İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF) MODEL AS A DECISION SUPPORT TOOL FOR A DEVELOPING COUNTRY- A CASE STUDY FROM TURKEY

Ph.D. Thesis by
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Department : Environmental Engineering

Programme : Environmental Sciences and Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

HİDROLOJİK SİMÜLASYON PROGRAMI – FORTRAN (HSPF) MODELİNİN GELİŞMEKTE OLAN BİR ÜLKE İÇİN KARAR DESTEK SİSTEMİ OLARAK KULLANILMASI – TÜRKİYE'DEN ÖRNEK VAKA İNCELEMESİ

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FOREWORD

Though only my name appears on the cover of this dissertation, a great many people from three different countries have contributed to it through direct and indirect support all these years. Pursuing a PhD brought me to Turkey and the most beautiful city of the world Istanbul from my native Pakistan and its completion required me to visit USA. The completion of this PhD dissertation has made me adapt to two different cultures, to learn a new language and meet and be friends with so many wonderful people. I owe my gratitude to all those people in Turkey and United States of America and Pakistan who have made this dissertation possible and because of whom my graduate experience has been one that I will cherish forever.

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March 2009 Mansoor A. BALOCH
Civil Engineer, B.Sc., LEED-AP

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ABBREVIATIONS

ASCII : American Standard Code for Information Interchange
AGWETP : Active Groundwater Evapotranspiration Potential
AGWRC : Groundwater Recession Rate
AWD : Automatic Watershed Delineation
BASINS : Better Assessment Science Integrating point and Non point Sources
BOD : Biochemical Oxygen Demand
BMPs : Best Management Practices
BPJ : Best professional judgement
CC : Cost Categories
CEPSC : Interception storage capacity
DC : Data Categories
DEEPFR : Artificial Neural Network
DEM : Digital Elevation Model
FDC : Flow Duration Curve
GCMs : General Circulation Models
GenScn : Scenario Generation Tool
GIRAS : Geographic Information Retrieval and Analysis System
GIS : Geographic Information Systems
HRU : Hydrologic Response Unit
HSPEXP : Expert System for Hydrologic Calibration of HSPF
HSPF : Hydrological Simulation Program-FORTRAN
HUC : Hydrologic Unit Code
IHA : Indicators of Hydrologic Alteration
IMPLND : Impervious Land Segment
INFIL : Index to Mean Soil Infiltration Rate
INTFW : Interflow
IPCC : Intergovernmental Panel on Climate change
IRC : Interflow recession coefficient
IWM : Integrated Watershed Management
KVAR : Groundwater recession flow parameter
LSUR : Length of assumed overland flow plane
LZETP : Lower Zone Evapotranspiration Parameter
LZSN : Lower Zone Nominal Soil Moisture Storage
MPI : Model Performance Index
NLCD : National Land Cover Data (NLCD)
NPS : Non-point Sources
NSUR : Manning's n for overland flow plane
PERLND : Pervious Land Segment
PET : Potential Evapotranspiration
PREC : Precipitation
RCHRES : Reach Segment
SEW : State Electric Works
SHW : State Hydrologic Works

SLSUR : Average Slope of assumed overland flow path
SMW : State Metrologic Works
SWAT : Soil and Water Assessment Tool
TauDEM : Terrain Analysis Using Digital Elevation Models
UCI : Users Control Input
UNDP : United Nations Development Programme
USEPA : United States Environmental Protection Agency
USGS : United States Geological Services
UZSN : Nominal Upper Zone Soil Moisture Storage
WDM : Watershed Data Management
WDMUtil : Watershed Data Management Utility
WinHSPF : Windows HSPF
WoE : Weight of Evidence

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SUMMARY

Watersheds provide a manageable spatial unit for the quantification and management of the potential effects of land use and global climate changes on the quantity and quality of water. Watershed is a complex system that integrates natural resources, communities and bio diversity in a hydrologically defined spatial unit. Watershed modeling facilitates a profound understanding of watershed components and processes to comprehend and manage the risks associated with the impacts mentioned above. The application of watershed models has become an integral part of the decision making process for natural resource management in developed countries. Contrary to that despite being an important watershed assessment and management tool for the last two decades there has been only selected watershed modeling efforts in developing countries due to vast amount of diversified data requirements, lack of expertise in the techniques of modeling and model operations, and financial constraints in running a watershed-modeling project. The aim of this study is two folds. The primary aim of the study is to apply a detailed watershed model for the quantification of climate and land use change impacts on the hydrology and NPS pollution in the case study watershed in a developing country. Secondly, it aims to develop a pathway for researchers in developing countries that takes into account the data availability, cost of data collection and model performance to design a watershed modelling project tailor made to the specific modelling objectives based on a threshold level of data requirement, model results and cost, optimized for maximum benefit.

Better Assessment Science Integrating point and Non-point Sources (BASINS), and Hydrological Simulation Program-FORTRAN (HSPF), are used for the characterization of watershed hydrology and diffuse pollution and quantification of the effects of land use and climate change on the hydrologic regime and NPS pollutant loads in the Koycegiz watershed, Turkey. Land use changes were incorporated into the model by converting forest lands into agricultural and impervious land. Climate change was incorporated by modifying precipitation based on predicted values based on a literature review. The effects of rainfall and land use changes were analyzed on the hydrologic regime of the watershed and on NPS pollutant loads under various scenarios. The hydrologic alteration was analysed using Indicators of Hydrologic Alteration (IHA) method. Furthermore the applicability of BASINS/HSPF modeling system under data stringent conditions in developing countries is analyzed based on this application of BASINS/HSPF in Koycegiz watershed in Turkey. Model applicability components of data, cost and model performance are defined. A detailed data requirement analysis is then conducted for the application of BASINS and HSPF used for hydrological modeling. To analyze and define the relationships between the components of model applicability, Data and Cost categories and a Model Performance Index are defined. Data categories are defined on five data quality criteria of spatial resolution, coverage, continuity, consistency and compatibility. Cost categorization is defined based on the relative cost of acquired data. The Model Performance Index integrates model performance criteria and model acceptability. Based on the Weight of Evidence (WoE) analysis; Best Professional Judgment (BPJ) in modeling experience and literature review are used to define the relationships between Data, Cost and Model Performance Index and objective evidences are put forth to develop a hypothesis incorporating an application scenario for BASINS/HSPF application in a developing country identifying the minimum data requirement, corresponding relative cost and acceptability of model results, respectively.

The correlation coefficients for the mean daily and monthly flows were found to be 0.634 and 0.847 for calibration and 0.761 and 0.843 for validation respectively using the Expert System for the calibration of HSPF (HSPEXP). HSPEXP criteria between simulated and observed values varied from fair to very good, except for the summer flow volume and total of lowest 50% flows. Sediment, nitrate-N, orthophosphate-P, and BOD loads were determined for different land uses in the watershed. Agricultural activity was identified as the major source of sediments, and pastures with livestock grazing produced the highest NPS fluxes. Urbanization induced much higher NPS pollutant loads than agriculture, and modified the hydrologic regime severely in terms of magnitude, frequency and duration of the extreme flow conditions. With respect to climate change scenarios, a 10% decrease or increase in precipitation caused a corresponding 13% decrease or increase in the nitrate-N, 14% in orthophosphate-P and 13% in BOD loadings. The results emphasize the importance of advanced modeling tools even in the absence of high quality, continuous and consistent data. This analysis is informative in the demonstration of application of BASINS and HSPF in a data limited developing country and also the results demonstrate the need for erosion control, nutrient management and habitat conservation in light of urbanization and potential climate change. Based on this study a pathway for researchers, engineers and watershed modelers in developing countries is proposed for ascertaining data availability, cost analysis and corresponding acceptability of model results for decision making. It is concluded that the proposed pathway will help to optimize costs for data acquisition based on model performance and project objectives.

HİDROLOJİK SİMÜLASYON PROGRAMI – FORTRAN (HSPF) MODELİNİN GELİŞMEKTE OLAN BİR ÜLKE İÇİN KARAR DESTEK SİSTEMİ OLARAK KULLANILMASI – TÜRKİYE'DEN ÖRNEK VAKA İNCELEMESİ

ÖZET

Havzalar, arazi kullanımı ve küresel iklim değişimlerinin suyun miktarı ve kalitesi üzerindeki potansiyel etkilerinin tespit edilmesinde ve bu etkilerin yönetiminde büyük bir önem teşkil eden alansal birimlerdir. Havza; doğal kaynakları, toplulukları ve biyolojik çeşitliliği içeren hidrolojik olarak tanımlanmış bir alandır. Havza modellemesi, havza bileşenlerinin ayrıntılı bir şekilde anlaşılmasına yardımcı olurken, yukarıda belirtilen faktörlerin etkilerinden doğabilecek risklerin de kavranmasını ve yönetimini sağlar. Havza modellerinin uygulanması gelişmiş ülkelerde doğal kaynakların yönetimiyle ilgili karar alma süreçlerinin önemli bir parçası haline gelmiştir. Havza modelleri, havza değerlendirmesi ve yönetimi konusunda önemli araçlar olmalarına karşın; çok miktarda ve çeşitli veri gerektirmeleri, modelleme ve modelin yürütülmesi konularındaki tecrübesizlikler ve mali kısıtlamalar gibi sebeplerden ötürü gelişmekte olan ülkelerde ancak son yıllarda ve sınırlı bir şekilde uygulanmaya başlanmıştır. Bu çalışmanın amacı ayrıntılı bir havza modeli uygulayarak iklim ve arazi kullanımı değişimlerinin, seçilen havzanın hidrolojisi ile havzadaki yayılı kaynaklarından gelen kirleticiler üzerindeki etkilerini belirlemektir. Diğer bir amaç ise gelişmekte olan ülkelerdeki araştırmacılara veri erişilebilirliğini, veri toplama maliyetini ve model performansını dikkate alan, veri gereksinimi, model sonuçları, maliyet konularında eşik seviyeleri gözeten, maksimum fayda sağlamak için optimize edilmiş, amaca hizmet eden bir havza modellemesi projesinin tasarımında rehberlik etmektir.

Köyceğiz Havzası için havza hidrolojisi ve yayılı kirlenmenin karakterizasyonu ile iklim ve arazi kullanımı değişikliklerinin havzanın hidrolojisi ve yayılı kaynaklardan gelen kirletici yükleri üzerindeki etkilerini belirlemek amacıyla BASINS (Better Assessment Science Integrating point and Non-point Sources) ve Hidrolojik Simulasyon Programı-FORTRAN (HSPF) kullanılmıştır. Arazi kullanımı değişimleri; orman alanlarının tarım arazilerine ve geçirimsiz arazilere dönüştürülmesiyle, iklim değişimleri ise ilgili literatürde verilen değerler baz alınarak yapılan yağış tahminlerinin modifiye edilmesiyle modele dahil edilmiştir. Yağış ve arazi kullanımında meydana gelen değişimlerin, havzanın hidrolojik rejimi ve yayılı kaynaklardan gelen kirletici yükleri üzerindeki etkileri, çeşitli senaryolar oluşturularak incelenmiştir. Hidrolojik değişimler Hidrolojik Değişim Göstergeleri (IHA) metodu kullanılarak değerlendirilmiştir. BASIN/HSPF modelleme sisteminin Köyceğiz Havzası'na uygulanmasıyla söz konusu sistemin gelişmekte olan ülkelerdeki kısıtlı veri koşullarında uygulanabilirliği de analiz edilmiştir. Model uygulanabilirliğinin bileşenleri olan veri, maliyet ve model performansı tanımlanmıştır. Hidrolojik modellemede BASINS ve HSPF uygulamaları için ayrıntılı bir veri gereksinimi analizi yürütülmüştür. Model uygulanabilirliği

bileşenleri arasındaki ilişkileri incelemek ve tanımlamak amacıyla, veri ve maliyet kategorileri ile Model Performansı İndeksi tanımlanmıştır. Veri kategorileri; konuma bağlı çözünürlük, kapsama, süreklilik, tutarlılık ve uyumluluk olmak üzere beş adet kalite ölçütüne göre belirlenmiştir. Maliyet kategorizasyonu ise veri elde etme maliyeti baz alınarak yapılmıştır. Model Performans İndeksi, model performansı kriteri ile modelin kabul edilebilirliğini içerir. En İyi Profesyonel Yargı (Best Professional Judgment, BPJ) yöntemi ve literatür taraması sonuçları kullanılarak; veri, maliyet ve Model Performans İndeksi arasındaki ilişkiler belirlenmiştir. Bu ilişkilerin belirlenmesinde Kanıtın Ağırlığı (Weight of Evidence, WoE) analizi baz alınmıştır. Gelişmekte olan ülkelerde kullanmak amacıyla, minimize edilmiş veri gereksinimi, göreceli olarak düşük maliyet ve model sonuçlarının kabul edilebilirliğini içeren BASINS/HSPF uygulamasını kapsayan bir hipotez geliştirmek için nesnel kanıtlar ileri sürülmüştür.

HSFP kalibrasyonunda kullanılan HSPEXP sistemi yardımıyla günlük ve aylık ortalama akımlara ait korelasyon katsayıları kalibrasyon için 0,634 ve 0,847, validasyon için 0,761 ve 0,843 olarak bulunmuştur. Modellenen değerler ile gözlenen değerler arasındaki HSPEXP ölçütleri, yaz mevsimi akış hacmi ile en düşük %50 akımların toplamı dışında iyi ile çok iyi arasında değişmektedir. Havzadaki değişik arazi kullanımları için rüsubat, nitrat azotu, ortofosfat fosforu ve BOİ yükleri tespit edilmiştir. Tarımsal faliyetler rüsubatın ana kaynağı olarak belirlenirken, hayvancılığın yapıldığı meralar ise en yüksek yayılı kirletici akımına yol açan alanlar olarak tanımlanmıştır. Şehirleşme, tarım faaliyetlerine göre çok daha fazla miktarda yayılı kirletici akışı meydana getirmekte ve hidrolojik rejimi uç koşullardaki akışların büyüklüğü, sıklığı ve süresi açısından önemli ölçüde etkilemektedir. İklim değişikliği senaryolarına göre yağış miktarındaki %10'luk artış ya da azalma; nitrat azotu yükünde %13'lük, ortofosfat fosforu yükünde %14'lük, BOİ yükünde ise %13'lük bir artış veya azalmaya neden olacaktır. Bu sonuçlar yüksek kalitede, sürekli ve uyumlu verilerin bulunmadığı durumlarda bile gelişmiş modelleme araçlarının kullanımının önemini vurgulamaktadır. Bu analizler BASINS ve HSPF'in gelişmekte olan ülkelerdeki kısıtlı veri koşullarında uygulanmasını gösterme konusunda bilgi verici nitelikte olup, elde edilen sonuçlar erozyon kontrolü, besin elementi yönetimi ve doğal yaşam ortamının korunması gerekliliklerini, şehirleşme ve potansiyel iklim değişiklikleri ışığında göstermektedir. Söz konusu çalışma, gelişmekte olan ülkelerdeki araştırmacılar, mühendisler ve havza modellemecilerine veri erişilebilirliğinin tespit edilmesi, maliyet analizi ve elde edilen model sonuçlarının karar vermede kullanılabilirliği konularında yön göstermeyi hedeflemektedir. Ayrıca, veri elde etme maliyetlerinin model performansı ve amaçları baz alınarak optimize edilmesi hususunda da rehberlik etmektedir.

1. INTRODUCTION

1.1 Aims and Scope

Global climate change and changes in the land uses have enormous impacts on the hydrological regime and the water quality of a stream. There is a need for quantification of these impacts to mitigate their adverse effects on the integrity of natural resources and human communities. Watersheds provide a manageable spatial unit for the quantification and management of these potential effects. A watershed is a complex system that integrates natural resources, communities and biodiversity in a hydrologically defined spatial unit. A profound understanding of watershed components and processes is needed to comprehend and manage the effects of global climate change and land use changes. This necessitates adopting a detailed, multi-process and multi- component analysis approach. Watershed systems approach is an extensive, holistic and long-term strategy for natural resources management at catchment scale and watershed modeling encompasses representation, analysis and quantification of cause and effect relationships on a watershed scale. The advances in computer technology have made it possible for modelers to study and analyze the different interactions between watershed components and processes to achieve a broader understanding of anthropogenic activity and natural environment, and to support sustainable decision making for the management and conservation of natural resources in a watershed. The application of watershed models has become an integral part of the decision making process for natural resource management in developed countries. Contrary to that, despite being an important watershed assessment and management tool for the last two decades, there has been only selected watershed modeling efforts in developing countries due to vast amount of diversified data requirements, lack of expertise in the techniques of modeling and model operations, and financial constraints in running a watershed-modeling project.

The aim of this study is two folds. The primary aim of the study is to apply a detailed watershed model for the quantification of climate and land use change impacts on the hydrology and NPS pollution in the case study watershed in a developing country. Secondly, it aims to develop a pathway for researchers in developing countries that takes into account the data availability, cost of data collection and model performance to design a watershed modelling project tailor made to the specific modelling objectives based on a threshold level of data requirement, model results and cost, optimized for maximum benefit.

United Nations Development Program (UNDP) classifies Republic of Turkey as a developing country based on its Human Development Index classification system. As in most of the developing countries watershed modeling and management resaerch is a relatively new practice in Turkey. Most of the watersheds in Turkey bear the same characteristics of lack of monitoring and comprehensive resource management planning. The case study watershed of Koycegiz is located in the southwest of Turkey. The watershed is a unique area with special ecological, historical and recreational characteristics. Part of the watershed has been declared a special protected are due to its sensitive and vulnerable coastal habitats of endangered and endemic species. It exhibits rural characteristics with three major human functions of agriculture, tourism and fisheries. The human functions not only rely heavily on the natural equilibrium of aquatic and ecologic systems, but are also in conflict with the integrity of the natural environment in the watershed. Lack of monitoring, analysis and mitigation efforts seriously undermines the conservation of natural resources in the watershed and makes it vulnerable to increased ecological stresses induced by above-mentioned anthropogenic activities. By quantifying the impacts of land use changes, this study addresses the potential adverse effects of deforestation, extensive agriculture and increased tourism (increase in impervious areas) on the hydrologic regime and the water quality in the watershed. Both these factors are a determinant of stresses in the natural ecosystems. Furthermore, changes in the precipitation regime have been identified as a direct effect of global climate change. This study also quantifies the impacts of such a change on the quantity and quality of water in the Koycegiz watershed for the sustainability of its major functions as a source of livelihoods for its communities, and as a habitat for its special flora and fauna. It is important to note that the identification and quantification of individual ecological stresses are a topic of a separate research and are beyond the scope of this study.

In order to analyze and quantify the impacts of land use and climate changes in the Koycegiz watershed, it was imperative to adopt a watershed systems approach requiring the application of a comprehensive watershed model. The data requirements for such an application are extensive and diverse. Therefore, the second major aim of the study was to address the critical issues that are confronted by most of the researchers in developing countries when they initiate a watershed-modeling project for the identification, analysis and mitigation of hydrologic and water quality problems in a watershed. These issues are addressed based on the analysis of the application of Better Assessment Science Integrating point and Non-point Sources (BASINS), and Hydrological Simulation Program-FORTRAN (HSPF) in the case study watershed. The first step was to identify the data requirements for the modeling systems. Contrary to common understanding, data requirements not only incorporate data availability, but also the quality of available data. Therefore, the second step was to identify the quality attributes of the available or required data for watershed model application. After identifying the quality and quantity of a certain dataset required, the cost of obtaining such a dataset was considered. Finally based on the application of BASINS/HSPF in the case study watershed, the effect of using such a dataset on the acceptability of model results incorporated into a single term 'model performance' was analyzed. It is however emphasized here that given the practical limitations and the scope of the study, these analyzes were based on the weight of evidence approach and were subjective in nature. An absolute minimum data requirement for model application is determined based on a threshold level of availability and quality of data, cost of data acquisition and model performance. Based on this absolute minimum data requirement, a model applicability pathway is determined for the application of BASINS/HSPF in developing countries under data stringent conditions.

1.2 Research Objectives

The specific objectives of this research are to;

- Apply BASINS/HSPF for the characterization of hydrology and non point source (NPS) pollution in the Koycegiz watershed in Turkey using absolute minimum data requirement for model application,

- Characterize the hydrologic regime of Namnam stream in the Koycegiz watershed for the present and the future land use changes and changes in precipitation trends,
- Forecast and assess the impact of land use and climate changes on hydrologic regime and the NPS pollution loads in the Koycegiz watershed,
- Identify and discuss the decision-making imperatives resulting from such potential changes in land use and precipitation regime, and
- Define and introduce a pathway for researchers in developing countries that consider data availability, cost of data collection and model performance to design a watershed modelling project tailor made to the specific modelling objectives based on a threshold level of data requirement, model results and cost, optimized for maximum benefit.

1.3 Research Questions

The research endeavors to find the answers for the following questions:

- What are the steps involved in applying a detailed watershed model in a developing country?
- What is the performance efficiency of a detailed model (that is normally applied in a data rich environment) in a data poor environment?
- What is the extent of defensibility of simulation results in terms of decision-making?
- What are the techniques, tools and strategies for overcoming typical developing country problems like data deficiency, financial constraints and lack of expertise in model operations?
- What are the critical watershed land uses for diffuse pollution control?
- What are the effects of land use changes on NPS pollutant loads and hydrological regime of watershed?
- What are the effects of climate change on NPS pollutant loads on NPS loads and hydrological regime of the watershed?
- What are the decision support imperatives for possible decision scenarios of watershed functions under various land use and climate change scenarios?

1.4 Research Significance

Watershed modeling provides great opportunities for decision makers in developing countries to sustainably manage and conserve the natural resources and ecological integrity of aquatic and ecologic systems. This study is the first research endeavor in Turkey that quantifies the impacts of land use modifications and climate change on the hydrologic regime and NPS loadings on watershed scale in an ecologically significant region of the country using a comprehensive detailed watershed modeling system. Furthermore, the research highlights the data requirements, data sources and data generation steps for the application of BASINS/HSPF in the case study watershed and presents a model applicability pathway for researchers in developing countries interested in analyzing watershed problems using BASINS and HSPF. The research also develops a hypothesis presenting the relationship between data, cost and model performance for the prioritization of resources towards achieving an optimum model performance based on threshold data availability.

1.5 Dissertation Outline

The second chapter defines the problem statement and the scope of the research in the light of a literature review. It discusses the impacts of climate and land use changes and emphasizes the need for watershed modeling as a decision support tool for the quantification and mitigation of these effects. It discusses the specific issues related to watershed modeling in developing countries, and examines the importance of watershed modeling approaches for resource conservation in developing countries. It introduces and presents the justifications for selecting BASINS/HSPF for the case study application. Finally, it highlights the implications of the research in the light of research outputs.

BASINS and its core watershed model HSPF are discussed in detail in Chapter 3. It presents the system architecture of BASINS, its major components and capabilities. An introduction of HSPF is followed by description of its components, capabilities, support software. Recent applications of BASINS/HSPF are discussed where applications outside USA have been emphasized.

Chapter 4 gives an introduction to the case study watershed. It describes the steps involved in identification of data needs, collection of data, data generation and data conversion for model application.

Chapter 5 describes the watershed modeling strategy for the characterization of hydrology and NPS pollution in the watershed, and analyses land use and climate change impacts on hydrologic regime and NPS pollution. Steps involved in watershed delineation, characterization and preparation of input files for model application are described. Hydrologic calibration and validation strategies are discussed in detail. Furthermore, scenario development and scenario analysis strategy are also referred in Chapter 5.

