 mm to 1900 mm, which is pretty wet.

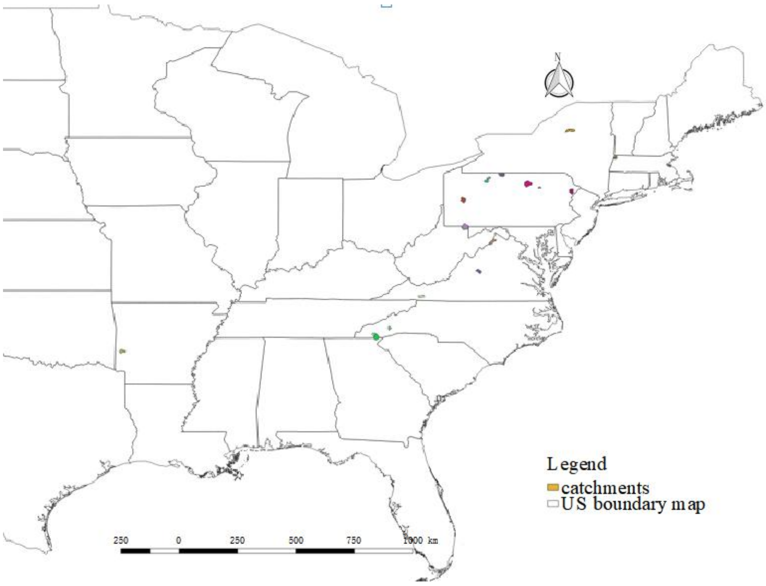


Figure 4.7 Locations of those catchments with more than 60% deciduous forest coverage in US

Table 4.1 Physical and hydrometeorological characteristics of these watersheds with more than 60% deciduous forest coverage

Area	Code	Deciduous forest coverage (%)	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage [-]	Long-term mean values from 1981 to 2013				
							Tmax (℃)	Tmin (℃)	Tave (℃)	P(mm/d)	P(mm/y)
6	3574500	78.36	377	0.879	237	0.793	20.6	8.7	14.7	4.3	1567
2	1439500	77.22	386	0.997	94	0.555	14.4	2.9	8.6	3.6	1328
2	1634500	76.06	442	0.778	182	0.284	17.3	4.7	11.0	2.9	1074
6	3500240	75.51	893	0.959	83	0.677	18.4	5.5	12.0	5.0	1808
5	3011800	75.16	633	1.000	75	0.085	12.7	0.7	6.7	3.6	1297
2	1552500	71.60	548	0.995	64	0.369	12.9	2.0	7.4	3.6	1314
2	1550000	70.50	530	0.988	83	0.888	13.3	2.0	7.6	3.3	1188
5	3028000	70.12	597	0.979	52	0.572	12.9	0.9	6.9	3.4	1258
5	3010655	69.81	623	0.991	97	0.781	12.9	0.8	6.9	3.2	1165
2	2027000	69.12	555	0.940	49	0.675	17.7	5.5	11.6	3.5	1289
2	1333000	68.45	468	0.984	89	0.165	12.5	1.2	6.8	3.6	1319
6	3471500	68.13	903	0.821	84	0.998	16.6	4.1	10.4	3.4	1229
5	3070500	67.30	609	0.717	165	0.476	15.2	3.9	9.6	3.7	1345
11	7340300	66.96	394	0.959	71	0.519	20.9	8.5	14.7	4.4	1599
4	4256000	64.10	494	1.000	26	0.999	11.2	-0.3	5.4	3.6	1317
6	3500000	63.93	848	0.957	126	0.352	18.6	5.9	12.2	5.1	1869
5	3049000	61.26	377	0.716	95	0.361	15.7	3.3	9.5	3.3	1205
6	3456500	61.06	1239	0.965	82	0.423	16.1	4.4	10.3	4.8	1761

Evergreen forest

Secondly, the Figure 4.8 is the Budyko framework of all catchments with different percentages of evergreen forest coverage. The blue and pink dots are distributed from humid regions to arid regions. So the catchments with more than 60% evergreen forest coverage are in a large range of climates. As for the blue points, most of them are below the Budyko curve. And in the Figures 4.9, the relationship of evergreen forest coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in five bins has decreasing trend. Among them, the Figures 4.9 (b), (c) and (e) have the satisfied p values. Although in the first bin, most catchments have large percentage of evergreen forest coverage, the number of points in Figure 4.9 (a) is very small. There is no significance for the regression result. Obviously, most points at large percentage of evergreen forest coverage have negative Δ (E_A / P). It means the evergreen forest coverage causes less evaporation and more stream flow in a given precipitation.

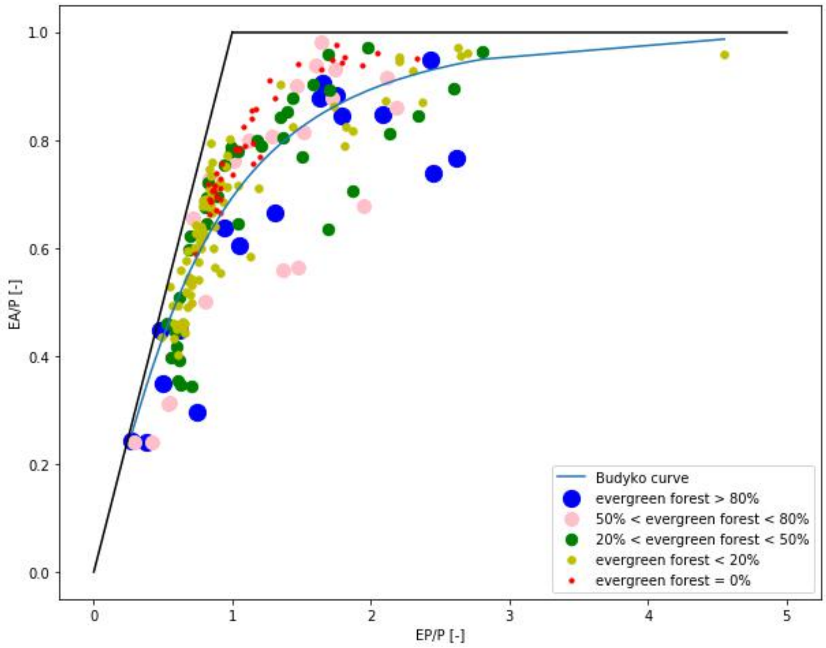
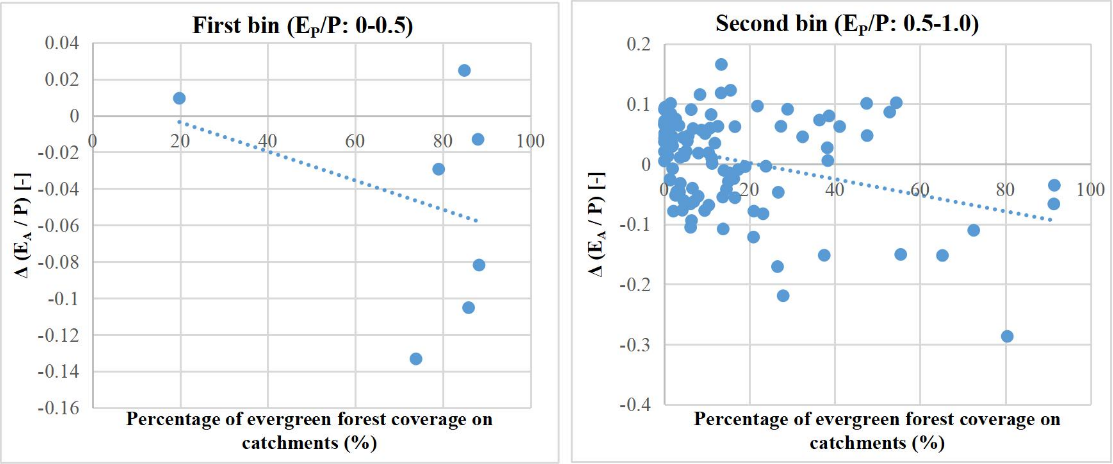
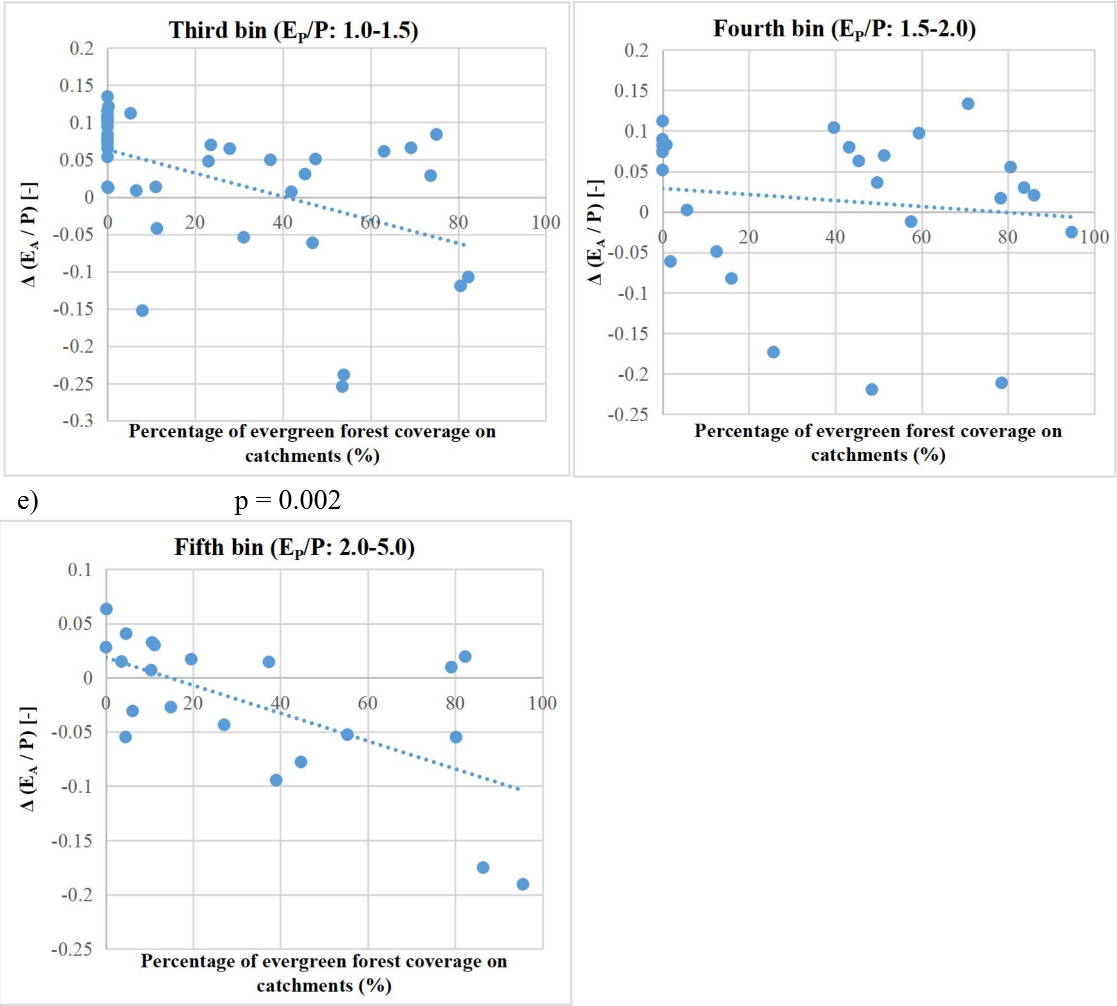


Figure 4.8 The Budyko framework of all catchments with different percentages of evergreen forest coverage


a) p = 0.477

b) p < 0.001



c) p = 0.003

d) p = 0.535

e) p = 0.002

Figures 4.9 Relationship of evergreen forest coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in five bins

In US, evergreen forests are found largely in the temperate mid-latitudes of western America, including New Mexico, Oregon and the north of Texas from Figure 4.10. The big northern forests are not suitable for human living permanently. In these regions, because of the late snow in spring and short summer, the agriculture cannot be developed well. However, the coniferous forests are approximately ideal as a home for the fox, marten, weasel, beaver, and many other fur-bearing animals.

For the physical characteristics of the watersheds with more than 80% evergreen forest coverage in Table 4.2, they are located in uplands because their mean elevations are very large compared with the average elevation of 200 catchments, 713 m. The low temperature and high air pressure in upland can decrease the evaporation of forest. And most mean slopes are close to 1 except some catchments in area 15. As a whole, these catchments are in rather steep terrain. For the climate, the long-term annual average precipitation of these catchments is very different, from 451 mm to 2689 mm. In the middle of US, there are some catchments located in areas 10, 11, 13 and 15. The annual average precipitation of them is between 400mm to 600 mm, which is quite smaller than the precipitation (more than 1000 mm and even more than 2000mm) of those catchments located in the north-west of US (area 17). The maximum temperature is 20 °C and the minimum temperature is about -3.6°C. The average temperature of these catchments is from 4°C to 13°C. For the middle west of America, the area 16 and 18, their temperature and precipitation are in the middle range compared with other areas.

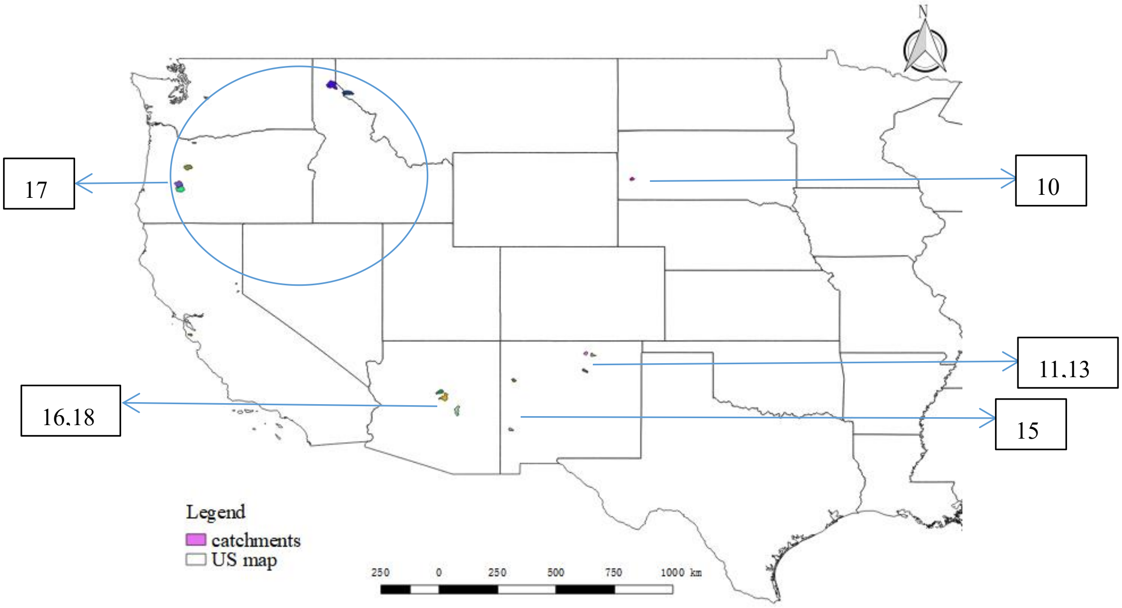


Figure 4.10 Locations of these catchments with more than 80% evergreen forest coverage in US

Table 4.2 Physical and hydrometeorological characteristics of the watersheds with more than 80% evergreen forest coverage

Area	Code	Evergreen forest coverage (%)	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage [-]	Long-term mean values from 1981 to 2013				
							Tmax (°C)	Tmin (°C)	Tave (°C)	P(mm/d)	P(mm/y)
10	6404000	80.59	1534	0.710	44	0.664	13.5	-0.5	6.5	1.5	533
11	7208500	83.72	2885	0.681	193	0.072	12.1	-3.0	4.6	1.7	613
13	8269000	95.53	2923	0.762	74	0.270	11.6	-3.6	4.0	1.6	584
13	8380500	94.73	2649	0.824	249	0.741	14.0	-1.2	6.4	1.7	617
15	9430600	86.41	2361	0.713	82	1.000	16.5	1.1	8.8	1.6	598
15	9505800	86.05	2021	0.531	36	0.575	17.6	2.6	10.1	1.8	661
15	9386900	82.30	2413	0.301	23	0.435	16.0	-1.5	7.2	1.2	451
15	9505350	80.20	1870	0.502	47	0.444	18.9	2.6	10.7	1.6	599
15	9497980	79.12	1690	0.873	39	0.276	20.6	5.4	13.0	1.7	610
16	1034350	82.29	2188	0.899	49	0.284	12.8	-1.6	5.6	2.7	972
16	1033666	80.45	2217	0.791	183	0.736	12.4	-0.2	6.1	3.8	1404
17	1239070	91.48	1356	0.996	54	0.620	10.7	-0.5	5.1	3.1	1123
17	1241100	91.36	1203	0.992	25	0.340	10.8	0.4	5.6	3.5	1262
17	1431670	88.27	948	1.000	130	0.383	14.5	2.6	8.5	4.6	1680
17	1211500	88.02	940	0.995	226	0.682	10.0	2.0	6.0	7.2	2617
17	1418500	85.87	883	1.000	148	0.906	13.7	2.6	8.1	5.8	2119
17	1415450	84.92	852	1.000	65	0.480	14.5	3.1	8.8	4.7	1702
17	1414150	79.04	726	1.000	97	0.911	13.0	3.6	8.3	7.4	2690
18	1116250	80.53	340	0.821	71	0.655	19.0	6.1	12.5	2.6	960

Mixed forest

Thirdly, from the Figure 4.11, the blue dots represent these catchment with more than 20% mixed forest coverage are in wet regions. When their evaporation index (E_A / P) is larger than 0.4, blue dots are distributed above the Budyko curve. It means in semi-humid regions, the evaporation and of the catchment with mixed forest is bigger and the stream flow will be smaller with a given precipitation. It needs to be emphasized that because the percentage of mixed forest coverage in all catchments are smaller than 50%, the evaporation and runoff of each catchment are more likely affected by other land types. Therefore, it cannot be concluded about the role of mixed forest.

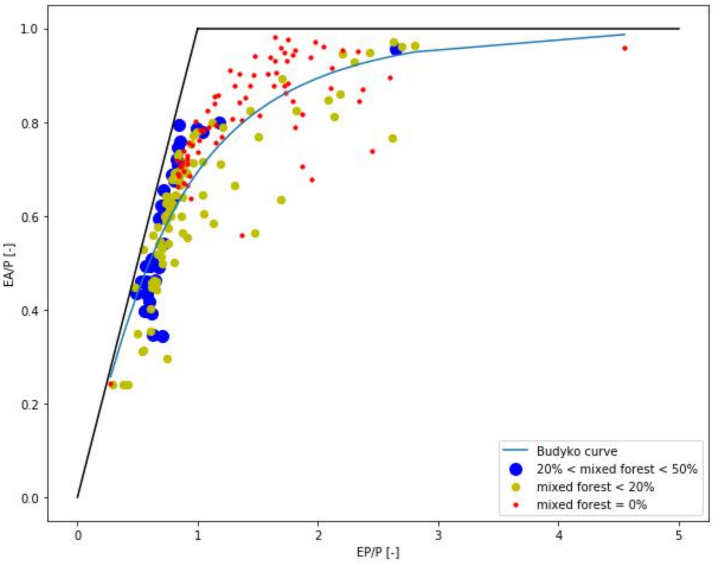


Figure 4.11 The Budyko framework of all catchments with different percentages of mixed forest coverage

Overall, forest plays an important role in hydrological cycle. It is helpful for regulating climate, conserving water sources, preventing strong wind and fixing sand. What is more, forest can adjust the distribution of annual runoff, increase stream flow in dry season, and reduce stream flow in flood season. The canopy of forest intercepts a part of precipitation through their dense foliage and litter layer. The developed root system creates enough infiltration capacity to increase the groundwater level especially in dry season. According to the observations by some relevant departments, when the root system into the soil reaches 1 m deep, each hectare of forest can store 500-2000 m^3 water, which is called 'green reservoir'. However, it is worth noting that the role of forests in regulating flooding is affected by many factors. For example, the capacity of canopy interception is related to rainfall intensity, duration, wind force, tree species, canopy density and so on. For the watersheds studied in this paper, due to a series of special reasons such as slopes and locations, more forests actually lead to greater runoff, which is very interesting.

4.1.2 Grassland

From the Budyko framework of all catchments with different percentages of grassland coverage in Figure 4.12, the dryness indexes of those catchments with more than 50% grassland (blue dots) are bigger than 1. Most of them are distributed above the Budyko curve, and close to the water limit. It means grassland exists in relatively dry regions and causes greater evaporation index. From the Figures 4.13, the p values of Figure 4.13 (a) and (b) are bigger than 0.05. So the increasing trends between grassland coverage percentages and $\Delta (E_A / P)$ of the catchments in the two bins are not reliable. However, it is evident that most points with more than 50% grassland have positive Δ (E_A / P). It means grassland on catchments leads to higher evaporation and lower stream flow with a given precipitation. It is consistent to the information shown in Figure 4.12.

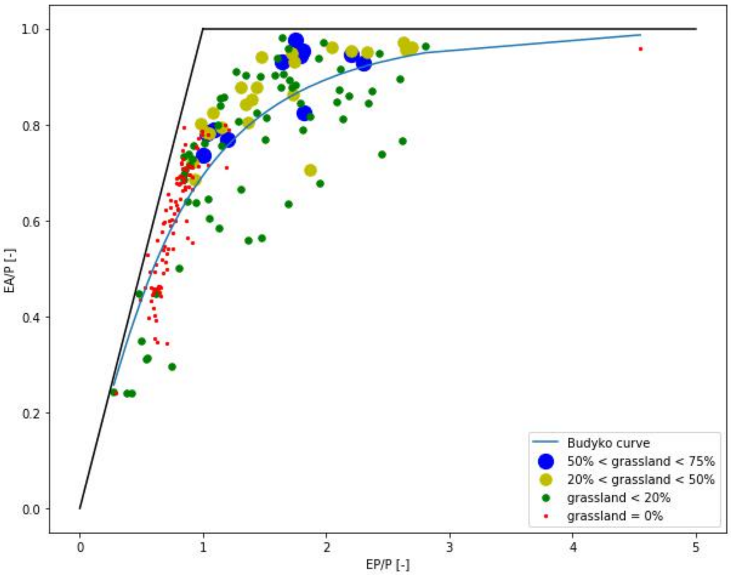
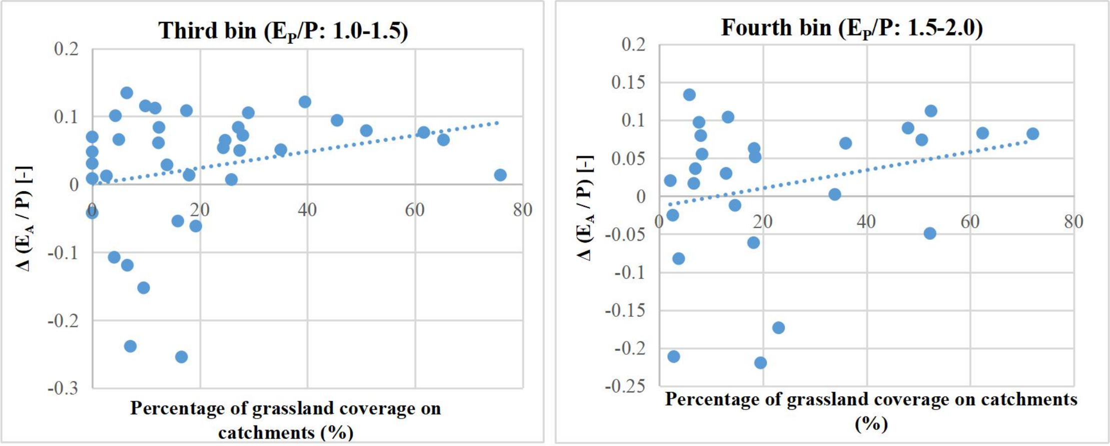
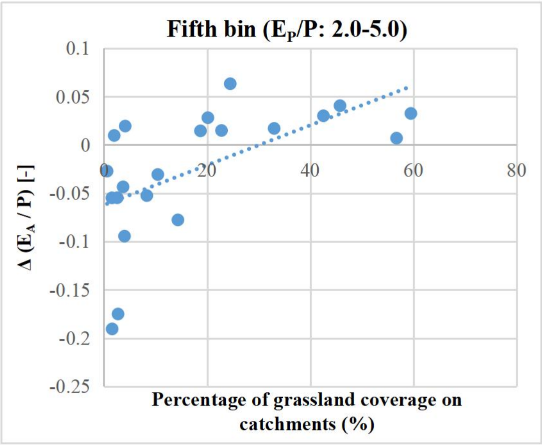


Figure 4.12 The Budyko framework of all catchments with different percentages of grassland coverage

a) p = 0.144 b) p = 0.204



c) p = 0.006



Figures 4.13 Relationship of grassland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the third, fourth and fifth bins

The maximum percolation rates in the catchments with more than half of grassland effect the dryness index from the Figure 4.14. Those orange points in drier regions have low maximum percolation rates (<100), because there is no excessive precipitation to percolate. By contrast, those blue points in semi-arid regions have high maximum percolation rates (>100). It shows the climate has influences on the maximum percolation rate in grassland. However, regardless of the maximum percolation rate, most points in Figure 4.14 are above the Budyko curve. By checking the average precipitation and mean slopes from the Table 4.3, it can explain the greater evaporation index on grassland to some extent. The mean slopes of these catchments with more than 50% grassland coverage are small, so rainfall is not easy to quickly form surface runoff. And the root system of grassland is short and underdeveloped, which is not enough to save too much water and form underground runoff. In very flat terrain, when the precipitation is less, rainfall will evaporate more in arid and hot climates.

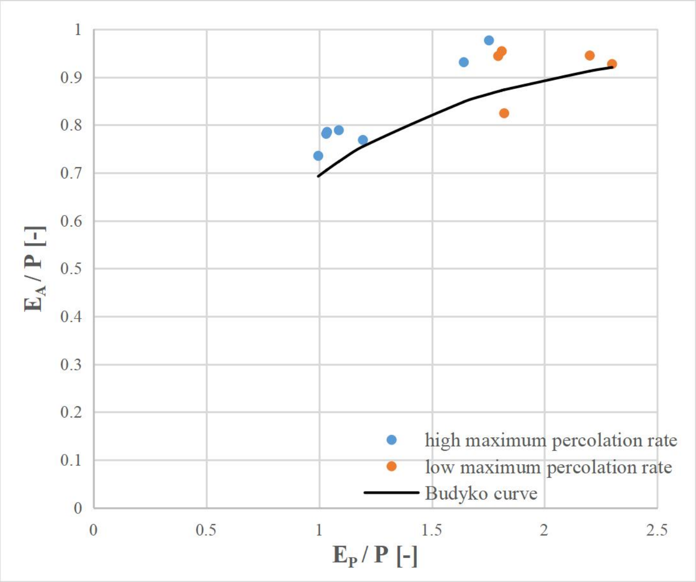


Figure 4.14 The Budyko framework of those catchments with more than 50% grassland coverage in high maximum percolation rates (blue dots) and those catchments with more than 50% grassland coverage in low maximum percolation rates (orange dots)

This is a specific description of the locations as well as physical and hydrometeorological characteristics for the catchments with more than half of grassland. From the Figure 4.15, they spread in the middle and westernmost margin of US, mainly in California, Kansas, north of Texas and North Dakota. Among them, there are two northern catchments, located in the largest national grassland in US, named Little Missouri National Grassland. They have relatively lower temperature with average 5℃. And the long-term annual average precipitation is less than 500 mm. The grassland there has both short and long grass. The land surface of grassland is extensively eroded by rainfall and wind, making a unique feature. For the mean elevation in the Table 4.3, these catchments are located in lowland, which is in contrast with the high elevation of the forest. For other catchments in the south of America, their average temperature is from 12℃ to 17℃ and the annual average rainfall is between 500 mm and 1000 mm. Although it is wetter than the northern catchments, compared with the climate that forest grows in, drier regions are more suitable for forming grassland.

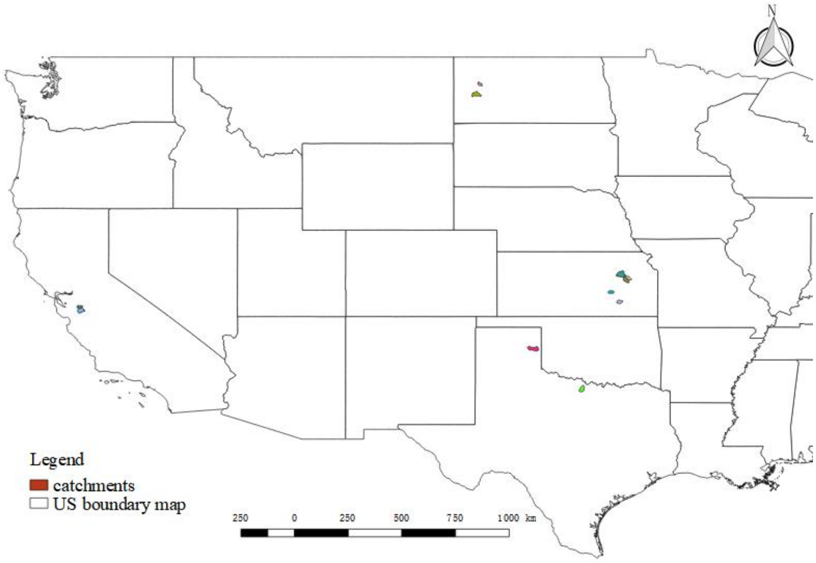


Figure 4.15 Locations of those catchments with more than 50% grassland coverage

Table 4.3 Physical and hydrometeorological characteristics of the watersheds with more than 50% grassland coverage

Area	Code	Grassland coverage %	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage[-]	Long-term mean values from 1981 to 2013				
							Tmax (℃)	Tmin (℃)	Tave (℃)	P(mm/d)	P(mm/y)
11	7180500	75.86	436	0.001	188	0.129	19.4	6.6	13.0	2.6	935
10	6332515	72.08	715	0.000	67	0.301	12.3	-1.3	5.5	1.2	451
10	6888500	65.28	401	0.013	163	0.143	18.6	6.0	12.3	2.6	945
11	7315200	62.39	301	0.092	147	0.129	24.4	10.8	17.6	2.2	813
10	6910800	61.62	391	0.007	232	0.173	18.7	6.3	12.5	2.6	961
11	7167500	60.24	382	0.016	234	0.042	19.9	6.9	13.4	2.7	1002
18	11274630	59.50	547	0.280	67	0.297	21.2	7.3	14.2	1.2	454
18	11274500	56.72	439	0.305	57	0.335	21.7	7.5	14.6	1.2	436
11	7301410	52.43	800	0.000	150	0.140	22.1	7.1	14.6	1.7	606
18	11180500	52.23	245	0.055	56	0.288	20.5	8.4	14.5	1.5	538
10	6911900	50.95	372	0.017	211	0.201	18.7	6.4	12.5	2.6	960
10	6339100	50.64	757	0.000	29	0.141	12.7	-0.9	5.9	1.2	432

On grassland, the increase in solar radiation and temperature accelerates the depletion of soil moisture. The effects of radiation, temperature and vapour pressure deficit on stomatal opening may cause larger evaporation in grassland.

Of course, grassland has many benefits for the ecosystem. Firstly, grassland can effectively improve the water-holding capacity of soil and slow down the erosion of surface soil by rainfall, which is conducive to improve water supply. Besides, grassland has a significant effect on regulating the variation of air temperature, rainfall frequency, and reducing meteorological disasters. Inappropriate management for grassland and overgrazing will lead to a reduction in vegetation and groundwater supply. Grassland occupies the largest area except forest in these studied catchments. Therefore, the researches and planning for grassland are very important.