The development of an optimum model applicability pathway for researchers in developing countries is described in Chapter 6. Components of a modeling study are defined and a weight of evidence approach is adopted to subjectively define categories for data, cost and a model performance index which in turn leads to quantification of the relationship between data cost and model performance.

Chapter 7 presents the results of watershed delineation, characterization, hydrologic model calibration, scenario analysis using BASINS and HSPF. The decision support imperatives are also presented as a result of scenario analysis based on land use and climate change scenarios. Furthermore, the results of a weight of evidence analysis are presented to identify an optimum model applicability pathway for researchers in developing countries. Chapter 8 presents the conclusions of the research.

2. BACKGROUND

2.1 Problem Statement

The hydrological response of a watershed defines the changes and fluctuations in the quantity and quality of water in a stream (Costa *et al*., 2003), which in turn defines the flow regime of the stream and its functions within a watershed as a source for water for different beneficial uses varying from human consumption, agriculture, industry, recreation to natural habitat conservation (Krosovskaia and Gottschalk, 2003). The characterization of hydrologic regime of a stream and its subsequent manipulation can be utilized for conservation of sustainable management of watershed resources (Luo *et al*., 2006). The main factors that characterize the hydrological response, and hence the flow regime and water quality of a stream are the geomorphology and the precipitation regime in the watershed.

Precipitation regime of a watershed is the driving force for the hydrologic processes in the stream networks (Poff *et al*., 2006; Johnston *et al*., 2008; Shaw and Cooper, 2008). The Intergovernmental Panel on Climate Change (IPCC, 2007) forecasts increase in flooding risks and drought in different regions of the world due to climate change and its potential hydrological effects. Recent observations confirm increases in global mean temperatures and atmospheric water vapor leading to an increase in mean precipitation in high altitudes, reductions in China and Australia and increased variance in equatorial regions. Global average annual rainfall will increase, although many mid latitude and lower latitude land regions will become drier (McMichael *et al*., 2006). Dore (2005) reviewed the precipitation patterns in the world for available data and found that the changing pattern of the precipitation around the world is perhaps the most important aspect in the vast subject of climate change. The effects of these changes in precipitation trends and on water quality, hydrologic regimes of the streams, and the hydrologic responses of watershed processes deserve urgent and systematic attention (Vidal and Wade, 2008). The understanding of these complex relationships is crucial for development of a sustainable Integrated Watershed Management (IWM) strategy.

Similarly, land use is probably the most influenced geomorphologic characteristics of a watershed by anthropogenic intervention. It plays a complex multi-faceted role in the hydrological cycle in modifying the hydrologic response of a watershed, the water quality and flow regime of a stream (Poff *et al.*, 2006). An increase in the annual mean discharge by 24% and high-flow season discharge by 28% has been reported in the forested areas of Brazil because of extensive agriculture without a significant change in the precipitation (Costa *et al*., 2003). It has been well reported that extensive agriculture can result in an increase of levels of nitrate and phosphorus (Jones *et al*., 2001; Cuffney *et al*., 2000). Similarly, livestock grazing and dairies may increase the presence of fecal bacteria in the water (Bach *et al*., 2002), provoke erosion problems and increase the turbidity of stream waters (Strunk, 2003). Conversion of agricultural areas, forests, grassland and wetlands to urban areas increases imperviousness in the form of roofs, sidewalks, roads, parking lots, and turf grass that can dramatically alter the natural hydrologic condition within a watershed (In *et al*., 2003). It is well understood that the outcome of this alteration is typically reflected in increases in the volume and rate of surface runoff and decreases in groundwater recharge and base flow which eventually lead to larger and more frequent incidents of local flooding, reduced residential and municipal water supplies, decreased base flow into stream channels during dry weather, increased lake and wetlands water levels, modified watershed water balance, and increased erosion of river channel beds and banks (Orlando and Urchin, 2007). These modifications have profound effects on the habitat for aquatic organisms and thus the natural ecological resources of the watershed system.

The effects of climate change and land use modifications are much more pronounced in developing countries where specific monitoring programs and tools are not in place to warn about the adverse affects of such changes on a watershed scale. To understand these effects, it is imperative that a systematic and holistic analysis of processes be carried out. The need for watershed scale analysis necessitates the adoption and application of dynamic watershed simulation modeling techniques to achieve the goals of sustainability due to complexity and magnitude of watershed systems (Choi and Deal, 2008).

2.2 Watershed modeling

Watershed simulation models or watershed models may best be termed as planning and decision support tools for sustainable development (ESCAP-UN, 1997). Watershed models simulate natural transportation processes like water flow, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of natural and human activities on these processes (Reimold, 1998; Kavvas *et al*., 1998; Shepherd *et al*., 1999). They enable to calculate the impacts of current, possible and planned actions on hydrology, pollution loadings, water quality and ecology (Hickey and Diaz, 1999; Mankin *et al*., 1999; Rudra *et al*., 1999). Simulation of these processes plays a fundamental role in addressing water resources, environmental, and social problems encountered.

2.3 Watershed Modeling in Developing Countries

In developed countries, watershed models have become a main tool in addressing a wide spectrum of environmental and water resources problems, including planning and development for potential adverse effects of geomorphologic and climate changes; however, this situation is not equally valid for the majority of developing and under developed world. The main reason of this deficiency is the lack of environmental data that fulfils the needs for watershed modeling (Erturk *et al*., 2007). As environmental data are heterogeneous and large in amount and variety, they necessitate collaboration of different institutions and state offices. Therefore, data organization is of utmost importance for watershed studies as well as development of data storage, sharing and publication protocols (e.g. database structure and internal file formats), and data storage tools such as database management extensions and plug-ins. This strategy prevents waste of time and effort for providing data to the models for studies on watershed and/or water quality management. Lack of institutions and monitoring programs in developing countries limit the data collection, storage, and sharing opportunities for watershed and water quality researchers. Data collection processes in developing countries is characterized by;

- Limited funds and logistic support for monitoring programs, and data collection is restricted or not available,

- Authenticity of collected data is questionable because of lack of qualified and trained staff for monitoring programs and data collection, and
- Monitoring programs are project-oriented lacking an integrated and continuous collection system.

Several types of project-oriented environmental data are collected in developing countries, but they are not stored digitally until very recently in a few developing countries like Turkey (Erturk *et al*., 2006). Geocoding and converting these into a computer readable form is a time consuming task with lots of troubles. Another problem is that some of the spatial data with temporally dynamic character such as land-use maps have not been updated. Aerial photography and remote sensing imagery are not routinely used, partly due to high costs and lack of availability. Furthermore, any information that might be available is difficult to gather. Official departments in developing countries are commonly described as 'watertight compartments' meaning that information of all types is closely held by the state officials at all levels in the organization (Baloch and Tanik, 2008). Hence, data collection, storage, and sharing opportunities are inadequate for watershed and water quality researchers due to scanty financial resources and absence of viable institutions and monitoring programs in developing countries. This constitutes a wide gap in the research for sustainable management of natural resources and integrated watershed management in developing countries. This study presents a case study where a widely used comprehensive model is applied for characterization of hydrologic regime and NPS pollution in a watershed under different land use and climate change scenarios. The issues relevant to application of a watershed model in developing countries are identified and analyzed.

2.4 Importance of Watershed Modeling for Developing Countries

There are several well-known general watershed models currently in use. Despite their comprehensive structure, many of these models have not yet become standard tools in hydrological and watershed management practice in developing countries (Mishra and Singh, 2004). However, despite having these inherent issues with data availability in developing countries, it cannot be denied that watershed models are essential and effective tools for investigating the complex nature of processes that affect surface and subsurface hydrology, soil erosion, and transport and fate of chemical constituents in watersheds and for assessing the impacts of land use changes, agricultural activities, and best management practices (Singh *et al*., 2005).

Developing countries have limited resources to spend on projects towards sustainable development. These resources must be utilized in the most efficient and productive manner. Simulation and optimization models at watershed scale help to give the best scenarios for rural development, water resources development and conservation, agricultural sustainability and forest conservation planning. A model simply reduces the chances of a planning decision that results in gross errors. Avoiding repetitive decision and policy plans can contribute to the sustainable development of developing countries. Watershed models provide inexpensive, repetitive and non-invasive questioning about hypothetical scenarios and can support education and research into physical processes (Shepherd *et al*., 1999). Unsound and unsustainable development in developing and under developed countries has the potential to cause serious disturbance of natural ecosystems, produce major impairment of the natural environment including water bodies, exploit indigenous communities and increase poverty. Models assist the collation and interpretation of information, upon which decisions can be made for the management of water resources (He *et al*., 1993).

As discussed above, available data in developing countries seriously lack entirety on a watershed basis partly because of limited financial resources for a continuous monitoring program. Once calibrated, watershed models may help to fill in the gaps in available data giving more representative information for decision making. Furthermore, developing countries cannot afford to have an extensive network of monitoring stations because of limited resources. Financial resources dictate the number of monitoring stations, hence only most critical points have to be recognized for continuous monitoring. Recognition of most critical points is only possible with the help of modeling.

Most of the developing countries rely on agriculture for their economic growth and sustenance. Excessive use of fertilizers and pesticides for increased yields has created the chronic problem of NPS pollutants. Eutrophication has become a major problem for water resource managers (Tim, 1996). Intensive agriculture is a source of nutrient run-off with pollutants that are of diffuse, chronic and distributed nature. Without considering the entire watershed over a long period of time, non-point pollutants cannot be evaluated in terms of agricultural practices in the watershed and their impacts on receiving waterbodies. The watershed approach varies over spatial and temporal scales, making it difficult to describe without watershed models.

A frequent consequence of poor natural resource management is the occurrence of natural disaster events such as droughts, tropical cyclones and floods. Natural resource degradation in developing countries has increased the occurrence and severity of such hazards. Sound land use planning is a key instrument for the control and mitigation of natural disasters. These disasters can only be mitigated or controlled by planning on the entire watershed basis, taking a broad, catchment-wide view of the causes and effects of disaster occurrence. Analysis of this cause and effect relationship necessitates watershed modeling for creating land use scenarios and studying their impacts on natural environment.

Considering the important role that watershed models can play in the conservation and management of natural resources mentioned above, it is very pertinent that ways to address data issues for application of watershed models in developing countries be researched to solve complex natural resources management problems. Although data scarcity constitute a major obstacle for watershed modeling in developing countries, however with whatever data available, watershed modeling on even a small sub-watershed scale will give a snapshot of the situation. A trend may be achieved for consideration in decision making when this snapshot is intelligently translated into a wider picture of the overall watershed.

2.5 Model Selection

Selection of a watershed model is an important decision not only because of the time and resources a modeling effort involves, but also because of the technical expertise required to maintain a model. Before selecting a model for a watershed modeling effort, it has to be seen whether the model that fulfills other selection criteria is a public domain model or a commercial model. Because the cost of current version of the selected model and the cost of its renewed versions that may be available in future is a major factor if it is to be used in a developing country. Furthermore, the selection of the model should encompass not only current level of detail, but should also consider the future needs. The selected model should provide the flexibility from simple to complex level of details. Hence, before selecting a model, watershed managers should determine the future needs of modeling, and if a particular model can fulfill the modeling needs of a number of future projects, it may be advantageous to use this particular model for a current project even when the model is less than optimal for the current application. USEPA (1992) advises that it is desirable to select a model that meets the most application requirements and has demonstrated applications and continuous support from the developer and user communities. Even if the model is not ideal, USEPA (1992) recommends that the user allow for the development of in-house expertise, rather than switching models from application to application.

The current generation of watershed models is quite diverse and varies significantly in data and computational requirements (ESCAP-UN, 1997; Chen, 2001; Singh and Woolhiser, 2002). Watershed scale models may be classified as physically based or conceptual model. In the former, all physical processes are described mathematically and such models are constructed from physically based representations of processes and use parameters determined from known watershed characteristics through measurements or by estimation. In the latter, the physical processes are simplified on the basis of empirical rules (Al-Abed and Whiteley, 2002; Hayashi *et al*., 2004). For a watershed in a developing country with limited data resources, the selection of a conceptual or calibrated–parameter model will ease the data requirements for model parameterization (Mishra and Singh, 2004). Furthermore, the selected model should be widely used and be supported with continuous development and improvement from the original developers and users groups (USEPA, 1992). For a modeler in a developing country, a widely used continuously worked on model provides easier application and critical evaluation owing to support provided by developers and user groups. If a model is not widely used, it becomes more difficult to establish credibility and to interpret its results. The various stakeholders involved in a project study must be willing to accept model results. For the characterization of hydrology and NPS pollution in a watershed of a developing country under data stringent conditions a widely used, watershed scale, distributed and continuous model will be most suitable that can comprehensively simulate hydrology, NPS pollution and water quality processes.

Review of relevant literature reveals that Hydrological Simulation Program-FORTRAN (HSPF) fulfills all the criteria listed above. It is a conceptual, distributed, continuous watershed model that can simulate the continuous, dynamic event, or steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed, with an integrated linkage of surface, soil, and stream processes (Al-Abed & Whiteley, 2002; Singh and Woolhiser, 2002; Hayashi *et al*., 2004; Singh *et al*.. 2005; Xu *et al.,* 2007). This model is one of the most comprehensive, flexible and modular programs of watershed hydrology and water quality available. Because of its modular design and organized development, watershed simulations in HSPF can range from the simple to the complex, and utilize a variety of methods, processes, and functions (Skahill, 2004). HSPF can simulate urban and agricultural land use, surface and subsurface processes, runoff, sediment export, and the fate and transport of nutrients, pesticides, and other water quality constituents (Bicknell *et al*., 2001). HSPF is a widely used model with an increasingly large user group available for support regarding model application. The applications since its initial release in 1980 have been worldwide and number in the hundreds (Donigian *et al*., 1999). HSPF is supported by USEPA and is incorporated into Better Assessment Science Integrating Point and Non-point Sources (BASINS) as its core watershed model in the form of WinHSPF. BASINS is a multi functional watershed analysis and modeling system developed by USEPA for watershed and water quality based studies (USEPA, 2007). It integrates data acquisition, data preparation, watershed characterization, application of models, interpretation model results, and development of maps and tables in the form of its data processing tools WDMUtil and GenScn, core model in the form of WinHSPF and Map Window platform for delineation and characterization of watershed using its Geographic Information Systems (GIS) capabilities (Tong and Chen, 2002). HSPF has been used successfully in modeling the stream hydrology and loadings of sediment, nutrients, and pesticides from agricultural lands (Diaz-Ramirez *et al.,* 2008; Hayashi *et al.,* 2004; Laroche *et al.,* 1996; Munson, 1998; Shirinian-Orlando *et al.,* 2007). The selection of HSPF is further justified by the availability of an expert system for calibration of HSPF, HSPEXP (Lumb *et al*., 1994) and a database of HSPF parameters from past calibration studies HSPF-Parm (Donigian *et al*., 1999) developed by USEPA to assist watershed modelers in calibrating HSPF. Considering limited resources in developing countries for collection of data for estimation of model parameters the availability of these tools is a major advantage for the usage of BASINS/HSPF for solving watershed scale environmental problems.

2.6 Application of BASINS/HSPF in Turkey

Republic of Turkey is a developing country as per United Nations Development Programme's Human Development Index classification (UNDP, 2007). Despite being a developing country, there have been efforts towards application of HSPF in Turkey. Albek *et al*. (2004) used HSPF for the hydrological modeling of Seydi Suyu watershed. Goncu and Albek (2007) studied the effects of climate change on the hydrology of watersheds by modeling climate change scenarios on a hypothetical watershed with different land use simulations using HSPF. Yuceil *et al*. (2007) used HSPF for development of a model support system for rural non-point sources modeling in the Koycegiz watershed.

This study expands the work by Yuceil *et al*. (2007) and introduces GIS capabilities of BASINS and expert system calibration tool HSPEXP to simulate and characterize hydrology and NPS pollution in the Koycegiz watershed. Koycegiz watershed is situated at the southwest of Turkey. It consists of Koycegiz Lake that is connected to the Dalyan channels and lagoon system that joins the Mediterranean Sea. The area is one of the most sensitive and vulnerable coastal regions of Turkey boasting an important ecosystem, a high diversity of species and intense biological activity. Due to its important ecological significance it has been declared a special protection region (Gurel *et al*., 2005). This special status has earned it a popular place for tourism and its conjugate businesses. Apart from tourism, agriculture and fisheries are the major economic activities of the inhabitants for their livelihoods. These three major functions rely heavily on the sustainability of natural resources in the watershed and the Koycegiz Lake–Dalyan lagoon system.

Tourism and agriculture are associated with an increase in NPS pollution. NPS pollution has a random nature due to lack of strictly defined spatial and temporal attributes to it causing difficulties in identifying its sources and loads (Dzikiewicz, 2000). However, it is very closely associated with hydrological processes in a watershed. Therefore, identification of critical sources of NPS pollutants and determination of its loads under different hydrological conditions is necessary in Koycegiz watershed for sustainable decision-making alternatives. Furthermore, the Koycegiz lake lagoon system provides a major source of fish species in the watershed and the Namnam stream is the major stream that feeds Koycegiz Lake (Yuceil *et al*., 2007). Stream regimes have hydrologic and hydrodynamic interactions with connected lakes and their analysis and evaluation may provide insights into unexpected hydrologic behavior, controls on lotic and lentic ecosystem processes, and guidance toward more appropriately managing watershed ecosystems (Arp *et al*., 2006). Therefore, it is imperative that the hydrologic behavior of the Namnam stream in the Koycegiz watershed that feeds the lake-lagoon system be characterized and analyzed for effects of upstream watershed processes and changes in precipitation and land use. This is important because the quantity and the quality of water fed into the Koycegiz Lake and lagoon system determines the species diversity and the health of fish in the system.

Recent work has tended to focus on the evaluation of the alteration of natural regimes by human intervention and climate change (Westmacott and Burn, 1997; Loaiciga *et al*., 2000), characterization of the physical flow conditions for sustainable aquatic habitats, classification of regime types at local level and effects of land use on hydrological response and hence diffuse pollution on the stream water quality. The Indicators of Hydrologic Alteration (IHA) is an analysis method for the assessment of degree of hydrologic alteration due to a man made or natural impact within an ecosystem. IHA is based upon an analysis of hydrologic data from existing measurement points within an ecosystem or model generated data (Richter *et al*., 1996). The method uses 32 different parameters organized into five groups to statistically characterize hydrologic variation within each year. These parameters provide information on some of the most ecologically significant features of surface and groundwater regimes influencing aquatic, wetland and riparian ecosystems. Five major characteristics of flow related to biological integrity namely magnitude, duration, frequency, timing and rate of change are incorporated in the IHA method. The IHA method was chosen for analyzing the alteration in the flow regime of the watershed as result of land use changes and climate change scenarios. As discussed above, limited research exists in Turkey that analyses decision scenarios based on the effects of watershed land use and climate change on hydrologic characteristics of the stream, NPS pollution loadings, and hence the environmental stressors and the economic functions of a watershed. This study attempts to fill in the gap in literature of such an analysis by incorporating decision support scenarios in a watershed model applied for the Koycegiz watershed in Turkey.

The application of a detailed watershed model BASINS/HSPF for the characterization of hydrology and modeling NPS pollution in an ecologically important watershed in Turkey under data stringent conditions using absolute minimum data helps identify the issues related to data quantity and quality required for the application of such model in a developing country. The data stringent conditions imply availability of only absolute minimum data required as inputs for running a model. These datasets may not have the appropriate consistency, continuity, temporal and spatial coverage and resolution however are available for enhancement and estimation procedures. The data deficiency issues in developing countries in general are similar as prevalent for this case study watershed in Turkey. Therefore, a detailed analysis of this application is assessed in terms of data requirements and an optimum model applicability pathway is proposed for modelers in developing countries.

3. RESEARCH TOOLS

3.1 Introduction

Watershed models have evolved to address basin wide, spatially distributed hydrologic and water quality issues that require analysis at the same scale. This has created a continuous need of data pre-processing, post-processing and visualization tools. Geographic information system (GIS) technologies that can facilitate data overlay, spatial query, map-linked database lookup, and data visualization are widely used as tools directly coupled with internationally recognized watershed models for simulation of watershed processes. The Better Assessment Science Integrating point and Non-point Sources (BASINS) modeling system presents a commendable response to the need of monitoring, modeling, and assessment on GIS-platform. BASINS couples multiple spatial and tabular database management tools, pre- and post-analysis tools, robust statistical and report-making tools, and terrestrial and aquatic runoff and pollution modeling tools within a single package. Hydrological Simulation Program-Fortran (HSPF) is the core model of BASINS. BASINS provides powerful modeling capabilities of HSPF in the form of a Windows version of HSPF (WinHSPF) that is a robust, highly complex mathematically based computer code developed under USA Environmental Protection Agency (USEPA) sponsorship to simulate water quantity and quality processes on a continuous basis in natural and man-made water systems. HSPF uses input meteorological forcing data and parameters that are related to system geometry, land cover , soil characteristics, and land-use activities (e.g., agricultural practices) to simulate the water quantity and quality processes that occur within a catchment.

This chapter briefly describes the capabilities and structure of the tools (BASINS and HSPF) that were used for the simulation of hydrology and diffuse pollution in the Koycegiz watershed.

3.2 BASINS Toolkit

BASINS is a multi functional watershed analysis and modeling system developed by USEPA for watershed and water quality based studies. It integrates data acquisition and preparation, watershed characterization, application of models, interpretation of model results, and development of maps and tables for integrated analysis of watershed based assessments of point and non-point sources using advanced model pre-processing and post-processing tools and Geographic Information Systems (GIS).

The latest version of BASINS 4.0 toolkit is built on the open source Map Window GIS platform making it the most comprehensive watershed modeling and analysis system available for free download. The BASINS modeling system comprises of the WinHSPF, PLOAD and AQUATOX modeling tools along with data processing softwares WDMUtil and GenScn. PLOAD is a GIS and spreadsheet tool to calculate nonpoint sources of pollution in watersheds. AQUATOX is a fate and effects model for aquatic ecosystems.

WinHSPF is the windows interface version of the Hydrological Simulation Program-FORTRAN (HSPF) which provides the core watershed modeling tool for point and nonpoint sources in BASINS 4.0. WDMUtil is used to manage and create the watershed data management files (WDMs) that contain the meteorological data and other time series data used by HSPF. GenScn is a model post- processing and scenario analysis tool that is used to analyze output from HSPF. The system architecture of BASINS with its core watershed model HSPF is shown in Figure 3.1 along with its major components. A Windows-based Climate Assessment Tool, for assessing potential impacts of changing climate on stream flows and pollutant loads has also been added as a "plug-in" program interfaced with WinHSPF (USEPA, 2007).

3.2.1 BASINS Data Download Tool

The BASINS system has a built-in data download tool with access to a variety of databases for US watersheds updated and distributed through the BASINS internet site (www.epa.gov/waterscience/basins). These databases are extracted and formatted to facilitate watershed-based analysis and modeling. The databases are organized using a uniform sharing and publication protocol (e.g. database structure and internal file formats) for each kind of data obtained and compiled from a number of federal agencies including United States Geological Services (USGS), United States Environmental Protection Agency (USEPA), National Oceanic and Atmospheric Administration (NOAA), etc. The data is selected based on the relevance to environmental analysis, national availability, scale and resolution.

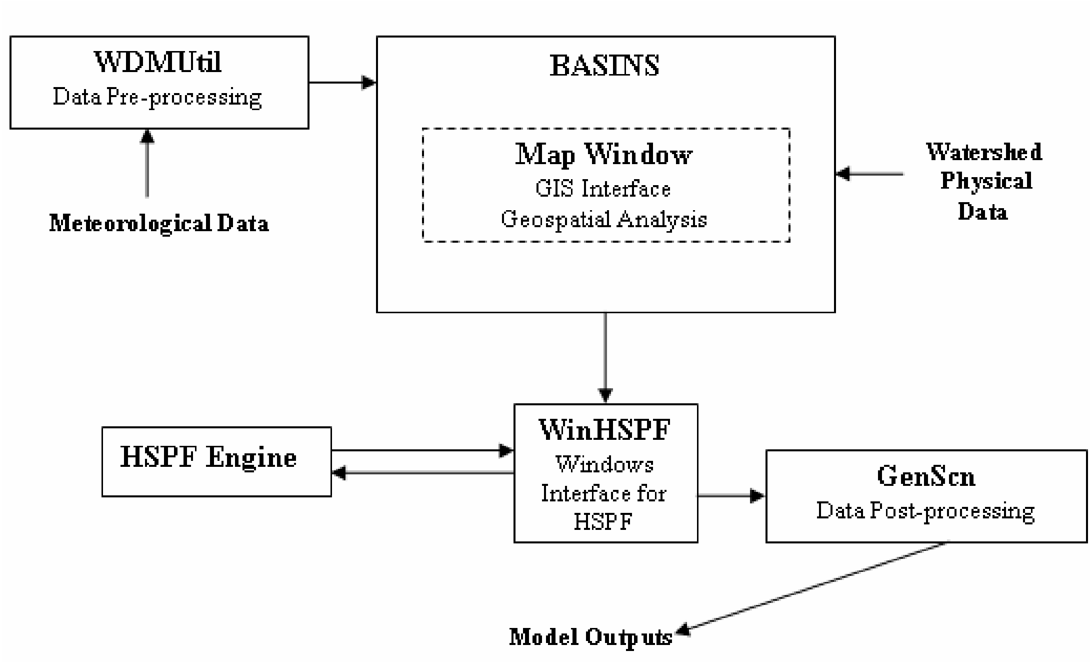

Figure 3.1: System architecture of BASINS modeling toolkit

The data is organized in such a way that data relevant to a specific Hydrologic Unit is readily downloadable identified by a unique hydrologic unit code (HUC) consisting of two to eight digits. These HUCs are based on the four levels of classification in the hydrologic unit system. The USA is divided and sub-divided into successively smaller hydrologic units which are classified into four levels: regions, sub-regions, accounting units, and cataloging units based on hydrological characteristics. The hydrological units are arranged within each other, from the smallest (cataloging units) to the largest (regions). In other words, HUC is the cataloging unit otherwise known as a watershed. The entire USA is divided into 2264 units (Seaber *et al*., 1987). The BASINS database download tool provides Base Cartographic Data, Physical watershed data, Environmental Monitoring Data, and Point Sources/Loading Data. Though the data downloaded using the database download tool of BASINS cannot be used outside USA, it is a useful feature for downloading complete datasets for training purposes in countries other than USA.

3.2.2 GIS Capabilities

The open source GIS software Map Window provides an integrative platform for characterization of a watershed using BASINS. It enables the visualization and integration of data sources with corresponding spatial characteristics of a watershed. The software has the ability to transfer and share GIS standard data (shape file, dbf, and GeoTiff) between other licensed GIS software. The GIS functions in the BASINS interface are provided by the different modules merged into the modeling system as plug-ins. The "GIS Tools" plug-in empowers advanced functional capabilities for analysis of rasters, vectors and images. "Watershed Delineation" plug-in is used to determine watershed boundaries and definition of sub watersheds and stream reaches. Similarly "Watershed Characterization" can be used to determine the geomorphologic characteristics used as input to different modeling tools available within BASINS. GIS shape files can be created and edited using the "Shapefile Editor" plug-in. The interface provides functionalities for advanced editing of data representation as maps and layers.

3.3 Core Watershed Model: HSPF

Watershed modeling or hydrologic simulation began in 1950s and 1960s with the advent of the digital computer. The exponential increase in the power of computers has revolutionized numerical simulation and statistical simulation ever since. The groundbreaking development of the Stanford Watershed Model (SWM) by Crawford and Linsley in 1966 (Crawford and Linsley, 1966) was just the beginning of an era that reflects advances in watershed models at an unprecedented pace. SWM was the first attempt to model virtually the entire hydrologic cycle. During the decades of the 1970s and the 1980s, a number of mathematical models were developed. Indeed, there has been a proliferation of watershed hydrology models since, with growing emphasis on physically based models.The HSPF model resulted from an EPA-funded comprehensive watershed model development effort that was conducted in the late 1970's. The effort involved integrating the field-scale EPA Agricultural Runoff Management model (ARM) (and the EPA Nonpoint Source Runoff model (NPS) models with the Hydrocomp Simulation Program (HSP), including HSP Quality. HSP was a descendant of the Stanford Watershed model. HSPF was first released publicly in 1980, as Release No.5. Currently, version 12 of HSPF is available as public domain software that can be downloaded from USEPA .

HSPF is generally classified as a lumped parameter model; however, the spatial variability in a watershed can be simulated if the watershed is appropriately subdivided into land segments that are perceived to exhibit a homogeneous hydrologic and water quality response.

HSPF can simulate at temporal scales ranging from minutes to days. Due to its flexible modular design, HSPF can model systems of varying size and complexity; for example, "from a parking lot to a three acre farm to the "Chesapeake Bay" (Munson, 1998). Depending upon available resources, an HSPF modeler has access to a number of different simulation algorithms at different levels of detail and sophistication. For example, with HSPF, one could model nutrient processes in a watershed using straightforward relationships based on water and/or sediment yield or by explicitly modeling the various nutrient transformations and associated transport. The simulation algorithms available within HSPF are a mixture of physically-based and empirical approaches.

User support, code maintenance, and further refinement and enhancement of the HSPF model are ongoing. Since its original development, the HSPF model has been applied in various climatic regions around the world. It has been applied throughout North America. Donigian *et al*. (1997) noted that HSPF "*is the only available model that can simulate the continuous, dynamic event, or steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed, with an integrated linkage of surface, soil, and stream processes.*"

Currently, HSPF is the core watershed model for USEPA's BASINS modeling system discussed above. WinHSPF is the latest version of HSPF with a windows interface that can be used as stand alone application or integrated with BASINS. The integration of Geographical Information Systems (GIS) and data processing capabilities within BASINS helps overcome many operational difficulties of HSPF DOS program (Version 11.0) that provided an unfriendly user interface known for its overwhelming expanse of model parameters and options, its extreme sensitivity to incorrect input formats, and its reliance on binary weather data files (Endreny, 2002).

3.3.1 General Description of HSPF

For an HSPF model, the watershed is subdivided into individual land segments that are assumed to produce a homogeneous hydrologic and water quality response. Factors that influence land segmentation for a typical HSPF model application include the meteorological forcing terms, characteristics of the watershed system itself (e.g., topography, geology, soils, land use, channel properties, etc.), and calibration endpoints, among others. A given land segment may contain one or many modeled sub-watersheds. A set of pervious land areas, directly connected impervious land areas, and reaches that may be open or closed channels, or completely mixed impoundments, constitute the land area and hydrography for a given land segment. A drainage area, or a sub-watershed, is associated with each specified reach. HSPF contains three application modules and five utility modules as shown in Table 3.1.

Table 3.1: HSPF Application and Utility Modules

APPLICATION MODULES		
PERLND	IMPLND	RCHRES
Snow	Snow	Hydraulics
Water	Water	Conservative
Sediment	Solids	Temperature
Quality	Quality	Sediment
Pesticide		Non-conservative
Nitrogen		BOD/DO
Phosphorus		Nitrogen
Tracer		Phosphorus
		Carbon
		Plankton

UTILITY MODULES						
COPY	MUTSIN	PLTGEN	DURANL	GENER	DISPLY	REPORT

The three application modules simulate the hydrologic/hydraulic and water quality components of the watershed. The utility modules are used to manipulate and analyze time-series data. Brief description of each of the modules is given below.

3.3.2 Application Modules

The three application modules are;

PERLND - Simulates run-off and water quality constituents from pervious land areas in the watershed.

IMPLND - Simulates impervious land area runoff and water quality.

RCHRES - Simulates the movement of runoff water and its associated water quality constituents in stream channels and mixed reservoirs.

PERLND simulates the water quality and quantity processes that occur on pervious land areas. It is the most frequently used part of HSPF. To simulate these processes, PERLND models the movement of water along three paths; overland flow, interflow, and groundwater flow. Each of these three paths experiences differences in time delay and differences in interactions between water and its various dissolved constituents. A variety of storage zones are used to represent the processes that occur on the land surface and in the soil horizons. Snow accumulation and melt are also included in the PERLND module so that the complete range of physical processes affecting the generation of water and associated water quality constituents can be represented. Some of the many capabilities available in the PERLND module include the simulation of water budget, snow accumulation and melt, sediment production and removal, nitrogen and phosphorous behavior, pesticide behavior, and movement of a tracer chemical.

IMPLND is used in urban areas where limited or no infiltration occurs. However, some land processes do occur, and water, solids, and various pollutants are removed from the land surface by moving laterally down slope to a pervious area, stream channel, or reservoir. IMPLND includes all of the pollutant wash off capabilities of the commonly used urban run-off models, such as the STORM, SWMM, and NPS models (USEPA, 1992).

RCHRES is used to route runoff and water quality constituents simulated by PERLND and IMPLND through stream channel networks and reservoirs. RCHRES can be used to model a number of processes including hydraulic behavior, water temperature, inorganic sediment deposition, scour, and transport by particle size, chemical partitioning, hydrolysis, volatilization, oxidation, biodegradation, and radionuclide decay, dissolved oxygen (DO) and biochemical oxygen demand (BOD) balances, inorganic nitrogen and phosphorous balances, plankton populations, and pH, carbon dioxide, total inorganic carbon, and alkalinity.

3.3.3 Utility Modules

The five utility modules are used to access, manipulate, and analyze time series information stored by the user in HSPF's Time Series Store (TSS) and Watershed Data Management (WDM) files. These time series, such as hourly precipitation, daily evaporation, daily stream flow, are used by the application modules and are often a valuable resource in the analysis of a watershed's characteristics. The five utility modules are:

- COPY - copy data in the TSS to another file,
- PLTGEN - generates a plot file for data display on a plotter,
- DISPLY - creates data display tables,
- DURANL - performs frequency, duration, and excursion analyses; computes statistics; and performs toxicity/lethality analysis, and
- GENER - permits the transformation of a time series to produce a second, different time series.

3.3.4 Support Software

The EPA, USGS, and others have developed several software programs to support HSPF model development and application. Among others, these include IOWDM (http://water.usgs.gov/software/iowdm.html), ANNIE (Flynn *et al*., 1995), METCMP (Flynn and Lumb, 1991), WDMUtil (USEPA, 2001), HSPFParm (Donigian *et al*., 1999), HSPEXP (Lumb *et al*., 1994), WinHSPF, GenScn (Kittle *et al*., 1998), the HSPF interface within the Watershed Modeling System (WMS) developed jointly by the USACE Waterways Experiment Station and Brigham Young University (Brigham Young University, 1999), and the model-independent parameter estimation tool PEST (Doherty 2002; Doherty and Johnston, 2003). With the exception of the WMS, all of the above-noted software is in the public domain. The following support softwares have been used in this study:

- WDMUtil
- HSPFParm

- HSPEXP
- GenScn
- WinHSPF

In addition, as discussed above HSPF is the nonpoint source model interfaced within the public domain BASINS modeling system developed and freely distributed by the EPA's office of water to support Total Maximum Daily Load (TMDL) analysis.

3.3.5 Capabilities and Limitations

Donigian *et al*. (1995) listed several potential applications and uses of the HSPF model:

- Flood control planning and operations,
- Hydropower studies,
- River basin and watershed planning,
- Storm drainage analyses,
- Water quality planning and management,
- Point and non point source pollution analyses,
- Soil erosion and sediment transport studies,
- Evaluation of urban and agricultural best management practices (BMPs),
- Fate, transport, exposure assessment, and control of pesticides, nutrients, toxic substances, and
- Time-series data storage, analysis, and display.

USEPA (1992) lists documented strengths and weaknesses of the HSPF model. Strengths include its comprehensive treatment of watershed-scale hydrologic and water quality processes, flexible design, widespread applicability, sustained support by both the EPA and USGS, and its companion WDM file and utility software. Weaknesses listed include, among others, its lumped parameter approach, uni-directional treatment of flow hydraulics, limited treatment of the urban drainage system, lack of comprehensive parameter guidance, extensive data requirements, and the user training that is typically required to operate the model. One of the notable strengths of the HSPF model is its ability to account for the land use distribution within a given modeled watershed. This information, or a blending of this information with other data describing the watershed, serves as a basis for part of the model parameterization process.

3.4 Data Requirements

Data requirements for an HSPF model application can be grouped into three broad categories (Munson, 1998) namely physical watershed-specific data, meteorological data and calibration data. Physical watershed-specific data that include elevation, channel geometry, soils, vegetation, and land use and land cover (LULC) are necessary to adequately describe the watershed. In developed countries these data can be obtained from Geographical Information System (GIS) databases and regulatory agencies. In developing countries however due to lack of systematic databases some of these data may be obtained through the use of historical records of metereology, topographical, landuse and soil maps, while for others field observations, and data collection may be needed.. The built-in GIS capabilities of BASINS allow for mapping and evaluation at multiple scales.

Meteorological time series data requirements for the HSPF model vary depending upon which processes are modeled. USACE and USEPA (2000) list the meteorological time series data requirements for various individual compartments within the PERLND, IMPLND, and RCHRES application modules. In general, HSPF requires six meteorological time series to model stream flow. These include precipitation, potential evapotranspiration, air temperature, dew point temperature, wind speed, and solar radiation. Water quality simulations also require time series of cloud cover. Empirical data are required to calibrate and validate processes simulated by HSPF. These data are not input to HSPF, but are used to evaluate model performance. A detailed data analysis for BASINS and its core watershed model HSPF used for this study is presented in the next chapter.

3.5 Application of BASINS/HSPF

BASINS was developed by USEPA as an umbrella modeling system for determination of Total Maximum Daily Loads (TMDLs) in individual water bodies pursuant to its goals for reducing water pollution. The integration of BASINS with modeling softwares Hydrological Simulation Program-FORTRAN (HSPF) and Soil and Water assessment Tool (SWAT) and PLOAD necessitates utilization of its advanced pre and post processing capabilities for application of aforementioned models. The application of BASINS as a watershed analysis and water quality modeling system in US has been widely cited in the literature (Carrubba, 2000; Bergman *et al*., 2002; Endreny *et al*., 2003; Elkaddah and Carey, 2003; Im *et al*., 2004; Shirinian-Orlando and Uchrin, 2007; Choi and Deal, 2008).

Ackerman *et al*. (2005) assessed the performance of HSPF in arid environments in Southern California testing its ability to predict annual volume, daily average flow, and hourly flow. Daily flow predictions correlated well with measured flow following rain events, but predictions were poor during extended dry weather periods in the developed watershed. It was observed that this modeling difficulty during dry-weather periods reflected the large influence of, and the poor accounting in the model for, artificially introduced water from human activities, such as landscape overwatering, that can be important sources of water in urbanized and environments. Ribarova *et al*. (2008) modeled the nitrogen and phosphorus concentrations in the Iskar River, Bulgaria, to test the ability of HSPF to describe nutrient pollution during a first flood event. They conclude that further application of the HSPF model may be valuable in providing a better understanding and in forecasting nutrient concentrations during first flood events. Al-Abed and Al-Sharif (2008) calibrated the hydrological component of the Hydrological Simulation Program-FORTRAN (HSPF) model for the Zarqa River Basin, which is considered as the largest watershed in Jordan. The calibration of the HSPF water quantity parameters was aided by GIS and by the automatic calibration model (PEST). The coefficient of determination, R-2 for the calibration and verification years of the monthly flows was 0.81 and 0.76, respectively. Diaz-Ramirez *et al*. (2008) used HSPF in interface with BASINS version.3.0 to study hydrology, soil erosion, and sediment transport of the Rio Caonillas watershed in Puerto Rico. The study demonstrated that HSPF is capable of stimulating hydrology and suspended sediment in the river for tropical island watersheds, principally for analysis on a monthly basis. Mishra *et al*. (2007) employed HSPF for simulating runoff and sediment yield during the monsoon months (June-October) from a small watershed situated in a subhumid subtropical region of India. They concluded that the model parameters obtained in this study could serve as reference values for model application in similar climatic regions, with practical implications in watershed planning and management and designing best management practices.

Apart from above mentioned studies, watershed modeling tools within BASINS especially HSPF has been successfully applied as stand alone application in Canada (Laroche *et al*., 1996), Australia (Rahman and Salbe, 1995), Turkey (Albek *et al*., 2004), Greece (Tzoraki and Nikolaidis, 2007) and China (Hayashi *et al*., 2004) for understanding watershed hydrology and identification of diffuse pollution on a catchment scale. However, BASINS has not been applied frequently in countries outside USA because of the intrinsic design and setup of data download tool for watersheds in USA. As has been discussed above, the data download tool is not the only tool available in the application packs of BASINS. It provides a convenient means of accessing data in a model compatible format without any effort other than clicking on the download button; however, BASINS is not about data availability only. The data manipulation tools WDMUtil and GenScn can be used for data operations once the data is reformatted for use with these softwares. The GIS capabilities may be used to characterize watershed, and for preparation, the input files for model execution. This study utilizes local data obtained from national local sources and uses the data analysis and processing tools in BASINS for application of HSPF.

4. CASE STUDY WATERSHED AND DATA ANALYSIS

4.1 Koycegiz - Case Study Watershed

The Koycegiz-Dalyan Watershed is situated in the southwest of Turkey as shown in Figure 4.1, hosting the Koycegiz Lake that joins the Dalyan Lagoon, which joins the Mediterranean Sea. It is a unique area with special ecological, historical and recreational characteristics. It is one of the most sensitive and vulnerable coastal regions of the country in terms of endangered and endemic species (Gurel *et al*., 2005).

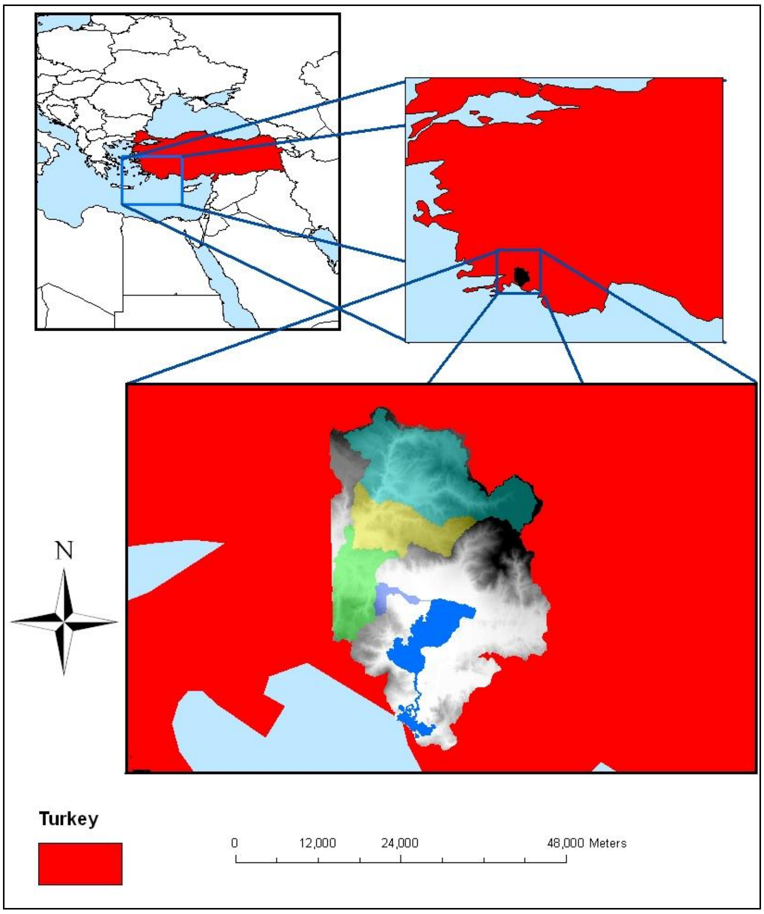

Figure 4.1: The geographical location of the Study Area

The watershed hosts a population of almost 45,000 population mainly dealing with agriculture, tourism and fishery, but there is no significant industrial activity in the region. The geology of the watershed bears karstic characteristics. The seasonal groundwater variations are 0.05–6.55m between May and November. The groundwater discharge of the plains happens in two ways: artificial discharge and groundwater flow straight to the sea (Bayari *et al*., 1995). Main rivers that feed Koycegiz Lake are Namnam and Yuvarlakçay. The only outlet of the Koycegiz Lake is Mediterranean Sea through Dalyan Lagoon Channel System.

The area shows predominantly rural characteristics with three major human functions namely fishery, tourism, and agriculture. The main crops raised are citrus fruits, cotton, corn, horticulture, and wheat. The pesticide usage is rather diverse in the region, with 42 different types of pesticides regularly applied. Agricultural and tourism activities conflict with fishery function due to the boat traffic along the channels where the fishery takes place, and agricultural activities on the fertile lands pollute the aquatic environment via use of pesticides and chemicals conveyed by irrigation (overland flow) and interflow, which conflicts with fish growth in the neighboring fishery facilities. Natural and ecological reserves improve tourism functions; however, increases in tourism enhances pollution in the water body and deteriorate the pristine regions of the environment as well as the living habitat. Gurel *et al*. (2005) present detailed information about the environmental, socio-economical and sectoral characteristics of the Koycegiz watershed.

4.2 Data Analysis

The term 'Data' refers to measurements and/or observations required for characterization and representation of physical watershed, the magnitude and temporal aspects of agents of change and resulting processes within it. For the application of BASINS/HSPF for watershed modeling the watershed data may be classified into three types namely parameter estimation data, Forcing data and model verification data. Table 4.1 lists the data requirements for the hydrologic and water quality modeling using BASINS/HSPF.

4.2.1 Parameter Estimation Data

This information is required for characterization and representation of physical aspects of the watershed defined by parameters mainly related to topography, soil characteristics, land use and agricultural practices with definite space and time attributes. The major data groups within this type of data are geologic, geomorphologic, agricultural, hydraulic and hydrological data. An abundance of this kind of data in a finer resolution will result in a better representation of watershed and a more intricate analysis of watershed processes. BASINS uses the digital elevation model (DEM) of the watershed for its delineation and extraction of stream network. It also uses land use/cover map along with hydrologic soil classification maps to characterize the watershed into sub-basins or hydrologic response units (HRUs) of homogenous characteristics.

Table 4.1: Data Requirements for Hydrologic and Water Quality Modeling using BASINS/HSPF

Data Type	Constituents
Parameter Estimation Data	Digital Elevation Model (DEM) Hydrologic Soil Groups Map Soil Characteristics Land Use Map Vegetation Types Vegetation Density Vegetation Root Depth Ground Water Geology Stream Channel Characteristics Stage Discharge Rating Curves Isohyetal Map For The Watershed Fertilizer Application Data Pesticide Application Data Crop Pattern Base Flow Inter Flow Stream Aquifer Interaction Data Groundwater Table Depth
Forcing Data	Precipitation Evaporation Evapotranspiration Maximum Temperature Minimum Temperature Mean Temperature Solar Radiation Cloud Cover Wind Velocity Dew point Temperature Point Source Pollutant Data
Model Verification Data	Flow Rates Stage Measured Pollutant Data

For the Koycegiz watershed, 1:25000 scaled digitized maps in AutoCAD drawing exchange file format were obtained from the National General Command of Mapping. The digitized topographical maps were converted into a 30m DEM raster grid for the entire Koycegiz watershed. Land-use maps for the Koycegiz watershed were obtained from the General Directorate of Rural Affairs under the Ministry of Agriculture and Rural Affairs of Turkey. Hydrologic soil classification map was not available for the watershed. The DEM and the developed land use map are shown in Figure 4.2.