4.1.3 Hay/pasture land

From the Figure 4.16, it shows the Budyko framework of all catchments with different percentages of hay/pasture land coverage. The blue dots which represent these catchments with more than 50% hay/pasture land coverage are concentrated in sub-humid regions ($0.5 < E_P / P < 1$). And they are all above the Budyko curve. Figure 4.17 shows the relationship of hay/pasture land coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second bin. According to the p value, the $\Delta (E_A / P)$ has an increasing trend with the increasing percentages of hay/pasture coverage on these catchments. For the points with more than half of hay/pasture land coverage, they all have positive $\Delta (E_A / P)$. However, the percentages of hay/pasture land coverage in all catchments are smaller than 75%. There are a few catchments mainly covered by hay/pasture land.

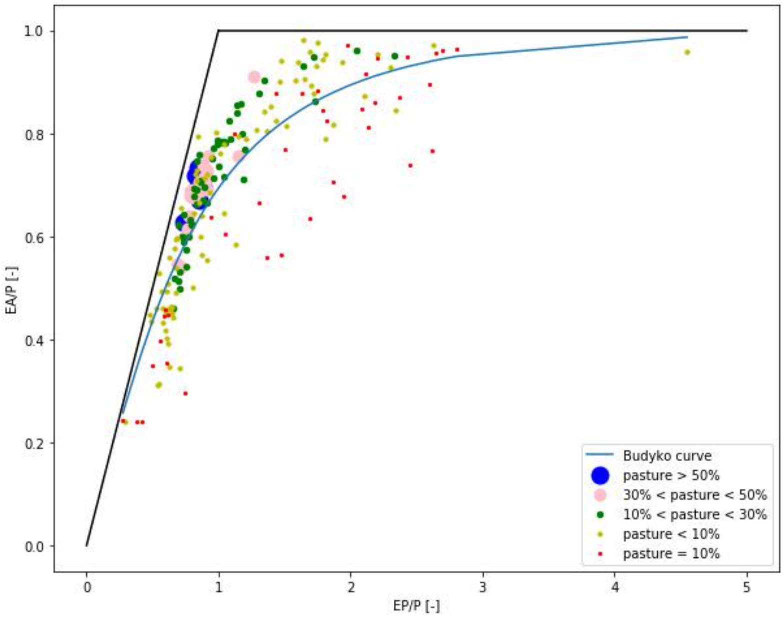
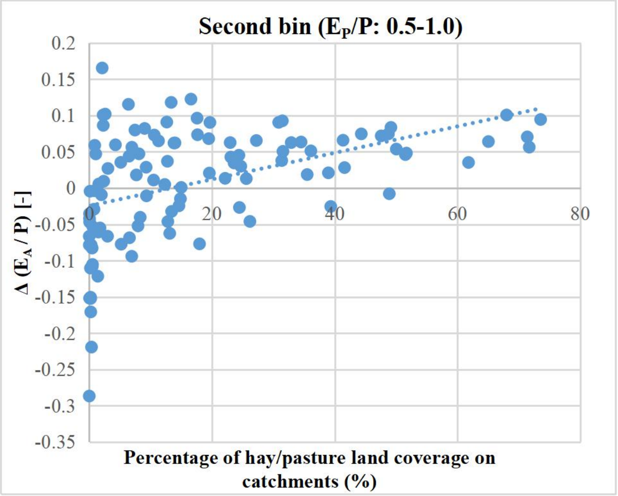


Figure 4.16 The Budyko framework of all catchments with different percentages of hay/pasture land coverage



p value < 0.001

Figure 4.17 Relationship of hay/pasture land coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second bin

According to the report of National Resources Conservation Service, pasture lands are located in total 50 states of the US. Privately owned pasture lands occupy over 27% (about 528 million acres) of the total acreage of the contiguous 48 states. These lands constitute the largest private lands use category. For the locations of these catchments with more than 50% hay/pasture land among the study samples, they are mainly located in Missouri and south of Illinois from the Figure 4.18. And hay/pasture grows is lowland according to the small mean elevations of these catchments. For the climate in the Table 4.4, the average temperature of these catchments is about 13℃, which is very mild, with neither too high nor too low. Besides, the annual average precipitation is a little more than 1000 mm that is larger than the precipitation of grassland.

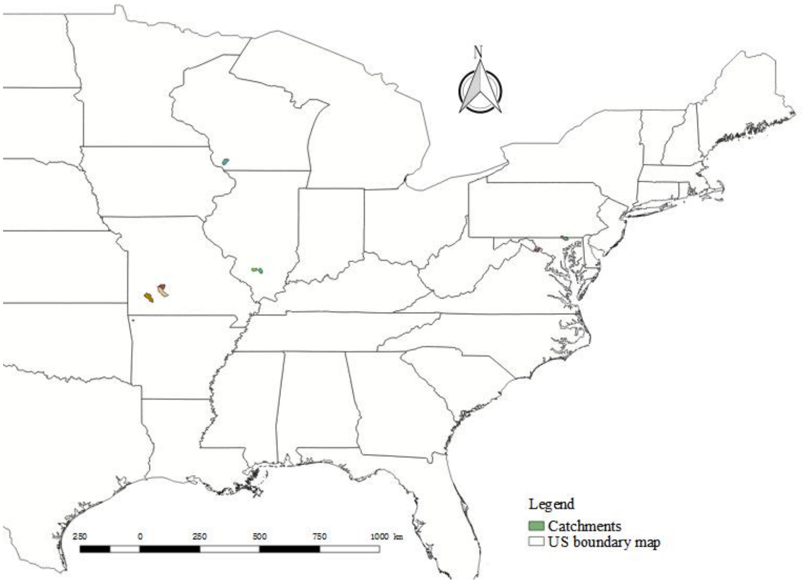


Figure 4.18 Locations of those catchments with more than 50% hay/pasture land coverage

Table 4.4 Physical and hydrometeorological characteristics of the watersheds with more than 50% hay/pasture land coverage

Area	Code	Hay/pasture land coverage %	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage[-]	Long-term mean values from 1981 to 2013				
							Tmax (℃)	Tmin (℃)	Tave (℃)	P(mm/d)	P(mm/y)
11	7195800	73.53	404	0.223	177	0.322	20.7	8.3	14.5	3.5	1269
10	6918460	71.68	350	0.113	151	0.568	19.6	7.3	13.5	3.3	1197
7	5414000	71.35	306	0.485	173	0.770	13.7	2.5	8.1	2.6	957
10	6921200	67.98	324	0.253	247	0.270	19.4	7.2	13.3	3.3	1186
10	6921070	65.03	362	0.278	122	0.172	19.4	7.1	13.3	3.3	1190
2	1638480	61.79	175	0.466	149	0.182	18.4	6.4	12.4	3.0	1102
7	5593575	51.67	149	0.074	241	0.157	18.9	7.4	13.2	3.0	1111
2	1580000	51.50	195	0.424	138	0.336	17.7	6.2	12.0	3.4	1249
7	5595730	50.02	154	0.088	243	0.382	18.8	7.3	13.0	3.2	1155

The Pictures 4.1 show the pasture lands on land surface from Google earth. It is clearly seen that the pasture lands are light green (in red circle). The reasons why these catchments with large percentage of hay/pasture land coverage have large evaporation and low runoff at a given precipitation are almost as the same as the reasons about grassland. The mean slopes of them are small in the Table 4.4 and the root system of hay/pasture is also short and undeveloped. Therefore, rainfall is not easy to quickly form surface runoff and the root system is also not enough to save too much water to form underground runoff. The difference is that pasture grows in wet and warm regions, however, grass grows in dry and hot climates. With higher precipitation, a portion of soil pores could be stored by water, so more precipitation will evaporate.

Pictures 4.1 Pasture land on surface from Google earth

4.1.4 Cropland

The Budyko framework of all catchments with different percentages of cropland coverage shows that the dryness indexes of the catchments with more than 50% cropland coverage (blue and pink dots) are bigger than 1from the Figure 4.19. Most of them are located in semi-arid and arid regions. It is also clear to see that the blue and pink dots are all above the Budyko curve. This means the long-term daily average actual evaporation of cropland is higher and the stream flow is lower with a given precipitation. From the p values of two-dimensional Figures 4.20, the Figures 4.20 (a) and (b) have significance. So the cropland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second and third bins have an increasing trend. Besides, all the points with more than 50% cropland have positive Δ (E_A / P), which conforms to the contents in the Figure 4.19.

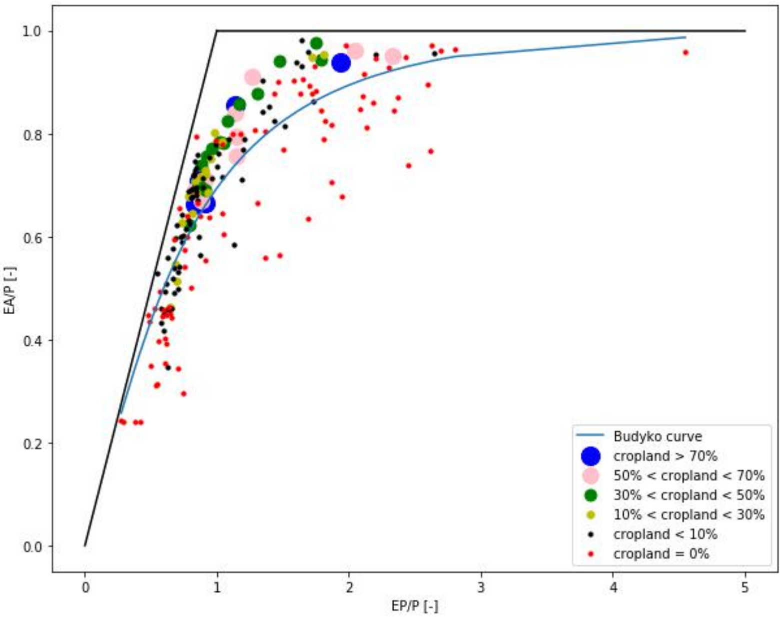
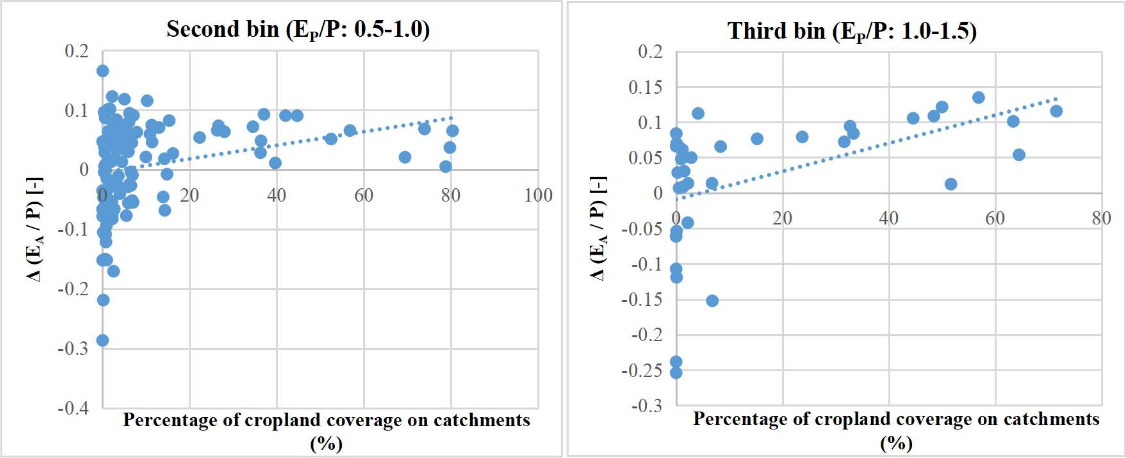
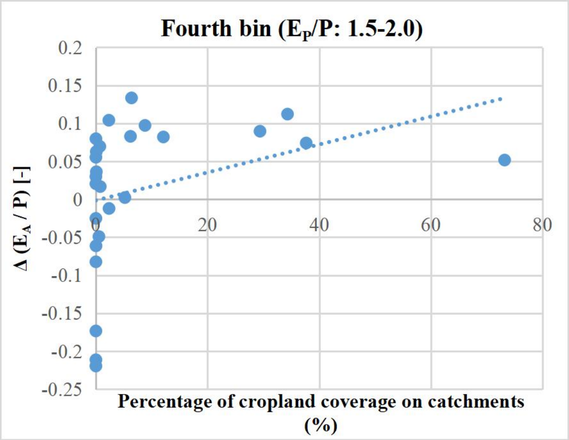


Figure 4.19 The Budyko framework of all catchments with different percentages of cropland coverage

a) $p = 0.004$ b) $p = 0.002$



c) $p = 0.104$



Figures 4.20 Relationship of cropland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second, third and fourth bins

From National Resources Conservation Service, croplands are used for the production and harvest. Croplands are divided into cultivated cropland and non-cultivated cropland. Cultivated croplands mainly comprise row crops and close-grown crops. Non-cultivated croplands include horticultural croplands. On the Figure 4.21, these catchments where at least half are cropland are mainly in the mid-east of US. Some eastern catchments belong to the big areas 4, 5 and 7. They are located in Ohio, Illinois and the east of Missouri. Their average temperatures are from 9℃ to 13℃ from the Table 4.5. And the long-term annual mean precipitation is around 1000 mm. In Ohio, there is a biggest manufacturing soybean and corn production base. Greenhouse and nursery products comprise about 11% of Ohio's total agricultural income. And Illinois is a major produced base of soybeans, corn and swine. The variations of climate and soil types in the state promote a lot of other clops grow. In the middle part, there are some catchments in the big areas 10, 11, 12, located in Dakota, east of Nebraska, Kansas and north of Texas. In mid-north, the mean temperature is less than 10 ℃ that is relatively low. In mid-south, the mean temperature is around 15 ℃. Their annual average precipitation is from 400 mm to 900 mm. It shows that in these croplands, precipitation is not abundant for farming and more irrigation is required. In addition, the mean slopes are small and they are in lowlands, which are similar with the terrain of grassland.

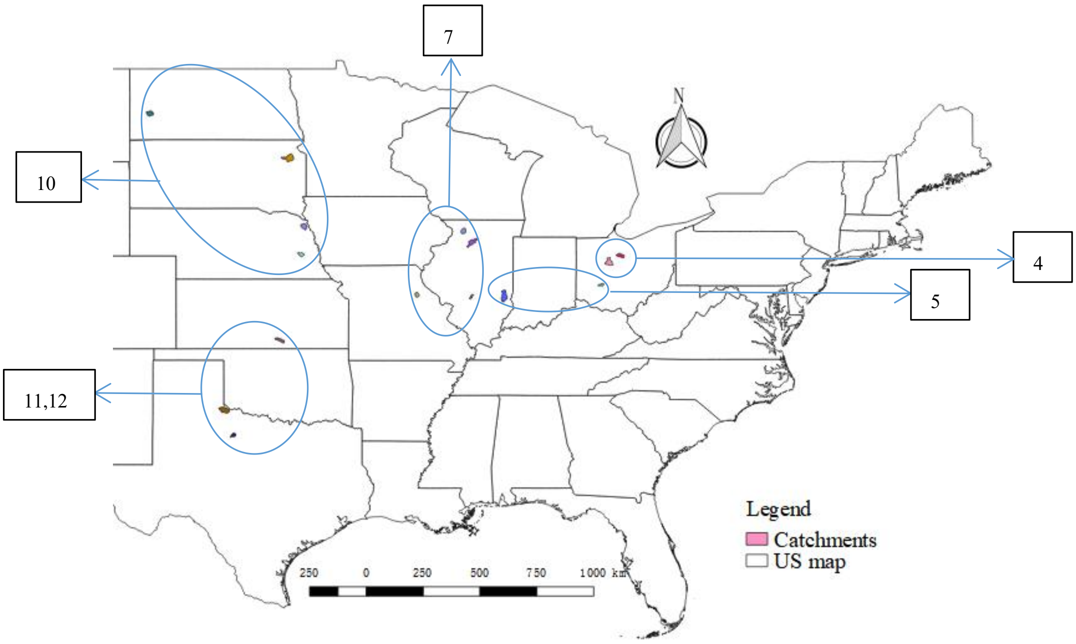


Figure 4.21 Locations of those catchments with more than 50% cropland coverage

Table 4.5 Physical and hydrometeorological characteristics of the watersheds with more than 50% cropland coverage

Area	Code	Cropland coverage %	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage[-]	Long-term mean values from 1981 to 2013				
							Tmax (℃)	Tmin (℃)	Tave (℃)	P(mm/d)	P(mm/y)
4	4196800	78.80	269	0.005	248	0.218	15.8	5.0	10.4	2.7	982
4	4197100	69.45	289	0.007	245	0.069	15.3	4.7	10.0	2.8	1018
5	3241500	79.74	321	0.026	205	0.353	16.5	5.4	11.0	3.0	1104
5	3346000	56.80	182	0.095	230	0.546	18.0	6.6	12.3	3.1	1143
7	5556500	80.37	249	0.123	148	0.335	15.2	3.8	9.5	2.8	1011
7	5444000	73.94	253	0.119	230	0.184	14.8	3.2	9.0	2.8	1009
7	5593900	52.47	203	0.072	237	0.242	18.0	6.5	12.2	2.9	1051
7	5507600	51.66	228	0.039	216	0.079	17.9	6.3	12.1	2.9	1071
10	6344600	73.23	820	0.000	118	0.047	12.7	-0.9	5.9	1.2	427
10	6803530	71.47	395	0.000	116	0.190	16.9	4.2	10.5	2.2	797
10	6601000	63.36	411	0.037	137	0.292	15.7	3.0	9.4	2.1	772
10	6479438	56.86	564	0.003	145	0.127	12.0	0.2	6.1	1.7	635
11	7145700	64.45	402	0.035	250	0.162	20.7	7.7	14.2	2.4	892
11	7299670	56.77	501	0.001	168	0.412	24.4	9.4	16.9	1.7	619
12	8082700	50.90	448	0.000	133	0.314	25.0	10.4	17.7	1.8	654

In general, the agricultural growing season is shorter than that of the native vegetation, such as the Corn Belt area of the Midwest. The seasonal potential evapotranspiration in agricultural areas would be expected to be distinctly less than that of the native vegetation. However, since the average annual precipitation of these cropland is significantly smaller than that of eastern forests, there are powerful irrigation systems on cropland. The Pictures 4.2 from Google earth show the irrigation systems (white cylinders in red rectangle) on cropland. The plant height and leaf area of the crop are the main factors affecting the transmission of light energy and soil surface evaporation. Moreover, watersheds with large areas of irrigated land are likely to have greater evapotranspiration, thus leading to lower stream flows (Figure 4.22) [35]. In arid and semi-arid areas, the growth of crops often needs to be achieved through irrigation. Large-scale irrigation systems increase the moisture in the surface atmosphere, which helps to form rainfall.

The amount of soil infiltration can increase on cultivated land. The flood season is the most suitable for crop growth, because crop growth requires more water. Therefore, the increase of cropland can reduce runoff and weaken peak flow. However, when the floods exceeds a certain limit, more farmland will be submerged by the flood. Balancing the floods and the area of croplands is helpful to manage the croplands and obtain more harvest.

Pictures 4.2 Irrigation systems on cropland from Google earth

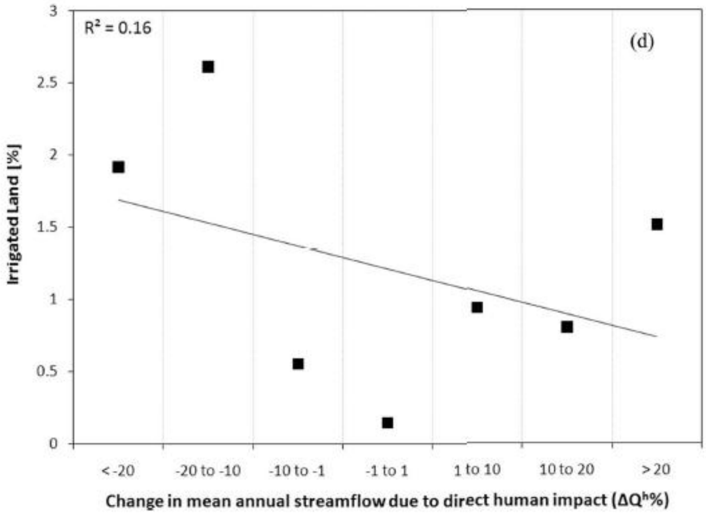


Figure 4.22 Comparison of the estimated stream flow changes with the percentages of irrigated land

4.1.5 Shrub land

From the the Budyko framework of all catchments with different percentages of shrub land coverage in Figure 4.23, the number of these catchments with more than 65% shrub land coverage (blue dots) is very small. It is obvious that their dryness indexes are more than 1.5, which means drier regions are more suitable for shrub to grow. Meanwhile, the blue points are all distributed below the Budyko curve. The Figures 4.24 show the relationship of shrub land coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the fourth and fifth bins. Although it is no trend on the two figures according to their p values, the points with more than 65% shrub land coverage all have negative Δ (E_A / P). Therefore, the evaporation is smaller and stream flow is bigger at a given precipitation on shrub land in dry regions.

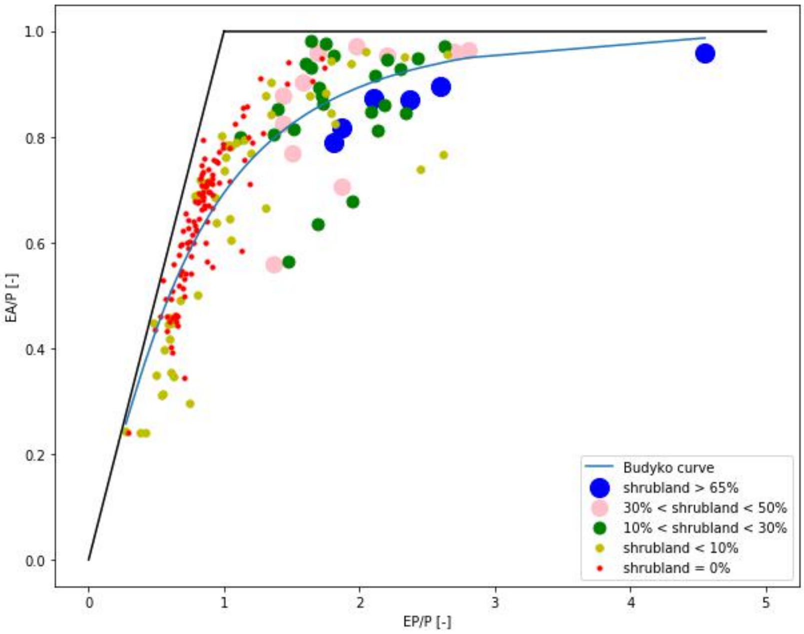
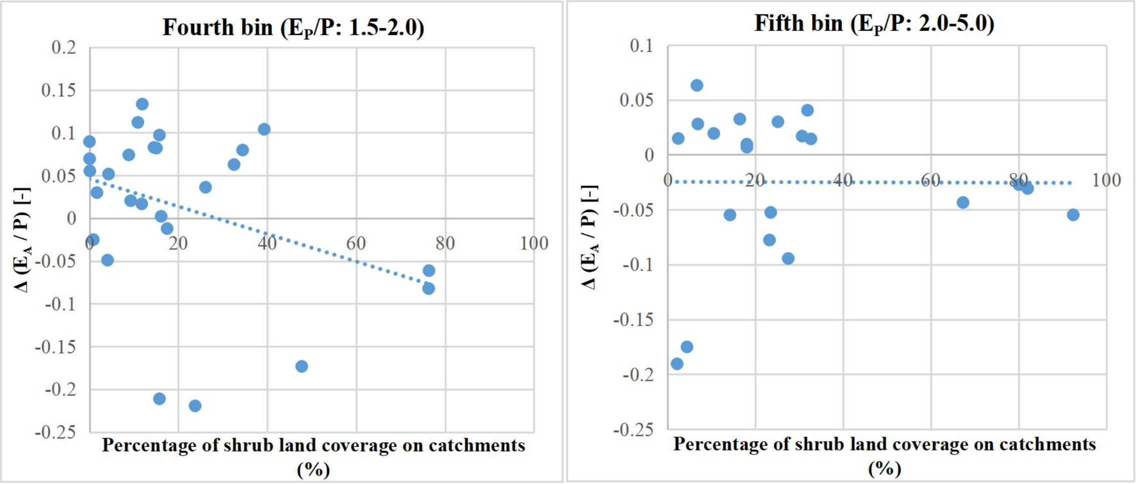


Figure 4.23 The Budyko framework of all catchments with different percentages of shrub land coverage



a) $p = 0.082$

b) $p = 0.985$

Figures 4.24 Relationship of shrub land coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the fourth and fifth bins

Those catchments with large percentage of shrub land are mainly concentrated in the mid-west of US, including Oregon and Idaho from the Figure 4.25. In the Table 4.6, these catchments with more than 65% shrub land are located in uplands. Higher elevation will lead to lower temperature, smaller evaporation, and larger runoff accordingly. For the climates, the average temperature is only about 6℃ except the catchment located in the south of America in big area 15. Their annual mean precipitation is from 200 mm to 600 mm, which is lower than the precipitation on any of other land uses. Therefore, shrub is suitable to grow in dry and cold regions.

From U.S. Department of Agriculture, the principal shrub land ecosystems of the western US include sagebrush, mountain brush, salt desert, creosote bush, sand-sage prairie, coastal sage, mesquite and so on. Shrubs usually have a more competitive advantage relative to the growth environment of other plants. In semi-arid, temperate, and continental climates, shrubs are more likely to grow under shady conditions, poorly aerated soil, cold winters, and short growing seasons. These promote that shrubby habitats are arid and cold.

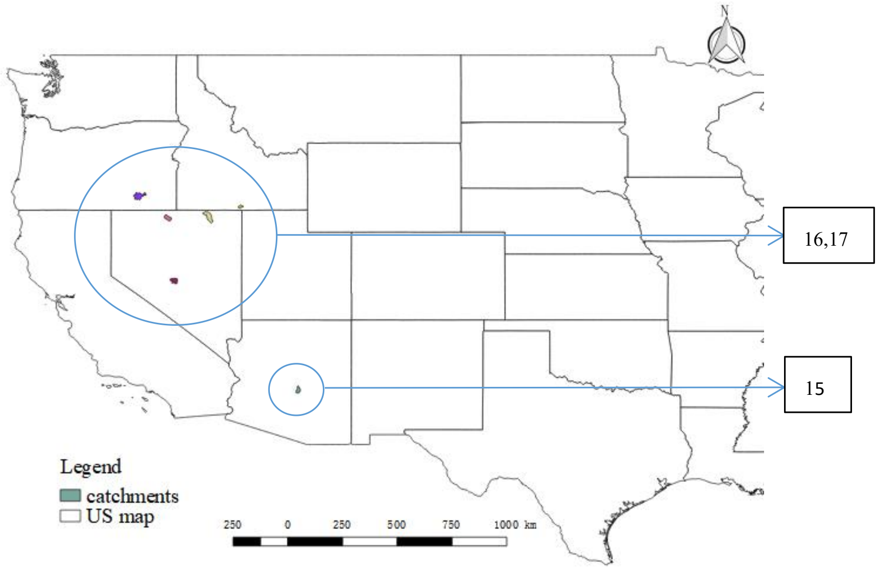


Figure 4.25 Locations of those catchments with more than 65% shrub land coverage

Table 4.6 Physical and hydrometeorological characteristics of the watersheds with more than 65% shrub land coverage

Area	Code	Shrub land coverage %	Mean elevation (m)	Mean slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage[-]	Long-term mean values from 1981 to 2013				
							Tmax (℃)	Tmin (℃)	Tave (℃)	P(mm/d)	P(mm/y)
16	10329500	92.43	1907	0.002	51	0.199	13.6	-0.3	6.7	1.4	517
17	13083000	82.05	1995	0.008	141	0.214	12.9	-0.8	6.1	1.5	563
16	10249300	80.07	2069	0.062	200	0.695	16.1	0.5	8.3	0.7	243
17	13161500	76.37	2043	0.034	128	0.069	12.8	-1.7	5.5	1.4	500
17	10396000	76.30	1816	0.005	90	0.438	13.2	-0.2	6.5	1.6	590
15	9510200	67.32	1147	0.158	55	0.433	24.8	9.8	17.3	1.3	477

The Pictures 4.3 show the shrub land zone from Google earth. In the red circulation, there are shrub lands. And between the staggered shrub, there are a lot of bare lands (white and brown colors), and the evaporation of bare lands is very small. So these blue points are below Budyko curve in Figure 4.23. Besides, since the evapotranspiration of shrub land may be controlled by stomatal resistance, it will result in a small amount of evaporation [36]. Compared with forests, shrubs are smaller in size, shorter in plant height, and limited in the area of shrub coverage. Therefore, there are a few researches about shrub land in arid and semi-arid regions. [37].

Pictures 4.3 Shrub land on surface from Google earth

4.1.6 Wetland

From Figure 4.26, it is clear that wetlands are generally formed in sub-humid landscape. Due to energy limit, the actual evaporation will be limited. In Figure 4.27, there is no trend between the wetland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second bin. Because in all 200 catchments, the proportions of wetland are not very large, and no wetland in a catchment occupies more than half of the area. Therefore, the evaporation and stream flow of each catchment are more likely affected by other land types.

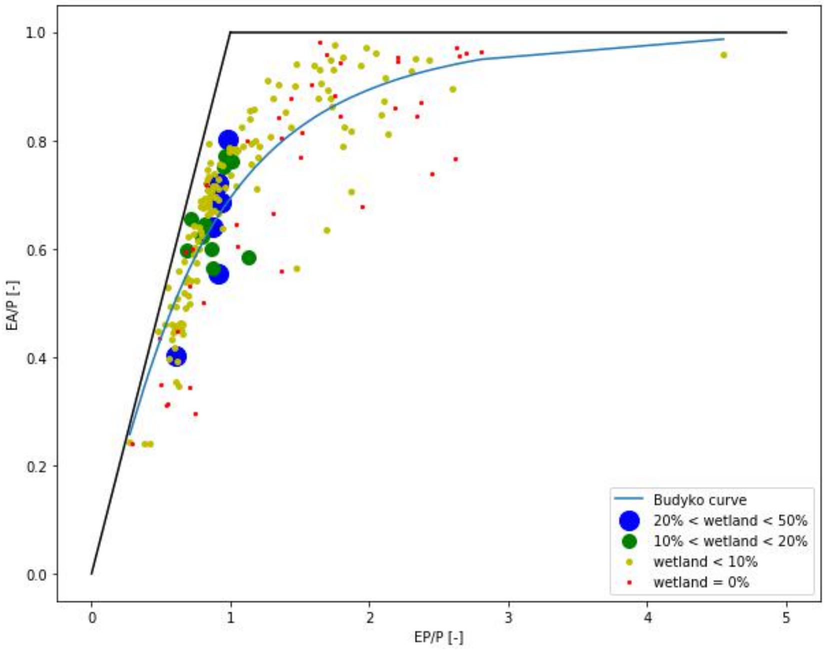
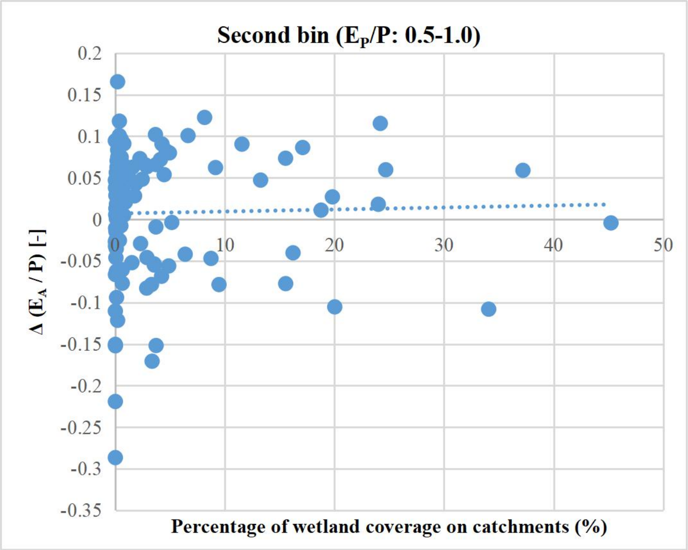


Figure 4.26 The Budyko framework of all catchments with different percentages of wetland coverage



p = 0.821

Figure 4.27 Relationship of wetland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the second bin

Although the areas of wetland are small in all studied samples, the benefits of wetland to ecosystem cannot be ignored. Wetlands are defined by the U.S. government as the inundated or saturated areas by surface or ground water at a sufficient frequency and duration. Under normal circumstances do support, a prevalence of vegetation has typically adapted for life in saturated soil conditions. Pictures 4.4 show the wetlands beside water bodies in the south of US. Wetlands play an important and irreplaceable role in maintaining water quality, resisting flooding and erosion, improving climatic conditions, controlling water pollution and maintaining regional ecological balance. Wetlands also provide a habitat to some threatened and endangered species on the planet. If the natural wetlands gradually disappear, the entire ecosystem and ecology will be greatly affected, and the potential flood risk will emerge. Not only is it the responsibility of humans to protect natural wetlands, but the construction of artificial wetlands also needs to be widely concerned.