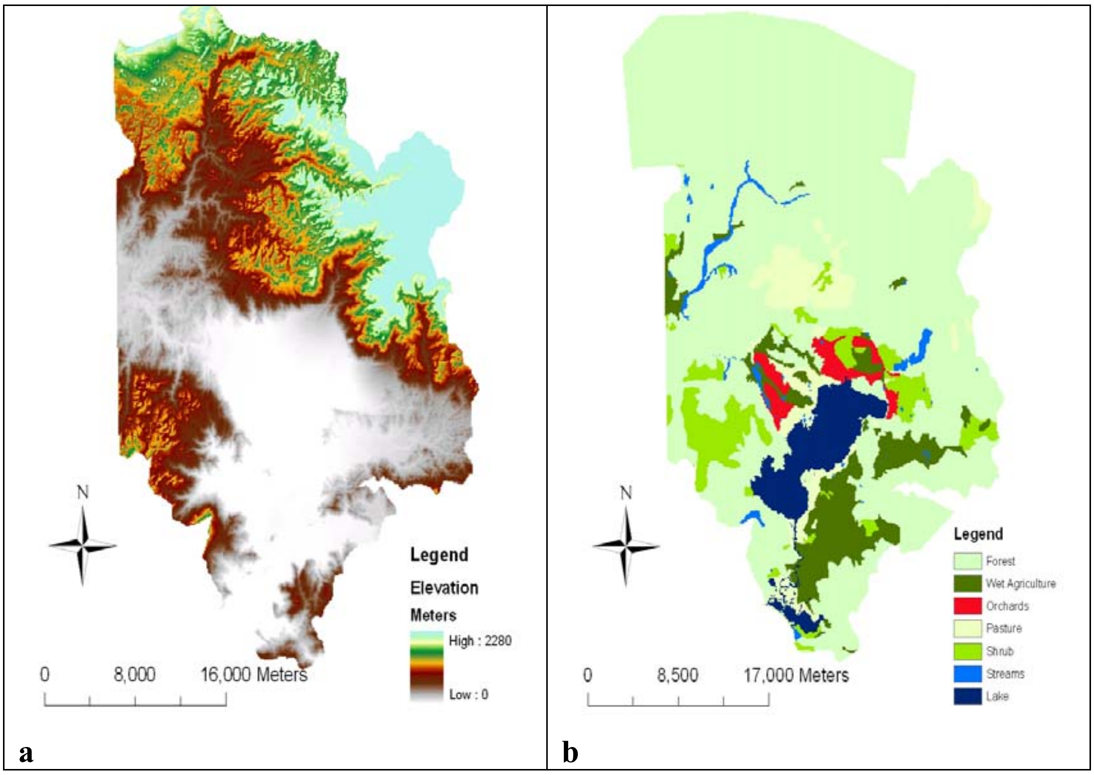

Figure 4.2: Koycegiz Watershed a) Digital Elevation Model b) Land use/ cover map

4.2.2 Forcing Data

Forcing data refers to information related to events that drive watershed processes. The major constituents of this kind of data are spatial and temporal attributes of hydro-meteorological events like precipitation, evaporation, temperature, solar radiation, wind velocity, etc. This is the main input to a watershed model, because as the name suggests this data is required for execution of a model run as it forces watershed processes.

HSPF requires meteorological time series of precipitation, potential evapotranspiration, air temperature (maximum and minimum), dew-point temperature, wind velocity, and solar radiation to simulate the components of the watershed hydrology. Meteorological time series for Precipitation, Evaporation, Average Humidity, Wind Speed, Wind Direction and Temperature were purchased from the State Meteorological Works (SMW) for the five stations within and surrounding the watershed. The meteorological analysis was carried out by Yuceil *et al*. (2007), and Koycegiz Station was selected as the most representative meteorological station for the Koycegiz watershed. Solar radiation and potential evapotranspiration were computed using the built in computation feature within the WDMUtil component of BASINS. Maximum and minimum temperature were estimated from 8 hourly measured temperature using a correlation between maximum temperature and the 8 hourly temperature, and minimum temperature and the 8 hourly temperature for the year 1998, for which measured maximum, minimum and mean air temperatures were available. Dew point temperature was estimated using Magnus-Tetens formula from the humidity measurements (Lawrence, 2005). Solar radiation was computed using monthly average values of cloud cover for the watershed in WDMUtil computation tool. Evaporation data was available for the months of April to December. The missing data were estimated using Penman pan evaporation computation feature within WDMUtil.

The available datasets from Koycegiz watershed are tabulated in Table 4.2. Many of the datasets required for modeling objectives were computed from measured datasets as shown in Table 4.3.

Table 4.2: Measured Meteorological Data available for Koycegiz Station

PARAMETER	TIME INTERVAL
Total Precipitation (mm)	Daily, 0700, 1400 and 2100 measurements
Total Evaporation (mm)	Daily except for the months of January, February, March and December
Average Humidity (%)	Daily, 0700, 1400 and 2100 measurements
Average Humidity (%)	Daily (From Hydrograph)
Wind Speed (m/s)	Seven Hourly measurements at 0700, 1400 and 2100 hrs
Wind Direction	Seven Hourly measurements at 0700, 1400 and 2100 hrs
Temperature (Deg C)	Seven Hourly measurements at 0700, 1400 and 2100 hrs
Cloud Cover (0-10)	Monthly Average

4.2.2.1 Estimation of Maximum and Minimum Temperatures

As the data for maximum and minimum air temperatures for the Koycegiz metereologic station were not available, therefore, an estimation was to be carried out based on some acceptable reasoning. As the measured temperature for 07:00, 14:00 and 21:00 were available a comparative analysis was carried out by sorting the maximum and minimum temperatures among the three available datsets. It was found that the measured temperature at 14:00 hours was most likely the maximum temperature among the measured seven hourly temperatures. Similarly, temperature measured at 07:00 hours was the most likely minimum temperature. The measured maximum, minimum and average temperatures for the year 1998 were available alongwith the seven hourly measured temperatures. A factor "F" was defined as under and estimation for maximum, minimum and mean air temperatures for the rest of the data years was carried out as given below:

Daily Maximum Temperature 19XX= 1400 Temperature 19XX * F

Where

F= (Max Temperature 1998 in Kelvin / 1400 Temperature1998 in Kelvin)

and

Daily Minimum Temperature19XX= 0700 Temperature 1999 * F

Where

F= (Min Temperature 1998 in Kelvin / 0700 Temperature1998 in Kelvin)

Similarily

Daily Average Temperature19XX = Mean Temperature 1999 * F

Where

*F= (Daily Average Temperature 1998 in Kelvin / MeanTemperature1998 in Kelvin***)**

(Mean Temperature = temperature measured at 0700, 1400 and 2100 divided by 3)

4.2.2.2 Estimation of Dewpoint Temperature

For the estimation of dewpoint temperature, the following algorithm based on the Magnus-Tetens formula (Lawrance, 2005) to calculate the dew point in degrees Celsius to within ±0.4 °C is used. It is valid for

$0\ °C < T < 100\ °C$

$0.01 < RH < 1.0$

$0\ °C < T_d < 50\ °C$

Where,

T = temperature in degrees Celsius

RH = is the relative humidity as a fraction (not percent)

T_d = the dew point temperature to be calculated

The formula is:

$$T_d = \frac{b\,\gamma(T,RH)}{a - \gamma(T,RH)} \qquad \textbf{(4.1)}$$

Where,

$$\gamma(T,RH) = \frac{a\,T}{b+T} + \ln RH \qquad \textbf{(4.2)}$$

a = 17.27

b = 237.7 °C

ln is the natural logarithm.

The required daily values of relative humidity and temperatures were utilized for calculation of the daily values of dewpoint temperature.

Table 4.3 lists the computed time series and the required input time series for their computation. Different methods may be available for computation of a specific required time series. The method chosen depends on available measured data and its usage in technical literature. For example Potential Evapotranspiration (PET) may be computed using Hammon's or Jensen's methods based on the availability of measured or computed solar radiation.

Table 4.3: Computed and required input Time Series in WDMUtil

Computed Time Series	**Input Time Series**
Solar Radiation	Cloud Cover, Latitude
Daily Jensen PET	Min Air Temp., Max Air Temp., Solar Radiation
Daily PET Hammon	Min Air Temp., Max Air Temp., Latitude
Daily Penmen Pan Evaporation	Min Air Temp., Max Air Temp., Dew point Temperature, Wind Movement, Solar Radiation
Wind Travel	Wind Speed
Percent Cloud Cover	Percent Sun
Dew point Temperature	Mean Temperature, Relative Humidity
Min Air Temp., Max Air Temp.	Seven Hourly measurements at 07:00, 14:00 and 21:00 hrs

4.2.3 Model Verification Data

The model verification data is required for assessment of model generated results over a span of time for a specific variable at a specific location. This data is 'observed data' for the variable and is used to judge the closeness of fit between model simulated results and actual data. This is also known as calibration data. Examples may be flow data or water quality data for calibration of a hydrology or a water quality model.

HSPF requires hydrological time series of runoff, sediment yield, and water quality constituents' measurements for model calibration and validation. As a result of flow rate, sediment, and water quality data investigations, only some flow rate data sets for Namnam and Yuvarlak streams within the watershed were retrieved from the National State Hydraulic Works (SHW). These data sets comprised measurements from a single monitoring station on Namnam stream from 1980 to 1986, and from 1990 to 1999. Another set of measurements was from a station run by the General Directorate of State Electrical Works (SEW) on Yuvarlak Stream through 1960-1964 and 1966-1968. Sediment and water quality data could not be retrieved for any of the streams in the watershed. These data, on average, were measured on a daily basis at the watershed outlet. Furthermore, on-site observations, communication with experts, and literature review (Gonenc *et al.*, 2002) showed that Yuvarlak stream had significant groundwater contributions to its flow. As there were no reliable data present for groundwater flow, it would be extremely problematical to calibrate the water budget at this basin. The data for Yuvarlak stream was also less preferable due to fewer number of measurements and their discontinuous pattern. Namnam stream is the largest stream, with its basin representing 55% of the entire Koycegiz-Dalyan watershed and 62% of the Koycegiz Lake sub-watershed. Namnam data sets present a longer time series and are considerably up-to-date. Namnam is much preferable in terms of the groundwater intrusion problem. The basin system shows a flow pattern that is primarily precipitation mandated. Groundwater contribution is assumed to be less significant, as majority of its huge basin is covered with a very shallow soil cover with an impervious rock formation underneath. Hence, even without the groundwater flow data, it would be more possible to calibrate and validate a hydrological model on this basin. As a result of the arguments presented above, it was decided that the extent of the model application should be limited to the Namnam sub-basin and its stream system.

4.3 Data Conversion

One of the major redundancy factor preventing scientists from developing countries to indulge in watershed modeling research using advanced tools is data compatibility or for that matter non compatibility. The modeling tools require input data in a specific format. This is a major step in developing countries where data is gathered from different sources lacking a common format. The following sections describe the data conversion steps involved for the Koycegiz watershed data.

4.3.1 Topographic Data

The topographical data in BASINS is required in DEM raster grid format. A DEM is a raster of elevation values. Rasters define the world as a regular set of cells in a grid pattern. Typically, these cells are square and evenly spaced in the x and y directions. In a DEM raster grid the elevation is represented by the attribute value associated with each cell location (Bolstad, 2003). The National General Command of Mapping provided digitized versions 1:25000 scaled maps in AutoCAD drawing exchange file format. The digitized topographic maps were converted into a 30 m DEM raster grid for the entire Koycegiz watershed.

4.3.2 Land Use Data

Land use maps for the Koycegiz watershed were obtained from the General Directorate of Rural Affairs under the Ministry of Agriculture and Rural Affairs of the Republic of Turkey. The Geographic Information Retrieval and Analysis System (GIRAS) and the National Land Cover Data (NLCD) land–use/cover classification systems are used for application GIS applications within BASINS and its core models. However, a user defined land-use/cover classification may also be provided that may require additional steps for integration with model network development. The land-use classification of the available land-use map for the Koycegiz watershed was not compatible with the above mentioned classification systems. For easier integration with model network development, the land use map was modified based on the GIRAS land use/cover classification.

4.3.3 Meteorologic and Flow Data

To create time series in WDM format using data from an external source requires performing a data import step in WDMUtil program. Hence imported data can then be used by BASINS and its affiliated models including HSPF. The available meteorological data obtained from SMW is in ASCII format in text files where the time based data were presented by a cross table. The cross table presents daily values of an annual data set separately for each year. Each daily value is placed in cross table with 12 columns (months) and 31 rows (days), where its position reveals the exact date that record belongs as shown in Figure 4.3.

T.C.
B A S B A K A N L I K
DEVLET METEOROLOJI ISLERI GENEL MUDURLUGU
Elektronik Bilgi Islem Mudurlugu
ANKARA

ISTASYON ADI : KOYCEGIZ
ISTASYON NO :17924
YIL :1999

GUNLUK TOPLAM YAGIS (mm)

GUN	OCAK	SUBAT	MART	NISAN	MAYIS	HAZRN	TEMMUZ	AGUST	EYLUL	EKIM	KASIM	ARALK
1		7.5		6.0								
2		16.6							36.3			
3				5.2		0.5			0.8		0.2	
4	42.1			19.1								
5	58.0			9.0								
7		51.0										
8		16.5		0.5								
9		17.1	6.0									
10		1.4										
11	0.6	7.4										
12				13.4								20.8
13		16.8		5.8								32.3
14		10.2		0.4					0.6			12.1
15	17.0	3.7		0.2		0.3					8.7	2.3
16	1.3										0.6	
17		4.6										
18		16.4								16.1		
19		11.4							0.3		18.0	
20			28.0									
21			5.6								0.2	
22	0.6	8.4	0.6									
23		1.9										26.2
24		34.1								11.4	8.4	1.7
25		1.6	10.9		0.6			39.6			0.5	
26	6.1											
27	7.1			0.2		1.5						7.8
28	2.6		9.0			1.0						10.4
29	39.4		14.1									16.0
30	61.0		30.8									1.9
31	25.2		22.5									2.3

Figure 4.3: Daily precipitation Data as provided by SMW

Despite the practical advantage of compact presentation of entire annual data in a single table, the raw data obtained from SMW needed to be converted to a WDMUtil compatible format as WDMUtil package uses a linear record based system. Thus, in order to transform these data sets into linear data tables structure a Microsoft Excel spreadsheet application was developed by using Visual Basic for Applications macro programming language. With this application, all meteorological data sets were transformed into linear records and tab delimited text files for each parameter were created compatible for importing them to WDMUtil shown in Figure 4.4.

1/1/1999	0
1/2/1999	0
1/3/1999	0
1/4/1999	42.1
1/5/1999	58
1/6/1999	0
1/7/1999	0
1/8/1999	0
1/9/1999	0
1/10/1999	0
1/11/1999	0.6
1/12/1999	0
1/13/1999	0
1/14/1999	0
1/15/1999	17
1/16/1999	1.3

Figure 4.4: Sample delimited text file for importing to WDMUtil

All time series are read into WDMUtil using a data import scripting language. A user interface, or wizard, for developing data import scripts is included in WDMUtil.

When a file is specified to be imported, a list of available scripts is displayed. If the user knows that a specific script will properly process the imported data as is usually indicated with a green highlight, they may select that script and run it to read the data. If no script exists for the data imported, the wizard may be used to develop a new script or the user may develop the script with a text editor.

4.4 Data Quality Issues

The discussion above has so far been related to the availability and acquisition of data and its conversion to a model input format. However, one of the major factors in data acquisition has been the quality of the acquired data. To begin with, the entire Koycegiz watershed has one metereological station, namely Koycegiz within its physical boundaries. The main boundaries of the watershed are; the northern high mountains with parallel alignment to the Mediterranean Coastline, which forms the southern borders and high hills and steep slopes on the east and the west. Koycegiz meteorological station is located in the flatter plains of the watershed. After a detailed analysis of the surrounding four stations that were physically located outside the boundaries of the watershed, Koycegiz station was found to be the most representative of the precipitation regime in the watershed. The fact that it is the best among what is available does not necessary mean that it represents the entire watershed. Especially, the northern high mountains might be responsible for precipitation not accounted for by the meteorological station located in the plains. Similarly, the evaporation data for the Koycegiz station obtained from SMW did not include measurements from December to March. The missing data were estimated using the built-in computation features of WDMUtil.

5. WATERSHED MODELING STRATEGY USING BASINS AND HSPF

5.1 Introduction

This chapter describes the steps involved in the application of BASINS and HSPF for the simulation of watershed hydrology and non point source pollution in the case study watershed of Koycegiz. Furthermore, it also describes the development of scenarios for the study of the impacts of climate and land use changes on the hydrologic regime of Namnam stream and the NPS loadings within the watershed.

Data analysis and input data preparation for the application of BASINS and HSPF were discussed in the previous chapter. WDMUtil, support software of BASINS was used for data pre-processing. The major step after data analysis is the creation of model setup for subsequent definition of system boundaries and identification of its components. This step is carried out by using BASINS for the delineation and characterization of the watershed. Once the boundaries have been defined and its components and their characteristics have been identified, the simulation step can be initiated. For this study, the simulation step consisted of using HSPF for hydrological modeling, NPS modeling and scenario analysis for decision support analysis. The hydrological model was calibrated using HSPEXP. The NPS pollutant loads could not be calibrated due to lack of measured water quality monitoring data. Land use change and changes in precipitation regime due to global climate change based on prediction estimates from literature were incorporated into the model and simulated. The model results were analyzed using GenScn support software of BASINS. The modeling processes and the softwares used are shown in Figure 5.1.

5.2 Application of BASINS

5.2.1 Watershed Delineation

Watershed delineation refers to the process of creating the boundaries of a watershed based on the extent of the contributing area for a particular control point or outlet. Watershed delineation is part of the process known as watershed segmentation that divides the watershed into discrete land and channel segments for watershed behavior analysis. Delineation is required for characterization of the watershed and preparation of HSPF modeling input files.

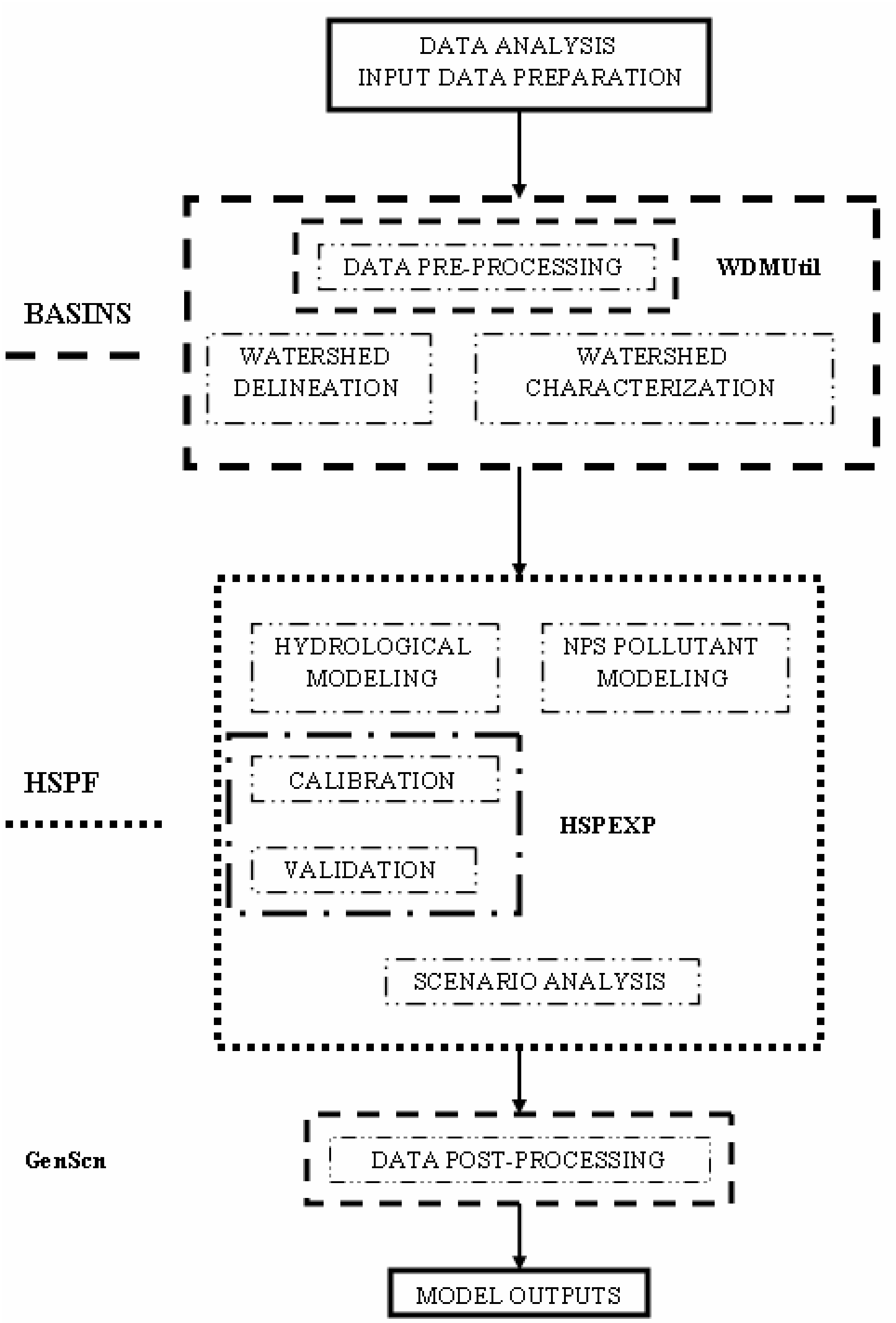

Figure 5.1: Modeling Process for Koycegiz Watershed

BASINS bears two built-in tools for delineation of watersheds. A watershed may be delineated manually or an alternative DEM based automatic delineation tool may be used for defining the boundaries of the watershed. Automatic Watershed Delineation

(AWD) tool of BASINS was used for delineation of Koycegiz watershed. AWD utilizes Terrain Analysis Using Digital Elevation Models (TauDEM) algorithm developed by Tarboton (1997). TauDEM is a set of tools for the analysis of terrain using DEM. The functions provided by TauDEM algorithm for watershed delineation are briefly discussed below. The processes involved in the TauDEM algorithm are shown in Figure 5.2 and are described briefly in the following section.

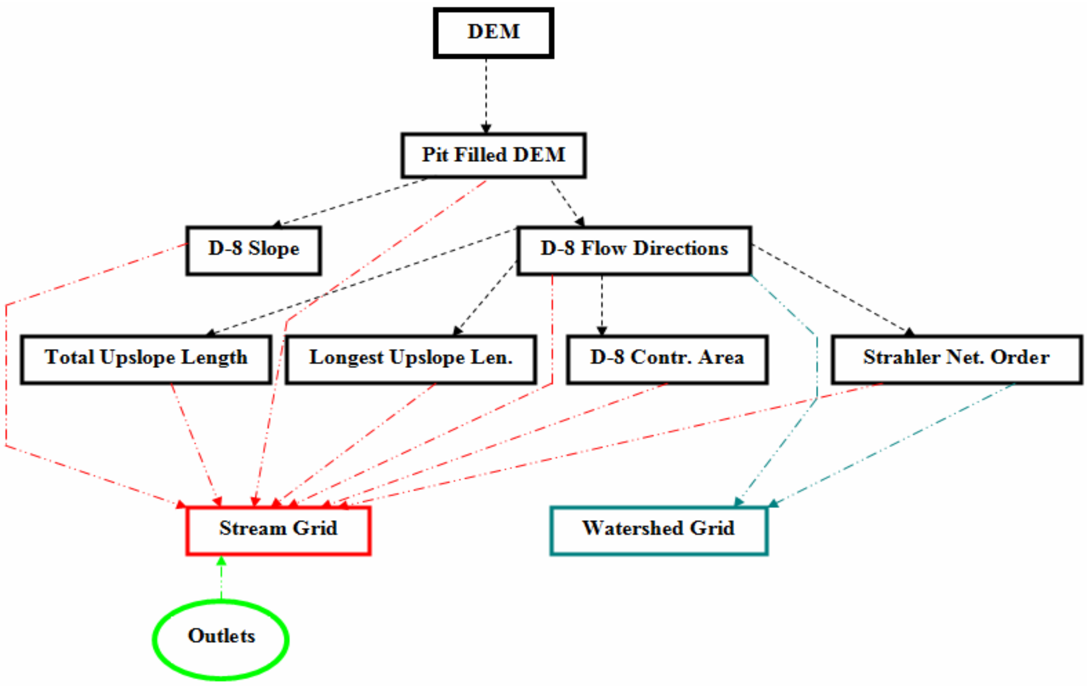

Figure 5.2: TauDEM Processes

5.2.1.1 Pit Filling

The first step in any of the hydrologic modeling tools is to remove the pits or the sinks in the elevation grid. Pits or sinks are low elevation areas in DEMs that are completely surrounded by higher terrain that do not drain out anywhere. The reason that sinks need to be filled in is because a drainage network is built that finds the flow path of every cell, eventually off the edge of the grid. If cells do not drain off the edge of the grid, they may attempt to drain into each other, which will lead to an endless processing loop. They are removed by raising their elevation to the point where they drain off the edge of the DEM. Figure 5.3 a shows a sink in the DEM that might cause an endless processing loop. This pit or sink has been filled by raising its elevation shown in Figure 5.3 b so that all cells have an outlet cell of equal or lower elevation. The pit in the original DEM and the filled DEM are highlighted in bold italic in the Figure.

14	12	5	9
12	10	***4***	12
13	8	7	8
14	13	12	11

a

14	12	5	9
12	10	***5***	12
13	8	7	8
14	13	12	11

b

Figure 5.3: (a) Original DEM with pit, (b) Pit filled DEM

5.2.1.2 Determination of Steepest Slope

Slope is evaluated in the direction of steepest descent and is reported as drop/distance, i.e. tangent of the angle. Flow direction is reported as "no data" for any grid cell adjacent to the edge of the DEM domain, or adjacent to a no data value in the DEM.

5.2.1.3 Determination of Flow Directions

Flow direction of each individual cell in a grid determines the direction of drainage of a landscape. The D8 algorithm (O'Callaghan and Mark, 1984) is a single flow direction algorithm that assigns flow direction from each grid cell to one of its adjacent or diagonal neighbors is calculated using steepest descent. The encoding is shown, i.e. 1-East, 2-North East, 3-North, 4-North West, 5-West, 6-South West, 7-South, 8-South East in Figure 5.4. An alternative method Dinf approach (Tarboton, 1997) may also be selected for determination of flow direction. The Dinf assigns a flow direction based on steepest slope on a triangular facet. The flow path may also be assigned based on an existing stream network; however, the enforcing of flow along a flow path should be used when the stream data source is deemed to be better than the DEM.

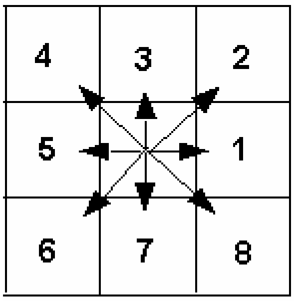

Figure 5.4: D8 flow direction numbering convention (as used in BASINS)

5.2.1.4 Determination of Contributing Area

Contributing area counted in terms of the number of grid cells is calculated using a recursive procedure (Mark, 1988). The contribution at each grid cell is taken as one and the contributing area for each grid cell is taken as its own contribution plus the contribution from upslope neighbors that drain into it. If an outlet is assigned at a specific predefined location for calibration purposes in the watershed the contributing area is evaluated recursively starting from points (outlets). Starting the recursive evaluation at outlet points results in only the contributing area that drains to the designated outlets being evaluated. The determination of contributing araea is further explained in Figure 5.5 where D8 flow directions (Figure 5.5 b) for each cell in a DEM (Figure 5.5 a) are determeined. Figure 5.5 c shows the symbolic representation of flow from each cell and Figure 5.5 d is the resultant flow accumulation grid showing the number of cells flowing into each cell.

76	70	67	69	56	47
72	65	54	47	44	48
67	51	42	35	36	46
62	56	53	20	29	22
66	59	45	19	14	17
72	51	32	10	9	10

a

8	8	8	7	7	6
8	8	8	7	7	6
1	1	8	7	6	7
2	2	1	8	7	6
8	8	1	7	7	7
1	1	1	1	7	5

b

↘	↘	↘	↓	↓	↙
↘	↘	↘	↓	↓	↙
→	→	↘	↓	↙	↓
↗	↗	→	↘	↓	↙
↘	↘	→	↓	↓	↓
→	→	→	→	↓	←

c

1	1	1	1	1	1
1	2	2	3	3	1
1	4	8	6	5	1
1	1	1	21	1	2
1	1	1	2	25	1
1	3	5	8	36	2

d

Figure 5.5: Determination of flow accumulation grid (a) Elevations, (b) Flow direction grid (c) Symbolic flow directions, (d) Flow accumulation grid

5.2.1.5 Strahler's Network Order

The D8 flow direction grid defines a grid network that extends to each grid cell. This function orders this network according to the Strahler ordering system. Cells that do not have any other grid cells draining in to them are order 1. When two (or more) flow paths of different order join the order of the downstream flow, path is the order of the highest incoming flow path. When two (or more) flow paths of equal order join, the downstream flow path is increased by 1. For the example shown in Figure 5.5 the schematic of the drainage network is shown in Figure 5.6. It has to be noted that for this example the threshold value for flow contributing cells has been assumed to be one. Therefore all the cells are considered part of the stream network.

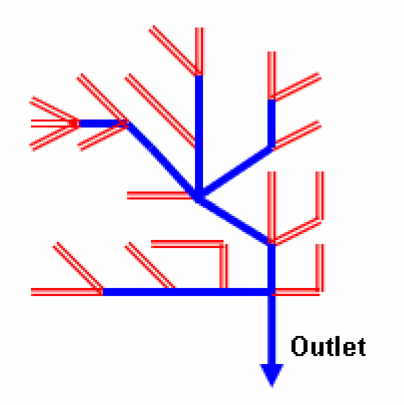

Figure 5.6: Schematic of drainage network

5.2.1.6 The Longest Upslope Length

The longest upslope length is the length of the flow path from the furthest cell that drains to each cell.

5.2.1.7 The Total Upslope Path Length

The total upslope path length is the length of the entire grid network upslope of each grid cell. Lengths are measured between cell centers taking into account cell size and whether the direction is adjacent or diagonal.

5.2.1.8 Stream Network Extraction

Stream network extraction is the culminative end result of all the processes mentioned above based on user defined values of drainage area or a shape file of an existing stream netwrok. TauDEM employs multiple methods for the extraction of channel networks including curvature-based methods sensitive to spatially variable drainage density and objective methods based on stream drops or stream ordering threshold values provided by the user. An existing stream network may be “burned in" by using an enforced flow path with "Fill Pits" and "D8 Flow Directions" functions. The stream network raster is then defined from these flow directions. No parameters are required. Stream network may also be extracted based on DEM operations by providing a user specified threshold value for contributing area, grid order, area and slope or area and length alternatively. The details of the operations may be found in Tarboton *et al*. (1991, 1992) and Tarboton and Ames (2001).

5.2.1.9 Watershed Segmentation

After the extraction of stream network based on user defined thresholds the sub-watershed draining to each stream segment (reach) is delineated and association between watershed and stream segments is defined.

5.3 Delineation of Koycegiz Watershed

The delineation of Koycegiz watershed involved the steps described as follows.The DEM for the watershed was imported into the BASINS interface. The DEM was projected using the World Geographical System Universal Transverse Mercator zone 35 N for Turkey. AWD plug-in was used for delineation of the watershed due to its advanced stream network burn-in functionality. The elevation units were selected to be meters and the input DEM for the watershed was selected as the Base Elevation Data (DEM) layer. The option for providing an existing stream network was not used because of lack of high quality stream network data for the Koycegiz watershed. Entire watershed was considered for delineation without specifying a focusing mask or the extents. Size and number of sub-watersheds must be defined according to the objectives of the study. An unnecessary large number of sub-watersheds complicate the modeling process, as for each sub-watershed, model parameters have to be defined that results in increasing the calibration parameters. To obtain a delineated watershed with a suitable number of sub-watersheds and reaches, the definition of a reach in terms of threshold values for contributing cells/area were optimized by using different values of thresholds, and finally a threshold of 75 hectares was used for optimum delineation of the watershed. For model calibration purposes, the outlets of HSPF stream models should potentially correspond with gauge stations. Therefore, the location of Namnam River gauge station was specified as an outlet to obtain a reach outlet at the location for calibration purposes.

5.3.1 Watershed Characterization

Watershed characterization in BASINS can be used to define point sources, their location in the watershed, identify impaired water bodies, and retrieve land use distribution reports. It mainly relies on data downloaded from the BASINS website databases related to the pilot watershed. However, watershed physical characteristics like length and slopes of reaches, land uses and sub-watersheds are determined using the Map Window GIS feature in BASINS. For application of HSPF, the physical characteristics of the watershed are automatically stored in four different ASCII files. These files are needed for initiation of HSPF User's Control Input (UCI) file:

- Watershed File (*.WSD)
- Reach File (*.RCH)
- Channel Geometry File (*.PTF)
- Point Sources File (*.PSR)

These files contain the areas of watersheds associated with each reach, areas of different land uses associated with each reach, type of different land uses, distribution of impervious and pervious land uses associated with each reach, length of each reach segment, slope of each reach segment and channel geometry of each reach. Besides creating the input files for HSPF, the GIS capabilities may also be used to determine certain other characteristics for parameter estimation. These include the elevation of individual land uses and their mean slopes. Table 5.1 shows the areas, mean elevation and mean slopes for the individual land use segments.

Table 5.1: Topographical Characteristic of Land Segments

Land use Segment	Area (hectares)	Mean Elevation (m)	Mean Slope (% rise)
Forest	39264	751.48	27.22
Agriculture	1103	106.44	2.3
Pasture	4343	721.09	18.18
Shrub land	2543	500.73	14.71
Orchards	571	9.75	0.28
Others (Water, Wetlands)	858	183.96	3.70
Total	48682	716.64	25.82

Due to the availability of calibration data for Namnam catchment of the Koycegiz watershed, the model network was setup to simulate only hydrology and NPS pollution in this catchment. It was divided into 4 sub-watersheds and 4 reaches. The total area of the sub-watershed is 120296 acres (48682 hectares). The major land use/ cover in the watershed is forest with pasture and shrub land as the next most abundant type.

Table 5.2 shows the areas and their land use distribution associated with individual sub-watersheds. It has to be noted that land use categories were condensed into 5 main categories for simplification of modeling process. Furthermore, 1 acre (0.404 hectares) of land was assigned as impervious in the forest category so that land use change may be introduced in the model for scenario analysis. For the modeling process, the 5 main categories will be considered for determination of hydrological and water quality parameters.

Table 5.2: Land uses associated with individual sub-watersheds

Land use Segment	**SW-1**	**SW-2**	**SW-3**	**SW-4**	**Total**	**Area**
	Area (hectares)					**%**
Forest	4592	6527	5317	22828	39264	80.6
Agriculture	831	137	100	35	1103	2.30
Pasture	1295	645	1989	414	4343	8.92
Shrub land	1808	574	161	0	2543	5.22
Orchards	571	0	0	0	571	1.20
Others (Water, Wetlands)	118	241	286	213	858	1.76
Total	9215	8124	7853	23490	48682	100
% distribution	19	17	16	48	100	

Table 5.3 shows the characteristics of the individual reaches in the model network. Delta H refers to the change in elevation across the length of reach whereas N Exits is the number of outlets from each reach. Model network has been setup such that outlet for reach no 2 is located at Namnam gauge station. Therefore, flow from reach no 2 will be used for calibration and validation of the hydrologic model.

Table 5.3: Characteristics of Reaches

Reach No	**Length (miles)**	**Delta H (ft)**	**Downstream ID**	**N Exits**
1	6.22	128	0	1
2	6.38	230	1	1
3	5.18	405	2	1
4	2.2	214	3	1

Point sources in the watershed were assumed to be negligible for the setting up of the model netwrok. Though delineation of the entire Koycegiz watershed was carried out using BASINS delineation tool, the watershed characterization was limited to the Namnam sub-watershed in the drainage area of the Koycegiz lake. The input files required for constructing the HSPF Users Control Input (UCI) file were created in BASINS. Upon initialization of WinHSPF watershed file, weather data file and project file were specified. Koycegiz Meteorological Station was specified as the initial meteorological station.

5.4 Application of HSPF for Hydrological Modeling

HSPF is a flexible modular watershed model permitting simulation of processes over a range of simplistic to complex formulations (USEPA, 1999). Keeping in mind the objectives of the study the section PWATER, IWATER and HYDR were activated in the UCI file for the simulation of basic hydrology and flow routing in PERLND, IMPLND and RCHRES modules of the model. Pertinent sections for simulation of sediment and water quality constituents will be activated after calibration and validation of hydrologic model.

5.4.1 Hydrologic Simulation

The PERLND and IMPLND application modules simulate runoff and water quality constituents from pervious and directly connected impervious land areas in the watershed, respectively. Within a given drainage area or sub-watershed, the RCHRES module is used to route runoff and water quality constituents simulated by the PERLND and IMPLND modules through a single reach of open or closed channel or a completely mixed impoundment. Bicknell *et al*. (2001) and Donigian *et al*. (1995) provide detailed descriptions of the individual compartments within the PERLND, IMPLND, and RCHRES application modules.

The PWATER compartment of the PERLND application module models the complete land-side water budget for a pervious land section, and it is the key compartment in the PERLND module. It forms the basis for all subsequent water quality simulations. Figure 5.7 present the flow diagram for the surface hydrologic cycle as modeled in HSPF after Socolofsky (1997). Precipitation falling on the land surface is first intercepted by vegetation represented as interception storage in HSPF.

Interception storage in HSPF is modeled as a reservoir that must first be filled before any precipitation can reach the ground. The modeler specifies the interception storage capacity, and it can vary seasonally. Excess precipitation reaching the land surface is temporarily placed in surface detention storage, from where it will either enter the upper zone as potential direct runoff or it will infiltrate into the subsurface. The partitioning between these two pathways is a function of the soil moisture and the infiltration rate.

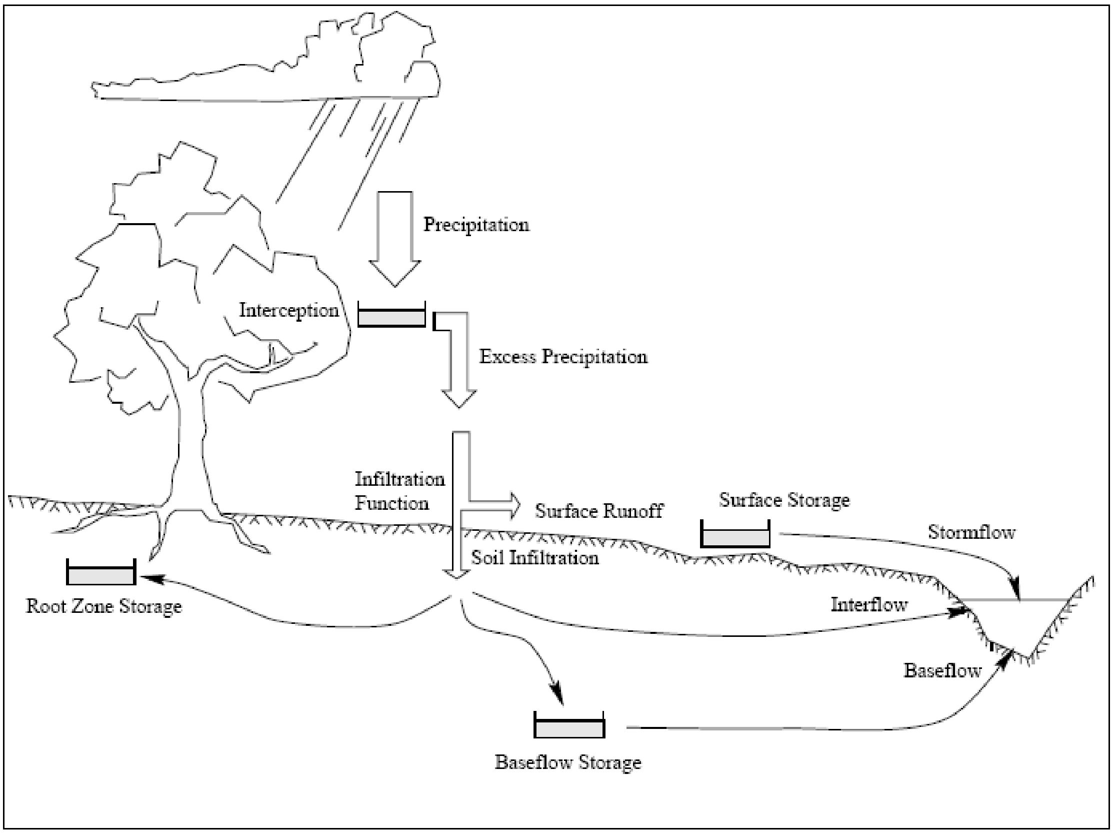

Figure 5.7: Flow diagram for the surface hydrologic cycle as modeled in HSPF

Potential direct runoff is further partitioned as direct surface runoff, interflow runoff, or upper zone storage. The amount of direct surface runoff within a particular time step is a function of slope, roughness (which can vary seasonally), and distance to a first-order stream. Interflow runoff is stored in a reservoir that empties based on a specified decay rate. Both the inflow and decay rate for interflow can vary seasonally. Upper zone storage represents ditches, swales or depressions in the watershed surface, and it can vary seasonally. Water in the upper zone storage can evaporate, percolate to the subsurface, or become direct runoff or interflow during the next time step. The partition between upper zone storage and direct surface runoff is a function of upper zone storage and its nominal value.

Infiltrated water is routed to lower zone storage, active groundwater storage, or deep inactive groundwater. Water is first put in the lower zone storage. Once the lower zone storage is satisfied, the remaining water is partitioned between deep/inactive groundwater and active groundwater storage. Active groundwater is stored in a reservoir and released as base flow based on a specified groundwater recession parameter.

PWATER attempts to meet the input evapotranspiration demand by evaporating water from five possible storages in the following sequence: base flow, interception storage, upper zone storage, active groundwater, and lower zone storage. Each of the storage has a user-specified resistance to evaporation. The resistance to evaporation for the lower zone storage can vary seasonally.

For a pervious land area, HSPF attempts to account for both the temporal and spatial dimensions of the infiltration process. The infiltration process is modeled based on Philip's equation, with cumulative infiltration represented as the ratio of the lower zone storage to its nominal storage value. The spatial distribution of infiltration over a pervious land area is modeled by specifying a linear probability density function for the infiltration capacity.

Inflow to the interflow reservoir is modeled in a manner quite similar to the approach utilized in model infiltration. In particular, what constitutes interflow is assumed to be proportional to the local infiltration capacity. The fraction of the remaining subsurface water goes to either lower zone storage or groundwater (active and/or inactive) based on the ratio of lower zone storage and its nominal value.

5.5 HSPF Hydrologic Model Calibration for Koycegiz Watershed

Calibration of an HSPF model is an iterative process of parameter estimation, comparison of simulated and observed values and refinement. Model validation is an extension of calibration process for assessment of model performance and its ability to predict field observations for a different simulation period.

The model calibration and validation for Koycegiz watershed focuses exclusively on the HSPF hydrological parameters. Water quality parameters are not discussed due to lack of observed data. Model performance and calibration are evaluated through qualitative and quantitative measures, involving both graphical comparisons and statistical tests. The flow data vailable for model verification at a single station on Namnam stream was for the period of 1990-1999. The flow data for the period of 1995-1999 was used for model calibration and the validation of the model was carrie dout using the flow data for the period 1990-1994.

5.5.1 Hydrologic Parameters

The PWATER section of PERLND module defines the parameters for simulation of basic hydrology in the watershed. Table 5.4 lists the PWATER parameters that can be varied during model calibration, normal ranges of these parameters, and comments on possible estimation sources for initial parameterization. A number of these parameters were estimated based on physical characteristics of the watershed determined using GIS. The movement and storage of the water as modeled in the PWATER module of HSPF alongwith the associated input and output parameters are described in Figures B.1 and B.2 provided in the appendix B. A detailed description of the estimations for the most important parameters are provided in the following section.

Table 5.4: PWATER parameters used

Name	Units	Range of Values				Function of	Comment
		Typical		Possible			
		Min	Max	Min	Max		
PWATER – PARAMETER SET 2							
FOREST	None	0.0	0.50	0.0	0.95	Forest Cover	Only when SNOW is active
LZSN	Inches	3.0	8.0	2.0	15.0	Soils, Climate	Calibration
INFILT	In/hr	0.01	0.25	0.001	0.50	Soils, Land Use	Calibration
LSUR	Feet	200	500	100	700	Topography	Estimate from topography, GIS
SLSUR	Ft/ft	0.01	0.15	0.001	0.30	Topography	Estimate from topography, GIS
KVARY	1/inches	0.0	3.0	0.0	5.0	Baseflow Recession Variation	Used when recession rate varies with groundwater
AGWRC	None	0.92	0.99	0.85	0.999	Baseflow Recession	Calibration
PWATER – PARAMETER SET 3							
PETMAX	Deg. F	35.0	45.0	32.0	48.0	Climate, Vegetation	Only when SNOW is active
PETMIN	Deg. F	30.0	35.0	30.0	40.0	Climate, Vegetation	Only when SNOW is active
INFEXP	None	2.0	2.0	1.0	3.0	Soils Variability	Default to 2.0
INFILD	None	2.0	2.0	1.0	3.0	Soils Variability	Default to 2.0
DEEPFR	None	0.0	0.20	0.0	0.50	Geology, GW Recharge	Accounts for subsurface losses
BASETP	None	0.0	0.05	0.0	0.20	Riparian Vegetation	Direct ET from riparian vege.
AGWETP	None	0.0	0.05	0.0	0.20	Marsh Wetland Extent	Direct ET from shallow GW
PWATER – PARAMETER SET 4							
CEPSC	Inches	0.03	0.20	0.01	0.40	Vegetation Type/Density	Monthly values usually used
UZSN	Inches	0.10	1.0	0.05	2.0	Surface Soil Conditions	Near surface retention
NSUR	None	0.15	0.35	0.05	0.50	Surface Conditions	Monthly values used for Ag.
INTFW	None	1.0	3.0	1.0	10.0	Soils, Topography	Calibration
IRC	None	0.5	0.7	0.3	0.85	Soils, Topography	Start with 0.7 then adjust
LZETP	None	0.2	0.7	0.1	0.9	Vegetation Type/Density	Calibration

5.6 Initial Parametrization of the Model

The values for some of the initial parameters provided by BASINS are physically based and may be estimated based on the physical characteristics of the watershed using the GIS capabilities of the system.. This section describes the development of the model based on the objectives of the study from the known physical features of the watershed and using parameter estimation guidelines for BASINS/HSPF.