Pictures 4.4 Wetland on surface from Google earth

4.2 Quantitative evaluation: Multiple linear regression

Backward multiple linear regression is a method to quantify the impacts of different land uses on evaporation and stream flow. In this thesis, since the the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation is explained as the best indicator in Chapter 2.1, it is selected as the dependent variable. The dryness index (E_P / P) and the fractions of the percentages of six main land types coverage in all catchments are the independent variables. The coefficient of each land use represents the weight of their effects on the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. If the coefficient is negative, which means this kind of land use contributes on negative $\Delta (E_A / P)$. By contrast, if the coefficient is positive, the land use contributes on positive $\Delta (E_A / P)$. In the first step of making backward multiple linear regression, all variables are introduced into the regression equation, and then one variable that is the least significant is eliminated until only one variable remains.

4.2.1 Considering all catchments as a whole

When using 200 catchments as the samples to make backward multiple linear regression, the dryness index is one independent variable that should be considered in each step. Because the dependent variable is always related to dryness index. Therefore, the independent variable E_P / P will not be removed in each step although sometimes its significance is the smallest. From the Table 4.7, the R^2 and adjusted R^2 decrease with the number of independent variables decreases. The negative adjusted R^2 can be regarded as 0, which means it is no relationship between the simulated $\Delta (E_A / P)$ and the original $\Delta (E_A / P)$. When the number of independent variables is one or two for the models 6 and 7, there is no significance. The R^2 is the largest when considering all kinds of land use, so the best-fit equation of backward multiple linear regression under this scenario is shown below.

Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =

$$-0.0946 + 0.0139 * E_P / P + 0.0447 * \text{forest\%} + 0.1566 * \text{grassland\%} - 0.0225 * \text{shrub land\%} + 0.1376 * \text{cropland\%} + 0.228 * \text{pasture land \%} + 0.1385 * \text{wetland\%} \qquad (7)$$

Where land use% is the fraction of the percentage of each land type coverage on catchments. From the Equation (7), except the coefficient of shrub land, the coefficients of other kinds of land use are positive. It means only shrub land contributes on negative difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. The rank of the positive coefficients is: forest < cropland < grassland < pasture land. Among them, the coefficients are also effected by the negative constant.

Table 4.7 Coefficients of different land types in backward multiple linear regression for all catchments

	constant	E_P/P	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	-0.0946	0.0139	0.0447	0.1566	-0.0255	0.1376	0.2280	0.1385	0.2920	0.2662	0.5404	<0.001	<0.01
2	0.1260	0.0130	-0.1803	-0.0702	-0.2445	-0.0812		-0.1041	0.2879	0.2658	0.5366	<0.001	
3	-0.0173	0.0059		0.0941	-0.0968	0.1335		0.0094	0.1832	0.1622	0.4281	<0.001	

4	-0.0064	0.0117		0.1080	-0.1482			-0.0044	0.0964	0.0779	0.3105	<0.001	no sig
5	0.0114	-0.0150		0.1213				0.0136	0.0517	0.0372	0.2273	0.0012	
6	0.0079	-0.0015						0.0225	0.0005	-0.0096	0.0226	0.7512	
7	0.0091	-0.0019							0.0002	-0.0048	0.0145	0.8380	

4.2.2 Separate regressions on five bins divided by dryness index

The backward multiple linear regressions are made on fives bins separately. As the same as the Chapter 4.2.1, the dependent variable is the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in each bin. However, the dryness index is no need to be regarded as a independent variable here. Because in each bin, these catchments have similar E_P / P. In the Table 4.8, the number of catchments which have dryness index from 0 to 0.5 is very small (only 7 catchments). Although the correlation is 1 between simulated Δ (E_A / P) and original Δ (E_A / P) for model 1, the results are not realistic, especially for the coefficients of cropland (-231.21) and wetland (595.06). Using a few samples to make multiple linear regression is inadvisable. From the Tables 4.9 to 4.12, the model 1 has the biggest R^2. The best-fit equations for model 1 are respectively shown below.

When the dryness index is from 0.5 to 1 in the Table 4.9, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =
0.2224 - 0.25 * forest% - 0.0217 * grassland% - 2.7624 * shrub land% - 0.1899 * cropland% - 0.0946 * pasture land % - 0.2462 * wetland% (8)

When the dryness index is from 1 to 1.5 in the Table 4.10, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =
0.6932 - 0.7312 * forest% - 0.613 * grassland% - 0.8949 * shrub land% - 0.6114 * cropland% - 0.5416 * pasture land % - 1.1205 * wetland% (9)

When the dryness index is from 1.5 to 2.0 in the Table 4.11, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =
-0.4818 + 0.5026 * forest% + 0.5768 * grassland% + 0.3838 * shrub land% + 0.6074 * cropland% + 1.0045 * pasture land % - 3.1772 * wetland% (10)

When the dryness index is from 2.0 to 5.0 in the Table 4.12, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =
0.1747 - 0.2712 * forest% - 0.0696 * grassland% - 0.2178 * shrub land% - 0.0508 * cropland% - 0.5692 * pasture land % + 21.0659 * wetland% (11)

In the two Equations (8) and (9), the coefficients of all land types are negative. But obviously, grassland, pasture land and cropland contribute to positive Δ (E_A / P) in Chapter 4.1. Because the magnitude of these data is below 1, the constant accounts for a big weight. These negative coefficients will be effected by the positive constant. The same problem appears in the Equation (11). On the contrary, in the Equation (10), the coefficients of land types are positive except wetland. That is may because in dry regions, the percentages of grassland, pasture, cropland coverage are large, the coefficients of them can represent the weights of their effects on positive Δ (E_A / P). However, the coefficient of wetland (-3.1772) cannot represent the effect of wetland on the dependent variable because in dry regions there is almost no wetland.

The backward multiple linear regression is used to get the best-fit model after removing independent variables one by one. While the the values of R^2 decrease and p values increase with the removal of independent variables. It has deviated from the original intention of this method. Moreover, the shortcomings of this method referred in Chapter 2.2.1 are seen from the simulated results. Each independent variable has a certain importance on dependent variable, and it is difficult to decide which variable to delete because the significance of some independent variables is very close. With the removal of independent variables, some relatively important variables are possibly missed in the final optimal regression equation. Overall, it seems that the backward multiple linear regression is not suitable to quantitatively evaluate the effects of different land types on the Δ (E_A / P) when considering all kinds of land types in each bin.

Table 4.8 Coefficients of different land types in backward multiple linear regression in the first bin (E_P / P: 0-0.5)

	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	-8.1910	8.3010	-7.7940	18.2840	-231.218	96.4980	595.066	1.0000	<0.001	1.0000	<0.001	<0.01
2	0.3660	-0.4300	4.4140	-9.1570	-23.1900	10.6480		0.9050	0.4222	0.9510	0.0010	
3	-0.5608	0.5240	0.0151		-73.7334	29.3547		0.7416	0.2249	0.8612	0.0128	<0.05
4	-0.7186	0.6517	2.6129		15.5429			0.5244	0.0487	0.7241	0.0657	no sig
5	-0.1125		2.7965		17.7572			0.2876	-0.0686	0.5363	0.2146	
6	-0.0354		-0.7695					0.0183	-0.1780	0.1353	0.7725	

Table 4.9 Coefficients of different land types in backward multiple linear regression in second bin (E_P / P: 0.5-1.0)

	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	0.2224	-0.2500	-0.0217	-2.7624	-0.1899	-0.0946	-0.2462	0.4067	0.3718	0.6377	<0.001	<0.01
2	-0.7256	0.7102	0.8363		0.7746	0.8751	0.8423	0.3055	0.2718	0.5527	<0.001	
3	0.1348	-0.1805	-0.1280		-0.0957		-0.0549	0.2481	0.2192	0.4981	<0.001	
4	-0.0064		0.0810		0.1133		0.0060	0.0824	0.0562	0.2871	0.0025	
5	0.0068		0.0839				-0.0048	0.0093	-0.0094	0.0965	0.3182	no sig
6	0.0077						0.0208	0.0005	-0.0089	0.0220	0.8205	

Table 4.10 Coefficients of different land types in backward multiple linear regression in third bin (E_P / P: 1.0-1.5)

	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	0.6932	-0.7312	-0.6130	-0.8949	-0.6114	-0.5416	-1.1205	0.3858	0.2630	0.6212	<0.001	<0.01
2	-0.1719	0.1510	0.2561		0.2518	0.3514	0.0497	0.3693	0.2676	0.6077	0.0001	
3	-0.0309	0.0032	0.1050		0.1956		-0.0366	0.2822	0.1925	0.5313	0.0007	
4	0.0906	-0.1462	-0.0332				-0.0721	0.2369	0.1676	0.4868	0.0023	
5	0.0016		0.1177				-0.0726	0.0605	0.0052	0.2459	0.1423	no sig
6	0.0277						-0.2169	0.0048	-0.0236	0.0693	0.6838	

Table 4.11 Coefficients of different land types in backward multiple linear regression in fourth bin (E_P / P: 1.5-2.0)

	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	-0.4818	0.5026	0.5768	0.3838	0.6074	1.0045	-3.1772	0.3695	0.1704	0.6079	0.0010	<0.01
2	-0.7479	0.7742	0.8523	0.6343	0.8544	1.0024		0.2637	0.0797	0.5135	0.0073	
3	0.0972	-0.0867	-0.0463	-0.2018		0.1571		0.1889	0.0344	0.4346	0.0265	<0.05
4	-0.0500	0.0467	0.1433			0.3359		0.1045	-0.0177	0.3232	0.1073	no sig
5	0.0090	-0.0169				0.3874		0.0621	-0.0194	0.2493	0.2194	
6	0.0314	-0.0400						0.0189	-0.0220	0.1375	0.5028	

Table 4.12 Coefficients of different land types in backward multiple linear regression in fifth bin (E_P / P: 2.0-5.0)

	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
1	0.1747	-0.2712	-0.0696	-0.2178	-0.0508	-0.5692	21.0659	0.5323	0.3318	0.7296	0.0002	<0.01
2	-0.0939		0.2230	0.0553	0.2449	-0.4047	20.1727	0.5077	0.3435	0.7125	0.0003	
3	-0.0432			0.0286	-0.0629	0.8514	-7.2225	0.1743	-0.0321	0.4175	0.0597	no sig
4	-0.0441			0.0292	0.1723		1.6492	0.1600	0.0118	0.4000	0.0724	
5	-0.0304			-0.0103			32.5740	0.0571	-0.0477	0.2389	0.2969	
6	-0.0246			-0.0011				<0.001	-0.0526	0.0044	0.9850	

4.2.3 Adjusted multiple linear regression: Selective variables in different bins

From the Chapter 4.2.2, it can be seen that it is unwise to blindly consider all land types in each bin to make backward multiple linear regression. Different bins represent different climates, and not all land types exist in each climatic condition. It is meaningless to regard the fractions of the percentages of non-existent land types coverage of catchments as independent variables under a certain climatic condition. In order to make useful multiple linear regression, only the existing land use types in each bin are considered. For example, when the catchments have the dryness index from 0 to 0.5, they are almost covered by forest from the Figure 4.2. So other land types will not be regarded as independent variables when making multiple linear regression for the first bin. For another example, shrub only grows in dry regions from the Figure 4.23. Therefore, when the E_P / P is from 1.5 to 2.0, the fractions of the percentages of shrub land can be considered as one independent variable. In such a method, the models have significance except the first bin in Table 4.13. Because the number of catchments in the first bin is too small, the simulated result is meaningless. Other best-fit regression equations are shown below.

When the dryness index is from 0.5 to 1 in the third row of Table 4.13, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation = -0.7256 + 0.7102 * forest% + 0.8363 * grassland% + 0.7746 * cropland% + 0.8751 * pasture land % + 0.8423 * wetland% (12)

When the dryness index is from 1 to 1.5 in the fourth row of Table 4.13, the best-fit regression equation is:
Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =
-0.032 + 0.0036 * forest% + 0.1065 * grassland% + 0.1962 * cropland% (13)

When the dryness index is from 1.5 to 2.0 in the fifth row of Table 4.13, the best-fit regression equation is:

Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =

-0.0042 + 0.0194 * forest% + 0.0795 * grassland% - 0.1007 * shrub land% + 0.1358 * cropland% (14)

When the dryness index is from 2.0 to 5.0 in the sixth row of Table 4.13, the best-fit regression equation is:

Simulated difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation =

0.0414 - 0.1345 * forest% + 0.0656 * grassland% - 0.0717 * shrub land% (15)

Table 4.13 Coefficients of different land types in multiple linear regression in five bins

E_P/P	constant	forest	grassland	shrubland	cropland	pasture	wetland	R^2	Adjusted R^2	correlation	p value	sig.
0-0.5	-0.7431	0.7415						0.3146	0.1776	0.5609	0.1902	no sig
0.5-1.0	-0.7256	0.7102	0.8363		0.7746	0.8751	0.8423	0.3055	0.2718	0.5527	<0.001	<0.01
1.0-1.5	-0.0320	0.0036	0.1065		0.1962			0.2821	0.2168	0.5311	0.0007	<0.01
1.5-2.0	-0.0042	0.0194	0.0795	-0.1007	0.1358			0.1891	0.0346	0.4348	0.0264	<0.05
2.0-5.0	0.0414	-0.1345	0.0656	-0.0717				0.5135	0.4277	0.7166	0.0003	<0.01

From the Equation (12), the coefficients of forest, grassland, cropland, pasture land and wetland are positive. They contribute to positive differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. So, they cause larger evaporation and lower stream flow in the second bin. Among them, the coefficients of grassland, pasture land and wetland are bigger, so they contribute more to positive Δ (E_A / P). The coefficients of forest and cropland are smaller, so they contribute less to positive Δ (E_A / P). It is to be noted that the constant in Equation (12) is much smaller than the constants in Equations (13), (14) and (15). These coefficients in Equation (12) should be much larger than the coefficients in other equations in order to balance the entire equation. The constants can affect the coefficients of each land use to some extent, but it cannot be avoided. Next, according to the Equation (13), forest, grassland and cropland all have positive contributions on Δ (E_A / P). The weights of them are ranked: forest < grassland < cropland. And for the Equations (14) and (15), obviously the coefficients of shrub land are negative. It means shrub land leads to negative Δ (E_A / P) and lower evaporation index, which conforms to the Figures 4.24 in Chapter 4.1.5. Overall, this method is meaningful to quantify the effects of each land use on the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in the five bins.

4.3 Quantitative evaluation: Fu's and Zhang's equations

4.3.1 Results from Fu's equation

The introduction of Fu’s equation is in Chapter 2.2.2. When using this method, the independent variables are the fractions of the percentages of seven land use types, including forest, grassland, shrub land, cropland, pasture land, wetland and human-impacted land. Among them, the human-impacted land cannot be ignored when using nonlinear regression to fit the dependent variable (E_A / P). Although the percentage of human-impacted land is very small, it still has a few contributions on the evaporation index. The percentage of perennial ice/snow land is zero in most catchments so it can be ignored here. It needs to be emphasized that the human-impacted lands are impermeable, so it is difficult to define a way to simulate the w value of human-impacted land. In order to simplify the expression, the E_A / P of human-impacted lands is equal to the original E_A / P multiply the percentage of human-impacted land in each catchment from the Equation (16). Moreover, wetlands presumably have no soil moisture limitations in E_A losses. It is assumed that E_A equals the smallest of the two variables, precipitation and E_P. This assumption ensures that E_A is always less than E_P or P, and is realistic for both dry and wet regions in the study areas [38]. That means:

When $P > E_P$, $E_A = E_P$

When $P < E_P$, $E_A = P$

The Equation (16) is shown below to fit the E_A / P using 200 catchments data. Then, the best-fit w values of each land cover type are calculated.

$$
\begin{aligned}
&\frac{E_A}{P} = \frac{E_A}{P} * human - impacted\ \% + \\
&(1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w_1}\right]^{\frac{1}{w_1}}) * forest\ \% + \\
&(1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w_2}\right]^{\frac{1}{w_2}}) * grassland\ \% + \\
&(1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w_3}\right]^{\frac{1}{w_3}}) * shrubland\ \% + \\
&(1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w_4}\right]^{\frac{1}{w_4}}) * cropland\ \% + \\
&(1 + \frac{E_P}{P} - \left[1 + \left(\frac{E_P}{P}\right)^{w_5}\right]^{\frac{1}{w_5}}) * pasture\ \% + \frac{E_A}{P}_{wetland}
\end{aligned}
\tag{16}
$$

Where the land type% is the fraction of the percentage of each land type, w_1, w_2, w_3, w_4 and w_5 represent the w values of forest land, grassland, shrub land, cropland and pasture land separately. The values of E_A / P for all catchments in wetland have been calculated and putted into the equation. By nonlinear regression, the best-fit w values using the Equation (16) of five land uses are shown in Table 4.14. The higher w value means higher E_A for a given P and E_P, hence lower runoff and vice versa. It is corresponding that the w values of pasture, grassland and cropland are larger, and they contribute on more positive difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. The w values of forest and shrub land are smaller compared with others, and they contribute on lower evaporation index. Best-fit w values of the five kinds of land use by Fu's equation are shown in Figure 4.28. The ranks of w values are: forest < shrub land < cropland < grassland < pasture land.

Table 4.14 Best-fit w values of different land types using Fu's equation

w	forest	grassland	shrubland	cropland	pasture	R^2	correlation	p value	sig.
Total	2.3178	3.4573	2.3396	3.1045	4.7119	0.8504	0.9222	<0.001	<0.01

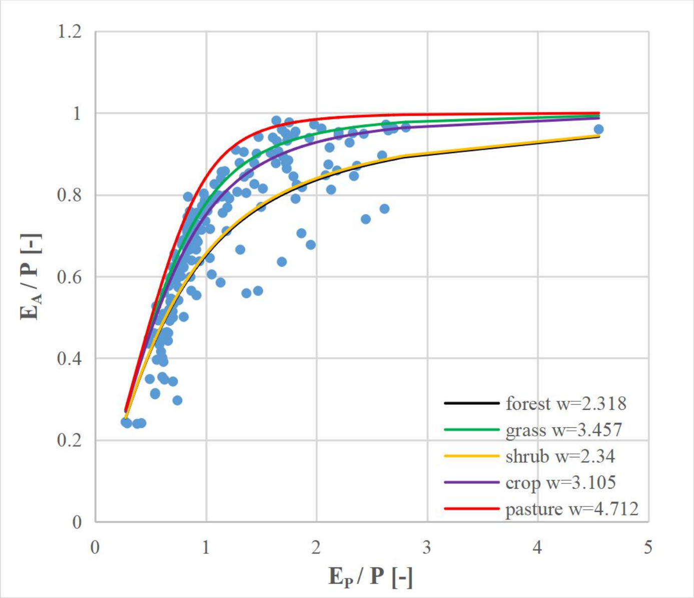


Figure 4.28 Plot of best-fit w values of five kinds of land use by Fu's equation

Figure 4.29 shows the effects of the parameter w on the changes of evaporation index (E_A / P). The blue curve represents that when w parameter increases from 2.3178 (forest) to 2.3396 (shrub land), the evaporation index only has a little increase. When the w parameter increases from 2.3396 (shrub land) to 3.1045 (cropland) as the red curve shows, the evaporation index increases more than 14% which is the largest ratio in the figure. The green curve describes the w value increases from 3.1045 (cropland) to 3.4573 (grassland), and the evaporation index does not change much. Lastly, when the w parameter increases from 3.4573 (grassland) to 4.7119 (pasture land), although the number of w has increased a lot, the evaporation index only increases about 8%. It means the sensitivity of the evaporation index decreases with the increasing w values. Besides, when the dryness index (E_P / P) is around 1, the sensitivity of evaporation index to the parameter w is the maximum (at the peak point). In this case, the controls of potential evaporation and precipitation over actual evaporation are the same [32].

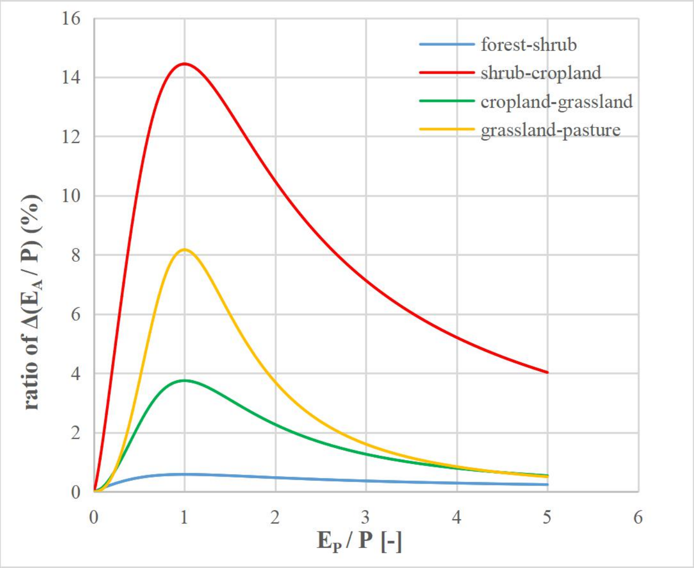


Figure 4.29 Sensitivity of the evaporation index (E_A/ P) to the catchment parameter (w) by Fu's equation

4.3.2 Results from Zhang's equation

The introduction of Zhang's equation is in Chapter 2.2.3. The dependent variable and independent variables are as the same as the data used in Chapter 4.3.1. The differences of w values for different land types in this method are mainly caused by root zone depth [14]. For human-impacted lands, w is set as 0 [38]. So the evaporation index can be expressed as:

$$\begin{aligned}\frac{E_A}{P} = {} & \left(\frac{1}{1+\frac{P}{E_P}}\right) * human-impacted\ \% + \\ & \left(\frac{1+w_1 * \frac{E_P}{P}}{1+w_1 * \frac{E_P}{P}+\frac{P}{E_P}}\right) * forest\ \% + \\ & \left(\frac{1+w_2 * \frac{E_P}{P}}{1+w_2 * \frac{E_P}{P}+\frac{P}{E_P}}\right) * grassland\ \% + \\ & \left(\frac{1+w_3 * \frac{E_P}{P}}{1+w_3 * \frac{E_P}{P}+\frac{P}{E_P}}\right) * shrubland\ \% + \\ & \left(\frac{1+w_4 * \frac{E_P}{P}}{1+w_4 * \frac{E_P}{P}+\frac{P}{E_P}}\right) * cropland\ \% + \\ & \left(\frac{1+w_5 * \frac{E_P}{P}}{1+w_5 * \frac{E_P}{P}+\frac{P}{E_P}}\right) * pasture\ \% + \frac{E_A}{P}_{wetland}\end{aligned} \tag{17}$$

Where the land type% is the fraction of the percentage of each land type, w_1, w_2, w_3, w_4 and w_5 represent the w values of forest land, grassland, shrub land, cropland and pasture land separately. Through nonlinear regression, the best-fit w values usingEquation (17) for the five land uses are shown in Table 4.15. Similarly, w values of pasture, grassland and cropland are larger, and the w values of forest and shrub land are smaller. The R^2 of this regression is close to 1 and the p value is smaller than 0.01. It means the simulated results are receivable. The rank of best-fit w values of the five kinds of land use by Zhang's equation: forest land < shrub land < cropland < grassland < pasture land. It is as the same as the rank when using Fu's equation in Chapter 4.3.1.

Table 4.15 Best-fit w values of different land types using Zhang's equation

w	forest	grassland	shrubland	cropland	pasture	R^2	correlation	p value	sig.
Total	0.8568	3.0414	0.8606	2.0862	3.3763	0.8368	0.9148	<0.001	<0.01

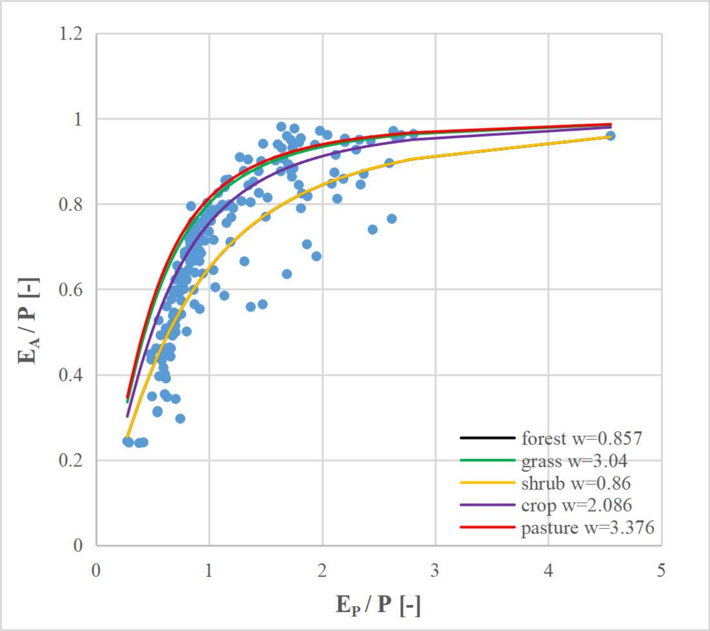


Figure 4.30 Best-fit w values of five kinds of land use by Zhang's equation

Figure 4.31 shows the effects of parameter w on the changes of evaporation index (E_A / P). The blue curve represents w parameter increases from 0.8568 (forest) to 0.8606 (shrub land), and the evaporation index almost stays unchanged. When the w parameter increases from 0.8606 (shrub land) to 2.0862 (cropland) as the red curve shows, the evaporation index increases more than 20% which is the largest ratio in the figure. The green curve describes w increases from 2.0862 (cropland) to 3.0414 (grassland), and the evaporation index has increased over 10%. Lastly, when the w parameter increases from 3.0414 (grassland) to 3.3763 (pasture land) from the yellow curve, the evaporation index does not change much. The results are different with the Figure 4.29. For the red curves in two figures, the evaporation index using Zhang's equation increases more. In addition, in the Figure 4.31, the green curve is above the yellow curve, which is opposite in the Figure 4.29. What is more, when the dryness index (E_P / P) is less than 1, the sensitivity of evaporation index by Zhang's equation to the parameter w is the maximum.

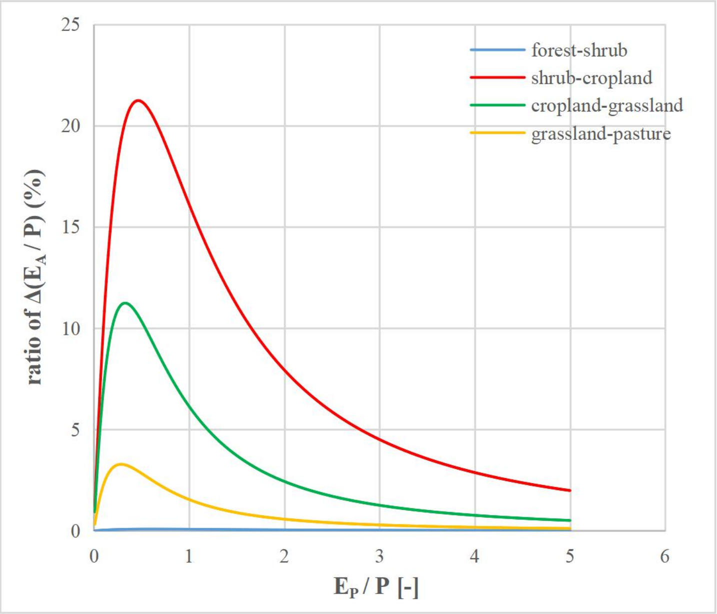


Figure 4.31 Sensitivity of the evaporation index (E_A / P) to the catchment parameter (w) in Zhang's equation

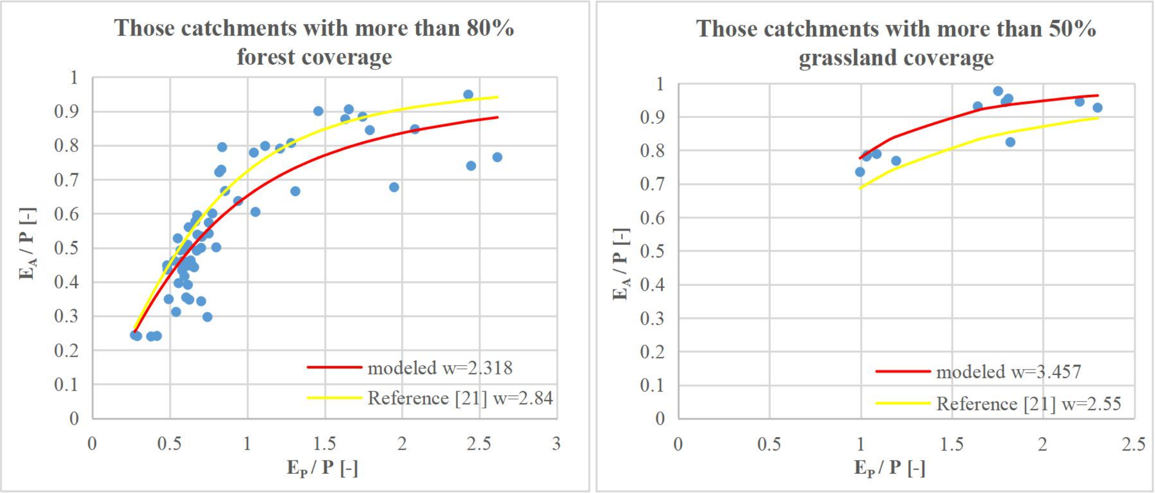
5

Discussions

5.1 Comparison with what others found from Fu's equation

In the reference [21], using Fu's equation, the best-fit values of w are 2.84 and 2.55 for the forested and grassed catchments with over 75% forest and grass respectively. The larger w value for forest suggests that forest lands cause higher evapotranspiration compared with grassed catchments because forests have deeper roots, lower aerodynamic resistance, more persistent leaf area [32]. In the Figure 5.1 (a), those catchments with more than 80% forest from the 200 study areas in this thesis are selected to plot the curves. And in the Figure 5.1 (b), those catchments with more than 50% grassland are selected to plot the curves. In the two figures, the red curves are drawn by the Equation (5) with best-fit w values for forest and grassland from the Table 4.14. The yellow curves are drawn by the Equation (5) with best-fit w values for forest and grassland from the reference [21].

When comparing the yellow and red curves in each figure, there are some reasons causing the differences. The catchments used in the reference [21] are located in southeast of Australia. While the catchments used in this thesis are from the United States. They have different areas, climates and topography. Secondly, in the reference [21], these catchments have at least 10 years and in most cases 20 years of unimpaired stream-flow data and the range of catchment areas is between 50 and 2000 km^2. Obviously the study period in the reference [21] is shorter than the study period (1981-2013) in this thesis. Moreover, the method for calculating the potential evaporation in the reference [21] is from the equation of Priestley and Taylor. Different potential evaporation data sets have different influences on the best-fit w values.



Figures 5.1 Comparisons of best-fit w values of forest and grassland in this thesis and the reference [21]

5.2 Comparison with what others found from Zhang's equation

According to the w values in some literature, the reference [40] described the best-fit w values for forest and herbaceous cover are 2.7 and 2.3 respectively. In the reference [23], the best-fit w values for forest and grassland are 2 and 0.5 separately. From the Figures 5.2, the simulated w value for forest in the Table 4.15 is less than the w values for forest in other literature. On the contrary, the simulated w value for grassland in this thesis is larger than the w values for grassland in other literature. For the data listed by the reference [34], the upper and lower limits of w value equal to 2.0 and 0.1 which are quite smaller than the w values by nonlinear regression in Table 4.15. Because the largest w is 3.376 for pasture land. There are some possible reasons causing the different results between this thesis and the reference [23].

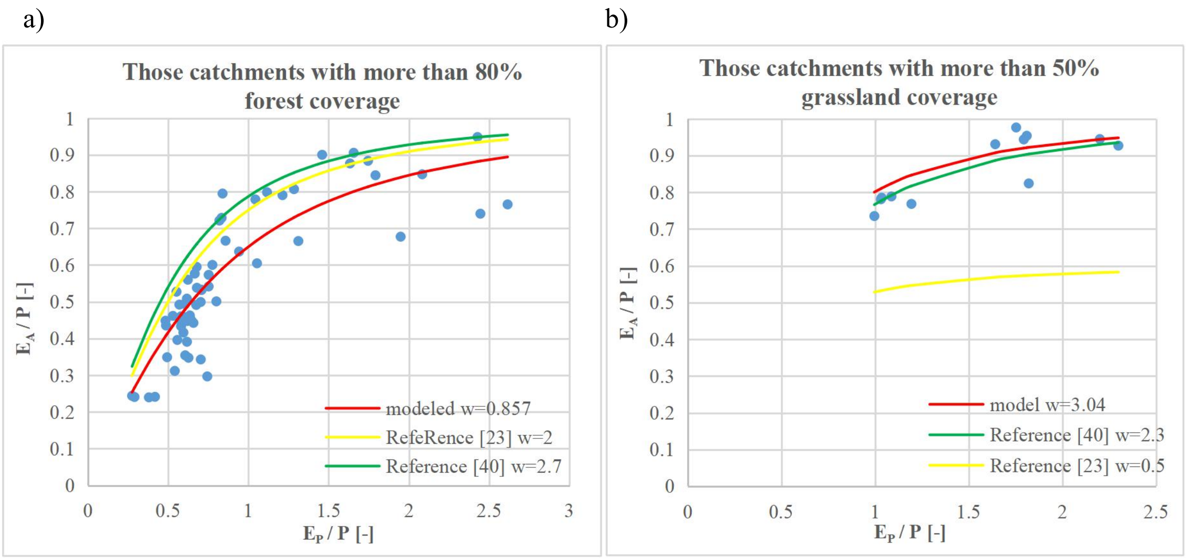
(1) The slopes of the catchments in the reference [23] are gentle. On the contrary, the slopes of the study areas in this thesis which have large percentage of forest coverage are steep, closing to 1. Steep slope is an important factor causing high runoff.

(2) The areas of the catchments in the reference [23] vary from 1 km^2 to 6 x 10^5 km^2. There are a part of large catchments from the world. However, the areas of the catchments in this thesis are all smaller than 1000 km^2. Unmeasured groundwater transfer and omitted surface-atmosphere feedback could lead to false estimation of the influence of land cover change on stream flow. This is because that on large catchments, land cover certainly influences overall evaporative energy and even modulates runoff [18]. Therefore, the different areas of catchments lead to different w values.

(3) The method for calculating potential evaporation in the reference [23] is different with the method in this thesis. In the reference [23], the potential evaporation was calculated using the equation of the reference [39] with average values of temperature and net radiation data. In this thesis, the reference [25] made 10 models for evaluation to select the optimal parameter set and uploaded the results in CAMEL.

(4) Errors exist in the precipitation, air temperature and other data sets, as well as the calculated actual evaporation through water balance. Different evaluation processes also result in some differences for simulating the best-fit w values [38].

There are also some possible reasons about the differences between this thesis and the reference [40]. Firstly, the reference [40] used 278 non-experimental Australian catchments with mixed land cover to detect a similar land cover influence by statistically analyzing Q. The 278 catchments that were selected had data for at least five (not necessarily consecutive) years between 1990 and 2006 (median 16 yr). In such data sets, climate is the primary reason for variation in response. And the data sets are very similar to the basic data used in the reference [21]. The best-fit w value (2.7) of forest in the reference [40] is larger than the simulated w value of forest in this thesis (0.8568). The w values of grassland are close to each other, compared to the yellow curve in Figure 5.6 (b) (w = 0.5 in the reference [23]). The difference in results may be related to the study period as well as the physical and hydrometeorological characteristics of watersheds. The best-fit w values for forest and grassland obtained from the catchments in Australian in the reference [40] and [21] are relatively similar to the findings in this thesis.



Figures 5.2 Comparisons of best-fit w values of forest and grassland in this thesis and the references [23] and [40] on Budyko framework

5.3 w value for each catchment

If the effects of different land use types are not considered and each catchment is regarded as a whole, the w value can be calculated in each catchment by the Equation (5) and Equation (6). There are 200 catchments totally, so 200 w values will be calculated through each equation. The long-term mean E_A, E_P and P of each catchment are as the same as the data used in previous chapters. The Figure 5.3 shows the normal distribution of 200 w values calculated by Fu's equation. According to the black line (the tallest point of red curve), the best-fit w value can be regarded as 2.8. Using the same way to plot the normal distribution of 200 w values calculated by Zhang's equation, it is shown as the Figure 5.4. The best-fit w value can be regarded as 2.0 (the highest frequency).

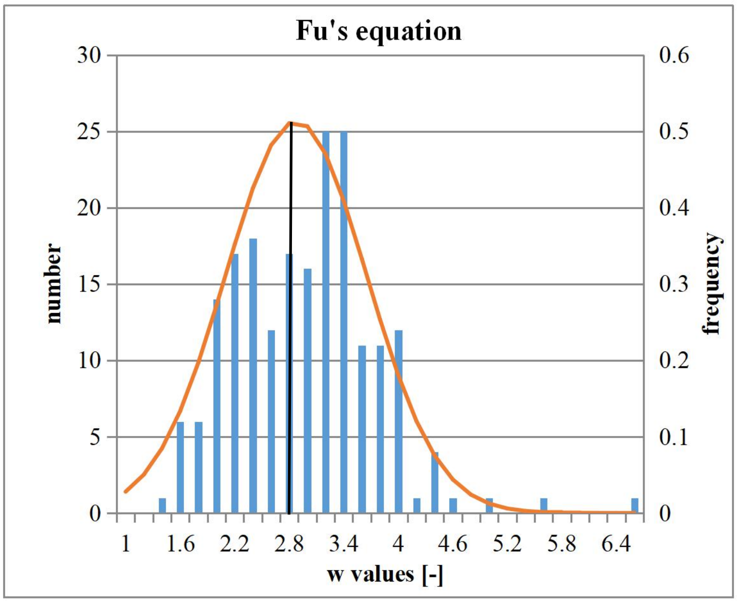


Figure 5.3 Normal distribution for w value of each catchment by Fu's equation

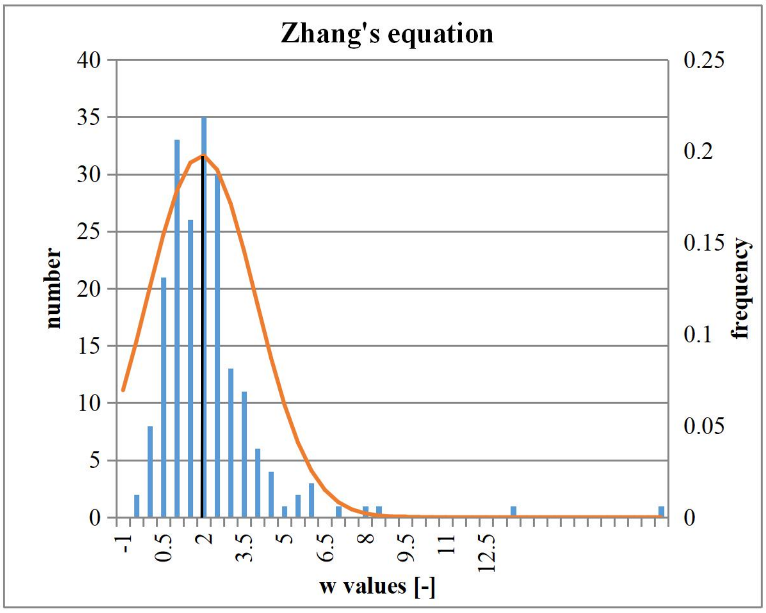


Figure 5.4 Normal distribution for w value of each catchment by Zhang's equation

From what others found, the reference [41] used 26 global river basins that are larger than 300000 km^2 to obtain the basin-specific w parameters by Fu's equation. In its original Budyko model, w is 2.6 as the yellow curve shown in the Figure 5.5. The reference [42] analyzed the effects of climate and land surface changes on water resources in northern (Tigray region) and southeastern (Somali region) Ethiopia during the period 2010-2014. And the blue curve shows 200 evaporation indexes calculated by Fu's equation (w = 2.9). The red Budyko curve is from the Equation (3) in Chapter 2. The purple and green curves show the results of normal distributions by Fu's equation and Zhang's equation respectively. It needs to be noticed here Zhang's equation is different from Fu's equation. Although the w value by Zhang's equation is smaller than the w value by Fu's equation, the green curve is above the purple curve. The five curves are close to each other. Therefore, these methods are all reliable.

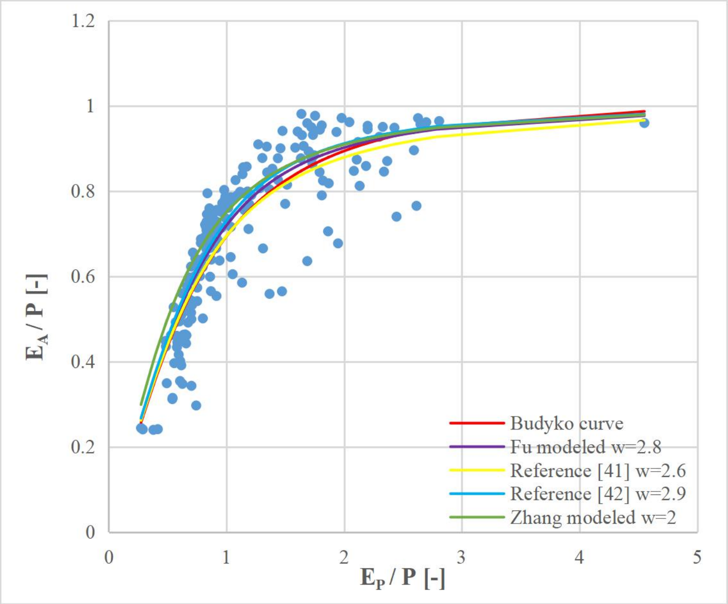


Figure 5.5 Comparisons of the normal distribution results with other researches

5.4 Reasons about the differences

Some possible reasons causing such a rank of the best-fit w values of the five land types by Fu's and Zhang's equations. Firstly, the best-fit w values of forest and shrub are the smallest. It means forest and shrub land lead to lower evaporation and higher stream flow with a given precipitation. However, there are different reasons between them. By checking the mean slopes of the study catchments with different kinds of land coverage, only the mean slopes of these catchment with large percentage of forest coverage are big, closing to 1, which are quite slant. Surface runoff is easy to generate on steep terrain. Besides, most forest coverage on the catchments in this thesis are distributed in the downstream. It is not conducive to exerting the regulating effect on runoff, so a large flood peak flow is easy to form. As for the shrub land, the first reason is that between the staggered shrub, there are a lot of bare lands the evaporation of which is small. Moreover, since the evaporation of shrub land may be controlled by stomatal resistance, it will result in a small amount of evaporation. In addition, the root systems of forest and shrub are long and developed compared with the root systems of other kinds of vegetation. It allows water to penetrate deep into the soil and increases groundwater recharge. These reasons explain why the w values of forest and shrub land are small.

As for the best-fit w values of cropland, it is a little bigger than the w values of forest and shrub land. Since the average annual precipitation of these catchments with large percentage of cropland is smaller, the growth of crops often needs to be achieved through irrigation in arid and semi-arid areas. Large-scale irrigation systems increase the moisture in the surface atmosphere, which helps to form rainfall. However, compared with the best-fit w values of grassland and pasture land, the w value of cropland is smaller. This is because the agricultural growing season is shorter than that of the native vegetation. The seasonal potential evapotranspiration in agricultural areas would be expected to be distinctly less than that of grass and pasture land.

Lastly, the best-fit w values of grassland and pasture land are bigger. Because the mean slopes of these catchments with more than 50% grassland or pasture land are very small, rainfall is not easy to quickly form surface runoff. And the root systems of both of them are short and underdeveloped, which is not enough to save too much water and form underground runoff. The difference is that grass grows in dry and hot climates. When the precipitation is less, rainfall will evaporate more. While pasture grows in wet and warm regions. With high precipitation, a portion of soil pores could be stored by water, then more precipitation will evaporate.

6

Conclusions and Recommendations

6.1 Conclusions

This thesis analyzes the effects of different land use types on evaporation and stream flow. From CAMEL, long-term daily mean potential evaporation, discharge and precipitation of 200 small catchments (<1000 km^2) in the whole continental United States between the study period 1981 - 2013 are used to make the Budyko framework [29]. In order to focus on the land use impacts and avoid the climatic impacts, the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments is regarded as the reference indicator. Then the Budyko framework is divided into five bins according to the dryness index (E_P / P). Six main land use types are forest, grassland, pasture land, cropland, shrub land and wetland. The long-term annual mean percentages of all land cove types in each catchment are obtained through R code. By analyzing the relationship of different percentages of each land type and the difference between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation from two-dimensional figures, the effects of the six main land types can be concluded qualitatively. Besides, using multiple linear regression method, Fu's and Zhang's equations [22][34], the effects of each land use on evaporation and stream flow can be quantified. From some physical and hydrometeorological characteristics of watersheds, the possible reasons causing the results can be explained to some extent. Moreover, some comparisons between the best-fit w values by Fu's equation and Zhang's equation in this thesis and what others found are referred in Chapter 5. There are some main conclusions about the research questions.

Research question 1: What are the influences of different land types on evaporation and stream flow by qualitative evaluation?

In Chapter 4.1, the qualitative evaluation results about the effects of different land use types on evaporation and stream flow are explained. Firstly, forest lands occupy the largest proportion in many watersheds. So it is the most significant to evaluate the effects of forest. From most previous studies, the results showed that more forest results in higher evaporation and lower runoff. However, in the figures 4.3, there are slightly decreasing trends between the percentages of forest coverage and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. It means more forest coverage causes less evaporation on catchments, which is opposite with the common sense in previous researches. The reference [36] assessed 1508 catchments and concluded that with specific climatic and land surface contexts, land cover has not the same impacts. Checking the physical and hydrometeorological characteristics of these watersheds with large percentage of forest coverage is helpful to find the possible reasons causing such a result. It will be concluded in the research question 3.

Next, the Budyko framework of all catchments with different percentages of grassland or cropland coverage are similar from Figures 4.12 and 4.19. The dryness indexes of those catchments with more than 50% grassland / cropland are bigger than 1. And most of them are distributed above the Budyko curve. Besides, the relationships of grassland or cropland coverage percentages and the differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation of the catchments in different bins are also similar. There is an increasing trend in dry regions. Almost all the points with more than 50% grassland / cropland have positive Δ (E_A / P). It means the two land uses on catchments lead to higher evaporation and lower stream flow with a given precipitation. However, the reference [10] conducted on-site measurements and analysis of forests and grasslands in the Amazon Basin. The results showed that the runoff is larger on grasslands compared with the runoff on forest. The reference [7] researched the hydrological effects of land use change in the Tocantins River Basin. The results showed that the increase in agricultural land reduces infiltration and evaporation, thereby increasing the annual average stream flow. Some possible reasons causing the differences compared with what others found will be concluded in the research question 3.

Then, although the effects of hay/pasture land on evaporation and stream flow are almost the same as the effects of grassland or cropland referred in the last paragraph, the difference is that these catchments with more than 50% hay/pasture land coverage are concentrated in sub-humid regions. And the percentages of hay/pasture land coverage in all catchments are smaller than 75%. There are a few catchments mainly covered by hay/pasture land.

As for the qualitative evaluation about the effects of shrub land on evaporation and stream flow, it shows that the catchments with large percentage of shrub land coverage are all below the Budyko curve and have negative Δ (E_A / P). Moreover, obviously, their dryness indexes are more than 1.5, which means drier regions are more suitable for shrub to grow. Therefore, the evaporation is smaller and stream flow is bigger at a given precipitation on shrub land. Lastly, for wetland, the proportions of it in all catchments are less than half of the area. Therefore, it cannot be concluded about the role of wetland.

Research question 2: What are the influences of different land types on evaporation and stream flow by quantitative evaluation?

Firstly, the Chapter 4.2 shows the quantitative evaluation results about the effects of six main land use types on evaporation and stream flow by multiple linear regression. From those results, the adjusted multiple linear regression in Chapter 4.2.3 is the most useful method. Only the fractions of the percentages of existing land types coverage of catchments in each bin are regarded as independent variables.

In humid regions (0 < dryness index < 0.5), those catchments are almost covered by forest. However, the number of the catchments in the first bin is too small, the simulated result is meaningless. In sub-humid regions (0.5 < dryness index < 1.0), except shrub land, other land uses can be considered as independent variables when making multiple linear regression. From the equation (12), the coefficients of all land uses are positive, which means their coverage on these catchments contributes on positive Δ (E_A / P) and results in higher evaporation as well as lower stream flow with a given precipitation. The rank of their coefficients are: pasture > wetland > grassland > cropland > forest.

In semi-arid regions (1.0 < dryness index < 1.5), the existing land types coverage of these catchments are forest land, grassland and cropland. The coefficients of them are all positive. So in the third bin, the three land types cause more evaporation with a given precipitation. The rank of their coefficients are: cropland > grassland > forest. In dry and very dry regions (1.5 < dryness index < 5.0), the coefficients of cropland, grassland are still keep positive. While the coefficients of shrub land are negative in the two bins. It means shrub land makes negative Δ (E_A/ P) and lower evaporation. It needs to be emphasized that the constants in regression equations can affect the coefficients of independent variables to some extent. But it is unavoidable.

Secondly, Fu's and Zhang's equations are also used to quantitatively evaluate the effects of the main land use types on evaporation and stream flow. By nonlinear regression, there are same ranks of best-fit w values from Fu's and Zhang's equations: forest land < shrub land < cropland < grassland < pasture land. The higher w means higher E_A for a given P and E_P, hence lower runoff and vice versa. Pasture land, grassland and cropland contribute on more positive differences between evaporation index estimated from data and theoretical evaporation index calculated from theoretical Budyko equation. Forest and shrub land contribute on lower evaporation index.

It is noticed that forest lands evaporate less than the grasslands evaporate, which is opposite with most previous studies. And the best-fit w value of forest land in this thesis is less than that in some literature. However, the best-fit w value of grassland in this thesis is larger than that in some literature. Some possible reasons are discussed in Chapter 5. The different slopes, different areas of the catchments, different methods for calculating potential evaporation may cause the differences between the catchments in this thesis and the catchments others studied. Besides, errors exist in the precipitation, air temperature and other data sets, as well as the calculated actual evaporation through water balance.

Research question 3: How different land uses lead to different effects on evaporation and stream flow?

There are so many reasons causing these results. Due to the data limit and process limit, it is impossible to find all possible reasons. In this thesis, by checking the physical and hydrometeorological characteristics, including means slopes, elevations, root systems, land surface coverage and so on, some possible reasons are found.

Firstly, most catchments with large percentage of forest coverage have small evaporation and high stream flow under a given precipitation. It is contradictory with the effects of forest in some previous studies. There are four possible reasons.

(1) The mean slopes of these catchments are big, closing to 1, which are quite slant. Surface runoff is easy to generate on steep terrain.
(2) Most forest lands in the study catchments are distributed in the downstream. It is not conducive to exerting the regulating effect on runoff. Therefore, a large flood peak flow is easy to form.
(3) The root systems of forest and shrub are long and developed compared with the root systems of other vegetation. It allows water to penetrate deep into the soil and increases groundwater recharge.
(4) These catchments are located in uplands because their mean elevations are much bigger than the average elevation of 200 catchments. The low temperature and high air pressure in upland can decrease the evaporation.

The New Zealand broad-leaved forests were studied and concluded that leaf characteristics and physiology appear to be more important to transpiration than vegetation physiognomy [43]. This indicates that it is difficult to generalize transpiration characteristics for forest land.

Secondly, those catchments with large percentage of grassland coverage have large evaporation. However, the reference [44] found that the evaporation of natural grassland was smaller than the evaporation of forest under the same canopy density. The contradiction is mainly related to the mean slopes and climates of catchments. The mean slopes of the study catchments in this thesis are small, so rainfall is not easy to quickly form surface runoff. And grass grows in dry and hot climates. When the precipitation is less, rainfall will evaporate more.

Thirdly, the effects of pasture land on evaporation and stream flow are similar with the effects of grassland. The difference is that pasture grows in wet and warm regions. With higher precipitation, a portion of soil pores could be stored by water, then more precipitation will evaporate. In addition, the root systems of pasture are short and underdeveloped, which is not enough to save too much water and form underground runoff.

Fourthly, the evaporation is higher and stream flow is lower at a given precipitation on cropland. This is mainly because the average annual precipitation of these catchments with large percentage of cropland coverage is small. And the growth of crops often needs to be achieved through irrigation in arid and semi-arid areas. Large-scale irrigation systems increase the moisture in the surface atmosphere, which helps to form rainfall and increase evaporation. The reference [45] studied the watersheds in the northwestern Ethiopian hilly region, and found that the causes of the decrease in stream flow were the destruction of natural forest, excessive grazing and the increase of cropland. It explains cropland has the effects on the increase of evaporation and the decrease of stream flow.

Lastly, the possible reasons about the lower evaporation and higher stream flow on shrub land coverage include the third and fourth reasons for the effects of forest coverage. Besides, between the staggered shrub on land surface, there are a lot of bare lands the evaporation of which is very small. What is more, since the evapotranspiration of shrub land may be controlled by stomatal resistance, it will result in a small amount of evaporation [46].

6.2 Recommendations

This thesis qualitatively and quantitatively evaluates the effects of different land uses on stream flow and evaporation across 200 catchments in the United States. It also compares the results by Fu's and Zhang's equations with what others found. The focus is on the effects of forest land, grassland, pasture land, cropland, shrub land and wetland, and some results have been achieved. Although the relevant references have been consulted as much as possible during the research processes, there are still some shortcomings. A lot of work and improvements are required to do in further researches .

(1) Errors exist in the data sets from CAMEL. Firstly, for the daily potential evaporation, there are some inevitable errors in the simulation processes. Secondly, the areas of each land use are extracted from the annual LULC maps with a resolution of 250 m between 1981 to 2013. However, in a long duration, there are some changes in the area of land use, such as deforestation. Using the long-term mean percentage of land use will cause some uncertainties for the research.

(2) This project mainly considers the impacts of land use on evaporation and runoff. In most hydrological studies including this thesis, the impacts of vegetation on precipitation is negligible, It is always considered that precipitation is not related to the land use type. However, the General Circulation Models (GCMs) used by some studies suggest that forests on the continental catchments may affect precipitation [34].

(3) The effects of land cover on evaporation and stream flow are not always consistent with the previous experiences. Because the possible reasons causing such a result are very complex. There are many factors other than land use that also play an important role in controlling hydrological responses. In addition to the mean slope, elevation, temperature considered in this thesis, effective soil moisture, soil type, vegetation structure, depth of groundwater level and so on may also affect the water balance [47]. However, due to the limitation of data and research process, it is impossible to analyze all effective factors. It is a question which is worth considering and digging into in future research.

(4) What is more, it is also possible to quantify the changes in water storage or groundwater in watersheds and assess their influences within the Budyko framework in future research [41].

Land use affects the hydrological characteristics of the underlying surface on catchments. It has a great influence on water cycle and water balance. Studying the effects of land use on evaporation and stream flow has a guiding significance for water resources management and natural resources protection. As hydrologists continue to realize the importance of land use, various measurements to protect ecological environment are being taken, such as afforestation, constructing hydraulic structures, large-scale irrigation and drainage, and land use changes. There are many advantages of these measurements, including increasing the water area, purifying the water quality, regulating the water balance and reducing flooding. The results of this thesis also have strategic guidance for future land planning.

7

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Appendix A Physical characteristics of 200 watersheds

	code	longitude center	latitude center	Area (km^2)	Mean elevation (m)	Mean Slope [-]	Maximum percolation rate(1-250) [-]	Fraction percolating from upper to lower zone free water storage [-]
1	1022500	-67.94	44.61	620	104	0.923	202	0.184
1	1031500	-69.31	45.18	767	305	0.955	179	0.385
1	1047000	-69.96	44.87	905	380	0.991	40	0.458
1	1052500	-71.06	44.88	396	646	1.000	36	0.147
1	1055000	-70.59	44.64	251	566	0.992	45	0.417
1	1057000	-70.54	44.30	198	291	0.942	156	0.298
1	1078000	-71.75	43.57	221	360	0.987	127	0.227
1	1134500	-71.84	44.51	210	536	0.996	31	0.216
1	1139000	-72.07	44.15	260	416	0.974	56	0.047
1	1142500	-72.66	43.93	80	406	0.980	61	0.061
1	1169000	-72.73	42.64	234	437	0.997	158	0.026
1	1170100	-72.67	42.70	110	421	0.997	137	0.092
1	1181000	-72.90	42.24	246	435	0.994	149	0.346
2	1333000	-73.20	42.71	112	468	0.984	89	0.165
2	1439500	-75.04	41.09	307	386	0.997	94	0.555
2	1451800	-75.63	40.66	149	205	0.492	97	0.341
2	1485500	-75.47	38.23	113	13	0.867	244	0.538
2	1491000	-75.79	39.00	292	15	0.232	223	0.427
2	1550000	-77.03	41.42	456	530	0.988	83	0.888
2	1552500	-76.53	41.36	62	548	0.996	64	0.369
2	1580000	-76.40	39.63	248	195	0.424	138	0.336
2	1583500	-76.68	39.51	164	168	0.516	155	0.385
2	1634500	-78.33	39.08	265	442	0.778	182	0.284
2	1638480	-77.58	39.25	233	175	0.466	149	0.182
2	1669000	-76.90	37.88	75	31	0.910	131	0.249
2	2027000	-78.98	37.72	241	555	0.941	49	0.675
3	2046000	-77.60	37.07	291	84	0.936	215	0.044
3	2059500	-79.52	37.17	487	336	0.842	73	0.792
3	2064000	-78.96	37.13	428	208	0.909	89	0.371
3	2065500	-78.76	37.08	253	185	0.906	136	0.929
3	2082950	-77.88	36.18	462	89	0.777	239	0.179
3	2118500	-80.75	36.00	401	359	0.706	131	0.332
3	2177000	-83.31	34.81	528	764	0.973	116	0.447
3	2212600	-83.72	33.10	189	152	0.927	73	0.303
3	2221525	-83.48	33.25	493	167	0.825	84	0.512
3	2245500	-81.85	29.98	351	36	0.824	71	0.726
3	2297155	-82.02	27.49	98	34	0.126	213	0.362
3	2298608	-82.16	27.34	315	22	0.076	239	0.617
3	2299950	-82.21	27.47	177	33	0.057	147	0.567
3	2349900	-83.90	32.20	124	109	0.099	69	0.760
3	2472500	-89.41	31.43	789	113	0.587	67	0.470
3	2479155	-89.02	31.03	138	65	0.936	43	0.230
3	2481000	-89.12	30.56	250	48	0.885	228	0.260
3	2481510	-89.27	30.48	801	66	0.782	164	0.253
4	4015330	-91.79	46.95	225	377	0.991	245	0.549
4	4040500	-88.58	46.58	421	490	1.000	67	0.592
4	4057510	-86.71	45.94	492	242	0.981	163	0.678
4	4063700	-88.46	45.76	372	471	0.998	226	0.278
4	4127997	-84.60	45.27	505	334	0.761	202	0.884
4	4161580	-83.09	42.80	67	306	0.315	220	0.073
4	4196800	-83.35	40.92	608	269	0.005	248	0.218
4	4197100	-83.11	41.02	388	289	0.007	245	0.069
4	4213000	-80.60	41.93	466	304	0.932	244	0.021

4	4216418	-78.28	42.86	196	466	0.917	188	0.019
4	4221000	-77.96	42.12	751	628	0.969	66	0.245
4	4224775	-77.70	42.54	232	494	0.868	148	0.196
4	4256000	-75.33	43.75	238	494	1.000	26	1.000
5	3010655	-78.20	41.96	255	623	0.992	97	0.781
5	3011800	-78.72	41.77	101	633	1.000	75	0.085
5	3028000	-78.69	41.58	166	597	0.980	52	0.572
5	3049000	-79.70	40.72	357	377	0.717	95	0.361
5	3070500	-79.70	39.62	519	609	0.717	165	0.476
5	3161000	-81.41	36.39	533	1028	0.996	103	0.921
5	3165000	-80.92	36.65	117	799	0.845	125	0.526
5	3170000	-80.56	37.04	800	758	0.885	135	0.302
5	3186500	-80.48	38.38	332	1069	0.993	36	0.999
5	3241500	-83.88	39.72	174	321	0.026	205	0.353
5	3285000	-84.66	37.64	823	312	0.530	173	0.197
5	3346000	-87.95	39.01	828	182	0.095	230	0.546
5	3384450	-88.55	37.47	112	192	0.913	235	0.123
6	3439000	-82.82	35.14	178	976	0.995	78	0.467
6	3456500	-82.87	35.46	137	1239	0.966	82	0.423
6	3463300	-82.18	35.83	113	1213	1.000	34	1.000
6	3471500	-81.63	36.76	198	903	0.822	84	0.998
6	3473000	-81.84	36.65	785	887	0.863	86	0.995
6	3479000	-81.82	36.24	238	1035	0.987	79	0.208
6	3488000	-81.75	36.90	574	805	0.832	147	0.294
6	3500000	-83.38	35.15	362	848	0.958	126	0.352
6	3500240	-83.39	35.16	149	893	0.959	83	0.677
6	3574500	-86.31	34.62	860	377	0.879	237	0.793
7	5393500	-89.98	45.45	226	503	1.000	121	0.310
7	5399500	-90.08	44.82	578	422	0.734	195	0.114
7	5414000	-90.64	42.73	368	306	0.485	173	0.770
7	5444000	-89.70	41.90	377	253	0.119	230	0.184
7	5487980	-93.27	41.25	879	302	0.260	244	0.598
7	5503800	-91.99	39.58	213	236	0.076	248	0.134
7	5507600	-91.68	39.43	276	228	0.039	216	0.079
7	5508805	-91.34	39.52	536	218	0.086	162	0.141
7	5556500	-89.50	41.37	507	249	0.123	148	0.335
7	5593575	-89.42	38.44	221	149	0.074	241	0.157
7	5593900	-89.35	39.15	146	203	0.072	237	0.242
7	5595730	-89.04	38.25	234	154	0.088	243	0.382
8	7291000	-90.78	31.50	482	123	0.978	57	0.377
8	7362100	-92.78	33.38	997	72	0.970	247	0.801
8	7373000	-92.41	31.54	134	55	0.904	65	0.447
8	7375000	-90.25	30.62	253	59	0.749	247	0.391
10	6332515	-102.77	47.79	191	715	0.000	67	0.301
10	6339100	-102.77	47.24	530	757	0.000	29	0.141
10	6344600	-103.05	47.03	409	820	0.000	118	0.047
10	6404000	-103.34	43.87	152	1534	0.710	44	0.664
10	6406000	-103.20	43.83	438	1311	0.533	69	0.998
10	6409000	-103.83	44.01	210	2023	0.795	202	0.192
10	6431500	-103.86	44.48	427	1785	0.904	165	0.746
10	6447500	-101.63	43.17	794	1035	0.000	155	0.311
10	6479438	-97.17	45.01	799	564	0.003	145	0.127
10	6601000	-96.49	42.32	453	411	0.037	137	0.292
10	6803510	-96.68	40.89	119	385	0.000	173	0.142
10	6803530	-96.54	41.02	309	395	0.000	116	0.190
10	6814000	-96.11	39.95	717	401	0.004	241	0.153
10	6853800	-98.25	39.90	597	567	0.000	112	0.286
10	6878000	-97.04	39.03	777	404	0.000	91	0.318
10	6888500	-96.15	39.06	843	401	0.014	163	0.143
10	6889200	-95.89	39.24	406	357	0.017	218	0.267