5.6.1 Channel Cross-Section and FTABLES

In HSPF, the outflow of water from the river segments is modeled using a collection of function tables (FTABLES). A function table is used to document, in discrete numerical form, a functional relationship between two or more variables. FTABLES are used to specify the depth volume- discharge relationship for operations in the RCHRES module (Bicknell *et al*., 2001).

Historical stage-discharge relationships are used to define the cross-section of the channel. After determination of the channel cross-section Manning's equation is used to develop FTABLES for the stream segment. For Namnam stream stage discharge data was not available hence default FTABLES generated by BASINS having values based on a trapezoidal channel cross-section are used.

5.6.2 Length of Overland Flow Plane (LSUR)

Length of overland flow plane (LSUR) approximates the average length of travel for water to reach a stream reach or any drainage path such as small streams, swales, ditches, etc. that rapidly deliver the water to the stream or water body within the sub watershed. The length of overland flow can be estimated from the drainage density of the sub-watersheds. It may be estimated from topographical data by dividing the watershed area by twice the length of all streams, gullies, ditches, etc that move the water to the stream. However, LSUR values derived from topographic data are often too large (i.e. over-estimated) when the data is of insufficient resolution to display the many small streams and drainage ways (US EPA, 2000).

For Koycegiz watershed the stream network data is of insufficient resolution for estimation of LSUR from topographical data directly. However, variation of LSUR with slope provides criteria for initial estimation. Flat slopes have larger LSUR values and vice versa; typical values range from 200 feet to 500 feet for slopes ranging from 15% to 1 % (US EPA, 2000). Estimated LSUR values for pervious land segments in the watershed are listed in Table 5.5 based on slope values of individual land segments.

Table 5.5: LSUR values for Koycegiz Watershed

PLS No	Land-use	Mean Slope (% rise)	LSUR (ft)
101	Forest	27.22	350
102	Agriculture	2.3	550
103	Pasture	18.18	350
105	Shrub land	14.71	300
106	Orchards	0.28	675
104	Water	3.70	600

5.6.3 Slope of Overland Flow Path (SLSUR)

This parameter was determined using SLSUR was calculated using the DEM for each land segment. The maximum and minimum elevations for each land segment are determined. The difference in the elevations is then divided by the Longest Flow Path, for each sub basin (Johnson, 2005). This calculation gives a general estimate for the slope of the terrain within each land segment. The SLSUR values for the Koycegiz watershed are listed in Table 5.6.

Table 5.6: SLSUR values for Koycegiz watershed

PLS No	Land-use	SLSUR (ft/ft)
101	Forest	0.15
102	Agriculture	0.023
103	Pasture	0.14
105	Shrub land	0.12
106	Orchards	0.0028
104	Water	0.037

5.6.4 Manning's n for Overland Flow Plane (NSUR)

NSUR values were defined based on land-use/cover. An average of the values given in EPA BASINS Technical Note 6 (USEPA, 2000) for different land-uses was applied to the 6 land-uses defined for the Koycegiz watershed. For the pervious land segment, Agriculture the Manning's 'n' values were defined as monthly values to reflect the seasonal changes in land conditions depending on cropping and tillage practices. Table 5.7 lists the NSUR values used for the Koycegiz watershed along with the associated land use description.

Table 5.7: Manning's n values for Koycegiz watershed

PLS No	Land-use	NSUR
101	Forest	0.45
102	Agriculture	0.25
103	Pasture	0.25
105	Shrub land	0.28
106	Orchards	0.30
104	Water	0.25

5.6.5 Index to Mean Soil Infiltration Rate (INFILT)

INFILT is the mean soil infiltration rate in inches per hour. It is the parameter that effectively controls the overall division of the available moisture from precipitation into surface and subsurface flow. INFILT is primarily based on soil characteristics and ranges of values have been related to the SCS hydrologic soil groups developed by United States Soil Conservation Services (USEPA, 2000). For the Koycegiz watershed at the time of this BASINS/HSPF study, appropriate soil data was not available for classification of soil into SCS hydrologic groups therefore initial values were estimated based on similar land use and weather conditions (US EPA, 1999). INFILT was however calibrated as a major parameter for hydrological modeling.

5.7 HSPEXP–Expert System for Calibration of HSPF

As mentioned above, calibration of HSPF is a systematic analysis of errors or differences between model simulated predictions and field observations which requires considerable effort and an expert understanding the model processes and watershed characteristics. To overcome the difficulties of repetitive cycles of simulation, comparison, interpretation and modification for parameter adjustment advanced parameter estimation tools have been developed to facilitate model calibration. In this regard, an Expert System for Calibration of HSPF (HSPEXP) developed by Lumb *et al.*, (1994) and an automatic parameter estimation software PEST (Doherty, 2002) may be used for calibration of HSPF. For calibration of Koycegiz hydrologic model, HSPEXP was used for determination of a single set of parameters capable of representing the entire range of flow data at Namnam gauge station. The following section briefly describes HSPEXP and its application for HSPF hydrologic calibration.

5.7.1 HSPEXP Phases

HSPEXP is an expert system that interactively allows the user to edit the input UCI file for HSPF, simulates the model, produces HSPF output, examines the statistics for that simulation and provides the user with expert advice on which parameter should be changed up or down to improve calibration (Lumb *et al*., 1994). HSPEXP uses over 35 rules involving over 80 conditions to recommend parameter adjustments. The rules are divided into four hierarchies based on ordered phases of annual volumes, low flows, storm flows and seasonal flows.

The rules in individual phases are tested and once satisfied the system moves to the next phase. Current versions of HSPEXP have the capability of calibrating only HSPF hydrologic models.

5.7.1.1 Annual Water Balance

The annual water balance is:

Runoff=Precipitation–Evapotranspiration–Deep Infiltration–Change in Soil Moisture

HSPF model requires input of forcing data, in this case precipitation and evaporation, to drive the hydrology of the watershed and the model. LZSN and LZETP affect evapotranspiration by influencing the amount of moisture available for that process. LZSN and INFILT affect the amount of precipitation that percolates. UZSN affects annual discharge volumes because of its influence on individual storm events. DEEPFR is used to represent loss from the annual water balance whenever there are losses that are measured at the flow gauge, such as recharge.

5.7.1.2 Seasonal Flow Distribution

The next step in hydrologic calibration is the seasonal or monthly distribution of runoff which is adjusted with the INFILT, AGWRC, and KVARY parameters. Seasonal distribution is accomplished by INFILT by dividing the precipitation between surface runoff, interflow, and groundwater storage. By increasing INFILT, the immediate surface runoff, which includes interflow, is reduced and increases the groundwater storage. By increasing the groundwater storage, a delay in the time required for water to reach the stream is caused, which therefore moves water volume between seasons. This often means transferring the surface water from storm events to low-flow periods during the dry season. The shape of this groundwater recession and base flow discharge is controlled by AGWRC and KVARY.

5.7.1.3 BASE Flow

AGWRC is calculated as the rate of base flow on one day divided by the base flow on the previous day, therefore, AGWRC is the parameter that controls the flow of water from groundwater storage into the stream. The KVARY index allows the model to have a non-linear recession so that the slope of recession can be changed as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flows show a definite seasonal change in recession rate.

5.7.1.4 Storm Event Calibration

This is the final step in the hydrological calibration of the HSPF model after the annual water balance where seasonal and monthly distributions have been satisfied. Calibration to selected storm events was completed using the following two parameters, INTFW and IRC. Both INTFW and IRC are used to fine-tune the shape of the hydrograph for a better fit with observed data. The parameters are first estimated from past experience and other studies in the area, and then adjusted during calibration. Adjustments to INFILT can also be made to improve simulation, but should be minor to prevent disruption in annual and monthly calibration results.

5.7.2 Setting up HSPEXP Calibration for Koycegiz Hydrologic Model

HSPEXP is a command line based software program. HSPEXP may be obtained free of cost from USGS website. The download version comes with all the installation instructions. Once installed a calibration of an HSPF hydrologic model can be carried out. This section describes the setting up of an HSPEXP calibration effort.

5.7.2.1 Input Time Series

HSPEXP requires 10 time series for calibration of an HSPF hydrologic model. The time series required by HSPEXP are listed below in Table 5.8. The expert system requires the time series listed above in the WDM file. For this purpose, the UCI file has to be modified to obtain the first eight time series in the project WDM file as result of a simulation. Furthermore, the time series for observed flow and precipitation should also be stored in the same WDM file i.e. project WDM file.

Table 5.8: Time series required by HSPEXP for Hydrologic calibration of HSPF

S. No.	Time Series	Description	Units
1	SIMQ	Simulated Total Runoff	inches
2	SURO	Simulated Surface Runoff	inches
3	IFWO	Simulated Interflow	inches
4	AGWO	Simulated Base Flow	inches
5	PETX	Potential Evapotranspiration	inches
6	SAET	Actual Evapotranspiration	inches
7	UZSX	Upper Zone Storage	inches
8	LZSX	Lower Zone Storage	inches
9	FLOW	Observed Flow	cfs
10	PREC	Observed Precipitation	inches

The simulated time series may be introduced in the project WDM file using the hydrologic calibration in the output editor of the WinHSPF interface by choosing the reach number for calibration. Except for the observed flow and observed precipitation time series, the rest of the required time series in Table 5.8 are the components of the hydrologic cycle and are generated by the model as a result of the hydrologic simulation. The time series are automatically introduced into the specified project WDM file after execution of model. The UCI file for the Koycegiz watershed was modified to obtain the required time series data in the WDM file.

5.7.2.2 Calibration Period

Based on availability of observed flow data, a suitable calibration period should be specified. Donigian (2002) and Lumb *et al.,* (1994) recommend a simulation period of several years (at least 3 to 5 years) for model calibration purposes in order to evaluate model parameters under a variety of climatic, soil moisture and watershed's physical condition. For Koycegiz watershed, observed flow data for Namnam stream is available from 01/10/1990 to 30/09/1999. Considering the availability of observed flow data a calibration period of 01/01/1995 to 30/09/1999 was selected for simulation of watershed hydrology.

5.7.2.3 Identification of Storm Events

Individual storm events in the observed flow and dataset numbers of the above mentioned time series have to be identified before starting the program. Individual storm events are identified manually by visual inspection of the observed flow curve and precipitation plot. Figure no 5.8 and 5.9 show the observed surface flow data and precipitation for winter and summer months within the calibration period for identification of storm events.

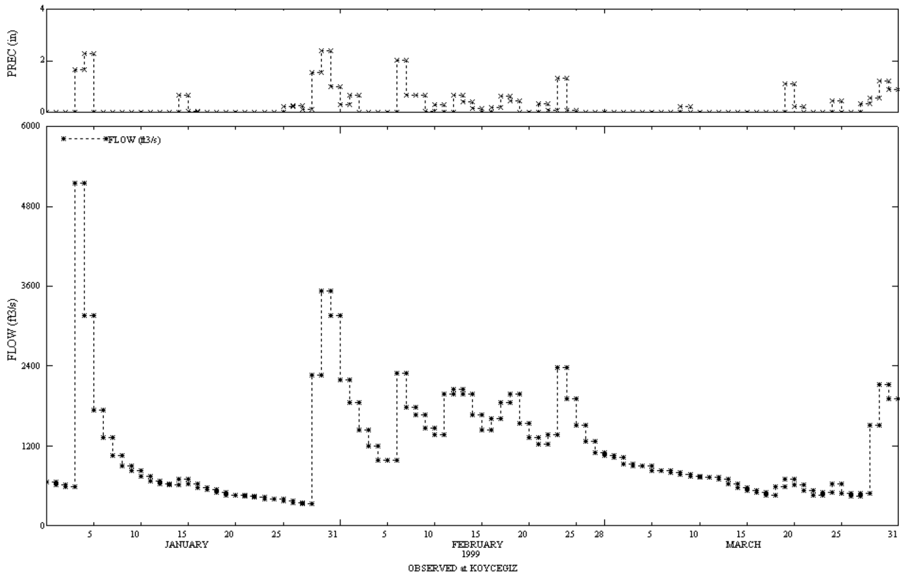

Figure 5.8: Identification of storm events

Based on careful visual inspection of storm peaks relevant to precipitation values, 30 major storm events were identified throughout the simulated period as per the requirement of the expert system these storm peaks are used for the comparison of high flow values for the calibration of the hydrologic model. The number of identified storms was uniformly distributed for each year and care was taken to include storm events in high flow as well as well as low flow conditions.

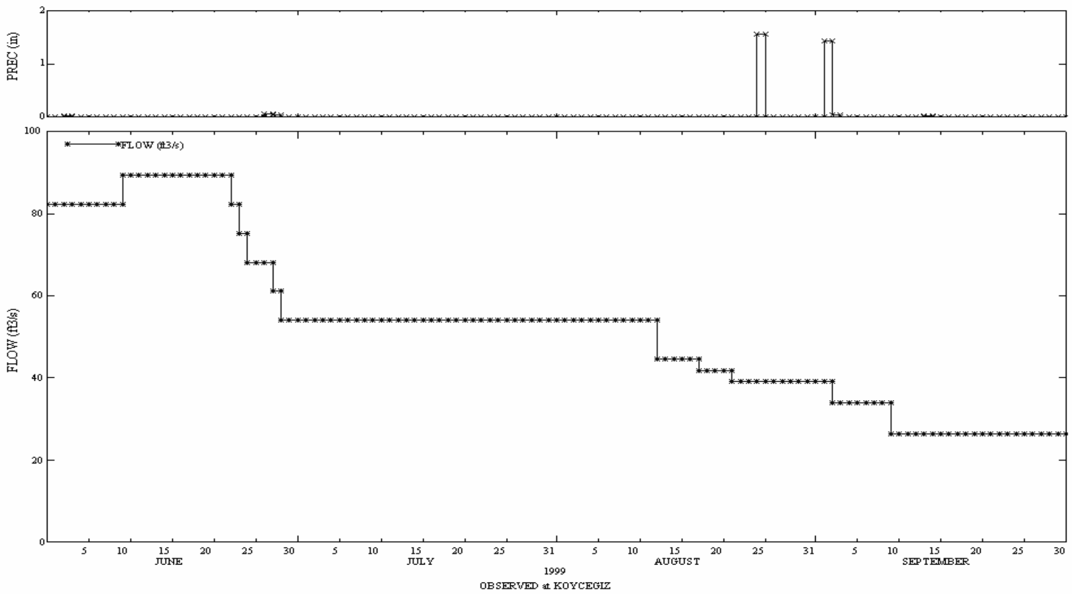

Figure 5.9: Identification of summer storms

5.7.2.4 Basins Description File

A basin description file (*.EXS) with the same name as that of UCI should be created within HSPEXP. It contains information about calibration period and watershed area. User specifies the individual dataset numbers for the required time series, and inputs on the number, dates and times of the individual storm events in the watershed.

For Koycegiz watershed, input time series, details of storm events and other required data were input to create a basin description file. After setting up the initial requirements and inputs of the expert system, HSPEXP was run for calibration of the hydrologic model for Koycegiz watershed.

5.7.3 HSPF Hydrologic Calibration Criteria

The result of a model calibration is a set of parameters that produce the best overall agreement between simulated and observed values during calibration based on a predefined set of criteria. These criteria known as model performance criteria, are sometimes referred to as calibration or validation criteria. It has to be accepted that no single criterion exists for model calibration and validation. Donigian (2002) recommends following graphical and statistical procedures for HSPF calibration and validation which will be used for verification of Koycegiz hydrologic model;

- Time series plots of observed and simulated flows (daily and monthly),
- Observed vs. simulated scatter plots, with a 45^{o} linear regression line displayed for flows (daily and monthly),
- Flow Duration Curves (FDC) for observed and simulated values,
- Correlation tests, (Linear Correlation Coefficient R), and
- Error Statistics.

Figure 5.10 shows value ranges for both correlation coefficients (R) for assessing model performance regarding daily and monthly flows.

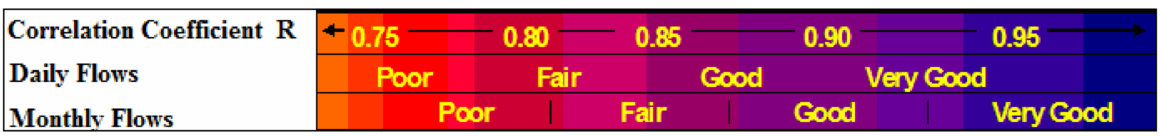

Figure 5.10: Correlation Coefficient ranges for Daily and Monthly Flow

Table 5.9 lists general calibration/validation tolerances or targets that have been provided to model users as part of HSPF training workshops over the past 10 years (Donigian, 2002).

Table 5.9: General Calibration/Validation Targets or Tolerances for HSPF Applications (Donigian, 2000)

Application	% Difference Between Simulated and Recorded Values		
	Very Good	Good	Fair
Hydrology/Flow	< 10	10 - 15	15 – 25
Sediment	< 20	20 - 30	30 – 45
Water Temperature	< 7	8 - 12	13 – 18
Water Quality/Nutrients	< 15	15 - 25	25 – 35
Pesticides/Toxics	< 20	20 - 30	30 – 40

Caveats: Relevant to monthly and annual values; storm peaks may differ more
Quality and detail of input and calibration data
Purpose of model application
Availability of alternative assessment procedures
Resource availability (i.e. time, money, personnel)

A simulation fulfilling all the criteria may be termed as a successful run, however, given the approximate nature of model formulations and the inherent uncertainty in the observed and input data, absolute criteria for watershed model acceptance or rejection are not recommended. The values in Table 5.9 attempt to provide some general guidance in terms of the percent mean errors or differences between simulated and observed values for the assessment of expected level of agreement or accuracy (i.e. very good, good, fair) from the model application. The expected level of agreement depends on many site and application-specific conditions, including the data quality, purpose of the study, available resources, and available alternative assessment procedures that could meet the study objectives.

In HSPEXP error statistics for the tolerance values can be defined by the user. However, the standard error statistics for assessment of HSPF hydrologic model using HSPEXP are shown in Table 5.10 (Donigian, 2002).

Table 5.10: Error statistics for assessment of HSPF using HSPEXP (Donigian, 2002)

Constituent	Criteria
Error in Total Volume	10 %
Error in low Flow Recession	0.01
Error in 50% Lowest Flows	10 %
Error in 10% Highest Flows	15 %
Error in Storm Peaks	15%
Seasonal Volume Error	10 %
Summer Storm Volume Error	15%

5.8 Model Validation

Model credibility is based on the ability of a single set of parameters to represent the entire range of observed data. This ability of model is tested through simulation of a different time span other than calibration period. If the calibrated parameter can reasonably represent a wide range of events, the model is said to be validated. The hydrologic model for the Koycegiz watershed was validated using flow data for the period 01/10/1990 to 31/12/1994. Furthermore, model was also run for the entire period of available data that is 01/10/1990 to 30/09/1999.

5.9 Modeling NPS Pollutants using HSPF

The impact of NPS pollutants on surface waters and aquatic ecology is of increasing concern for water quality managers and ecologists. There has been considerable current and past research effort focusing on the identification, generation, and fate and transport mechanisms of NPS pollutants (Dzikiewicz, 2000; Munafo *et al*., 2005; Kloiber, 2006; Polyakov *et al*., 2007; Collins and Anthony, 2008). The temporal and spatial dimensions of NPS loadings in a watershed can only be estimated based on a holistic approach integrating upstream watershed processes and stream water quality impairments. Watershed modeling provides the tools for the identification of critical NPS and estimation of NPS pollution loadings in a framework of integrated watershed management. HSPF has been used successfully in modeling the stream loadings of sediment, nutrients, and pesticides (Laroche *et al*., 1996; Bergman *et al*., 2002; Hayashi *et al*., 2004; Nasr *et al*., 2008; Ribarova *et al*., 2008).

In HSPF, the module SEDMNT simulates production and removal of sediment from a pervious land segment while the module SOLIDS simulates the accumulation and removal of solids by runoff, and other means from an impervious land segment. The PQUAL module simulates water quality constituents or pollutants in the outflows from a pervious land segment using simple relationships with water and/or sediment yield. The IQUAL module simulates water quality constituents or pollutants in the outflows form an impervious land segment.

This part of the study describes the extension of HSPF model for the determination of Sediment, Nitrate-N, Orthophosphate-P and Biochemical Oxygen Demand (BOD) for the Koycegiz watershed. A brief introduction of sediment and water quality constituents simulation using SEDMNT and PQUAL modules of HSPF is presented in the following sections. Further details of the formulations in the individual modules can be found in the Users Manual for the model (Bicknell *et al*., 2001).

5.9.1 Simulation of Sediment Loads

The SEDMNT compartment of the PERLND application module models sediment production and removal for pervious land areas in the watershed. The processes of detachment, wash-off of the detached sediment, and scour of the soil matrix are all modeled using simple two-parameter relationships of the form,

$$E = aq^b \tag{5.1}$$

where E represents detachment, wash-off, or scour; a and b are parameters; and q is either a model input or a model-generated quantity. For detachment, q is the rainfall rate; whereas, for wash-off and scour, q is the model-computed overland flow rate. The sediment load calculated from the land surface is a total load (i.e., there is no division into sand, silt, and clay classes). Detached sediment storage may be modified by two additional fluxes, lateral inflow from an upslope land area and/or net vertical sediment input resulting from wind and/or human activities. The soil matrix is assumed to have infinite storage.

5.9.2 Simulation of Nitrate-N, Orthophosphate-P and BOD loads

The PQUAL compartment of the PERLND application module simulates water quality constituents in the outflows from a pervious land area (i.e., overland flow, interflow, base flow, wash-off of detached sediment, and scour of the soil matrix) using straightforward relationships based on water and/or sediment yield. Constituents assumed to be transported with sediment may be modeled by specification of potency factors that relate constituent strength proportionally to the sediment removal computed in the SEDMNT compartment of the PERLND application module. General pollutant accumulation and wash-off equations, which relate constituent wash-off to constituent storage and computed surface runoff, are mechanisms for modeling generalized water quality constituents. A user-specified parameter in the second approach allows for modeling a “first flush” effect. PQUAL allows for the specification of monthly concentrations for the subsurface outflows (i.e., interflow and base flow).

The HSPF UCI file for the calibrated and validated hydrological model was modified for inclusion of sediment and water quality constituents within WinHSPF. Nitrate-N, Orthophosphate-P and BOD were included in the UCI file for determining their loadings from each individual land use. Corresponding time series were added into the output watershed data management file for simulation output time series. Due to lack of calibration data, parameter values for the SEDMNT and PQUAL were estimated based on BASINS/HSPF training documents. The sediment and water quality constituents were simulated for the simulation period October 1990 – September 1999. Due to lack of calibration data for sediment loadings or in stream concentration of suspended solids and other pollutants, the results of the simulation of sediment loads and pollutants loads from different land uses will be based on relative loading patterns from each land use.