10	6889500	-95.73	39.10	766	314	0.015	245	0.169
10	6910800	-95.96	38.57	444	391	0.007	232	0.173
10	6911900	-95.84	38.71	292	372	0.018	211	0.201
10	6917000	-94.71	38.02	768	304	0.059	250	0.230
10	6918460	-93.80	37.40	650	350	0.113	151	0.568
10	6921070	-93.37	37.68	717	362	0.278	122	0.172
10	6921200	-93.27	37.75	329	324	0.253	247	0.270
11	7060710	-92.21	36.00	152	298	0.854	54	0.297
11	7145700	-97.40	37.25	401	402	0.035	250	0.162
11	7167500	-96.22	37.71	321	382	0.017	234	0.042
11	7180500	-96.82	38.20	275	436	0.002	188	0.129
11	7184000	-95.03	37.28	514	281	0.008	249	0.236
11	7195800	-94.43	36.26	39	404	0.223	177	0.322
11	7196900	-94.49	35.88	106	403	0.541	139	0.490
11	7197000	-94.84	35.92	808	337	0.672	217	0.590
11	7208500	-104.97	36.37	159	2885	0.681	193	0.072
11	7261000	-92.40	35.30	456	216	0.253	165	0.121
11	7299670	-99.74	34.35	831	501	0.001	168	0.412
11	7301410	-100.12	35.47	774	800	0.000	150	0.140
11	7315200	-98.09	33.81	503	301	0.092	147	0.129
11	7340300	-94.24	34.38	253	394	0.959	71	0.519
12	8023080	-93.93	31.98	199	83	0.863	43	0.151
12	8066200	-94.96	30.72	375	81	0.846	23	0.086
12	8066300	-94.78	30.48	391	67	0.825	106	0.304
12	8070000	-95.10	30.34	845	89	0.830	100	0.228
12	8082700	-99.47	33.33	277	448	0.000	133	0.314
12	8086290	-99.00	32.65	734	455	0.007	58	0.064
12	8103900	-98.04	30.91	86	376	0.020	107	0.233
12	8104900	-97.69	30.63	348	340	0.026	162	0.132
12	8109700	-96.90	30.34	622	140	0.028	152	0.130
12	8150800	-99.10	30.64	562	558	0.039	117	0.153
12	8158700	-98.01	30.08	321	371	0.041	133	0.140
12	8158810	-97.94	30.16	34	319	0.055	28	0.841
12	8164300	-96.81	29.47	866	100	0.012	189	0.177
12	8164600	-96.82	28.89	264	39	0.057	83	0.894
12	8165300	-99.39	30.06	440	661	0.147	190	0.142
12	8196000	-99.78	29.50	344	561	0.640	105	0.488
12	8198500	-99.48	29.31	640	492	0.413	56	0.307
12	8200000	-99.25	29.57	249	472	0.663	181	0.370
12	8202700	-99.29	29.37	431	425	0.483	95	0.001
13	8269000	-105.50	36.44	163	2923	0.762	74	0.270
13	8380500	-105.32	35.65	200	2649	0.824	249	0.741
14	9035900	-106.03	39.80	71	3360	0.601	86	0.615
14	9047700	-105.97	39.59	25	3257	0.702	185	0.307
14	9210500	-110.42	42.10	399	2482	0.262	145	0.272
14	9223000	-110.71	42.11	334	2576	0.433	144	0.291
14	9306242	-108.47	39.92	87	2270	0.000	143	0.333
14	9312600	-111.04	39.88	198	2498	0.045	101	0.361
15	9386900	-108.55	35.28	186	2413	0.301	23	0.435
15	9404450	-112.60	37.34	196	2214	0.332	177	0.203
15	9430600	-108.65	33.17	191	2361	0.713	82	1.000
15	9497980	-110.86	33.83	517	1690	0.873	39	0.276
15	9505350	-111.78	34.73	370	1870	0.502	47	0.444
15	9505800	-111.69	34.54	625	2021	0.531	36	0.575
15	9510200	-111.54	33.69	428	1147	0.158	55	0.433
16	10172700	-112.38	39.98	260	2030	0.002	216	0.284
16	10172800	-112.57	40.50	76	2206	0.037	150	0.491
16	10205030	-111.53	38.91	151	2623	0.033	206	0.562
16	10249300	-117.25	38.89	609	2069	0.062	200	0.695
16	10329500	-117.42	41.53	514	1907	0.002	51	0.199

16	10336660	-120.16	39.11	32	2217	0.791	183	0.736
16	10343500	-120.24	39.43	28	2188	0.899	49	0.284
17	10396000	-118.87	42.79	970	1816	0.005	90	0.438
17	12082500	-122.08	46.75	360	1156	0.931	145	0.654
17	12115000	-121.63	47.37	111	940	0.995	226	0.682
17	12390700	-115.36	47.59	470	1356	0.996	54	0.620
17	12411000	-115.98	47.71	866	1203	0.992	25	0.340
17	13018300	-110.70	43.45	29	2545	0.810	114	0.639
17	13083000	-113.98	42.17	182	1995	0.008	141	0.214
17	13161500	-115.67	41.93	991	2043	0.034	128	0.069
17	14141500	-122.17	45.42	61	726	1.000	97	0.911
17	14154500	-122.87	43.74	550	852	1.000	65	0.480
17	14185000	-122.50	44.39	450	883	1.000	148	0.906
17	14316700	-122.73	43.35	588	948	1.000	130	0.383
18	11141280	-120.47	35.24	56	562	0.450	74	0.387
18	11151300	-121.07	36.27	648	609	0.137	84	0.090
18	11162500	-122.33	37.26	119	340	0.821	71	0.655
18	11180500	-122.02	37.61	27	245	0.056	56	0.288
18	11224500	-120.47	36.21	326	797	0.145	82	0.153
18	11253310	-120.43	36.40	235	682	0.120	99	0.198
18	11274500	-121.13	37.32	530	439	0.305	57	0.335
18	11274630	-121.21	37.49	285	547	0.280	67	0.297
18	11284400	-120.18	37.84	42	967	0.758	43	0.369
18	11383500	-121.95	40.01	633	1168	0.700	36	0.507
18	11468500	-123.74	39.43	273	284	1.000	48	0.250
18	11481200	-124.08	41.01	107	314	0.938	102	0.158
18	11482500	-124.05	41.30	723	567	0.983	167	0.724

Appendix B Hydrometeorological characteristics of 200 watersheds

	code	Long-term mean values from 1981 to 2013										
		Daily P (mm/d)	Yearly P (mm/y)	Daily Q (mm/d)	Yearly Q (mm/y)	Daily E_P (mm/d)	Yearly E_P (mm/y)	Tmax (°C)	Tmin (°C)	Tave (°C)	E_P/P [-]	E_A/P [-]
1	1022500	3.6	1320	2.0	733	2.1	771	12.2	1.0	6.6	0.584	0.445
1	1031500	3.5	1269	2.0	741	2.1	755	10.6	-1.2	4.7	0.595	0.416
1	1047000	3.3	1216	2.2	793	2.1	762	10.4	-1.5	4.5	0.627	0.348
1	1052500	3.8	1373	2.3	829	2.1	765	8.8	-2.3	3.3	0.557	0.396
1	1055000	3.4	1254	2.2	810	2.1	760	9.7	-1.8	3.9	0.606	0.354
1	1057000	3.5	1290	1.8	652	2.1	777	11.8	0.3	6.1	0.602	0.494
1	1078000	3.5	1290	1.7	634	2.2	795	12.5	0.6	6.5	0.617	0.509
1	1134500	3.5	1279	1.9	692	2.1	764	10.3	-1.5	4.4	0.597	0.459
1	1139000	3.1	1143	1.6	581	2.1	771	11.4	-0.5	5.5	0.675	0.492
1	1142500	3.3	1203	1.8	645	2.1	781	11.8	0.0	5.9	0.650	0.464
1	1169000	3.9	1417	2.2	803	2.3	822	12.7	0.8	6.7	0.580	0.434
1	1170100	3.9	1412	2.1	762	2.2	819	12.7	0.8	6.8	0.580	0.460
1	1181000	3.8	1374	2.1	756	2.3	827	12.9	1.4	7.2	0.602	0.450
2	1333000	3.6	1319	2.0	716	2.2	807	12.5	1.2	6.8	0.612	0.457
2	1439500	3.6	1328	2.0	730	2.3	855	14.4	2.9	8.6	0.644	0.450
2	1451800	3.5	1283	1.6	583	2.4	882	16.2	4.7	10.4	0.687	0.546
2	1485500	3.2	1177	1.1	416	2.6	961	19.6	8.6	14.1	0.817	0.646
2	1491000	3.3	1187	1.2	449	2.6	948	19.0	8.0	13.5	0.798	0.622
2	1550000	3.3	1188	1.6	595	2.3	835	13.3	2.0	7.6	0.703	0.500
2	1552500	3.6	1314	2.0	714	2.3	834	12.9	2.0	7.4	0.635	0.457
2	1580000	3.4	1249	1.3	466	2.5	922	17.7	6.2	12.0	0.738	0.627
2	1583500	3.3	1190	1.0	383	2.6	932	18.1	6.9	12.5	0.783	0.678
2	1634500	2.9	1074	1.0	358	2.5	921	17.3	4.7	11.0	0.858	0.666

2	1638480	3.0	1102	1.0	364	2.6	936	18.4	6.4	12.4	0.850	0.669
2	1669000	3.2	1176	0.9	343	2.7	978	20.5	8.5	14.5	0.831	0.708
2	2027000	3.5	1289	1.6	591	2.7	969	17.7	5.5	11.6	0.752	0.542
3	2046000	3.3	1196	0.8	304	2.7	999	20.9	7.8	14.4	0.835	0.746
3	2059500	3.1	1143	0.9	325	3.3	1186	19.6	6.8	13.2	1.038	0.716
3	2064000	3.1	1131	0.9	324	3.0	1086	20.1	7.0	13.6	0.960	0.714
3	2065500	3.1	1143	0.9	330	3.7	1358	20.3	7.1	13.7	1.188	0.711
3	2082950	3.3	1191	0.8	295	3.1	1124	21.6	8.4	15.0	0.943	0.753
3	2118500	3.5	1295	1.1	416	2.9	1048	20.6	7.2	13.9	0.810	0.679
3	2177000	5.3	1939	2.9	1044	2.8	1027	19.1	6.5	12.8	0.530	0.462
3	2212600	3.3	1210	0.7	254	4.0	1467	23.9	10.7	17.3	1.212	0.791
3	2221525	3.3	1204	0.7	265	3.3	1188	23.6	10.6	17.1	0.987	0.780
3	2245500	3.7	1360	0.9	326	3.8	1381	26.6	14.7	20.6	1.015	0.760
3	2297155	3.9	1436	0.8	283	3.9	1409	28.7	16.6	22.7	0.982	0.803
3	2298608	3.9	1418	1.2	447	3.6	1315	28.8	16.8	22.8	0.927	0.685
3	2299950	3.9	1426	1.1	398	3.6	1305	28.7	16.8	22.7	0.915	0.721
3	2349900	3.3	1214	0.8	277	3.2	1172	24.9	11.7	18.3	0.965	0.772
3	2472500	4.3	1562	1.3	474	3.8	1389	24.8	11.8	18.3	0.889	0.696
3	2479155	4.5	1631	1.5	561	3.2	1168	25.3	12.3	18.8	0.716	0.656
3	2481000	4.7	1723	1.9	693	3.2	1174	25.3	13.5	19.4	0.682	0.598
3	2481510	4.6	1676	1.7	632	3.2	1174	25.3	13.2	19.2	0.700	0.623
4	4015330	2.3	824	1.0	358	2.0	716	9.9	-1.6	4.2	0.869	0.565
4	4040500	2.5	911	1.1	407	2.3	835	10.3	-1.6	4.3	0.916	0.554
4	4057510	2.4	861	0.9	311	2.1	750	10.9	0.6	5.8	0.871	0.639
4	4063700	2.3	833	0.7	239	2.0	747	10.7	-1.4	4.7	0.897	0.713
4	4127997	2.5	928	1.1	385	2.9	1051	11.9	0.7	6.3	1.133	0.585
4	4161580	2.5	907	0.6	226	2.4	867	13.9	3.3	8.6	0.956	0.751
4	4196800	2.7	982	0.9	328	2.5	896	15.8	5.0	10.4	0.913	0.666
4	4197100	2.8	1018	0.9	336	2.5	900	15.3	4.7	10.0	0.884	0.670
4	4213000	3.3	1206	1.6	585	2.3	844	14.3	3.7	9.0	0.700	0.515
4	4216418	3.1	1146	1.4	525	2.2	816	12.7	2.4	7.5	0.712	0.542
4	4221000	3.1	1132	1.3	464	2.3	828	12.9	0.8	6.8	0.731	0.590
4	4224775	2.9	1045	1.1	383	2.2	818	13.0	1.7	7.4	0.783	0.633
4	4256000	3.6	1317	2.2	788	2.2	800	11.2	-0.3	5.4	0.607	0.401
5	3010655	3.2	1165	1.5	545	2.3	825	12.9	0.8	6.9	0.708	0.533
5	3011800	3.6	1297	1.9	697	2.3	824	12.7	0.7	6.7	0.635	0.463
5	3028000	3.4	1258	1.9	701	2.3	827	12.9	0.9	6.9	0.658	0.443
5	3049000	3.3	1205	1.3	484	2.4	870	15.7	3.3	9.5	0.722	0.599
5	3070500	3.7	1345	2.0	724	2.4	889	15.2	3.9	9.6	0.661	0.462
5	3161000	4.0	1465	1.9	705	2.7	980	16.0	4.5	10.2	0.669	0.519
5	3165000	3.7	1333	1.5	530	2.7	992	17.4	4.6	11.0	0.744	0.603
5	3170000	3.4	1229	1.1	393	2.8	1032	17.4	4.9	11.1	0.840	0.680
5	3186500	4.1	1489	2.5	907	2.5	919	13.5	2.8	8.2	0.617	0.391
5	3241500	3.0	1104	1.0	372	2.5	919	16.5	5.4	11.0	0.832	0.663
5	3285000	3.5	1291	1.4	496	2.7	988	19.3	7.2	13.2	0.766	0.616
5	3346000	3.1	1143	1.0	352	2.6	951	18.0	6.6	12.3	0.832	0.692
5	3384450	3.7	1354	1.3	485	2.7	997	19.7	7.6	13.7	0.736	0.642
6	3439000	5.6	2037	3.2	1150	2.7	991	17.6	5.6	11.6	0.487	0.436
6	3456500	4.8	1761	2.4	894	2.7	1004	16.1	4.4	10.3	0.570	0.492
6	3463300	4.5	1629	2.9	1070	3.1	1146	15.8	4.4	10.1	0.703	0.343
6	3471500	3.4	1229	1.3	491	2.6	953	16.6	4.1	10.4	0.776	0.601
6	3473000	3.5	1259	1.5	537	2.6	948	16.7	4.4	10.6	0.753	0.573
6	3479000	3.9	1435	1.8	663	2.7	974	16.1	4.8	10.4	0.679	0.538
6	3488000	3.3	1196	1.2	450	2.6	955	17.2	4.5	10.8	0.799	0.624
6	3500000	5.1	1869	2.4	883	2.8	1032	18.6	5.9	12.2	0.552	0.528
6	3500240	5.0	1808	2.2	796	3.1	1126	18.4	5.5	12.0	0.623	0.560
6	3574500	4.3	1567	1.8	663	2.9	1043	20.6	8.7	14.7	0.666	0.577
7	5393500	2.4	884	1.0	355	2.1	762	10.7	-1.0	4.9	0.862	0.599
7	5399500	2.3	851	0.7	264	2.1	779	11.6	0.1	5.9	0.915	0.690

7	5414000	2.6	957	0.7	272	2.3	837	13.7	2.5	8.1	0.875	0.715
7	5444000	2.8	1009	0.8	294	2.4	872	14.8	3.2	9.0	0.864	0.708
7	5487980	2.7	974	0.7	265	2.4	893	16.0	4.2	10.1	0.917	0.728
7	5503800	2.9	1067	0.8	278	2.6	943	17.7	6.1	11.9	0.883	0.739
7	5507600	2.9	1071	0.7	262	3.4	1235	17.9	6.3	12.1	1.153	0.756
7	5508805	2.9	1057	0.7	258	2.7	971	17.8	6.2	12.0	0.919	0.756
7	5556500	2.8	1011	0.8	297	2.4	876	15.2	3.8	9.5	0.866	0.706
7	5593575	3.0	1111	0.9	338	2.7	979	18.9	7.4	13.2	0.881	0.696
7	5593900	2.9	1051	0.8	304	2.6	957	18.0	6.5	12.2	0.911	0.711
7	5595730	3.2	1155	1.0	363	2.7	976	18.8	7.3	13.0	0.846	0.686
8	7291000	4.3	1560	1.3	480	3.5	1274	24.8	12.0	18.4	0.817	0.692
8	7362100	3.7	1363	1.0	380	3.1	1117	23.7	10.8	17.2	0.819	0.721
8	7373000	4.2	1542	1.1	419	3.5	1285	25.0	12.6	18.8	0.833	0.729
8	7375000	4.6	1669	1.5	540	3.7	1344	25.4	13.0	19.2	0.805	0.677
10	6332515	1.2	451	0.1	21	2.2	816	12.3	-1.3	5.5	1.810	0.954
10	6339100	1.2	432	0.1	24	2.1	775	12.7	-0.9	5.9	1.794	0.944
10	6344600	1.2	427	0.1	26	2.3	826	12.7	-0.9	5.9	1.935	0.939
10	6404000	1.5	533	0.1	50	2.4	883	13.5	-0.5	6.5	1.656	0.906
10	6406000	1.4	501	0.1	34	2.4	869	14.3	0.1	7.2	1.736	0.932
10	6409000	1.7	622	0.2	62	2.5	908	10.8	-3.0	3.9	1.459	0.900
10	6431500	1.9	707	0.4	137	2.5	907	11.7	-1.6	5.1	1.284	0.807
10	6447500	1.4	516	0.1	26	2.4	889	15.9	1.0	8.4	1.722	0.950
10	6479438	1.7	635	0.2	57	2.2	807	12.0	0.2	6.1	1.271	0.910
10	6601000	2.1	772	0.3	124	2.4	877	15.7	3.0	9.4	1.137	0.840
10	6803510	2.1	780	0.3	111	2.5	915	17.2	4.3	10.7	1.172	0.857
10	6803530	2.2	797	0.3	115	2.5	911	16.9	4.2	10.5	1.143	0.856
10	6814000	2.4	874	0.4	152	2.6	942	17.7	4.9	11.3	1.078	0.826
10	6853800	2.0	714	0.1	42	2.9	1055	18.1	4.1	11.1	1.477	0.941
10	6878000	2.2	811	0.3	99	2.9	1058	19.2	6.1	12.7	1.306	0.878
10	6888500	2.6	945	0.5	199	2.8	1028	18.6	6.0	12.3	1.088	0.789
10	6889200	2.6	938	0.6	204	2.7	981	18.5	5.9	12.2	1.046	0.782
10	6889500	2.6	947	0.6	205	2.6	963	18.6	6.1	12.4	1.016	0.784
10	6910800	2.6	961	0.6	210	2.7	992	18.7	6.3	12.5	1.032	0.781
10	6911900	2.6	960	0.6	206	2.7	994	18.7	6.4	12.5	1.036	0.785
10	6917000	3.1	1126	0.9	320	2.8	1004	19.4	7.3	13.4	0.892	0.716
10	6918460	3.3	1197	1.0	374	2.8	1009	19.6	7.3	13.5	0.843	0.688
10	6921070	3.3	1190	1.0	361	2.8	1008	19.4	7.1	13.3	0.847	0.697
10	6921200	3.3	1186	0.9	316	2.8	1005	19.4	7.2	13.3	0.847	0.734
11	7060710	3.7	1354	0.8	278	3.1	1136	20.9	8.0	14.4	0.839	0.795
11	7145700	2.4	892	0.5	183	2.8	1023	20.7	7.7	14.2	1.146	0.795
11	7167500	2.7	1002	0.7	265	2.7	999	19.9	6.9	13.4	0.997	0.736
11	7180500	2.6	935	0.6	216	3.1	1117	19.4	6.6	13.0	1.195	0.769
11	7184000	3.2	1181	0.9	346	2.8	1006	19.9	7.8	13.9	0.851	0.707
11	7195800	3.5	1269	1.0	358	2.9	1047	20.7	8.3	14.5	0.825	0.718
11	7196900	3.6	1331	1.1	416	2.9	1043	20.8	8.9	14.8	0.784	0.687
11	7197000	3.6	1300	1.1	404	2.9	1050	21.2	9.0	15.1	0.807	0.689
11	7208500	1.7	613	0.2	75	2.7	1000	12.1	-3.0	4.6	1.633	0.877
11	7261000	3.7	1364	1.4	493	2.9	1062	21.6	9.1	15.4	0.778	0.639
11	7299670	1.7	619	0.1	31	3.9	1441	24.4	9.4	16.9	2.329	0.951
11	7301410	1.7	606	0.0	14	2.9	1063	22.1	7.1	14.6	1.754	0.977
11	7315200	2.2	813	0.2	56	3.7	1335	24.4	10.8	17.6	1.642	0.931
11	7340300	4.4	1599	1.8	648	3.0	1084	20.9	8.5	14.7	0.677	0.595
12	8023080	3.9	1406	0.9	338	3.3	1204	24.8	12.1	18.5	0.856	0.759
12	8066200	3.6	1326	0.8	282	3.6	1315	25.7	13.2	19.5	0.992	0.787
12	8066300	3.8	1385	0.8	307	4.0	1445	25.7	13.5	19.6	1.043	0.779
12	8070000	3.5	1278	0.7	257	4.1	1509	25.8	13.6	19.7	1.181	0.799
12	8082700	1.8	654	0.1	25	3.7	1337	25.0	10.4	17.7	2.045	0.962
12	8086290	1.9	711	0.1	33	4.3	1565	25.0	10.9	17.9	2.200	0.953
12	8103900	2.3	846	0.3	104	3.3	1215	25.3	12.1	18.7	1.437	0.877

12	8104900	2.4	880	0.4	130	3.4	1225	25.5	12.5	19.0	1.391	0.852
12	8109700	2.5	922	0.2	88	3.4	1238	26.3	13.7	20.0	1.343	0.904
12	8150800	2.0	742	0.1	30	3.4	1251	25.4	11.2	18.3	1.687	0.959
12	8158700	2.5	915	0.4	143	3.4	1232	25.7	12.6	19.2	1.346	0.844
12	8158810	2.5	902	0.5	177	3.4	1232	25.9	13.0	19.5	1.366	0.804
12	8164300	2.7	995	0.4	136	4.7	1723	26.7	14.5	20.6	1.731	0.864
12	8164600	2.9	1054	0.5	184	4.2	1516	27.1	15.6	21.3	1.439	0.826
12	8165300	2.1	776	0.2	76	3.4	1231	25.0	10.9	18.0	1.585	0.902
12	8196000	2.0	725	0.2	89	3.4	1251	25.9	12.1	19.0	1.724	0.877
12	8198500	2.1	777	0.1	47	3.4	1247	26.2	12.3	19.2	1.606	0.940
12	8200000	2.2	818	0.4	151	3.4	1239	26.2	12.2	19.2	1.515	0.815
12	8202700	2.1	765	0.0	15	3.4	1252	26.5	12.7	19.6	1.637	0.981
13	8269000	1.6	584	0.4	152	3.9	1428	11.6	-3.6	4.0	2.445	0.740
13	8380500	1.7	617	0.3	96	3.0	1105	14.0	-1.2	6.4	1.792	0.845
14	9035900	2.7	976	1.2	431	3.7	1334	5.5	-6.3	-0.4	1.367	0.559
14	9047700	2.0	744	0.7	240	4.0	1449	7.4	-5.8	0.8	1.949	0.677
14	9210500	1.4	520	0.4	153	2.7	969	9.5	-5.1	2.2	1.864	0.706
14	9223000	1.8	644	0.6	235	3.0	1086	8.8	-4.8	2.0	1.687	0.636
14	9306242	1.3	471	0.0	17	3.6	1322	13.1	-1.2	6.0	2.808	0.964
14	9312600	1.6	600	0.3	113	3.5	1279	11.2	-2.9	4.2	2.132	0.812
15	9386900	1.2	451	0.1	23	3.0	1096	16.0	-1.5	7.2	2.427	0.949
15	9404450	1.4	511	0.2	72	3.1	1118	15.6	0.2	7.9	2.186	0.859
15	9430600	1.6	598	0.4	140	4.3	1563	16.5	1.1	8.8	2.615	0.765
15	9497980	1.7	610	0.1	52	3.5	1292	20.6	5.4	13.0	2.118	0.915
15	9505350	1.6	599	0.3	92	3.4	1249	18.9	2.6	10.7	2.083	0.847
15	9505800	1.8	661	0.2	77	3.2	1154	17.6	2.6	10.1	1.745	0.884
15	9510200	1.3	477	0.1	50	3.4	1238	24.8	9.8	17.3	2.593	0.896
16	1017270	1.4	521	0.0	15	2.8	1031	14.9	0.5	7.7	1.979	0.971
16	1017280	2.0	733	0.2	78	3.4	1245	12.9	1.6	7.2	1.698	0.893
16	1020503	1.7	634	0.3	98	4.1	1482	11.3	-2.2	4.6	2.339	0.846
16	1024930	0.7	243	0.0	10	3.0	1108	16.1	0.5	8.3	4.551	0.960
16	1032950	1.4	517	0.2	67	3.4	1223	13.6	-0.3	6.7	2.366	0.870
16	1033666	3.8	1404	2.7	987	2.9	1044	12.4	-0.2	6.1	0.744	0.297
16	1034350	2.7	972	1.1	384	2.8	1024	12.8	-1.6	5.6	1.054	0.605
17	1039600	1.6	590	0.3	124	2.9	1068	13.2	-0.2	6.5	1.811	0.790
17	1208250	6.9	2526	5.2	1916	2.9	1055	10.2	1.4	5.8	0.418	0.241
17	1211500	7.2	2617	5.4	1978	2.0	720	10.0	2.0	6.0	0.275	0.244
17	1239070	3.1	1123	1.1	408	2.9	1058	10.7	-0.5	5.1	0.942	0.637
17	1241100	3.5	1262	1.9	697	2.1	782	10.8	0.4	5.6	0.620	0.448
17	1301830	2.3	834	1.0	363	3.4	1228	8.5	-5.4	1.5	1.473	0.565
17	1308300	1.5	563	0.2	71	3.3	1187	12.9	-0.8	6.1	2.108	0.874
17	1316150	1.4	500	0.2	91	2.6	935	12.8	-1.7	5.5	1.870	0.818
17	1414150	7.4	2690	5.6	2042	2.1	781	13.0	3.6	8.3	0.290	0.241
17	1415450	4.7	1702	2.6	939	2.3	823	14.5	3.1	8.8	0.483	0.448
17	1418500	5.8	2119	4.4	1611	2.2	806	13.7	2.6	8.1	0.380	0.240
17	1431670	4.6	1680	3.0	1093	2.3	829	14.5	2.6	8.5	0.494	0.349
18	1114128	1.8	670	0.4	154	2.8	1005	22.1	4.9	13.5	1.500	0.770
18	1115130	1.3	476	0.1	20	3.5	1260	23.2	4.2	13.7	2.649	0.957
18	1116250	2.6	960	0.9	321	3.4	1259	19.0	6.1	12.5	1.311	0.665
18	1118050	1.5	538	0.3	95	2.7	980	20.5	8.4	14.5	1.821	0.824
18	1122450	1.3	462	0.0	18	3.4	1247	23.5	3.5	13.5	2.698	0.962
18	1125331	1.1	413	0.0	12	3.0	1085	23.7	4.6	14.2	2.628	0.971
18	1127450	1.2	436	0.1	32	2.7	1002	21.7	7.5	14.6	2.299	0.927
18	1127463	1.2	454	0.1	25	2.7	999	21.2	7.3	14.2	2.200	0.945
18	1128440	2.8	1019	0.6	206	3.1	1137	19.9	5.8	12.9	1.116	0.798
18	1138350	3.6	1310	1.3	465	3.7	1358	17.6	3.0	10.3	1.037	0.645
18	1146850	3.6	1308	1.8	652	2.9	1047	19.7	5.4	12.6	0.800	0.501
18	1148120	4.4	1600	3.0	1096	2.4	869	15.5	5.9	10.7	0.543	0.315
18	1148250	4.6	1688	3.2	1162	2.5	914	15.0	4.2	9.6	0.541	0.312

Appendix C Percentages of all land uses coverage on 200 watersheds

	code	Water %	Developed %	Mechanically Disturbed National Forests %	Mechanically Disturbed Other Public Lands %	Mechanically Disturbed Private %	Mining %	Barren %	Deciduous Forest %	Evergreen Forest %	Mixed Forest %	Grassland %	Shrubland %	Cropland %	Hay/Pasture Land %	Herbaceous Wetland %	Woody Wetland %	Perennial Ice/Snow %
1	1022500	3.94	0.38	0.00	0.00	1.88	0.02	0.09	21.09	26.71	33.09	0.00	3.80	0.21	0.07	1.50	7.23	0.00
1	1031500	3.19	0.48	0.00	0.00	1.88	0.01	0.07	32.37	23.14	32.82	0.00	0.49	2.23	0.46	0.70	2.16	0.00
1	1047000	0.76	0.60	0.00	0.01	1.11	0.00	0.23	42.49	26.55	21.95	0.00	0.19	2.52	0.24	0.62	2.73	0.00
1	1052500	0.38	0.00	0.00	0.00	1.53	0.01	0.27	44.00	20.99	29.18	0.00	0.30	0.03	0.01	1.26	2.04	0.00
1	1055000	0.42	0.17	0.00	0.03	1.27	0.01	0.02	40.58	37.50	14.80	0.00	0.48	0.95	0.05	0.22	3.50	0.00
1	1057000	1.50	0.73	0.00	0.00	0.55	0.00	0.00	43.89	17.35	23.41	0.00	0.06	6.85	1.97	1.45	2.26	0.00
1	1078000	0.77	0.89	0.00	0.02	0.65	0.13	0.00	30.47	23.81	30.71	0.00	0.00	6.52	0.86	1.13	4.02	0.00
1	1134500	0.06	0.06	0.00	0.23	0.97	0.03	0.21	50.17	14.55	25.54	0.00	1.31	0.45	0.04	1.13	5.24	0.00
1	1139000	1.25	0.69	0.00	0.24	0.62	0.11	0.17	39.56	13.69	30.34	0.00	1.01	7.01	1.75	1.53	2.02	0.00
1	1142500	0.00	1.33	0.00	0.00	0.78	0.12	0.08	36.78	10.40	25.47	0.00	0.00	14.29	6.55	1.87	2.34	0.00
1	1169000	0.43	2.13	0.00	0.01	0.42	0.04	0.13	41.97	16.55	25.82	0.00	0.10	5.90	1.64	0.69	4.18	0.00
1	1170100	0.51	0.27	0.00	0.00	0.36	0.00	0.06	46.63	15.00	28.32	0.00	0.03	5.75	0.76	0.34	1.96	0.00
1	1181000	1.81	2.34	0.00	0.03	0.28	0.02	0.08	57.31	7.92	23.94	0.00	0.00	2.14	0.59	0.31	3.24	0.00
2	1333000	0.06	5.72	0.00	0.01	0.08	0.00	0.16	68.45	2.61	6.65	0.00	0.00	6.81	7.94	0.34	1.17	0.00
2	1439500	2.27	0.40	0.00	0.22	0.38	0.10	0.00	77.22	2.12	7.41	0.00	0.00	0.11	0.32	2.07	7.39	0.00
2	1451800	0.29	1.45	0.00	0.00	0.17	0.00	0.00	29.16	1.93	2.82	0.00	0.00	14.79	48.88	0.21	0.29	0.00
2	1485500	0.22	0.59	0.00	0.65	2.31	0.01	0.02	10.44	38.22	8.54	0.00	0.00	16.16	3.04	1.16	18.65	0.00
2	1491000	0.24	1.25	0.00	0.06	0.58	0.00	0.01	19.33	3.68	5.94	0.00	0.00	39.66	10.48	0.19	18.58	0.00
2	1550000	0.15	0.15	0.00	0.55	0.85	0.38	0.00	70.50	6.92	6.02	0.00	0.00	1.28	13.11	0.08	0.01	0.00
2	1552500	0.20	0.10	0.00	0.42	2.07	0.09	0.00	71.60	6.12	13.53	0.00	0.00	2.69	2.98	0.20	0.00	0.00
2	1580000	0.36	0.86	0.00	0.02	0.34	0.08	0.00	31.06	1.79	2.12	0.00	0.00	11.37	51.50	0.33	0.18	0.00
2	1583500	0.29	1.13	0.00	0.00	0.68	0.00	0.00	31.39	1.75	4.20	0.00	0.00	11.28	48.74	0.30	0.23	0.00
2	1634500	0.19	0.02	0.10	0.00	0.29	0.00	0.00	76.06	1.66	11.86	0.00	0.00	0.51	9.26	0.05	0.00	0.00
2	1638480	0.23	0.47	0.00	0.00	0.19	0.04	0.00	14.79	1.16	16.35	0.00	0.00	4.32	61.79	0.16	0.50	0.00
2	1669000	0.33	0.00	0.00	0.00	3.25	0.00	0.00	29.39	10.97	27.11	0.00	0.00	15.29	9.02	0.50	4.15	0.00
2	2027000	0.20	0.22	0.00	0.00	0.23	0.04	0.00	69.12	3.56	12.88	0.00	0.00	0.89	12.80	0.05	0.00	0.00
3	2046000	0.32	0.58	0.00	0.00	2.16	0.04	0.00	41.40	13.30	23.46	0.00	0.00	5.03	13.34	0.07	0.30	0.00
3	2059500	0.22	1.18	0.00	0.00	0.88	0.10	0.00	49.52	6.57	12.19	0.00	0.00	1.33	27.80	0.10	0.08	0.00
3	2064000	0.35	1.70	0.00	0.01	1.79	0.05	0.00	41.59	11.84	15.24	0.00	0.00	3.29	23.59	0.06	0.48	0.00
3	2065500	0.16	0.83	0.00	0.00	1.73	0.01	0.00	44.98	11.28	15.54	0.00	0.00	2.19	20.08	0.41	2.80	0.00
3	2082950	0.14	0.82	0.00	0.04	2.82	0.01	0.03	29.28	38.63	9.80	0.00	0.00	6.06	7.44	0.12	4.82	0.00
3	2118500	0.14	1.42	0.00	0.00	1.00	0.11	0.12	40.49	12.56	13.20	0.00	0.00	7.86	22.95	0.03	0.11	0.00
3	2177000	0.16	0.63	0.05	0.00	0.02	0.00	0.00	22.15	38.34	36.62	0.00	0.00	0.44	1.55	0.00	0.04	0.00
3	2212600	0.26	0.10	0.21	0.00	0.72	0.10	0.00	35.03	45.05	14.59	0.00	0.00	1.52	1.65	0.03	0.73	0.00
3	2221525	0.50	0.83	0.02	0.03	1.70	0.06	0.05	34.66	28.90	12.76	0.00	0.00	7.08	12.63	0.03	0.75	0.00
3	2245500	1.20	2.21	0.00	0.73	2.90	0.70	0.36	0.00	63.08	0.02	12.31	1.27	1.19	0.24	1.90	11.89	0.00
3	2297155	0.32	2.86	0.00	0.00	1.14	1.85	0.00	0.00	8.35	0.91	43.50	0.27	10.24	6.38	7.10	17.08	0.00
3	2298608	0.73	2.87	0.00	0.02	0.33	0.46	0.00	0.00	7.99	0.51	40.97	0.23	14.21	7.67	7.06	16.93	0.00
3	2299950	1.30	2.25	0.00	0.00	0.79	0.18	0.95	0.00	10.71	0.60	43.31	0.08	10.90	4.26	5.44	19.23	0.00
3	2349900	0.14	0.42	0.00	0.00	0.87	0.00	0.05	12.38	6.30	3.93	0.00	0.00	44.69	19.66	0.00	11.55	0.00
3	2472500	0.69	0.27	0.00	0.00	3.36	0.01	0.01	16.08	32.43	15.90	0.00	0.00	6.74	24.38	0.02	0.11	0.00
3	2479155	0.09	0.14	0.18	1.79	0.19	0.00	0.00	1.79	52.87	22.98	0.00	0.00	0.60	2.28	0.02	17.08	0.00
3	2481000	0.10	0.04	0.29	0.00	3.56	0.00	0.00	2.03	47.55	22.50	0.00	0.00	2.59	8.09	0.01	13.25	0.00
3	2481510	0.48	0.26	0.00	0.00	4.26	0.05	0.01	3.88	41.13	23.01	0.00	0.00	3.81	13.97	0.37	8.77	0.00
4	4015330	0.14	0.82	0.00	0.61	2.37	0.09	0.00	41.80	9.45	18.44	0.08	0.00	5.46	5.20	0.19	15.35	0.00
4	4040500	2.78	0.10	0.00	0.36	1.48	0.02	0.00	33.97	13.78	11.82	0.42	0.00	0.71	0.49	4.40	29.67	0.00
4	4057510	2.74	0.01	1.20	0.00	1.00	0.00	0.00	19.91	18.96	9.19	1.24	0.00	0.38	0.13	5.28	39.94	0.00

4	4063700	0.98	0.01	0.41	0.01	0.61	0.00	0.00	38.71	6.72	10.79	0.72	0.00	2.94	0.89	2.41	34.78	0.00
4	4127997	1.41	0.63	0.00	0.65	1.31	0.01	0.00	50.69	7.97	4.85	9.56	0.00	6.81	3.25	0.99	11.88	0.00
4	4161580	4.36	1.66	0.00	0.00	0.04	0.00	0.00	31.92	2.22	0.00	0.00	0.00	26.62	17.63	2.95	12.58	0.00
4	4196800	0.48	0.09	0.00	0.00	0.01	0.01	0.00	7.46	0.00	0.00	0.10	0.00	78.80	12.30	0.40	0.36	0.00
4	4197100	0.15	0.74	0.00	0.00	0.02	0.00	0.00	9.15	0.00	0.01	0.00	0.00	69.45	19.56	0.14	0.78	0.00
4	4213000	0.50	1.80	0.00	0.00	0.11	0.08	0.00	47.08	2.89	4.58	0.00	0.00	13.91	26.17	0.57	2.31	0.00
4	4216418	1.07	1.22	0.00	0.00	0.08	0.01	0.00	18.61	1.30	31.92	0.00	0.00	6.08	39.34	0.00	0.37	0.00
4	4221000	0.05	0.96	0.00	0.00	0.28	0.03	0.00	56.92	0.83	10.87	0.00	0.00	4.43	25.58	0.00	0.05	0.00
4	4224775	0.44	0.48	0.00	0.07	0.07	0.06	0.00	28.68	1.92	37.51	0.00	0.00	5.93	24.69	0.00	0.16	0.00
4	4256000	1.41	0.00	0.00	0.00	0.51	0.00	0.00	64.10	6.16	7.12	0.00	0.00	0.15	0.53	0.71	19.31	0.00
5	3010655	0.05	0.29	0.00	0.07	1.32	0.07	0.00	69.81	3.73	9.94	0.00	0.00	1.29	13.42	0.00	0.01	0.00
5	3011800	0.00	0.86	0.22	0.08	2.03	0.02	0.00	75.16	4.52	14.43	0.00	0.00	0.57	1.47	0.00	0.63	0.00
5	3028000	0.04	1.13	0.09	0.00	1.59	0.26	0.00	70.12	6.36	12.50	0.00	0.00	0.89	6.92	0.00	0.11	0.00
5	3049000	0.00	1.39	0.00	0.00	0.07	1.53	0.00	61.26	1.37	3.40	0.00	0.00	6.51	24.46	0.00	0.00	0.00
5	3070500	0.48	0.58	0.00	0.02	0.09	0.29	0.00	67.30	4.19	6.25	0.00	0.00	2.21	17.96	0.14	0.49	0.00
5	3161000	0.41	2.81	0.00	0.00	0.22	0.02	0.04	42.45	16.27	19.84	0.00	0.00	3.27	14.61	0.05	0.02	0.00
5	3165000	0.00	7.31	0.00	0.00	0.22	0.00	0.00	30.48	10.38	13.36	0.00	0.00	2.65	35.50	0.11	0.00	0.00
5	3170000	0.30	0.18	0.00	0.00	0.17	0.00	0.00	38.71	9.55	14.65	0.00	0.00	4.75	31.55	0.09	0.05	0.00
5	3186500	0.22	0.04	0.06	0.00	0.04	0.00	0.00	47.30	20.90	29.06	0.00	0.00	0.78	1.39	0.09	0.11	0.00
5	3241500	0.13	1.32	0.00	0.00	0.00	0.02	0.00	5.84	0.00	0.00	0.00	0.00	79.74	12.73	0.04	0.18	0.00
5	3285000	0.11	1.92	0.00	0.00	0.34	0.00	0.00	28.91	5.11	14.25	0.00	0.00	9.95	38.96	0.02	0.44	0.00
5	3346000	0.05	1.16	0.00	0.00	0.03	0.10	0.00	10.94	0.26	0.30	0.39	0.00	56.80	27.22	0.08	2.66	0.00
5	3384450	0.11	0.06	0.00	0.00	0.04	0.00	0.00	47.72	16.55	15.46	0.31	0.00	5.78	13.80	0.00	0.17	0.00
6	3439000	0.11	2.21	0.01	0.00	0.01	0.10	0.00	44.90	19.83	29.96	0.00	0.00	0.74	2.13	0.00	0.00	0.00
6	3456500	0.05	3.58	0.00	0.00	0.05	0.00	0.00	61.06	11.11	20.94	0.00	0.00	0.73	2.35	0.00	0.14	0.00
6	3463300	0.06	1.10	0.00	0.00	0.01	0.00	0.00	37.15	27.87	33.29	0.00	0.00	0.17	0.37	0.00	0.00	0.00
6	3471500	0.00	1.45	0.10	0.00	0.13	0.00	0.00	68.13	11.19	3.26	0.00	0.00	0.67	14.98	0.03	0.06	0.00
6	3473000	0.00	0.91	0.05	0.00	0.11	0.00	0.02	57.24	15.18	10.62	0.00	0.00	0.96	14.85	0.01	0.05	0.00
6	3479000	0.16	2.09	0.00	0.00	0.09	0.08	0.00	54.02	13.97	16.62	0.00	0.00	3.63	9.32	0.00	0.03	0.00
6	3488000	0.18	0.20	0.13	0.08	0.61	0.05	0.00	58.39	4.65	11.47	0.00	0.00	2.02	22.13	0.05	0.03	0.00
6	3500000	0.09	0.65	0.03	0.02	0.08	0.13	0.00	63.93	8.69	16.86	0.00	0.00	2.51	6.94	0.00	0.09	0.00
6	3500240	0.00	1.48	0.21	0.00	0.07	0.13	0.04	75.51	4.39	9.38	0.00	0.00	2.24	6.49	0.00	0.08	0.00
6	3574500	0.06	0.24	0.00	0.00	1.38	0.01	0.00	78.36	1.72	7.08	0.00	0.00	5.59	5.13	0.02	0.40	0.00
7	5393500	1.71	0.13	0.00	0.00	1.69	0.00	0.00	49.38	6.57	11.94	0.10	0.00	3.97	8.30	1.65	14.57	0.00
7	5399500	0.10	1.39	0.00	0.00	0.13	0.00	0.00	15.42	0.63	2.18	0.53	0.00	36.27	41.58	0.11	1.65	0.00
7	5414000	0.00	0.57	0.00	0.00	0.00	0.02	0.00	14.79	0.02	0.05	0.07	0.00	12.97	71.35	0.10	0.06	0.00
7	5444000	0.01	1.55	0.00	0.00	0.01	0.08	0.02	4.50	0.07	0.08	0.05	0.00	73.94	19.46	0.00	0.23	0.00
7	5487980	0.42	2.52	0.00	0.00	0.00	0.02	0.00	17.11	0.00	0.28	8.25	0.00	26.33	41.34	0.32	3.41	0.00
7	5503800	0.18	1.86	0.00	0.00	0.00	0.00	0.00	15.98	0.00	0.32	4.55	0.00	42.00	30.86	0.80	3.46	0.00
7	5507600	0.18	1.15	0.00	0.00	0.00	0.00	0.02	8.02	0.16	0.50	2.64	0.00	51.66	35.08	0.13	0.46	0.00
7	5508805	0.28	1.04	0.00	0.00	0.04	0.01	0.03	24.39	0.08	0.92	4.08	0.00	37.05	31.46	0.06	0.56	0.00
7	5556500	0.08	1.95	0.00	0.00	0.00	0.03	0.00	5.29	0.03	0.09	0.09	0.02	80.37	11.28	0.04	0.74	0.00
7	5593575	0.41	2.32	0.00	0.00	0.01	0.04	0.03	6.03	0.09	0.30	0.29	0.00	36.37	51.67	0.03	2.42	0.00
7	5593900	0.11	3.22	0.00	0.00	0.01	0.00	0.20	5.57	0.09	0.55	0.48	0.00	52.47	36.10	0.00	1.20	0.00
7	5595730	0.30	0.81	0.00	0.00	0.04	0.01	0.00	20.29	0.36	0.05	1.38	0.00	22.29	50.02	0.05	4.40	0.00
8	7291000	0.65	0.06	0.57	0.00	2.01	0.09	0.34	23.82	36.39	19.13	0.00	0.00	4.12	10.59	0.00	2.24	0.00
8	7362100	0.30	0.25	0.00	0.00	5.12	0.16	0.01	15.81	47.45	20.80	0.00	0.00	1.22	2.26	0.07	6.57	0.00
8	7373000	0.42	1.06	1.07	0.00	1.39	1.29	0.00	16.36	54.40	16.09	0.00	0.00	1.65	2.60	0.00	3.66	0.00
8	7375000	0.69	0.00	0.00	0.00	2.58	0.00	0.00	7.21	27.35	24.37	0.00	0.00	3.34	32.90	0.05	1.51	0.00
10	6332515	0.14	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	72.08	15.06	12.09	0.52	0.07	0.01	0.00
10	6339100	0.56	0.25	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	50.64	8.84	37.68	1.88	0.00	0.00	0.00
10	6344600	0.44	0.28	0.00	0.00	0.00	0.29	0.00	0.01	0.00	0.00	18.50	4.29	73.23	2.91	0.05	0.00	0.00
10	6404000	0.08	1.20	0.54	0.00	0.14	0.00	5.03	1.13	80.59	0.00	8.25	0.08	0.00	2.86	0.10	0.00	0.00
10	6406000	0.06	0.64	0.32	0.00	0.21	0.00	1.90	1.49	51.32	0.00	35.96	0.03	0.71	7.30	0.04	0.00	0.00
10	6409000	0.03	0.21	2.44	0.00	0.13	0.00	0.00	6.42	75.04	0.35	12.41	0.05	0.03	2.07	0.70	0.13	0.00
10	6431500	0.01	0.31	1.49	0.00	0.25	0.74	0.00	6.43	73.70	0.03	13.90	0.01	0.30	1.20	1.46	0.19	0.00
10	6447500	0.50	0.12	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.00	48.00	0.00	29.40	16.87	5.04	0.00	0.00

10	6479438	0.95	0.42	0.00	0.00	0.00	0.03	0.00	0.77	0.02	0.00	6.42	0.00	56.86	31.01	3.52	0.02	0.00
10	6601000	0.26	0.90	0.00	0.00	0.00	0.00	0.00	2.62	0.00	0.04	4.31	0.00	63.36	28.26	0.23	0.01	0.00
10	6803510	0.21	1.76	0.00	0.00	0.00	0.00	0.02	1.94	0.00	0.00	17.51	0.00	48.45	27.69	2.42	0.00	0.00
10	6803530	0.04	0.45	0.00	0.00	0.00	0.00	0.00	1.22	0.00	0.04	9.89	0.00	71.47	14.45	2.42	0.02	0.00
10	6814000	0.23	0.49	0.00	0.00	0.00	0.00	0.00	4.27	0.00	0.16	29.01	0.00	44.55	20.80	0.13	0.37	0.00
10	6853800	0.48	0.06	0.00	0.00	0.00	0.00	0.04	6.04	0.23	0.00	39.54	0.00	49.98	3.59	0.04	0.00	0.00
10	6878000	0.46	0.20	0.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00	45.51	1.94	32.70	17.38	0.50	0.00	0.00
10	6888500	0.70	0.59	0.00	0.00	0.00	0.00	0.00	2.67	0.02	0.06	65.28	6.71	8.36	15.21	0.39	0.03	0.00
10	6889200	0.64	0.09	0.00	0.00	0.00	0.00	0.00	5.60	0.01	0.22	27.99	5.97	31.59	26.76	1.10	0.03	0.00
10	6889500	0.81	0.47	0.00	0.00	0.00	0.05	0.00	6.26	0.02	0.29	27.14	4.26	33.33	25.98	1.32	0.07	0.00
10	6910800	0.86	0.32	0.00	0.00	0.00	0.00	0.00	2.31	0.00	0.03	61.62	3.83	15.23	15.14	0.61	0.04	0.00
10	6911900	0.27	0.67	0.00	0.00	0.00	0.04	0.02	3.99	0.00	0.32	50.95	1.14	23.72	18.13	0.62	0.15	0.00
10	6917000	0.67	0.36	0.00	0.00	0.00	0.03	0.00	14.34	1.69	4.36	12.36	0.81	27.97	34.50	1.90	0.99	0.00
10	6918460	0.44	0.58	0.00	0.00	0.04	0.07	0.01	20.73	0.62	2.98	0.58	0.07	1.73	71.68	0.01	0.47	0.00
10	6921070	0.75	0.84	0.00	0.00	0.04	0.01	0.01	22.66	3.41	3.30	1.98	0.03	1.28	65.03	0.04	0.63	0.00
10	6921200	0.59	1.44	0.00	0.00	0.05	0.00	0.00	22.86	1.47	1.89	1.64	0.04	1.68	67.98	0.02	0.34	0.00
11	7060710	0.16	0.00	0.00	0.04	0.02	0.00	0.00	56.58	13.36	27.45	0.00	0.04	0.04	2.10	0.04	0.16	0.00
11	7145700	0.28	2.17	0.00	0.00	0.00	0.00	0.00	0.13	0.01	0.07	24.36	1.16	64.45	6.97	0.39	0.00	0.00
11	7167500	0.45	0.12	0.00	0.00	0.00	0.09	0.00	1.88	0.04	0.16	60.24	7.28	4.83	23.06	1.76	0.09	0.00
11	7180500	0.59	0.07	0.00	0.00	0.00	0.00	0.00	1.19	0.01	0.00	75.86	3.31	6.73	11.91	0.34	0.00	0.00
11	7184000	1.19	1.04	0.01	0.00	0.00	0.31	0.00	6.12	0.11	0.20	3.93	0.87	34.53	47.56	1.58	2.54	0.00
11	7195800	0.16	0.16	0.00	0.00	0.01	0.00	0.00	18.37	0.16	0.65	0.00	0.76	6.19	73.53	0.00	0.00	0.00
11	7196900	0.40	0.63	0.00	0.00	0.34	0.00	0.00	22.55	1.52	21.77	0.00	0.18	3.25	49.15	0.06	0.15	0.00
11	7197000	0.49	0.49	0.00	0.00	0.25	0.00	0.02	37.15	2.67	10.92	0.00	0.96	2.51	44.32	0.05	0.16	0.00
11	7208500	0.08	0.00	0.00	0.00	0.42	0.00	0.00	0.98	83.72	0.08	12.89	1.67	0.00	0.01	0.03	0.12	0.00
11	7261000	0.22	0.47	0.00	0.00	1.01	0.03	0.00	44.08	5.37	17.00	0.00	0.01	0.44	31.36	0.00	0.01	0.00
11	7299670	0.11	0.72	0.00	0.00	0.00	0.12	0.04	0.08	0.01	0.05	20.17	6.88	56.77	15.04	0.02	0.00	0.00
11	7301410	0.49	0.40	0.00	0.00	0.00	0.00	0.50	0.05	0.02	0.01	52.43	10.89	34.33	0.85	0.04	0.00	0.00
11	7315200	0.90	0.04	0.00	0.00	0.00	0.00	0.02	4.46	0.89	0.01	62.39	14.51	6.20	10.32	0.25	0.00	0.00
11	7340300	0.12	0.02	1.00	0.00	1.73	0.00	0.00	66.96	5.61	23.50	0.00	0.00	0.00	1.06	0.00	0.00	0.00
12	8023080	0.33	0.97	0.00	0.00	3.82	0.04	0.06	25.30	15.52	27.03	0.00	0.00	2.21	16.57	0.38	7.77	0.00
12	8066200	0.19	2.40	0.00	0.00	4.26	0.44	0.11	14.71	21.84	37.62	0.00	0.00	0.34	17.56	0.50	0.03	0.00
12	8066300	0.17	1.56	0.00	0.00	4.53	0.00	0.12	9.24	23.57	49.16	0.00	0.00	0.10	9.82	0.14	1.58	0.00
12	8070000	0.39	1.41	0.00	0.00	2.95	0.01	0.10	11.33	23.03	38.14	0.00	0.00	0.97	19.78	0.70	1.18	0.00
12	8082700	0.45	0.00	0.00	0.00	0.00	0.00	0.15	0.09	0.11	0.00	24.49	6.67	50.90	16.92	0.20	0.00	0.00
12	8086290	0.85	0.96	0.00	0.00	0.00	0.16	0.13	5.49	4.64	0.15	45.77	31.87	5.48	4.50	0.00	0.00	0.00
12	8103900	0.00	0.00	0.00	0.00	0.00	0.00	0.51	3.30	27.88	0.00	24.70	42.98	0.56	0.07	0.00	0.00	0.00
12	8104900	0.38	2.15	0.01	0.00	0.00	0.35	0.68	9.43	37.17	0.00	27.40	18.42	2.85	1.10	0.07	0.00	0.00
12	8109700	0.75	0.31	0.00	0.00	0.28	0.23	0.60	39.64	5.26	0.01	11.70	8.45	4.13	28.34	0.28	0.00	0.00
12	8150800	0.14	0.02	0.00	0.00	0.00	0.01	0.40	2.33	39.68	0.00	13.27	39.31	2.32	2.52	0.00	0.00	0.00
12	8158700	0.23	0.61	0.01	0.00	0.00	0.04	0.34	6.44	47.46	0.00	35.06	7.08	1.58	1.16	0.00	0.00	0.00
12	8158810	0.18	5.70	0.00	0.00	0.00	0.00	0.18	9.68	41.93	0.00	25.87	14.97	0.55	0.92	0.00	0.00	0.00
12	8164300	0.23	0.94	0.01	0.00	0.02	0.21	0.07	14.02	5.67	0.04	33.87	16.12	5.19	22.89	0.64	0.07	0.00
12	8164600	0.38	1.07	0.00	0.00	0.38	0.06	0.35	14.64	11.01	1.50	18.01	38.54	2.24	9.58	2.21	0.03	0.00
12	8165300	0.31	0.14	0.02	0.00	0.00	0.00	0.33	1.08	45.44	0.00	18.30	32.52	0.07	1.79	0.00	0.00	0.00
12	8196000	0.11	0.00	0.34	0.00	0.00	0.00	0.58	0.60	78.30	0.00	6.66	11.77	0.78	0.84	0.02	0.00	0.00
12	8198500	0.14	0.35	0.32	0.00	0.00	0.02	0.74	2.02	59.38	0.00	7.66	15.73	8.80	4.80	0.02	0.00	0.00
12	8200000	0.13	0.00	0.34	0.00	0.00	0.00	1.14	5.30	57.55	0.00	14.61	17.47	2.36	1.10	0.00	0.00	0.00
12	8202700	0.00	0.03	0.41	0.00	0.00	0.00	0.53	2.02	70.77	0.00	5.81	11.87	6.39	2.16	0.00	0.00	0.00
13	8269000	0.00	0.00	0.00	0.00	0.28	0.03	0.12	0.23	95.53	0.04	1.61	2.16	0.00	0.00	0.00	0.01	0.00
13	8380500	0.00	0.00	0.01	0.00	0.35	0.00	0.09	1.31	94.73	0.02	2.60	0.88	0.00	0.00	0.00	0.00	0.00
14	9035900	0.00	0.00	0.14	0.00	0.00	0.07	0.18	3.50	53.89	0.00	7.09	33.12	0.00	0.00	0.00	0.00	2.01
14	9047700	0.00	0.00	0.67	0.00	0.00	0.00	0.00	1.52	78.52	0.00	2.79	15.74	0.00	0.00	0.00	0.00	0.76
14	9210500	0.06	0.00	0.15	0.05	0.02	0.00	0.20	1.29	25.69	0.54	23.02	47.75	0.00	0.00	0.62	0.62	0.00
14	9223000	0.14	0.00	0.44	0.04	0.15	0.00	0.04	2.77	48.48	1.44	19.55	23.77	0.00	0.00	1.12	2.03	0.04
14	9306242	0.00	0.18	0.00	0.00	0.00	0.00	0.43	7.58	37.36	3.07	18.73	32.65	0.00	0.00	0.00	0.00	0.00
14	9312600	0.00	0.09	0.06	0.00	0.27	0.00	0.09	18.33	39.01	10.61	4.01	27.48	0.00	0.02	0.03	0.00	0.00

15	9386900	0.16	0.00	0.53	0.00	0.58	0.03	0.00	0.00	82.30	1.73	4.14	10.51	0.00	0.00	0.02	0.00	0.00
15	9404450	0.10	0.06	0.00	0.00	0.00	0.00	0.38	9.22	55.33	3.06	8.33	23.48	0.00	0.03	0.00	0.00	0.00
15	9430600	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	86.41	6.23	2.75	4.41	0.00	0.00	0.00	0.00	0.00
15	9497980	0.01	0.13	0.15	0.00	0.00	0.01	0.20	0.00	79.12	0.23	2.01	18.04	0.00	0.07	0.00	0.03	0.00
15	9505350	0.02	1.38	0.22	0.00	0.00	0.00	0.00	0.00	80.20	2.40	1.57	14.20	0.00	0.00	0.01	0.00	0.00
15	9505800	0.01	0.01	0.49	0.00	0.00	0.00	0.00	1.34	86.05	0.69	2.13	9.27	0.00	0.00	0.00	0.00	0.00
15	9510200	0.10	0.00	0.19	0.00	0.00	0.00	1.27	0.19	27.08	0.09	3.73	67.32	0.01	0.00	0.00	0.01	0.00
16	10172700	0.00	0.21	0.00	0.00	0.00	0.00	0.24	13.73	43.21	0.05	8.00	34.45	0.00	0.05	0.02	0.02	0.00
16	10172800	0.00	0.25	0.00	0.00	0.00	0.00	1.23	13.88	49.70	1.31	6.96	26.10	0.08	0.16	0.16	0.00	0.16
16	10205030	0.04	0.00	0.23	0.00	0.00	0.00	0.95	16.23	44.69	0.12	14.36	23.21	0.00	0.12	0.00	0.00	0.04
16	10249300	0.00	0.05	0.00	0.00	0.00	1.14	2.61	0.02	14.87	0.07	0.64	80.07	0.00	0.45	0.08	0.00	0.00
16	10329500	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.21	4.51	0.00	2.59	92.43	0.00	0.06	0.00	0.00	0.02
16	10336660	3.30	0.39	0.31	0.00	0.22	0.00	0.00	0.00	80.45	4.47	2.52	8.35	0.00	0.00	0.00	0.00	0.00
16	10343500	0.00	0.00	1.41	0.00	0.07	0.00	0.00	0.00	82.29	3.51	4.09	8.64	0.00	0.00	0.00	0.00	0.00
17	10396000	0.29	0.05	0.00	0.00	0.00	0.00	1.66	0.04	15.96	0.02	3.74	76.30	0.00	1.38	0.51	0.01	0.05
17	12082500	0.91	0.07	0.27	0.68	0.25	0.00	5.61	6.48	73.86	3.46	1.32	2.06	0.02	0.00	0.00	0.14	4.88
17	12115000	0.44	0.15	0.00	0.00	0.16	0.00	1.16	5.41	88.02	0.96	2.53	1.12	0.00	0.00	0.00	0.06	0.00
17	12390700	0.04	0.04	1.23	0.03	0.15	0.00	0.23	0.12	91.48	0.06	3.54	2.95	0.00	0.04	0.01	0.07	0.01
17	12411000	0.18	0.03	1.38	0.00	0.00	0.00	0.13	0.02	91.36	2.44	1.13	3.30	0.00	0.00	0.00	0.01	0.00
17	13018300	0.00	0.00	0.06	0.00	0.00	0.00	2.55	2.13	53.56	2.34	16.60	22.55	0.00	0.00	0.00	0.21	0.00
17	13083000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.13	6.11	0.00	10.46	82.05	0.03	0.10	0.00	0.11	0.00
17	13161500	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.54	1.84	0.02	18.19	76.37	0.02	1.84	0.06	0.11	0.00
17	14141500	0.69	0.00	0.49	0.18	0.23	0.00	0.00	12.92	79.04	5.67	0.13	0.03	0.18	0.45	0.00	0.00	0.00
17	14154500	0.01	0.00	1.27	0.39	1.28	0.00	0.01	2.06	84.92	6.59	2.39	0.78	0.00	0.28	0.02	0.00	0.00
17	14185000	0.03	0.00	0.56	0.00	1.39	0.00	0.05	2.36	85.87	5.47	2.33	1.92	0.00	0.01	0.01	0.00	0.00
17	14316700	0.00	0.00	1.29	0.29	0.25	0.01	0.03	1.33	88.27	5.97	1.77	0.78	0.00	0.00	0.01	0.00	0.00
18	11141280	0.00	0.00	0.00	0.00	0.00	0.00	1.33	1.33	31.07	14.57	15.91	35.69	0.09	0.00	0.00	0.00	0.00
18	11151300	0.03	0.00	0.00	0.01	0.01	5.40	1.12	11.67	3.57	44.06	22.81	2.42	8.91	0.00	0.00	0.00	0.00
18	11162500	0.05	0.42	0.00	0.03	1.13	0.01	0.10	1.51	80.53	4.86	6.53	4.67	0.09	0.07	0.00	0.00	0.00
18	11180500	0.00	15.41	0.00	0.00	0.00	0.51	0.23	3.45	12.53	10.90	52.23	4.07	0.54	0.00	0.00	0.12	0.00
18	11224500	0.00	0.13	0.00	0.00	0.00	0.10	8.34	0.48	19.55	7.65	33.01	30.64	0.11	0.00	0.00	0.00	0.00
18	11253310	0.00	0.03	0.00	0.01	0.00	0.03	17.79	0.13	11.16	2.49	42.55	25.13	0.12	0.55	0.00	0.00	0.00
18	11274500	0.04	0.01	0.00	0.00	0.01	0.02	0.00	9.60	10.36	4.24	56.72	18.06	0.81	0.12	0.01	0.00	0.00
18	11274630	0.02	0.09	0.00	0.00	0.03	0.10	0.01	9.11	10.59	3.24	59.50	16.45	0.86	0.02	0.00	0.00	0.00
18	11284400	0.00	0.60	1.33	0.08	0.77	0.00	0.00	2.50	69.23	8.70	4.95	11.84	0.00	0.00	0.00	0.00	0.00
18	11383500	0.07	0.00	0.26	0.00	0.47	0.00	0.15	2.93	46.77	19.99	19.25	9.85	0.00	0.27	0.00	0.00	0.00
18	11468500	0.00	0.01	0.00	0.81	4.90	0.00	0.03	2.42	72.57	10.07	4.68	3.74	0.58	0.19	0.00	0.00	0.00
18	11481200	0.00	0.00	0.00	0.00	9.05	0.00	0.11	2.40	55.45	16.08	11.03	5.05	0.62	0.21	0.00	0.00	0.00
18	11482500	0.11	0.09	0.02	0.02	1.50	0.00	0.11	6.32	65.23	16.20	7.08	3.08	0.01	0.23	0.01	0.00	0.00

In Appendix D, human-impacted lands include water, developed, mechanically disturbed other public lands, mechanically disturbed private, mining and barren lands.