5.10 Scenario Analysis

One of the foremost objectives of watershed modeling is to assess and analyze the impacts of alterations in the watershed, induced by natural and anthropogenic activities. The understanding of these relationships and analysis of alternative scenarios provide a tool for development of sustainable practices and sound decision making. The HSPF hydrologic and water quality loading model for Koycegiz watershed describes the current conditions in the watershed explaining the hydrologic regime, sediment and pollutant loadings from different land uses. To further extend, the study of watershed behavior under different conditions this part of the study presents the development of different scenarios and analyze their results using HSPF. The effects of land use and climate change will be studied on the hydrological regime of the watershed and the nonpoint source pollutants.

5.10.1 Development of Scenarios

This study adopts a “What if?” approach to predict the effects of decision making and climate variability on the hydrologic regime and NPS pollution in the watershed under different scenarios. It is based on the hypothesis that growing economic needs can exert enormous pressure on the natural resources of the Koycegiz watershed due to an increase in the tourism and related activities. This may result in an increase in the number of hotels, resorts and recreation sites which is a slow, yet a very pronounced, change in the land cover and the geomorphology of the watershed. Another option of enhanced economic activity might be an increase in agricultural activities in the watershed. The regulatory measure by the government declaring it as a protected area has impeded these trends.

The main target of this study is to analyze and discuss the results of a decision making scenario where this protective regulatory measure is relaxed and major land use changes in the watershed are allowed. To quantify and describe the impacts of such a regulatory decision on water resources and water quality, the dynamic simulation characteristics of HSPF are used to model the present and future behavior of stream flow in Namnam River, and NPS pollution loads in the Koycegiz watershed. Furthermore, even under present land use conditions, the impacts of a warmer climate may induce changes in the precipitation pattern in the region. The effects of these changes might be far reaching for the special ecology in the watershed. Therefore, the development of scenario analysis for Koycegiz watershed was based on following alterations in the characteristics of the watershed:

- Land Use Modification
    - Deforestation
    - Extensive Agricultural Activities
    - Urbanization
- Climate Change
    - Increase in Precipitation
    - Decrease in Precipitation

5.10.2 Land Use Scenarios

The principal land cover feature of the Koycegiz watershed is its forests that constitute approximately 80% of its total area. Forests play a major role in sustaining the unique ecological equilibrium within the watershed. Deforestation is a major concern in many watersheds, causing serious environmental and ecological problems like loss of biodiversity, increase in erosion, and climate change. This study combines the direct anthropogenic alteration of watershed geomorphology by deforestation, urbanization, and extensive agriculture into land use scenarios for analysis of their impacts on hydrologic response and NPS pollution in the Koycegiz watershed. Considering the importance of forests for a healthy watershed, and effects of land use changes in the watershed, the following scenarios were created:

- 25% of Forests were converted into Agricultural areas (Deforestation, Extensive Agriculture)
- 25% of Forests were converted into Impervious Area (Deforestation, Urbanization)
- 50% of Forests were converted into Impervious Area (Deforestation, Urbanization)

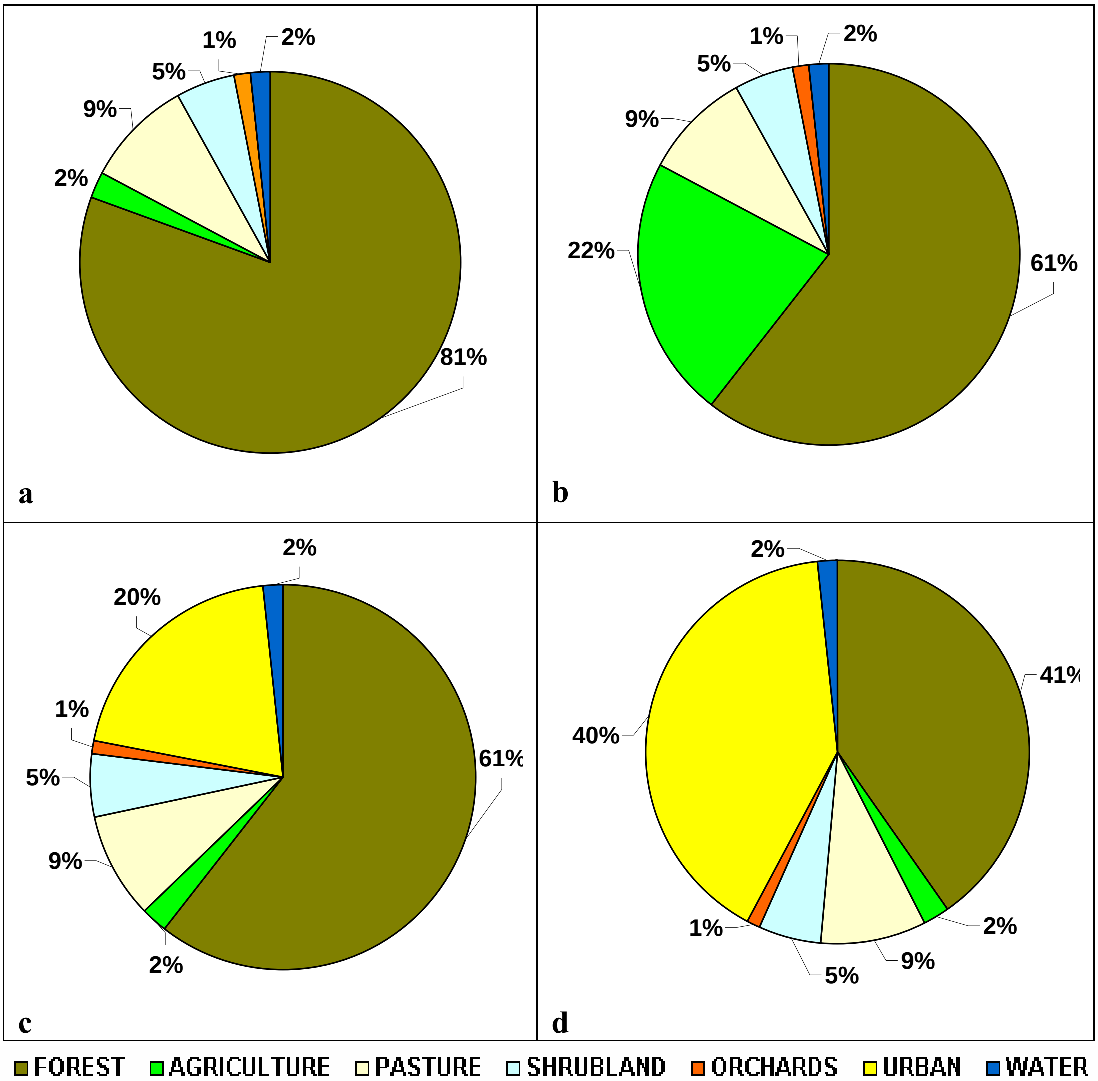

Figure 5.11: Distribution of Land Use in the watershed a) Baseline Scenario b) Extensive Agriculture – Deforestation c) Urbanization – Deforestation (Urban-1) d) Urbanization – Deforestation (Urban-2)

The distribution of land uses for the different scenarios is presented in Figure 5.11 for baseline scenario, extensive agriculture, 25% urbanization (Urban-1) and 50% urbanization (Urban-2), respectively.

As mentioned above the land use scenarios are created based on the assumption that increased tourism in the watershed may result in deforestation for tourist resorts. This will cause an increase in the impervious surfaces in the watershed due to development of tourism infrastructure. These scenarios are assumed for the purposes of research only. The likelihood of such extensive modification in land use characteristics is very negligible in near future as these may take decades to occur. However understanding their effects in advance can help policy makers sustain an equilibrium of the natural ecosystems in the watershed as a results of these changes.

5.10.3 Climate Change Scenarios

Effects of climate change on the hydrologic response and NPS pollution in the watershed were analyzed as changes in the precipitation. Dore (2005) has reported that precipitation over Northern Europe has increased by 10–40% in the 20th century, whereas some parts of Southern Europe have dried by as much as 20%. These trends are consistent with the findings of Onol and Semazzi (2008) that used the regional climate model (ICTP-RegCM3) to downscale the present and future scenario simulations generated by the NASA-Finite Volume General Circulation Model (fvGCM) over the Eastern Mediterranean region. They reported 24-48% seasonal precipitation changes in different parts of the Eastern Mediterranean region. The case study watershed lies in the south of Turkey within the climatic regime of Southern Europe and Eastern Mediterranean. To simulate the effects of climate change in the watershed, three scenarios were created that incorporate possible changes in precipitation regime due to global warming, keeping in mind the predicted trends in precipitation regime. The Intergovernmental Panel on Climate Change (IPCC, 2007) forecasts increase in risks of flooding and drought in different regions of the world due to climate change and its potential hydrological effects.

The impacts of climate change on the discharge regime of streams in the watershed were incorporated in the model by assuming changes in precipitation. For the present study, climate change scenarios were created to analyze both flooding as well as drought conditions. The precipitation changes were introduced in the HSPF model by creating the following scenarios;

- 20% increase in precipitation (20PIIP)
- 10% decrease in precipitation (10PDIP)
- 20% decrease in precipitation (20PDIP)

The precipitation change in input meteorological data was incorporated by multiplying the daily input data for precipitation by corresponding factors for simulating wet and dry change sin the climate.

5.10.4 Quantification of Model Scenario Impacts on Hydrologic Regime

Once the cause of impacts identified as land use change and precipitation regime change due to global climate variation are simulated using HSPF, the simulation outputs have to be analyzed for alterations resulting from these impacts. The effects of land use and climate changes on the hydrology of the Namnam stream are determined using the Indicators of Hydrologic Alteration (IHA) method. Though the IHA parameters are defined based on their importance for ecological integrity of streams, nonetheless they provide useful information about the availability of water and the health of aquatic system. The IHA method and its parameter groups are briefly described in the following section.

The time period for which hydrologic records exist prior to the presumed perturbation can be defined as the "pre-impact" period, and the period of record since initiation of the presumed perturbation can be defined as the "post-impact" period. For the identification of impacts on hydrologic regime, the basic data used in estimating all attribute values of impacts are daily mean water conditions represented by flow rates. The flow data before introducing the scenarios is used as base scenario representing the pre-impact period. After introduction of individual scenarios model, generated flow data is used as hydrologic conditions for that scenario representing the post-impact period. Once pre- and post-impact time periods have been defined, the hydrologic regimes from the two periods can be characterized and compared.

5.11 Hydrologic Alteration Analysis using IHA method

IHA method is a statistically driven analysis method used for identification of alterations in various aspects of a hydrologic regime induced by different upstream processes (Richter *et al.*, 1997; Olden and Poff, 2003). The IHA method is based on 32 biologically-relevant hydrologic attributes, divided into five major groups to statistically characterize intra-annual hydrologic variation. They provide a detailed representation of the hydrologic regime for the purpose of assessing hydrologic alteration.

5.11.1 IHA Parameter Groups

A brief description of the five major groups of IHA parameters are described below. The detailed significance of each parameter in these groups can be found in Richter *et al.,* (1997).

5.11.1.1 Magnitude of Monthly Water Conditions

The magnitude of the water condition at any given time is a measure of the availability or suitability of habitat, and defines such habitat attributes as wetted area or habitat volume, or the position of a water table relative to wetland or riparian plant rooting zones. This group includes 12 parameters, each of which measures the mean of the daily water conditions for a given month. The monthly mean of the daily water conditions describes "normal" daily conditions for the month, and thus provides a general measure of habitat availability or suitability. The similarity of monthly means within a year reflects conditions of relative hydrologic constancy, whereas inter-annual variation (e.g., coefficient of variation) in the mean water condition for a given month provides an expression of environmental contingency (Colwell 1974; Poff and Ward 1989). The terms "constancy" and "contingency" as used here refer to the degree to which monthly means vary from month to month (constancy), and the extent to which flows vary within any given month (contingency).

5.11.1.2 Magnitude and Duration of Annual Extreme Water Conditions

The timing of occurrence of particular water conditions can determine whether certain life cycle requirements are met, or influence the degree of stress or mortality associated with extreme water conditions such as floods or droughts. The 10 parameters in this group measure the magnitude of extreme (minimum and maximum) annual water conditions of various duration, ranging from daily to seasonal. The durations that are used follow natural or human-imposed cycles, and include the 1-day, 3- day, 7-day (weekly), 30-day (monthly), and 90-day (seasonal) extremes. For any given year, the 1-day maximum (or minimum) is represented by the highest (or lowest) single daily value occurring during the year; the multi-day maximum (or minimum) is represented by the highest (or lowest) multi-day average value occurring during the year. The mean magnitude of high and low water extremes of various duration provide measures of environmental stress and disturbance during the year; conversely, such extremes may be necessary precursors or triggers for reproduction of certain species. The inter-annual variation (e.g., coefficient of variation) in the magnitudes of these extremes provides another expression of contingency.

5.11.1.3 Timing of Annual Extreme Water Conditions

The frequency of occurrence of specific water conditions such as droughts or floods may be tied to reproduction or mortality events for various species, thereby influencing population dynamics. This group includes two parameters; one measuring the Julian date of the 1-day annual minimum water condition, and the other measuring the Julian date of the 1-day maximum water condition. The timing of the highest and lowest water conditions within annual cycles provides another measure of environmental disturbance or stress by describing the seasonal nature of these stresses. Key life cycle phases (e.g., reproduction) may be intimately linked to the timing of annual extremes, and thus human-induced changes in timing may cause reproductive failure, stress, or mortality. The inter-annual variation in timing of extreme events reflects environmental contingency that requires specific management and intervention strategies. This variation may also inflict indirect human health effects due to agent and vector ecosystem disturbances.

5.11.1.4 Frequency and Duration of High and Low Pulses

The duration of time over which a specific water condition exists may determine whether a particular life cycle phase can be completed, or the degree to which stressful effects such as inundation or desiccation can accumulate. Two parameters included in this group measure the number of annual occurrences during which the magnitude of the water condition exceeds an upper threshold or remains below a lower threshold, respectively, and other two parameters measure the mean duration of such high and low pulses. These measures of frequency and duration of high and low water conditions together portray the pulsing behavior of environmental variation within a year, and provide measures of the shape of these environmental pulses. Hydrologic pulses are defined here as those periods within a year in which the daily mean water condition either rises above the 75th percentile (high pulse) or drops below the 25th percentile (low pulse) of all daily values for the pre-impact time period.

5.11.1.5 Rate and Frequency of Change in Water Conditions

The rate of change in water conditions may be tied to the stranding of certain organisms along the water's edge or in ponded depressions, or the ability of plant roots to maintain contact with phreatic water supplies. The four parameters included in this group measure the number and mean rate of both positive and negative changes in water conditions from one day to the next. The rates and frequency of change in water conditions can be described in terms of the abruptness and number of intra-annual cycles of environmental variation, and provide a measure of the rate and frequency of intra-annual environmental change.

6. ANALYSIS OF THE CASE STUDY WATERTSHED APPLICATION

6.1 Introduction

This chapter presents a retrospective analysis of the application of BASINS and its core watershed model HSPF in the case study watershed of Koycegiz for addressing critical decision support scenarios of land use and climate change impacts. The purpose of this analysis is to define and introduce a pathway for researchers in developing countries that consider data availability, cost of data collection and model performance to design a watershed modelling project tailor made to the specific modelling objectives based on a threshold level of data requirement, model results and cost, optimized for maximum benefit. Although the analysis focuses on the BASINS and HSPF for watershed modelling applications in developing and under developed countries, the results may be used for a general modeling application under data poor conditions.

6.2 Methodology Used

As discussed in previous chapters, Turkey is a developing country and despite being a pilot project area for several years, Koycegiz watershed located in southern Turkey along the Mediterranean Sea coast bears all the characteristics of a case study watershed in a developing country. Data availability, acquisition of available data and the quality of acquired data have been major issues in devising a modeling project for the case study watershed. However, these issues were addressed and one of the most comprehensive modeling system alongwith its core watershed model were used for identification of potential stressors due to land use and climate chage impacts. The methodology is used to retrospectively analyze the data requirements for application of BASINS/HSPF, assess the quantity and quality of acquired data, evaluate the relative costs for acquiring the data. The acceptibility of model results keeping in view the objectives of the project rely on the availability of the absolute minimum data for the modeling system. In this regard components of model applicability in a developing country have to be defined and their relationships have to be determined to define a hypothesis for development of the threshold based optimum pathway.

6.2.1 Model Application Components

The applicability of a watershed model (BASINS/HSPF) in a developing country is mainly controlled by the availability of data and the associated costs of data collection and/or acquisition. A researcher in a developing country has to optimize the amount and resolution of data and its costs with a certain level of benefit obtained as a result of a watershed model application. The benefit is the acceptability of model results with a certain degree of uncertainty for decision-making defined by the model performance. Based on this criterion, three components/variables of a watershed modeling project are defined as data, cost and model performance. Figure 6.1 shows the three components of a watershed modeling study. In the following section, these three variables are defined.

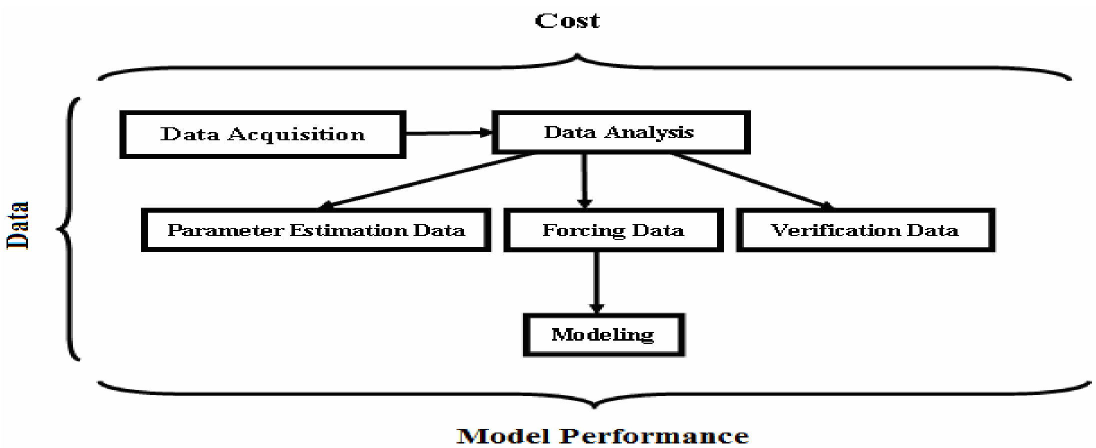

Figure 6.1: Model Application Components

6.2.2 Data

The term 'Data' refers to information required for characterization and representation of physical watershed, the magnitude and temporal aspects of change and resulting processes within it. For the application of BASINS/HSPF for watershed modeling the watershed data may be classified into three types (Munson, 1998), namely parameter estimation data, model forcing data and model verification data. These terms were explained in Chapter 4. A detailed analysis of the data requirement for BASINS and HSPF was carrie dout in the light of its application for the case study watershed. Table 6.1 lists the data requirements for the hydrologic modeling using BASINS/HSPF.

Table 6.1: Data Requirements for Hydrologic Modeling using BASINS/HSPF (General)

Data Type	Constituents
Parameter Estimation Data	Digital Elevation Model Hydrologic Soil Groups Map Land-use Map Vegetation Types Vegetation Density Vegetation Root Depth Groundwater Geology Stream Channel Characteristics Stage Discharge rating Curves Isohyetal Map for the Watershed
Forcing Data	Precipitation Evaporation Evapotranspiration Maximum Temperature Minimum Temperature Mean Temperature Solar Radiation Cloud Cover Wind Velocity
Model Verification Data	Flow Rates Stage

6.2.3 Cost

The cost is defined as a relative value of the monetary equivalent of money and services put in by a researcher to obtain a specific type and amount of data. It does not include indirect costs incurred upon for data collection or monitoring by a government agency or institution. Data obtained for a specific amount of money from a government agency will only incur the price of the data obtained, not the indirect costs by the government agency for collection of that data.

6.2.4 Model Performance

Model performance is the degree of acceptability for model generated results with a known degree of uncertainty for a particular modeling objective (Donigian, 2002). This degree of acceptability and uncertainty is determined by model calibration and validation. The fit between simulated and observed data is universally accepted as an indicator of model performance, which in turn is based on the estimation of a set of parameters delivering the best fit. However, the success of a modeling application is not only a high level of calibration. The inherent model uncertainties, uncertainty in input and calibration data, and the representation of watershed have roles to play in coming up with a certain level of calibration success (Donigian, 2000).

Different graphical and statistical analysis may be used for representation of model performance. The visual inspection of standard plot between observed and simulated datasets may provide an insight into model prediction performance. The root mean square error is a frequently-used measure of the differences between values predicted by a model or an estimator and the values actually observed from the system being modeled or estimated. Coefficient of correlation is another frequently-used statistical indicator of model performance (Donigian, 2000). The objectives of the modeling project play the most important role in defining the success of the modeling effort. A modeling study for flood analysis may be termed as successful if the storm flows are predicted accurately, though low flow conditions may not have been predicted as accurately by the model. In a nutshell, it is a relative term that integrates the objectives of the modeling project with the model prediction capabilities for fulfilling these objectives.

6.3 Development of an Optimized Model Applicability Pathway

The three basic components defining the applicability of a watershed model in a developing country are data, cost and model performance. There cannot be a universal fit for all configurations of data, and corresponding costs for a specific required degree of model performance as the amount and quality of data required will vary with the objectives and the scope of modeling project. Similarly, the cost of obtaining a specific quality and number of datasets is also dependent on the individual circumstances of the case study area, the institutional and information collection structure of the country. Due to the absence of any empirical data and specific studies that relate data, cost of data acquisition and model performance, a subjective assesment of evidence must be carried out to define the relationships between the components of model applicability in developing countries or data poor environments. This evidence must be collected from multiple lines of analysis. This approach is known as the "Weight of Evidence (WoE)" approach that may be adopted to define the behavior of the three components based on theoretical judgment and objective reasoning.

6.3.1 Weight of Evidence (WoE) Approach

Weight of Evidence (WoE) is a concept used in several fields (including law and statistics) referring to the preponderance of evidence to inform decision-making (Burton *et al*., 2002). WoE approaches reported in the literature vary broadly from subjective and qualitative to quantitative issues. No standard approach exists and no accepted guidelines exist describing how a WOE process should be conducted.

WoE has at least three characteristic uses; metaphorical, methodological (with several subcategories), and theoretical, roughly in order of their relative prevalence (Weed, 2005). Approaches to WoE can be widely divided into four different general categories of indices; statistical summarization, scoring systems, logic systems, and best professional judgment (Gough, 2007). In most cases, the "WoE assessment" is simply a qualitative comparison of the "Line of Evidence", where Best Professional Judgment (BPJ) is being used (Chapman *et al*., 2002). WoE evaluation is a determination of what is a reasonable conclusion in view of all available information without numerical safety factors or uncertainty factors while exercising one's best judgment (Doull *et al*., 1996).

6.3.1.1 Best Professional Judgement

In this study, BPJ approach is used to define the interrelationships of model applicability components. It comprises the use of expert opinion and judgment based on available data and site- and situation-specific conditions to determine an endpoint conclusion (Chapman *et al*., 2002; Gough, 2007).