Forests lands include deciduous forest, evergreen forest, mixed forest lands.

Wetlands include herbaceous wetland and woody wetland.

Appendix D Percentages of main land uses coverage on 200 watersheds

Area	code	human-impacted land %	Deciduous Forest %	Evergreen Forest %	Mixed Forest %	forest %	Grassland %	Shrubland %	Cropland %	Hay/Pasture Land %	wetland %
1	1022500	6.31	21.09	26.71	33.09	80.90	0.00	3.80	0.21	0.07	8.73
1	1031500	5.62	32.37	23.14	32.82	88.33	0.00	0.49	2.23	0.46	2.86
1	1047000	2.71	42.49	26.55	21.95	90.98	0.00	0.19	2.52	0.24	3.35
1	1052500	2.19	44.00	20.99	29.18	94.17	0.00	0.30	0.03	0.01	3.30
1	1055000	1.92	40.58	37.50	14.80	92.88	0.00	0.48	0.95	0.05	3.72
1	1057000	2.78	43.89	17.35	23.41	84.64	0.00	0.06	6.85	1.97	3.70
1	1078000	2.47	30.47	23.81	30.71	85.00	0.00	0.00	6.52	0.86	5.15
1	1134500	1.56	50.17	14.55	25.54	90.27	0.00	1.31	0.45	0.04	6.37
1	1139000	3.08	39.56	13.69	30.34	83.60	0.00	1.01	7.01	1.75	3.56
1	1142500	2.30	36.78	10.40	25.47	72.65	0.00	0.00	14.29	6.55	4.22
1	1169000	3.15	41.97	16.55	25.82	84.34	0.00	0.10	5.90	1.64	4.87
1	1170100	1.20	46.63	15.00	28.32	89.95	0.00	0.03	5.75	0.76	2.30
1	1181000	4.56	57.31	7.92	23.94	89.16	0.00	0.00	2.14	0.59	3.55
2	1333000	6.03	68.45	2.61	6.65	77.71	0.00	0.00	6.81	7.94	1.51
2	1439500	3.36	77.22	2.12	7.41	86.75	0.00	0.00	0.11	0.32	9.46
2	1451800	1.92	29.16	1.93	2.82	33.91	0.00	0.00	14.79	48.88	0.50
2	1485500	3.80	10.44	38.22	8.54	57.20	0.00	0.00	16.16	3.04	19.81
2	1491000	2.13	19.33	3.68	5.94	28.95	0.00	0.00	39.66	10.48	18.77
2	1550000	2.07	70.50	6.92	6.02	83.44	0.00	0.00	1.28	13.11	0.10
2	1552500	2.88	71.60	6.12	13.53	91.25	0.00	0.00	2.69	2.98	0.20
2	1580000	1.66	31.06	1.79	2.12	34.97	0.00	0.00	11.37	51.50	0.50
2	1583500	2.10	31.39	1.75	4.20	37.34	0.00	0.00	11.28	48.74	0.53
2	1634500	0.60	76.06	1.66	11.86	89.68	0.00	0.00	0.51	9.26	0.05
2	1638480	0.93	14.79	1.16	16.35	32.30	0.00	0.00	4.32	61.79	0.66
2	1669000	3.58	29.39	10.97	27.11	67.47	0.00	0.00	15.29	9.02	4.65
2	2027000	0.70	69.12	3.56	12.88	85.56	0.00	0.00	0.89	12.80	0.05
3	2046000	3.10	41.40	13.30	23.46	78.16	0.00	0.00	5.03	13.34	0.37
3	2059500	2.39	49.52	6.57	12.19	68.29	0.00	0.00	1.33	27.80	0.18
3	2064000	3.90	41.59	11.84	15.24	68.68	0.00	0.00	3.29	23.59	0.54
3	2065500	2.72	44.98	11.28	15.54	71.80	0.00	0.00	2.19	20.08	3.21
3	2082950	3.85	29.28	38.63	9.80	77.71	0.00	0.00	6.06	7.44	4.94
3	2118500	2.80	40.49	12.56	13.20	66.25	0.00	0.00	7.86	22.95	0.15
3	2177000	0.87	22.15	38.34	36.62	97.16	0.00	0.00	0.44	1.55	0.04
3	2212600	1.40	35.03	45.05	14.59	94.88	0.00	0.00	1.52	1.65	0.76
3	2221525	3.20	34.66	28.90	12.76	76.35	0.00	0.00	7.08	12.63	0.78
3	2245500	8.10	0.00	63.08	0.02	63.10	12.31	1.27	1.19	0.24	13.79
3	2297155	6.17	0.00	8.35	0.91	9.25	43.50	0.27	10.24	6.38	24.18
3	2298608	4.42	0.00	7.99	0.51	8.50	40.97	0.23	14.21	7.67	24.00
3	2299950	5.47	0.00	10.71	0.60	11.31	43.31	0.08	10.90	4.26	24.67
3	2349900	1.49	12.38	6.30	3.93	22.61	0.00	0.00	44.69	19.66	11.55
3	2472500	4.34	16.08	32.43	15.90	64.41	0.00	0.00	6.74	24.38	0.12
3	2479155	2.39	1.79	52.87	22.98	77.82	0.00	0.00	0.60	2.28	17.09
3	2481000	3.98	2.03	47.55	22.50	72.37	0.00	0.00	2.59	8.09	13.25
3	2481510	5.06	3.88	41.13	23.01	68.02	0.00	0.00	3.81	13.97	9.14
4	4015330	4.03	41.80	9.45	18.44	69.69	0.08	0.00	5.46	5.20	15.54
4	4040500	4.74	33.97	13.78	11.82	59.57	0.42	0.00	0.71	0.49	34.07
4	4057510	4.96	19.91	18.96	9.19	49.27	1.24	0.00	0.38	0.13	45.23
4	4063700	2.02	38.71	6.72	10.79	56.65	0.72	0.00	2.94	0.89	37.19
4	4127997	4.01	50.69	7.97	4.85	63.51	9.56	0.00	6.81	3.25	12.87
4	4161580	6.06	31.92	2.22	0.00	34.14	0.00	0.00	26.62	17.63	15.54
4	4196800	0.59	7.46	0.00	0.00	7.46	0.10	0.00	78.80	12.30	0.76
4	4197100	0.91	9.15	0.00	0.01	9.16	0.00	0.00	69.45	19.56	0.92
4	4213000	2.48	47.08	2.89	4.58	54.55	0.00	0.00	13.91	26.17	2.88

4	4216418	2.38	18.61	1.30	31.92	51.83	0.00	0.00	6.08	39.34	0.37
4	4221000	1.32	56.92	0.83	10.87	68.62	0.00	0.00	4.43	25.58	0.05
4	4224775	1.12	28.68	1.92	37.51	68.10	0.00	0.00	5.93	24.69	0.16
4	4256000	1.92	64.10	6.16	7.12	77.38	0.00	0.00	0.15	0.53	20.02
5	3010655	1.80	69.81	3.73	9.94	83.48	0.00	0.00	1.29	13.42	0.01
5	3011800	3.21	75.16	4.52	14.43	94.34	0.00	0.00	0.57	1.47	0.63
5	3028000	3.11	70.12	6.36	12.50	89.07	0.00	0.00	0.89	6.92	0.11
5	3049000	3.00	61.26	1.37	3.40	66.03	0.00	0.00	6.51	24.46	0.00
5	3070500	1.45	67.30	4.19	6.25	77.75	0.00	0.00	2.21	17.96	0.63
5	3161000	3.50	42.45	16.27	19.84	78.56	0.00	0.00	3.27	14.61	0.07
5	3165000	7.52	30.48	10.38	13.36	54.21	0.00	0.00	2.65	35.50	0.11
5	3170000	0.66	38.71	9.55	14.65	62.91	0.00	0.00	4.75	31.55	0.13
5	3186500	0.36	47.30	20.90	29.06	97.33	0.00	0.00	0.78	1.39	0.21
5	3241500	1.47	5.84	0.00	0.00	5.84	0.00	0.00	79.74	12.73	0.22
5	3285000	2.37	28.91	5.11	14.25	48.26	0.00	0.00	9.95	38.96	0.46
5	3346000	1.34	10.94	0.26	0.30	11.51	0.39	0.00	56.80	27.22	2.74
5	3384450	0.21	47.72	16.55	15.46	79.73	0.31	0.00	5.78	13.80	0.17
6	3439000	2.44	44.90	19.83	29.96	94.69	0.00	0.00	0.74	2.13	0.00
6	3456500	3.68	61.06	11.11	20.94	93.10	0.00	0.00	0.73	2.35	0.14
6	3463300	1.16	37.15	27.87	33.29	98.31	0.00	0.00	0.17	0.37	0.00
6	3471500	1.68	68.13	11.19	3.26	82.68	0.00	0.00	0.67	14.98	0.09
6	3473000	1.09	57.24	15.18	10.62	83.10	0.00	0.00	0.96	14.85	0.06
6	3479000	2.41	54.02	13.97	16.62	84.61	0.00	0.00	3.63	9.32	0.03
6	3488000	1.25	58.39	4.65	11.47	74.63	0.00	0.00	2.02	22.13	0.09
6	3500000	1.00	63.93	8.69	16.86	89.50	0.00	0.00	2.51	6.94	0.09
6	3500240	1.92	75.51	4.39	9.38	89.48	0.00	0.00	2.24	6.49	0.08
6	3574500	1.69	78.36	1.72	7.08	87.17	0.00	0.00	5.59	5.13	0.42
7	5393500	3.52	49.38	6.57	11.94	67.89	0.10	0.00	3.97	8.30	16.21
7	5399500	1.63	15.42	0.63	2.18	18.23	0.53	0.00	36.27	41.58	1.75
7	5414000	0.58	14.79	0.02	0.05	14.86	0.07	0.00	12.97	71.35	0.16
7	5444000	1.68	4.50	0.07	0.08	4.65	0.05	0.00	73.94	19.46	0.23
7	5487980	2.96	17.11	0.00	0.28	17.40	8.25	0.00	26.33	41.34	3.72
7	5503800	2.04	15.98	0.00	0.32	16.30	4.55	0.00	42.00	30.86	4.26
7	5507600	1.36	8.02	0.16	0.50	8.67	2.64	0.00	51.66	35.08	0.59
7	5508805	1.41	24.39	0.08	0.92	25.39	4.08	0.00	37.05	31.46	0.62
7	5556500	2.05	5.29	0.03	0.09	5.41	0.09	0.02	80.37	11.28	0.77
7	5593575	2.80	6.03	0.09	0.30	6.42	0.29	0.00	36.37	51.67	2.45
7	5593900	3.54	5.57	0.09	0.55	6.21	0.48	0.00	52.47	36.10	1.20
7	5595730	1.15	20.29	0.36	0.05	20.70	1.38	0.00	22.29	50.02	4.45
8	7291000	3.71	23.82	36.39	19.13	79.92	0.00	0.00	4.12	10.59	2.24
8	7362100	5.83	15.81	47.45	20.80	84.05	0.00	0.00	1.22	2.26	6.63
8	7373000	5.23	16.36	54.40	16.09	87.93	0.00	0.00	1.65	2.60	3.66
8	7375000	3.27	7.21	27.35	24.37	58.93	0.00	0.00	3.34	32.90	1.56
10	6332515	0.18	0.00	0.00	0.00	0.00	72.08	15.06	12.09	0.52	0.08
10	6339100	0.96	0.00	0.00	0.00	0.00	50.64	8.84	37.68	1.88	0.00
10	6344600	1.01	0.01	0.00	0.00	0.02	18.50	4.29	73.23	2.91	0.05
10	6404000	7.00	1.13	80.59	0.00	82.26	8.25	0.08	0.00	2.86	0.10
10	6406000	3.14	1.49	51.32	0.00	53.14	35.96	0.03	0.71	7.30	0.05
10	6409000	2.81	6.42	75.04	0.35	84.25	12.41	0.05	0.03	2.07	0.83
10	6431500	2.79	6.43	73.70	0.03	81.65	13.90	0.01	0.30	1.20	1.64
10	6447500	0.66	0.03	0.00	0.00	0.03	48.00	0.00	29.40	16.87	5.04
10	6479438	1.40	0.77	0.02	0.00	0.78	6.42	0.00	56.86	31.01	3.53
10	6601000	1.16	2.62	0.00	0.04	2.66	4.31	0.00	63.36	28.26	0.25
10	6803510	1.99	1.94	0.00	0.00	1.94	17.51	0.00	48.45	27.69	2.42
10	6803530	0.49	1.22	0.00	0.04	1.26	9.89	0.00	71.47	14.45	2.44
10	6814000	0.72	4.27	0.00	0.16	4.43	29.01	0.00	44.55	20.80	0.50
10	6853800	0.59	6.04	0.23	0.00	6.27	39.54	0.00	49.98	3.59	0.04
10	6878000	0.66	1.31	0.00	0.00	1.31	45.51	1.94	32.70	17.38	0.50
10	6888500	1.28	2.67	0.02	0.06	2.74	65.28	6.71	8.36	15.21	0.42
10	6889200	0.74	5.60	0.01	0.22	5.83	27.99	5.97	31.59	26.76	1.13

10	6889500	1.33	6.26	0.02	0.29	6.56	27.14	4.26	33.33	25.98	1.40
10	6910800	1.19	2.31	0.00	0.03	2.34	61.62	3.83	15.23	15.14	0.65
10	6911900	1.00	3.99	0.00	0.32	4.30	50.95	1.14	23.72	18.13	0.77
10	6917000	1.07	14.34	1.69	4.36	20.40	12.36	0.81	27.97	34.50	2.90
10	6918460	1.14	20.73	0.62	2.98	24.33	0.58	0.07	1.73	71.68	0.48
10	6921070	1.65	22.66	3.41	3.30	29.37	1.98	0.03	1.28	65.03	0.67
10	6921200	2.08	22.86	1.47	1.89	26.22	1.64	0.04	1.68	67.98	0.36
11	7060710	0.22	56.58	13.36	27.45	97.39	0.00	0.04	0.04	2.10	0.21
11	7145700	2.45	0.13	0.01	0.07	0.21	24.36	1.16	64.45	6.97	0.39
11	7167500	0.66	1.88	0.04	0.16	2.08	60.24	7.28	4.83	23.06	1.85
11	7180500	0.66	1.19	0.01	0.00	1.19	75.86	3.31	6.73	11.91	0.34
11	7184000	2.55	6.12	0.11	0.20	6.45	3.93	0.87	34.53	47.56	4.11
11	7195800	0.34	18.37	0.16	0.65	19.18	0.00	0.76	6.19	73.53	0.00
11	7196900	1.37	22.55	1.52	21.77	45.84	0.00	0.18	3.25	49.15	0.21
11	7197000	1.25	37.15	2.67	10.92	50.74	0.00	0.96	2.51	44.32	0.22
11	7208500	0.50	0.98	83.72	0.08	84.78	12.89	1.67	0.00	0.01	0.15
11	7261000	1.73	44.08	5.37	17.00	66.45	0.00	0.01	0.44	31.36	0.01
11	7299670	0.99	0.08	0.01	0.05	0.14	20.17	6.88	56.77	15.04	0.02
11	7301410	1.39	0.05	0.02	0.01	0.08	52.43	10.89	34.33	0.85	0.04
11	7315200	0.96	4.46	0.89	0.01	5.37	62.39	14.51	6.20	10.32	0.25
11	7340300	2.88	66.96	5.61	23.50	97.06	0.00	0.00	0.00	1.06	0.00
12	8023080	5.22	25.30	15.52	27.03	67.85	0.00	0.00	2.21	16.57	8.15
12	8066200	7.40	14.71	21.84	37.62	74.17	0.00	0.00	0.34	17.56	0.53
12	8066300	6.38	9.24	23.57	49.16	81.98	0.00	0.00	0.10	9.82	1.72
12	8070000	4.86	11.33	23.03	38.14	72.51	0.00	0.00	0.97	19.78	1.88
12	8082700	0.60	0.09	0.11	0.00	0.20	24.49	6.67	50.90	16.92	0.20
12	8086290	2.10	5.49	4.64	0.15	10.28	45.77	31.87	5.48	4.50	0.00
12	8103900	0.51	3.30	27.88	0.00	31.18	24.70	42.98	0.56	0.07	0.00
12	8104900	3.57	9.43	37.17	0.00	46.61	27.40	18.42	2.85	1.10	0.07
12	8109700	2.17	39.64	5.26	0.01	44.92	11.70	8.45	4.13	28.34	0.28
12	8150800	0.58	2.33	39.68	0.00	42.01	13.27	39.31	2.32	2.52	0.00
12	8158700	1.23	6.44	47.46	0.00	53.91	35.06	7.08	1.58	1.16	0.00
12	8158810	6.07	9.68	41.93	0.00	51.61	25.87	14.97	0.55	0.92	0.00
12	8164300	1.48	14.02	5.67	0.04	19.74	33.87	16.12	5.19	22.89	0.71
12	8164600	2.23	14.64	11.01	1.50	27.16	18.01	38.54	2.24	9.58	2.24
12	8165300	0.80	1.08	45.44	0.00	46.54	18.30	32.52	0.07	1.79	0.00
12	8196000	1.03	0.60	78.30	0.00	79.25	6.66	11.77	0.78	0.84	0.02
12	8198500	1.57	2.02	59.38	0.00	61.73	7.66	15.73	8.80	4.80	0.02
12	8200000	1.61	5.30	57.55	0.00	63.20	14.61	17.47	2.36	1.10	0.00
12	8202700	0.97	2.02	70.77	0.00	73.21	5.81	11.87	6.39	2.16	0.00
13	8269000	0.42	0.23	95.53	0.04	95.80	1.61	2.16	0.00	0.00	0.01
13	8380500	0.46	1.31	94.73	0.02	96.08	2.60	0.88	0.00	0.00	0.00
14	9035900	0.38	3.50	53.89	0.00	57.53	7.09	33.12	0.00	0.00	0.00
14	9047700	0.67	1.52	78.52	0.00	80.71	2.79	15.74	0.00	0.00	0.00
14	9210500	0.47	1.29	25.69	0.54	27.67	23.02	47.75	0.00	0.00	1.24
14	9223000	0.81	2.77	48.48	1.44	53.14	19.55	23.77	0.00	0.00	3.15
14	9306242	0.61	7.58	37.36	3.07	48.01	18.73	32.65	0.00	0.00	0.00
14	9312600	0.52	18.33	39.01	10.61	68.01	4.01	27.48	0.00	0.02	0.03
15	9386900	1.30	0.00	82.30	1.73	84.56	4.14	10.51	0.00	0.00	0.02
15	9404450	0.54	9.22	55.33	3.06	67.61	8.33	23.48	0.00	0.03	0.00
15	9430600	0.20	0.00	86.41	6.23	92.64	2.75	4.41	0.00	0.00	0.00
15	9497980	0.50	0.00	79.12	0.23	79.50	2.01	18.04	0.00	0.07	0.03
15	9505350	1.61	0.00	80.20	2.40	82.82	1.57	14.20	0.00	0.00	0.01
15	9505800	0.52	1.34	86.05	0.69	88.57	2.13	9.27	0.00	0.00	0.00
15	9510200	1.56	0.19	27.08	0.09	27.56	3.73	67.32	0.01	0.00	0.01
16	10172700	0.45	13.73	43.21	0.05	56.99	8.00	34.45	0.00	0.05	0.05
16	10172800	1.47	13.88	49.70	1.31	64.89	6.96	26.10	0.08	0.16	0.16
16	10205030	1.22	16.23	44.69	0.12	61.27	14.36	23.21	0.00	0.12	0.00
16	10249300	3.80	0.02	14.87	0.07	14.97	0.64	80.07	0.00	0.45	0.08
16	10329500	0.17	0.21	4.51	0.00	4.72	2.59	92.43	0.00	0.06	0.00

16	10336660	4.21	0.00	80.45	4.47	85.23	2.52	8.35	0.00	0.00	0.00
16	10343500	1.47	0.00	82.29	3.51	87.20	4.09	8.64	0.00	0.00	0.00
17	10396000	1.99	0.04	15.96	0.02	16.02	3.74	76.30	0.00	1.38	0.52
17	12082500	7.79	6.48	73.86	3.46	84.07	1.32	2.06	0.02	0.00	0.14
17	12115000	1.91	5.41	88.02	0.96	94.38	2.53	1.12	0.00	0.00	0.06
17	12390700	1.71	0.12	91.48	0.06	92.88	3.54	2.95	0.00	0.04	0.09
17	12411000	1.73	0.02	91.36	2.44	95.20	1.13	3.30	0.00	0.00	0.01
17	13018300	2.61	2.13	53.56	2.34	58.09	16.60	22.55	0.00	0.00	0.21
17	13083000	0.00	1.13	6.11	0.00	7.24	10.46	82.05	0.03	0.10	0.11
17	13161500	0.02	1.54	1.84	0.02	3.40	18.19	76.37	0.02	1.84	0.16
17	14141500	1.59	12.92	79.04	5.67	98.11	0.13	0.03	0.18	0.45	0.00
17	14154500	2.96	2.06	84.92	6.59	94.84	2.39	0.78	0.00	0.28	0.02
17	14185000	2.03	2.36	85.87	5.47	94.26	2.33	1.92	0.00	0.01	0.01
17	14316700	1.87	1.33	88.27	5.97	96.86	1.77	0.78	0.00	0.00	0.01
18	11141280	1.33	1.33	31.07	14.57	46.97	15.91	35.69	0.09	0.00	0.00
18	11151300	6.57	11.67	3.57	44.06	59.30	22.81	2.42	8.91	0.00	0.00
18	11162500	1.74	1.51	80.53	4.86	86.90	6.53	4.67	0.09	0.07	0.00
18	11180500	16.15	3.45	12.53	10.90	26.89	52.23	4.07	0.54	0.00	0.12
18	11224500	8.56	0.48	19.55	7.65	27.67	33.01	30.64	0.11	0.00	0.00
18	11253310	17.86	0.13	11.16	2.49	13.79	42.55	25.13	0.12	0.55	0.00
18	11274500	0.07	9.60	10.36	4.24	24.21	56.72	18.06	0.81	0.12	0.01
18	11274630	0.24	9.11	10.59	3.24	22.94	59.50	16.45	0.86	0.02	0.00
18	11284400	2.78	2.50	69.23	8.70	81.76	4.95	11.84	0.00	0.00	0.00
18	11383500	0.95	2.93	46.77	19.99	69.94	19.25	9.85	0.00	0.27	0.00
18	11468500	5.75	2.42	72.57	10.07	85.06	4.68	3.74	0.58	0.19	0.00
18	11481200	9.16	2.40	55.45	16.08	73.92	11.03	5.05	0.62	0.21	0.00
18	11482500	1.84	6.32	65.23	16.20	87.77	7.08	3.08	0.01	0.23	0.01

Appendix E Some pictures and figures for the data

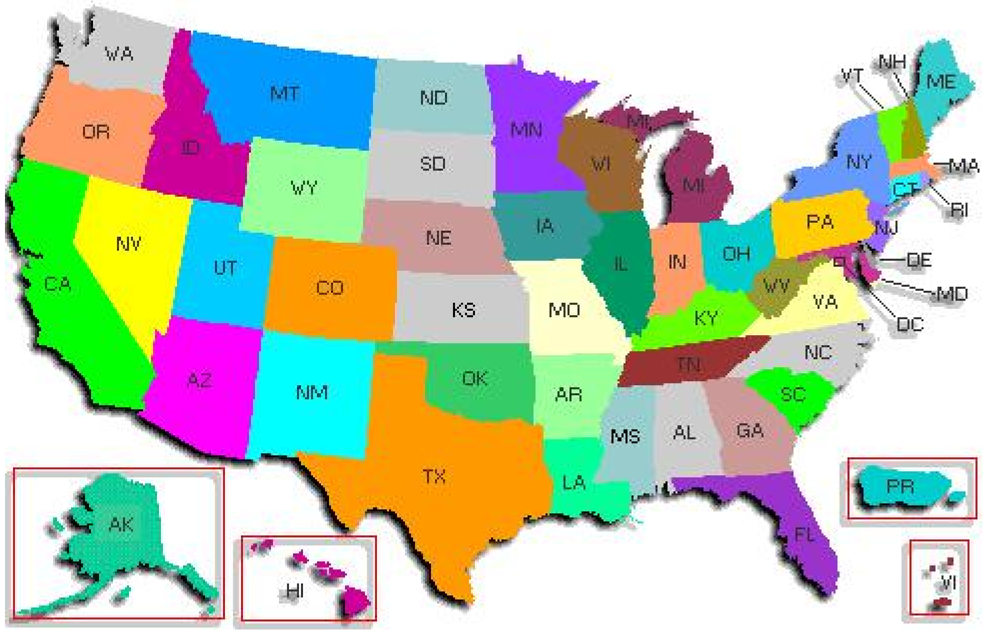

Figure E.1 The United States map from Google

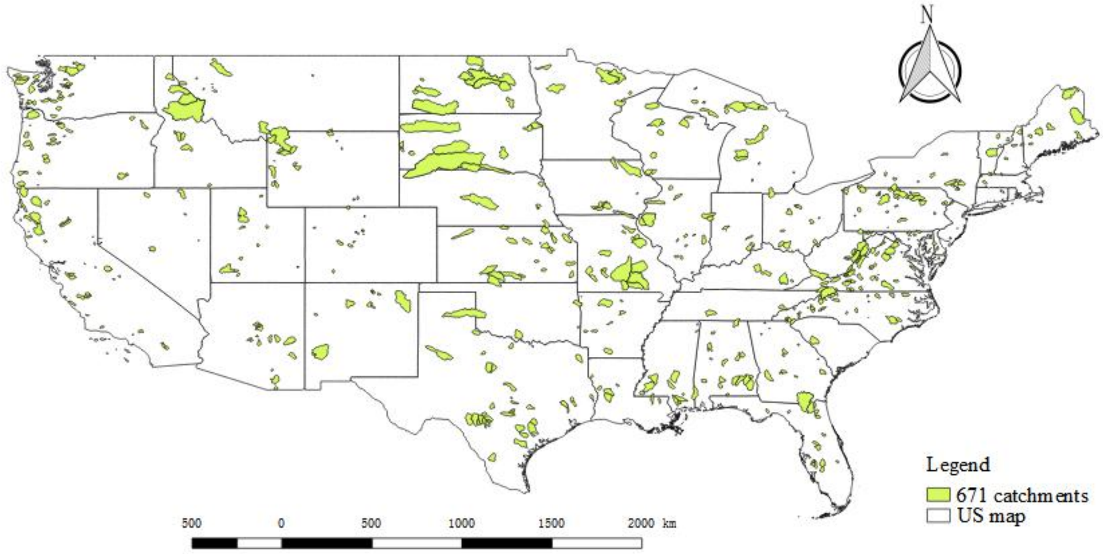

Figure E.2 671 catchments in CAMEL by Newman

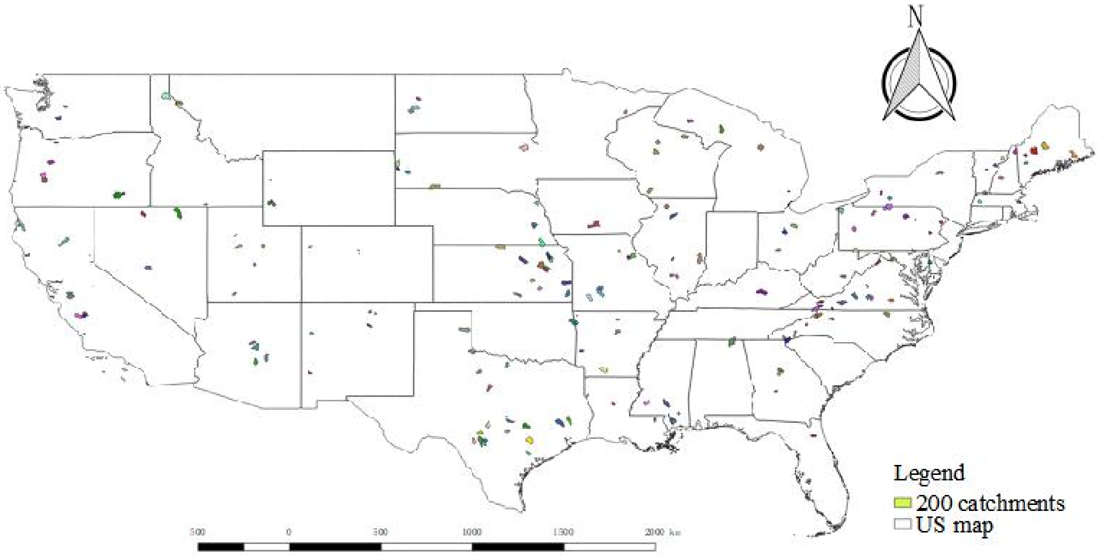

Figure E.3 200 selected catchments on US Map

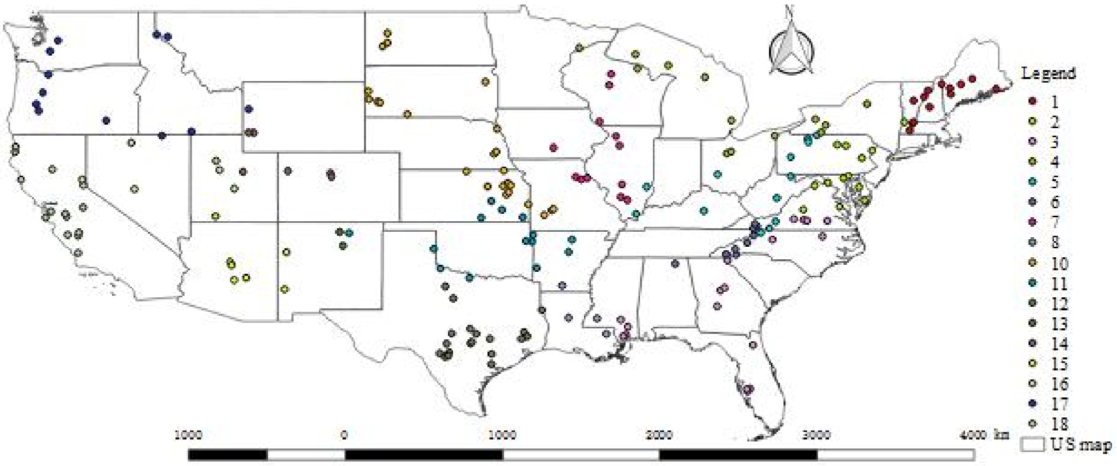

Figure E.4 Locations of runoff stations in 18 big areas (no catchment in the ninth area) on US Map

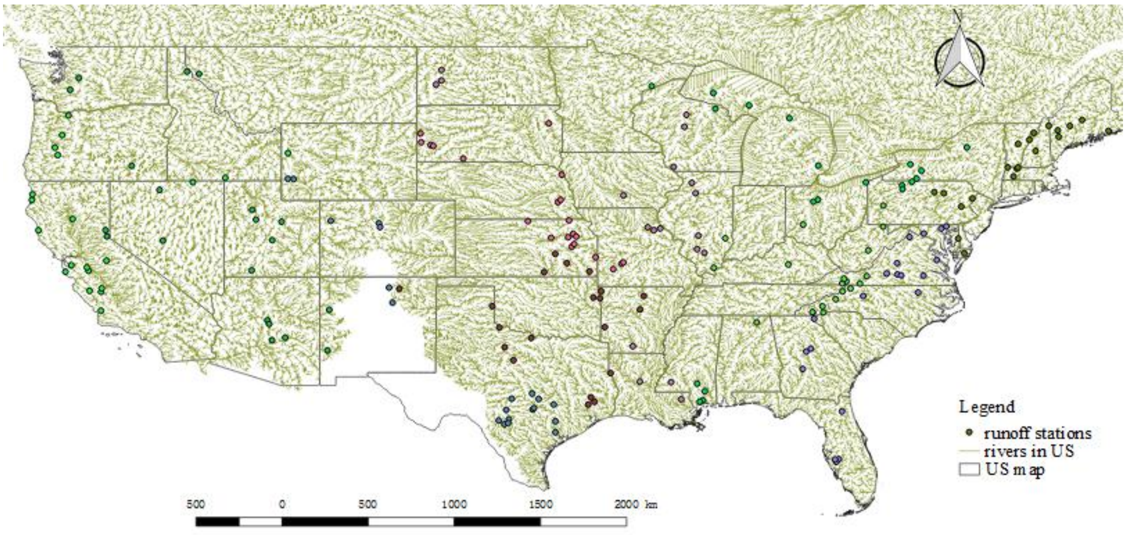

Figure E.5 Rivers and 200 runoff stations on US Map

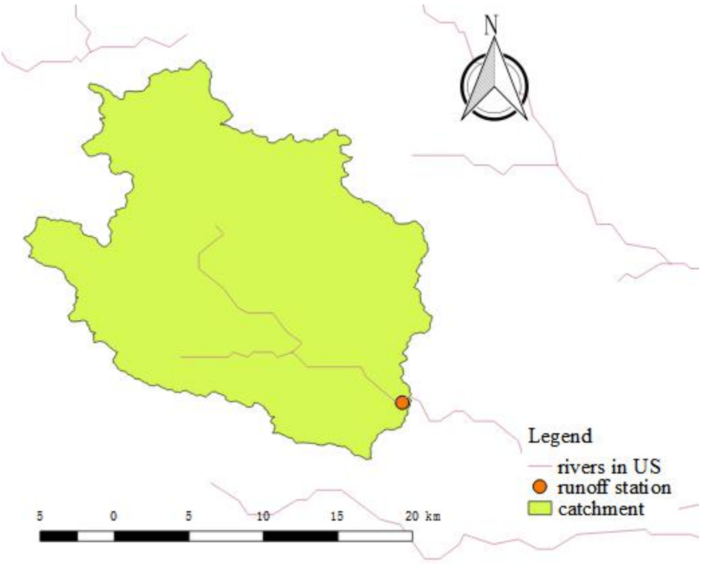

Figure E.6 One catchment and its runoff station in US river map

Table E.1 Distribution of 200 catchments in the United States

Name_State	Abbreviation	Number of catchments
Alabama	US.AL	1
Arizona	US.AZ	4
Arkansas	US.AR	6
California	US.CA	15
Colorado	US.CO	3
Connecticut	US.CT	0
Delaware	US.DE	0
District of Columbia	US.DC	0
Florida	US.FL	4
Georgia	US.GA	4
Idaho	US.ID	2
Illinois	US.IL	7
Indiana	US.IN	0
Iowa	US.IA	1
Kansas	US.KS	13
Kentucky	US.KY	1
Louisiana	US.LA	3
Maine	US.ME	5
Maryland	US.MD	4
Massachusetts	US.MA	4
Michigan	US.MI	4
Minnesota	US.MN	1
Mississippi	US.MS	5
Missouri	US.MO	6
Montana	US.MT	1
Nebraska	US.NE	3
Nevada	US.NV	3
New Hampshire	US.NH	2
New Jersey	US.NJ	0

New Mexico	US.NM	5
New York	US.NY	4
North Carolina	US.NC	9
North Dakota	US.ND	3
Ohio	US.OH	4
Oklahoma	US.OK	1
Oregon	US.OR	5
Pennsylvania	US.PA	8
Rhode Island	US.RI	0
South Carolina	US.SC	0
South Dakota	US.SD	6
Tennessee	US.TN	0
Texas	US.TX	21
Utah	US.UT	5
Vermont	US.VT	3
Virginia	US.VA	13
Washington	US.WA	2
West Virginia	US.WV	2
Wisconsin	US.WI	4
Wyoming	US.WY	3

Table E.2 Names of the rivers which 200 catchments belong to

Area	code	Sub_name	Maj_name
1	1022500	Maine Coastal	Atlantic Ocean Seaboard
1	1031500	Piscataquis	Atlantic Ocean Seaboard
1	1047000	Lower Kennebec	Atlantic Ocean Seaboard
1	1052500	Lower Androscoggin	Atlantic Ocean Seaboard
1	1055000	Lower Androscoggin	Atlantic Ocean Seaboard
1	1057000	Lower Androscoggin	Atlantic Ocean Seaboard
1	1078000	Pemigewasset	Atlantic Ocean Seaboard
1	1134500	Passumpsic	Atlantic Ocean Seaboard
1	1139000	Waits	Atlantic Ocean Seaboard
1	1142500	White	Atlantic Ocean Seaboard
1	1169000	Deerfield	Atlantic Ocean Seaboard
1	1170100	Deerfield	Atlantic Ocean Seaboard
1	1181000	Westfield	Atlantic Ocean Seaboard
2	1333000	Hudson / Hoosic	United States, North Atlantic Coast
2	1439500	Middle Delaware / Mongaup / Brodhead	United States, North Atlantic Coast
2	1451800	Lehigh	United States, North Atlantic Coast
2	1485500	Pocomoke	United States, North Atlantic Coast
2	1491000	Choptank	United States, North Atlantic Coast
2	1550000	Lower West Branch Susquehanna	United States, North Atlantic Coast
2	1552500	Lower West Branch Susquehanna	United States, North Atlantic Coast
2	1580000	Lower Susquehanna	United States, North Atlantic Coast
2	1583500	Gunpowder / Patapsco	United States, North Atlantic Coast
2	1634500	North Fork Shenandoah	United States, North Atlantic Coast
2	1638480	Middle Potomac / Catoctin	United States, North Atlantic Coast
2	1669000	Lower Rappahannock	United States, North Atlantic Coast
2	2027000	Middle James / Buffalo	United States, North Atlantic Coast
3	2046000	Nottoway	Gulf of Mexico, North Atlantic Coast
3	2059500	Upper Roanoke	Gulf of Mexico, North Atlantic Coast
3	2064000	Upper Roanoke	Gulf of Mexico, North Atlantic Coast
3	2065500	Upper Roanoke	Gulf of Mexico, North Atlantic Coast
3	2082950	Fishing	Gulf of Mexico, North Atlantic Coast
3	2118500	South Yadkin	Gulf of Mexico, North Atlantic Coast
3	2177000	Tugaloo	Gulf of Mexico, North Atlantic Coast

3	2212600	Ocmulgee	Gulf of Mexico, North Atlantic Coast
3	2221525	Upper Oconee	Gulf of Mexico, North Atlantic Coast
3	2245500	Lower St Johns	Gulf of Mexico, North Atlantic Coast
3	2297155	Peace	Gulf of Mexico, North Atlantic Coast
3	2298608	Myakka	Gulf of Mexico, North Atlantic Coast
3	2299950	Manatee	Gulf of Mexico, North Atlantic Coast
3	2349900	Upper Flint	Gulf of Mexico, North Atlantic Coast
3	2472500	Upper Leaf	Gulf of Mexico, North Atlantic Coast
3	2479155	Black	Gulf of Mexico, North Atlantic Coast
3	2481000	Mississippi Coastal	Gulf of Mexico, North Atlantic Coast
3	2481510	Mississippi Coastal	Gulf of Mexico, North Atlantic Coast
4	4015330	Lake Superior	St Lawrence
4	4040500	Sturgeon / Dead / Kelsey	St Lawrence
4	4057510	Fishdam / Sturgeon	St Lawrence
4	4063700	Menominee	St Lawrence
4	4127997	Cheboygan	St Lawrence
4	4161580	Clinton	St Lawrence
4	4196800	Sandusky	St Lawrence
4	4197100	Sandusky	St Lawrence
4	4213000	Chautauqua / Conneaut	St Lawrence
4	4216418	Niagara	St Lawrence
4	4221000	Genesee	St Lawrence
4	4224775	Genesee	St Lawrence
4	4256000	Black	St Lawrence
5	3010655	Upper Allegheny	Mississippi - Missouri
5	3011800	Upper Allegheny	Mississippi - Missouri
5	3028000	Clarion	Mississippi - Missouri
5	3049000	Lower Allegheny	Mississippi - Missouri
5	3070500	Cheat	Mississippi - Missouri
5	3161000	Upper New	Mississippi - Missouri
5	3165000	Upper New	Mississippi - Missouri
5	3170000	Upper New	Mississippi - Missouri
5	3186500	Gauley	Mississippi - Missouri
5	3241500	Little Miami	Mississippi - Missouri
5	3285000	Lower Kentucky	Mississippi - Missouri
5	3346000	Embarras	Mississippi - Missouri
5	3384450	Lower Ohio / Bay	Mississippi - Missouri
6	3439000	Upper French Broad	Mississippi - Missouri
6	3456500	Pigeon	Mississippi - Missouri
6	3463300	Nolichucky	Mississippi - Missouri
6	3471500	South Fork Holston	Mississippi - Missouri
6	3473000	South Fork Holston	Mississippi - Missouri
6	3479000	Watauga	Mississippi - Missouri
6	3488000	North Fork Holston	Mississippi - Missouri
6	3500000	Upper Little Tennessee	Mississippi - Missouri
6	3500240	Upper Little Tennessee	Mississippi - Missouri
6	3574500	Guntersville Lake	Mississippi - Missouri
7	5393500	Lake Dubay	Mississippi - Missouri
7	5399500	Castle Rock	Mississippi - Missouri
7	5414000	Grant / Little Maquoketa	Mississippi - Missouri
7	5444000	Lower Rock	Mississippi - Missouri
7	5487980	Lower Des Moines	Mississippi - Missouri
7	5503800	North Fork Salt	Mississippi - Missouri
7	5507600	Salt	Mississippi - Missouri
7	5508805	Salt	Mississippi - Missouri
7	5556500	Lower Illinois / Senachwine Lake	Mississippi - Missouri
7	5593575	Upper Kaskaskia	Mississippi - Missouri
7	5593900	Shoal	Mississippi - Missouri
7	5595730	Big Muddy	Mississippi - Missouri
8	7291000	Homochitto	Mississippi - Missouri
8	7362100	Lower Ouachita / Smackover	Mississippi - Missouri

8	7373000	Little	Mississippi - Missouri
8	7375000	Liberty Bayou / Tchefunchta / Lake Pontchartrain	Mississippi - Missouri
10	6332515	Lake Sakakawea	Mississippi - Missouri
10	6339100	Knife	Mississippi - Missouri
10	6344600	Upper Heart	Mississippi - Missouri
10	6404000	Middle Cheyenne / Spring	Mississippi - Missouri
10	6406000	Middle Cheyenne / Spring	Mississippi - Missouri
10	6409000	Redwater	Mississippi - Missouri
10	6431500	Redwater	Mississippi - Missouri
10	6447500	Little White	Mississippi - Missouri
10	6479438	Middle and Upper Big Soiux	Mississippi - Missouri
10	6601000	Blackbird / Soldier	Mississippi - Missouri
10	6803510	Salt	Mississippi - Missouri
10	6803530	Salt	Mississippi - Missouri
10	6814000	South Fork Big Namaha	Mississippi - Missouri
10	6853800	Middle and Lower Republican	Mississippi - Missouri
10	6878000	Lower Smoky Hill	Mississippi - Missouri
10	6888500	Middle Kansas	Mississippi - Missouri
10	6889200	Middle Kansas	Mississippi - Missouri
10	6889500	Middle Kansas	Mississippi - Missouri
10	6910800	Upper Marais Des Cygnes	Mississippi - Missouri
10	6911900	Upper Marais Des Cygnes	Mississippi - Missouri
10	6917000	Little Osage	Mississippi - Missouri
10	6918460	Sac	Mississippi - Missouri
10	6921070	Pomme De Terre	Mississippi - Missouri
10	6921200	Pomme De Terre	Mississippi - Missouri
11	7060710	Middle White	Mississippi - Missouri
11	7145700	Middle Arkansas / Slate	Mississippi - Missouri
11	7167500	Fall	Mississippi - Missouri
11	7180500	Cottonwood	Mississippi - Missouri
11	7184000	Upper Neosho	Mississippi - Missouri
11	7195800	Illinois	Mississippi - Missouri
11	7196900	Illinois	Mississippi - Missouri
11	7197000	Illinois	Mississippi - Missouri
11	7208500	Cimarron	Mississippi - Missouri
11	7261000	Cadron	Mississippi - Missouri
11	7301410	North Fork Red	Mississippi - Missouri
11	7301410	North Fork Red	Mississippi - Missouri
11	7315200	Little Witchita	Mississippi - Missouri
11	7340300	Lower Little Arkansas	Mississippi - Missouri
12	8023080	Lower Sabine / Toledo Bend Reservoir	Gulf Coast
12	8066200	Lower Trinity	Gulf Coast
12	8066300	Lower Trinity	Gulf Coast
12	8070000	East Fork San Jacinto	Gulf Coast
12	8082700	Middle Brazos / Millers	Gulf Coast
12	8086290	Hubbard	Gulf Coast
12	8103900	Lampasas	Gulf Coast
12	8104900	San Gabriel	Gulf Coast
12	8109700	Yagua	Gulf Coast
12	8150800	Llano	Gulf Coast
12	8158700	Lower Colorado	Gulf Coast
12	8158810	Lower Colorado	Gulf Coast
12	8164300	Navidad	Gulf Coast
12	8164600	West Matagorda Bay	Gulf Coast
12	8165300	Upper Guadalupe	Gulf Coast
12	8196000	Upper Frio	Gulf Coast
12	8198500	Upper Frio	Gulf Coast
12	8200000	Hondo	Gulf Coast
12	8202700	Hondo	Gulf Coast
13	8269000	Mora	Mississippi - Missouri
13	8380500	Mora	Mississippi - Missouri

14	9035900	Colorado Headwaters	North America, Colorado
14	9047700	Blue Colorado	North America, Colorado
14	9210500	Upper Green / Slate	North America, Colorado
14	9223000	Blacks Fork	North America, Colorado
14	9306242	Lower White	North America, Colorado
14	9312600	Price	North America, Colorado
15	9386900	Zuni	North America, Colorado
15	9404450	Upper Virgin	North America, Colorado
15	9430600	Upper Gila / Mangas	North America, Colorado
15	9497980	Upper Salt	North America, Colorado
15	9505350	Lower Verde	North America, Colorado
15	9505800	Lower Verde	North America, Colorado
15	9510200	Lower Verde	North America, Colorado
16	10172700	Rush / Tooele Valleys	Great Basin
16	10172800	Rush / Tooele Valleys	Great Basin
16	10205030	Middle Sevier	Great Basin
16	10249300	Northern Big Smoky Valley	Great Basin
16	10329500	Little Humboldt	Great Basin
16	10336660	Lake Tahoe / Truckee / Pyramid / Winnemucca Lakes	Great Basin
16	10343500	Lake Tahoe / Truckee / Pyramid / Winnemucca Lakes	Great Basin
17	10396000	Donner and Blitzen	Columbia and Northwestern United
17	12082500	Nisqually	Pacific and Arctic Coast
17	12115000	Lake Washington	Pacific and Arctic Coast
17	12390700	Lower Clark Fork	Columbia and Northwestern United
17	12411000	Coeur d Alene / Upper Spokane	Columbia and Northwestern United
17	13018300	Greys / Hobock	Columbia and Northwestern United
17	13083000	Goose	Columbia and Northwestern United
17	13161500	Bruneau	Columbia and Northwestern United
17	14141500	Lower Columbia / Sandy	Columbia and Northwestern United
17	14154500	Coast Fork Willamette	Columbia and Northwestern United
17	14185000	South Santiam	Columbia and Northwestern United
17	14316700	North Umpqua	Columbia and Northwestern United
18	11141280	Central Coastal	California
18	11151300	Salinas	California
18	11162500	San Francisco Coastal South	California
18	11180500	San Francisco Bay	California
18	11224500	Middle San Joaquin/ Chowchilla / Fresno / Panoche	California
18	11253310	Middle San Joaquin/ Chowchilla / Fresno / Panoche	California
18	11274500	Middle San Joaquin	California
18	11274630	Middle San Joaquin	California
18	11284400	Tuolumne	California
18	11383500	Mill / Big / Sacramento / Thomes	California
18	11468500	Big / Navarro / Garcia	California
18	11481200	Mad / Redwood	California
18	11482500	Mad / Redwood	California

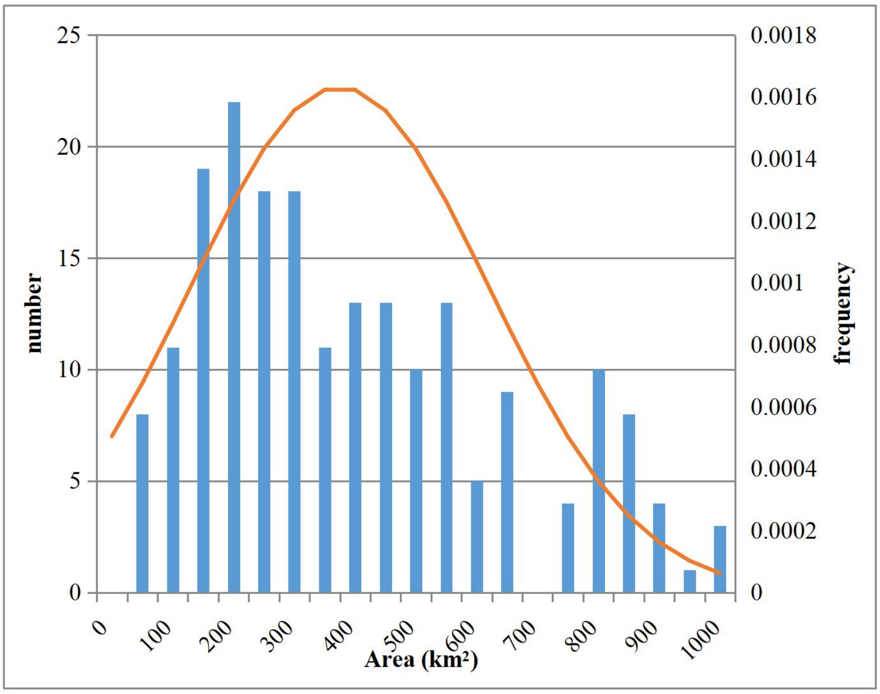

Figure E.7 Normal distribution for the areas (km^2) of 200 catchments

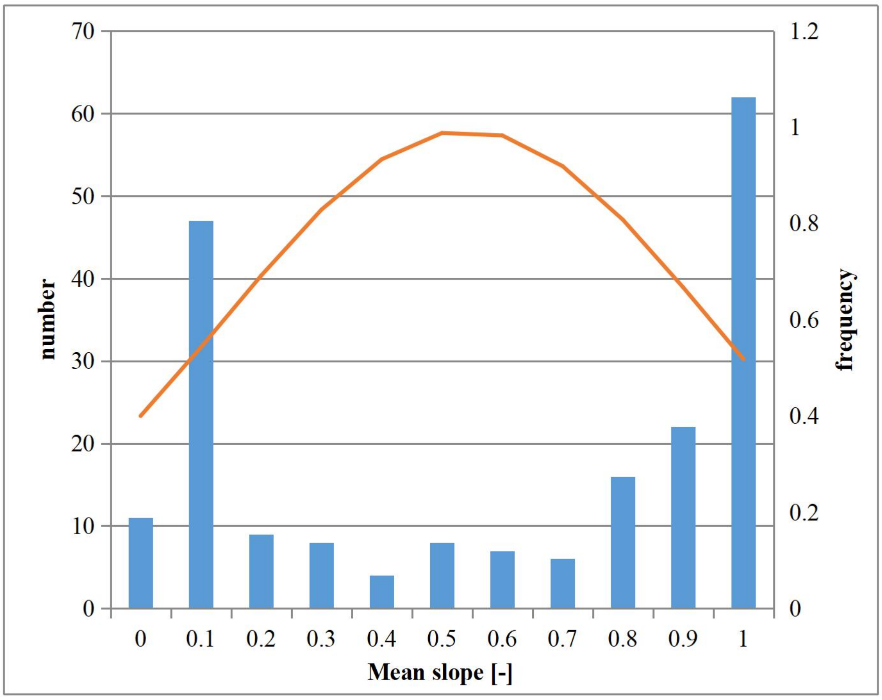

Figure E.8 Normal distribution for the mean slopes of 200 catchments

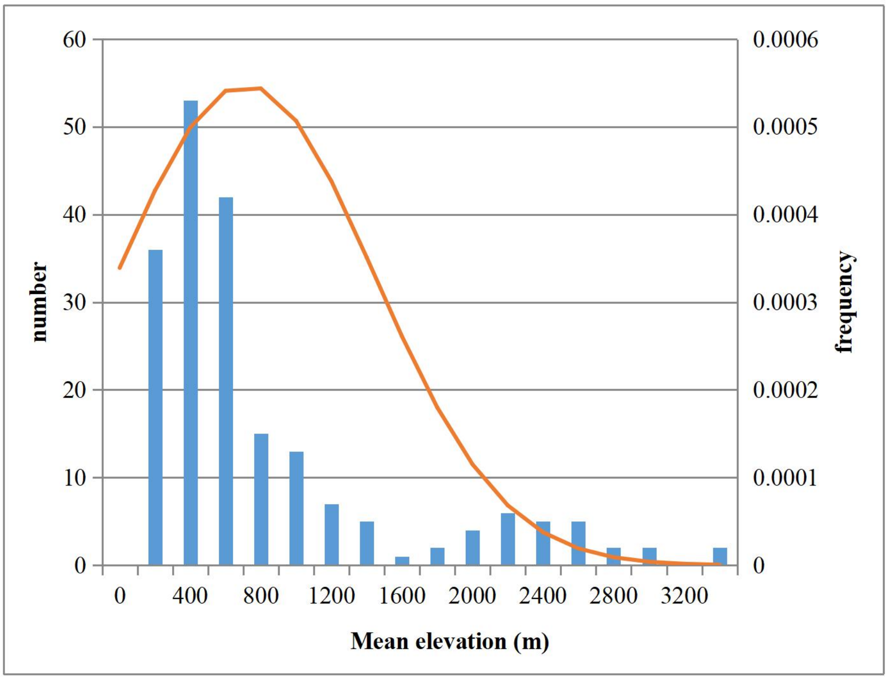

Figure E.9 Normal distribution for the mean elevations (m) of 200 catchments

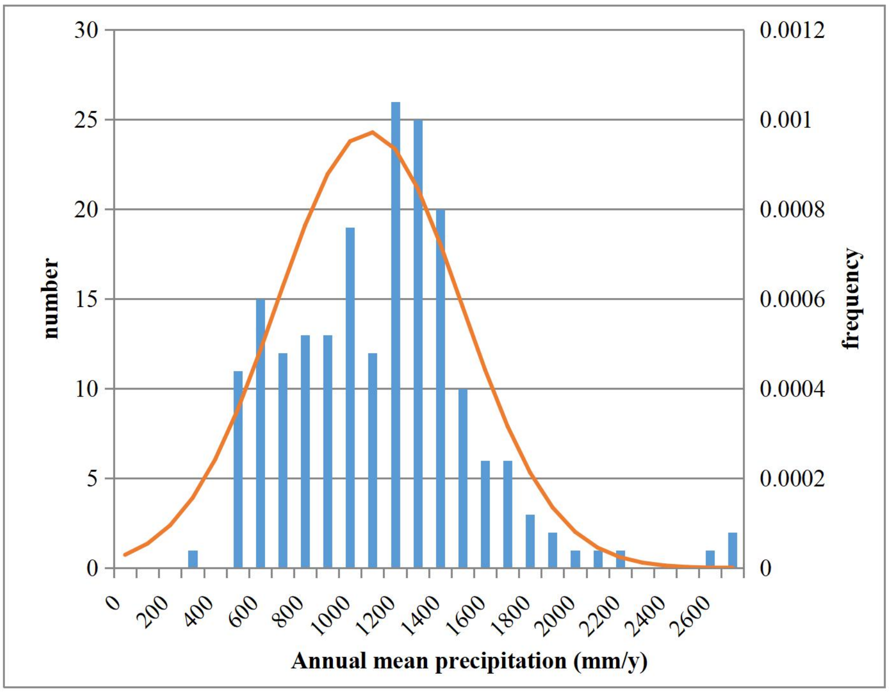

Figure E.10 Normal distribution for the annual mean precipitation (mm/y) of 200 catchments

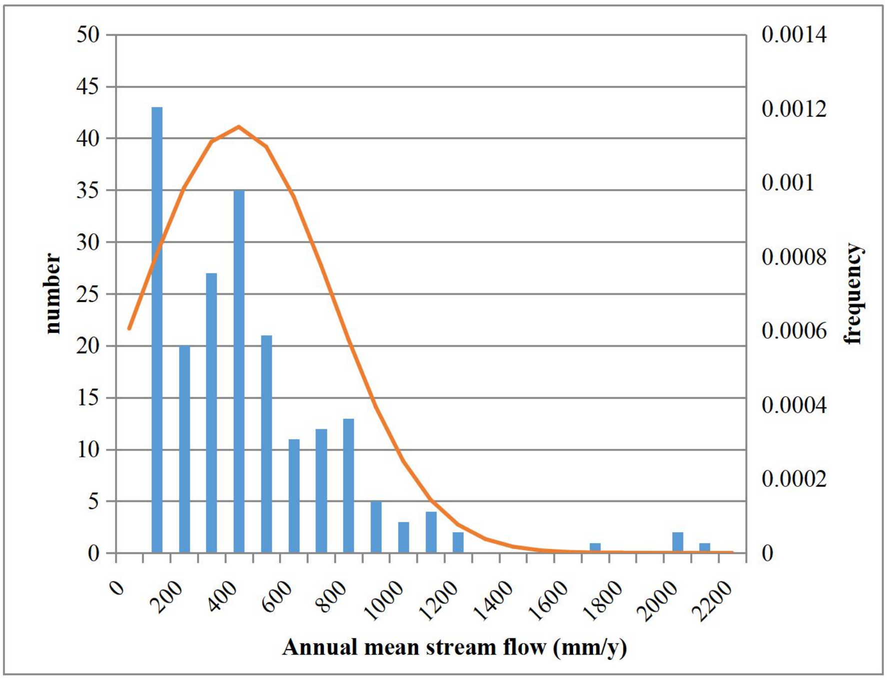

Figure E.11 Normal distribution for the annual mean stream flow (mm/y) of 200 catchments

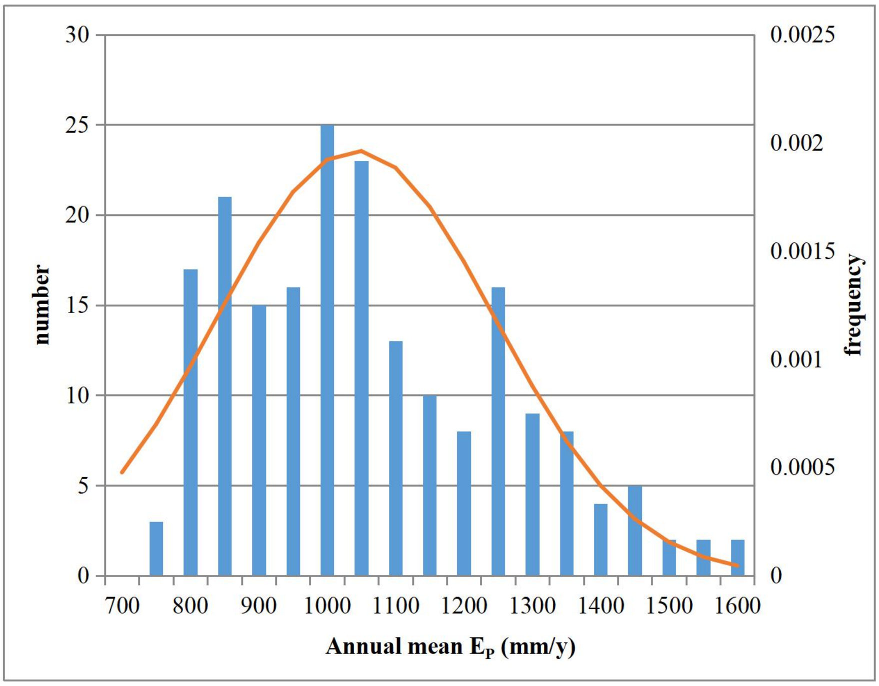

Figure E.12 Normal distribution for the annual mean potential evaporation (mm/y) of 200 catchments

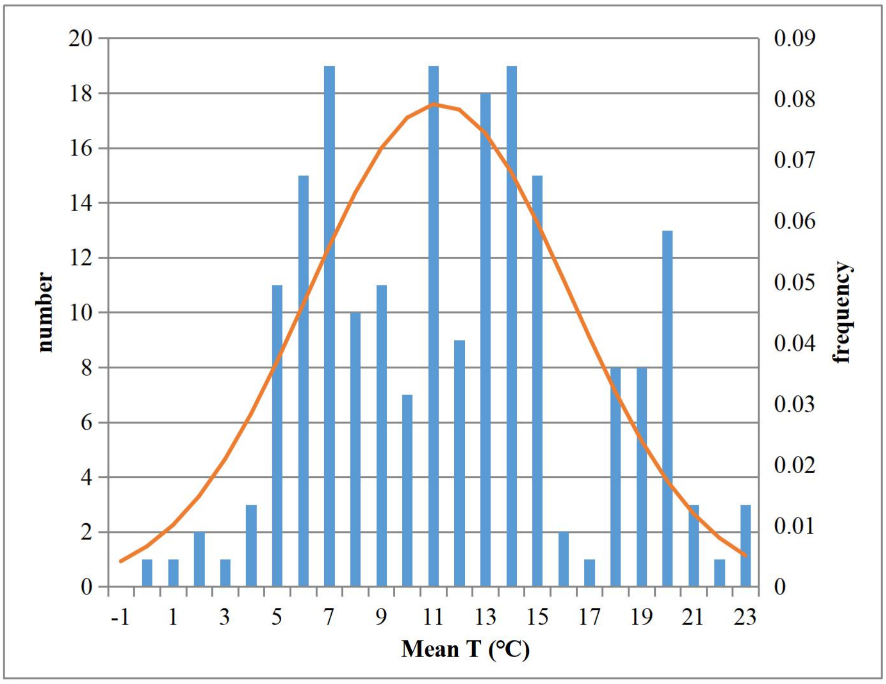

Figure E.13 Normal distribution for the mean temperature (°C) of 200 catchments