BASINS/HSPF was used for hydrologic modeling of Koycegiz watershed. The availability and acquisition of data, relative costs and model performance for hydrologic modeling are qualitatively quantified based on objective assessment. Qualitative categories for cost and data are defined with a corresponding model performance index. The cost and data categories are analyzed vis-à-vis model performance to devise a subjective theory of optimized model applicability based on objective analysis following multiple lines of evidence using BPJ. It is however emphasized here that due to lack of empirical data on availability of model input data, cost of that data and model performance, the quantification of the model application components is entirely subjective. It is based on the subjective professional judgement of the author. The following section describes the steps involved in the process.

6.4 Cost, Data and Model Performance Categorization

6.4.1 Cost Categories (CC)

The cost of acquisition of a specific dataset is arbitrarily defined by five classes. The categories do not reflect actual costs, but rather incorporate the relative amount of money to obtain that specific dataset. It varies from freely available data to high relative cost with the corresponding cost categories from free to an expensive cost attribute.

6.4.2 Data Categories (DC)

The data category quantifies the quality and quantity of that specific dataset into a single attribute varying from poor to excellent. The data category for a certain dataset must be assigned based on the objectives of the study, type of the dataset and its impact on the overall modeling project. Table 6.2 shows the attributes of corresponding cost and data categories. A data category attribute N represents non-available data.

Table 6.2: Cost and Data Categories

Cost Attribute	Cost Category	Data Attribute	Data Category
Free	A	Poor	A
Nominal	B	Fair	B
Medium	C	Good	C
Substantial	D	Very Good	D
Expensive	E	Excellent	E

The categorization of available data is assessed based on five criteria listed below;

- Spatial Resolution defines the detail to which the specific dataset represent the study area,
- Coverage refers to the spatial representation and temporal interval of a specific dataset,
- Continuity defines the lack of gaps in data,

- Consistency incorporates minimization of uncertainty in data collection, and
- Compatibility of data pertains to the availability of data in a format as required by the specific model in this case BASINS/HSPF.

The data attribute takes into account the importance of each criterion for the specific data constituent and categorizes it into a specific class. Table 6.3 lists the quality criteria for the specific datasets required for hydrological modeling using BASINS/HSPF.

Table 6.3: Quality Criteria for Datasets

Data Type	Constituents	Quality Criteria
Parameter Estimation Data	Digital Elevation Model (DEM)	1,4,5
	Hydrologic Soil Groups Map	1,2,3,4,5
	Land Use Map	1,2,3,4,5
	Vegetation Types	1,2,3,4,5
	Vegetation Density	1,2,4,5
	Vegetation Root Depth	1,2,3,4,5
	Groundwater Geology	1,2,3,4,5
	Stream Channel Characteristics	1,2,3,4,5
	Stage Discharge rating Curves	2,3,4,5
	Isohyetal Map for the Watershed	1,2,3,4,5
Forcing Data	Precipitation	2,3,4,5
	Evaporation	2,3,4,5
	Evapotranspiration	2,3,4,5
	Maximum Temperature	2,3,4,5
	Minimum Temperature	2,3,4,5
	Mean Temperature	2,3,4,5
	Solar Radiation	2,3,4,5
	Cloud Cover	2,3,4,5
	Wind Velocity	2,3,4,5
Model Verification Data	Flow Rates	2,3,4,5
	Stage	2,3,4,5

A DEM of finer resolution will definitely have a higher data score than a DEM of coarser spatial resolution. Precipitation data from a gauge that fully represents the precipitation regime has a higher data score than one that only represents a part of the watershed precipitation regime. Spatial resolution is an important quality criterion for the parameter estimation datasets in addition to other criteria. A finer resolution dataset will provide more detail to the model about the physical characteristics of the system and thus may improve the model performance. This will however cost more to obtain finer resolution datasets. The forcing data and model verification data though do not have spatial resolution as one of the quality criteria but these datasets need to be of sufficient coverage, continuity and consistency and be in a format compatible for use as model input.

6.4.3 Model Performance Index (MPI)

For this study, model performance index (MPI) that takes into account the objectives of the study, uncertainty in data and the results of visual and statistical analysis of the calibration and validation fit into a single model performance indicator are defined. It is an arbitrary and subjective interpretation of model performance based on the strength of evidence justifying a specific acceptability to that specific modeling study. It varies from 0 to 1. A value of 1 presents 100% calibration/validation, and correspondingly a higher acceptance while a value of 0 means absence of any correlation between simulated and observed data. The model performance for hydrologic modeling using BASINS/HSPF may be assessed based on the evidence from comparisons of standard plots, scatter plots, flow duration curves of the simulated and observed flows. Further evidence may be obtained by analyzing the components of observed and simulated. The modeler may also consider data uncertainty, any unaccounted sources and sinks, and the degree of representation of the watershed to subjectively assign a MPI value for the model performance.

6.5 Cost and Data Categorization for Datasets from Koycegiz Watershed

The quantification of data and cost into relative categories helps the user to quantify the relationship between data availability, data quality, and cost of data acquisition, which in turn determines the model performance. The available datasets from Koycegiz watershed are tabulated in Table 6.4. For modeling with HSPF, the preferred time interval for meterological data is hourly to accurately model water quality. However, daily time step is at least recommended . Many of the datasets required for modeling objectives were not available. Some of these non available datasets could be derived or computed from available measured datasets. These datasets were therefore computed and derived from measured datasets for use as input to the model . It is importatnt to note that even though measured model input data may not be available, data that can be used to derive or compute the model input data may constitute the minimum data required data for model application.

Table 6.4: Measured Meteorological Data available for Koycegiz Station

PARAMETER	**TIME INTERVAL**
Total Precipitation (mm)	Daily, 07:00, 14:00 and 21:00 measurements
Total Evaporation (mm)	Daily except for the months of Jan, Feb, Mar and Dec.
Average Humidity (%)	Daily, 07:00, 14:00 and 21:00 measurements
Average Humidity (%)	Daily (From Hydrograph)
Wind Speed (m/s)	Seven Hourly measurements at 07:00, 14:00 and 21:00 hrs
Wind Direction	Seven Hourly measurements at 07:00, 14:00 and 21:00 hrs
Temperature (^{0} C) Cloud Cover (0-10)	Seven Hourly measurements at 07:00, 14:00 and 21:00 hrs Monthly Average

Table 6.5 lists the computed time series and the required input time series for their computation. Different methods may be available for computation of a specific required time series. The method chosen depends on available measured data and its usage in technical literature. For example, Potential Evapotranspiration (PET) may be computed using Hammon's or Jensen's methods based on the availability of measured or computed solar radiation. Inb the case of non availability of solar radiation data Hammon's method may be used to compute PET. Also the required input time series in fact constitute the minimum required data for the derivation of input data for model simulation in the absence of directly measured input data.

Table 6.5: Computed and required input Time Series in WDMUtil

Computed Time Series	**Input Time Series**
Solar Radiation	Cloud Cover, Latitude
Daily Jensen PET	Min Air Temp., Max Air Temp., Solar Radiation
Daily PET Hammon	Min Air Temp., Max Air Temp., Latitude
Daily Penmen Pan Evaporation	Min Air Temp., Max Air Temp., Dew point Temperature, Wind Movement, Solar Radiation
Wind Travel	Wind Speed
Percent Cloud Cover	% Sun
Dew point Temperature	Mean Temperature, Relative Humidity
Min Air Temp., Max Air Temp.	Seven Hourly measurements at 07:00, 14:00 and 21:00 hrs

The computaion of dewpoint, maximum, minimum and mean temperatures was described in Chapter 4. The rest were computed using the built-in computation features of WDMUtil software using the available measured data for the watershed.

Table 6.6: Cost and Data Categorization for Datasets from Koycegiz watershed

Data Type	Constituents	Koycegiz	
		DC	**CC**
Parameter Estimation Data	Digital Elevation Model	C	B
	Hydrologic Soil Groups Map	N	-
	Land Use Map	B	B
	Vegetation Types	N	-
	Vegetation Density	N	-
	Ground Water Geology	N	-
	Channel Characteristics	N	-
	Rating Curves	N	-
	Isohyetal Map	N	-
Forcing Data	Precipitation	C	B
	Evaporation	C	B
	Evapotranspiration	N	-
	Maximum Temperature	B	B
	Minimum Temperature	B	B
	Mean Temperature	B	B
	Solar Radiation	A	C
	Cloud Cover	B	B
	Wind Velocity	B	B
Model Verification Data	Flow Rates	B	B
	Stage	N	-

The data and cost categories of the datasets available for Koycegiz watershed are listed in Table 6.6. The data categories for available data for the Koycegiz watershed fall under poor to good category based on the quality criteria tabulated in Table 6.3 for the corresponding dataset. The digital elevation model map for the Koycegiz watershed was of 100 m resolution developed from a 1:125000 contour maps. A finer resolution of DEM may have been categorized as very good to excellent data category. The contour maps were obtained for a nominal cost from the National General Command of Mapping.

Similarly, the land use map was obtained for a nominal cost from the General Directorate of Rural Affairs. The map has a coarse spatial resolution and is temporally not current. The flow rates were obtained for a nominal cost from the SHW for a period of 10 years. The dataset has been rated as poor because of lack of consistency and continuity. Therefore, it has been categorized as fair for the modeling project. Most of the other available data is categorized as fair based on the justifications provided in Table 6.7. The precipitation and evaporation datasets are categorized as good, however they demand further sophistication in coverage and continuity.

Table 6.7: Koycegiz Watershed Data Quality Categorization

Dataset	Justification for Categorization
DEM	Coarse Resolution
Land Use Map	Coarse Spatial Resolution
Precipitation	Insufficient Coverage
Evaporation	Insufficient Coverage, Inconsistent, Discontinuous
Maximum Temperature	Computed from 8 hourly Temperature Data
Minimum Temperature	Computed from 8 hourly Temperature Data
Mean Temperature	Computed from 8 hourly Temperature Data
Solar Radiation	Computed from monthly cloud cover data
Cloud Cover	Insufficient resolution
Wind Velocity	Insufficient resolution
Flow Rates	Inconsistent, Insufficient Coverage, Discontinuous

6.6 Weight of Evidence Analysis

As described above, the determination of the optimum model applicability pathway relies on the availability of data, cost of acquiring the available data, and the benefit in terms of model performance associated with using that data for a specific model application towards solving a specific watershed problem. The cost categories, data categories and model performance index provide the yardsticks for the quantification of the relationships between the three components of model applicability in a developing country or a data poor environment. However, such an analysis require empirical data to formulate mathematical relationships between the three components which in this case is non- existent. The only alternative for devising such a description of these relationships is to retrosepectively analyze the case study application in Koycegiz watershed for determining the effects of data quality on cost of data and their effects on model performance. Therefore, a weight of evidence analysis based on best professional judgement of the author is carried out that is subjective in nature; however, it is based on objective reasoning and evidence from the case study application of BASINS and HSPF.

7. RESULTS AND DISCUSSION

The results of the study are relevant to the two main components of the research. The first part of the results is related to the application of BASINS and HSPF as decision support tools in the Koycegiz watershed. The results of watershed delineation, characterization hydrologic model calibration, and simulation of NPS pollution are presented in detail to indicate the utility of these tools in decision making. Furthermore, the impacts of climate and land use change on the hydrologic regime and NPS pollution are presented and their implications for decision support are discussed.

The second part of the results comprises of the analysis of modeling application using BASINS and HSPF in the case study watershed. It presents the results of the weight of evidence analysis for the determination of the relationships between the model applicability components and the identification of an optimum model aplicability pathway for researchers in developing countries.

7.1 Results for Watershed Delineation and Characterization

The drainage area boundaries were defined and stream network was extracted using the DEM for the Koycegiz watershed. Major land use/land cover segments were defined using MapWindow GIS capabilities. Watershed segmentation into sub-watersheds was carried out and other physically-based attributes were calculated for watershed segments using the built-in delineation tool of BASINS. HSPF model within the BASINS models was selected for the application. The sub-basins, streams and land use GIS layers were created. Weather data file was created using WDMUtil in BASINS by inputing time series data for metereological data obtained from the Koycegiz Metereological Station. Project file was created using WDMUtil containing flow data for Namnam gauge station for calibration and validation purposes from October 1990 to September 1999. BASINS creates the input parameters for HSPF in English units; therefore, the meteorologic and flow data were converted into English units using the unit conversion features of WDMUtil. The HSPF input files Watershed File (*.WSD), Reach File (*.RCH), Channel Geometry File (*.PTF), Point Sources File (*.PSR), Meteorologic data (*.WDM) were created and HSPF was initiated within BASINS.

The configuration of model network is an important step before embarking upon a watershed modeling project. Based on the objectives and scope of the modeling project ,results of the preceding operations within the automatic watershed delineation process in BASINS are shown in Figures 7.1-7.3.

Figure 7.1 a shows the DEM of the entire Koycegiz watershed. Figure 7.1 b represents the DEM after pit filling. The DEM and the pit filled DEM correspond well with eachother implying existence of very few sinks in the original DEM that too at a micro level. These sinks therefore do not affect the final outcome of the delineation process as at such a microscale there impact may be considered negligible and insignificant. Figure 7.1 c shows the outcome of the determination of the slopes for the pit filled DEM of the Koycegiz watershed. The northern parts of the Koycegiz watershed are characterized by high and steep slopes except for the river bed. While the southern parts of the watershed is characterized by flat plains. Figure 7.1 d shows the flow directions based on the D-8 flow determination method. The flow directions in the northern part are dominated by north western flow directions that change to south east in the middle of the Koycegiz watershed towards the Koycegiz lake and then towards the south into the Dalyan lagoon.

It is important to note here that watershed delineation and segmentation in BASINS is an iterative process. The number of iterations depends on the optimization of the complexity of the system components to be considered in the modeling process. In BASINS, two different criteria shape define the boundaries of the system and its major components. One of the criterion is the threshold value of the contributing area assigned by the modeler, and the other one is the identification of outlets for reaches. For the Koycegiz watershed, after repetitive iterations, a threshold contributing to an area of 75 hectares was selected to optimize the number of sub-watersheds and reaches. The location of the Namnam gauge station was specified for calibration purposes. Due to the above mentioned criteria, only Namnam sub-watershed was incorporated into the system

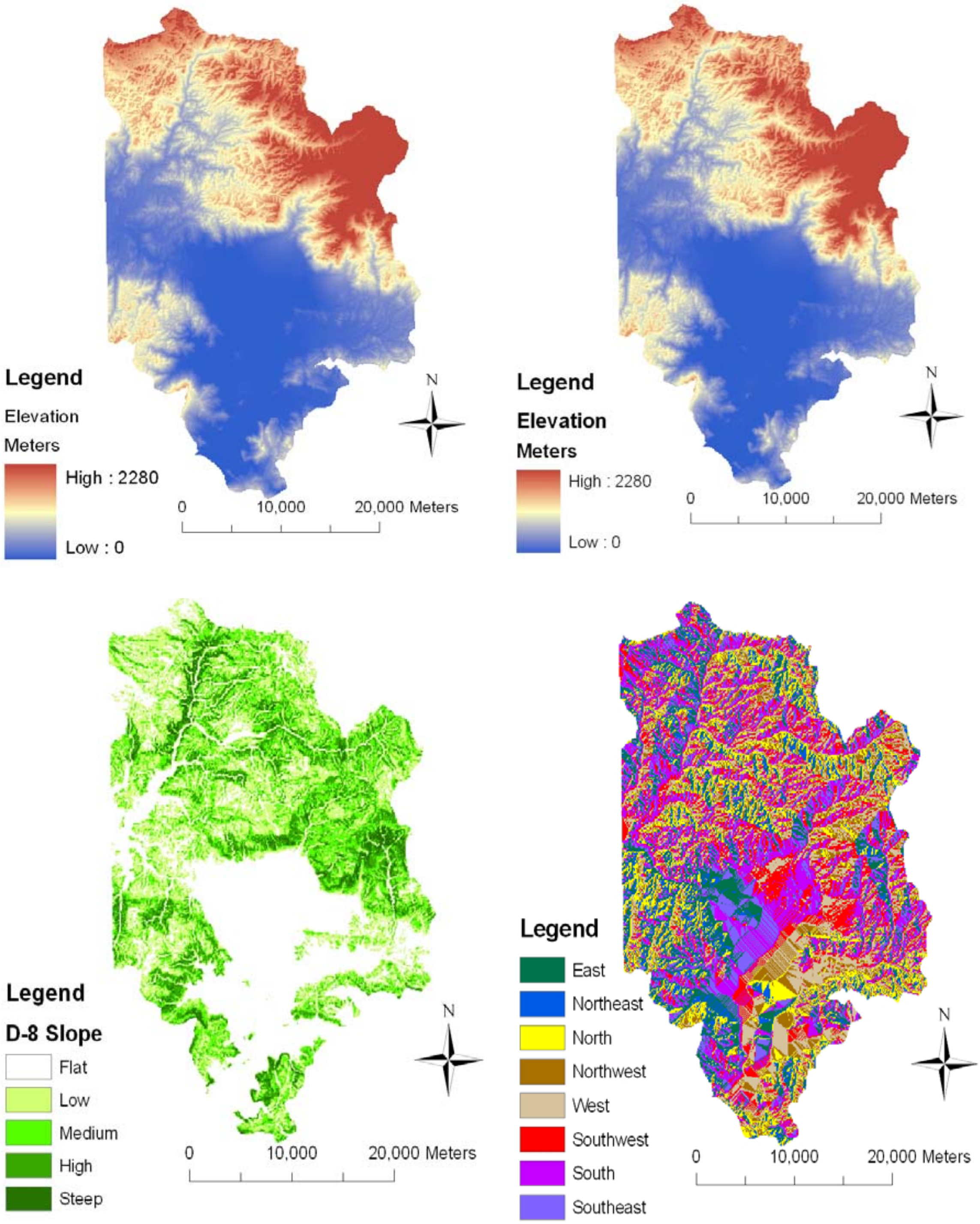

Figure 7.1: Watershed Delineation of Koycegiz Watershed: Clockwise from top left a) DEM b) Pit Filled DEM c) D-8 Flow Directions and d) D-8 Slopes

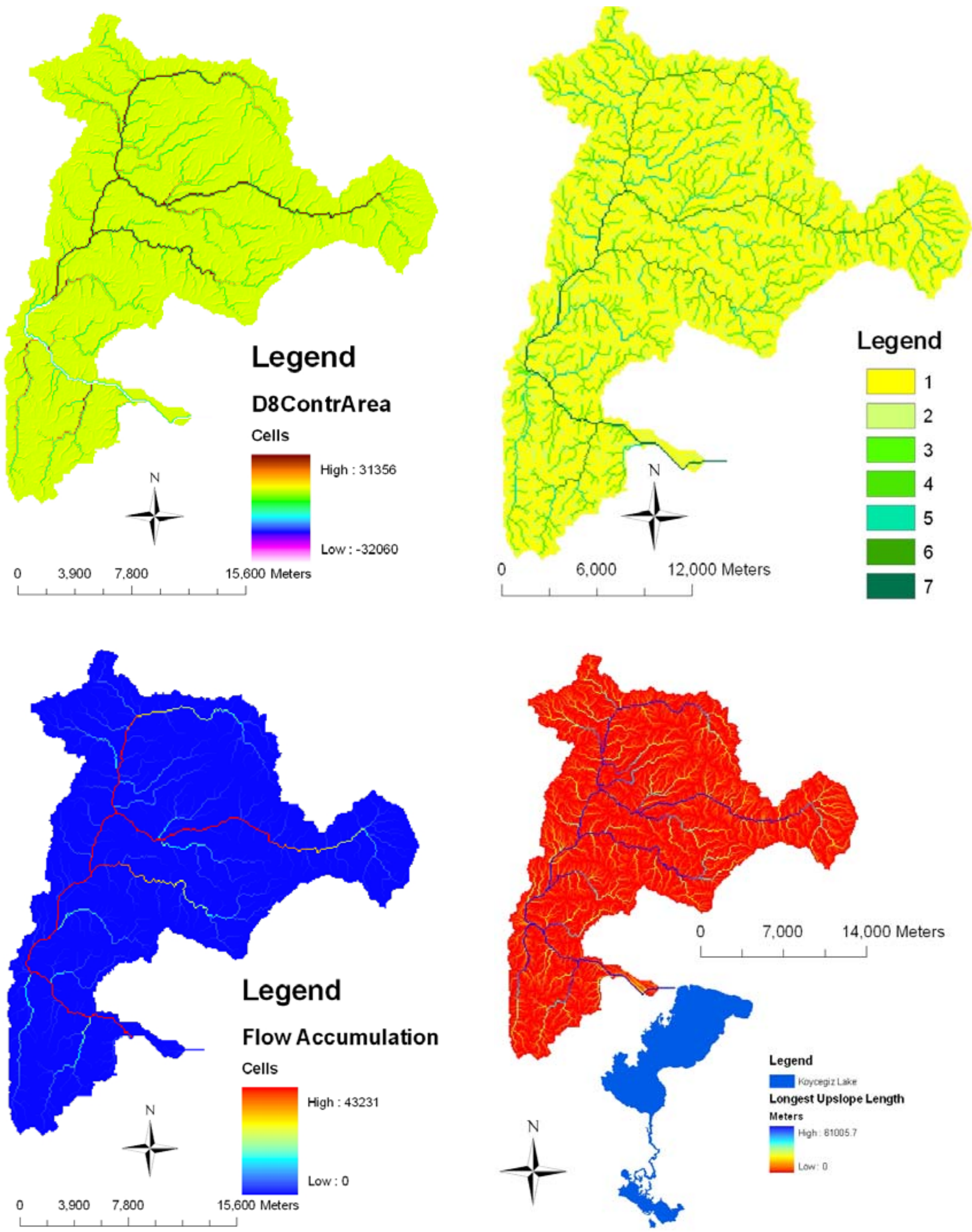

Figure 7.2: Delineation of Namnam Sub-Watershed: Clockwise from top left a) D-8 Contributing area b) Strahler's Network Order c) Longest Upslope Length and d) Flow Accumulation

boundaries for model setup, and subsequent simulation of hydrology and NPS pollution. Figure 7.2 a shows the contributing areas of the different flow paths in the Namnam watershed in the Koycegiz drainage basin after specifying Namnam flow station as the calibration outlet. The definition of stream segments is based on the provision of contributing area threshold by the user. The stream network is then defined consisting of many segments of varying orders. Figure 7.2 b shows the Strahler network orders for the stream segments in the Namnam watershed. Figure 7.2 c and d show the flow accumulation and longest upslope lengths for the Namnam watershed.

Determination of the areas of different land segments in the watershed alongwith their geomorphological characteristics provides useful information for the parametrization of the model. For the Namnam watershed the land cover is shown in the Figure 7.3 a and the respective elevation profiles of the corresponding land uses is presented in the Figure 7.3 b. The modeling setup was defined to consist of four reach segments associated with four sub-watersheds in order to minimiza complexity of the modeling process. Figure 7.3 c shows the sub watersheds and the reach segments for model simulation. Figure 7.3 d represents the final model setup.

As discussed in Chapter 5, the delineation of the watershed was performed using the "burn-in" feature of the automatic watershed delineation tool that defines stream segments based on the topographical parameters extracted from the DEM of the watershed. A comparison of the extracted and the existing stream network however did not exhibit any marked differences except for the outlet of the Namnam stream to Koycegiz Lake. The actual discharge point of Namnam stream into Koycegiz lake is located in the south of where the DEM generated outlet is located. This can be explained by the influence of anthropogenic activities and land use practices responsible for the modification of natural stream beds.

Based on the delineation and characterization of the Koycegiz watershed it can be said that BASINS provides broader room for experimentation with watershed model network for optimizing the number of sub watersheds and reaches in accordance to the objectives of the study and modeling needs.

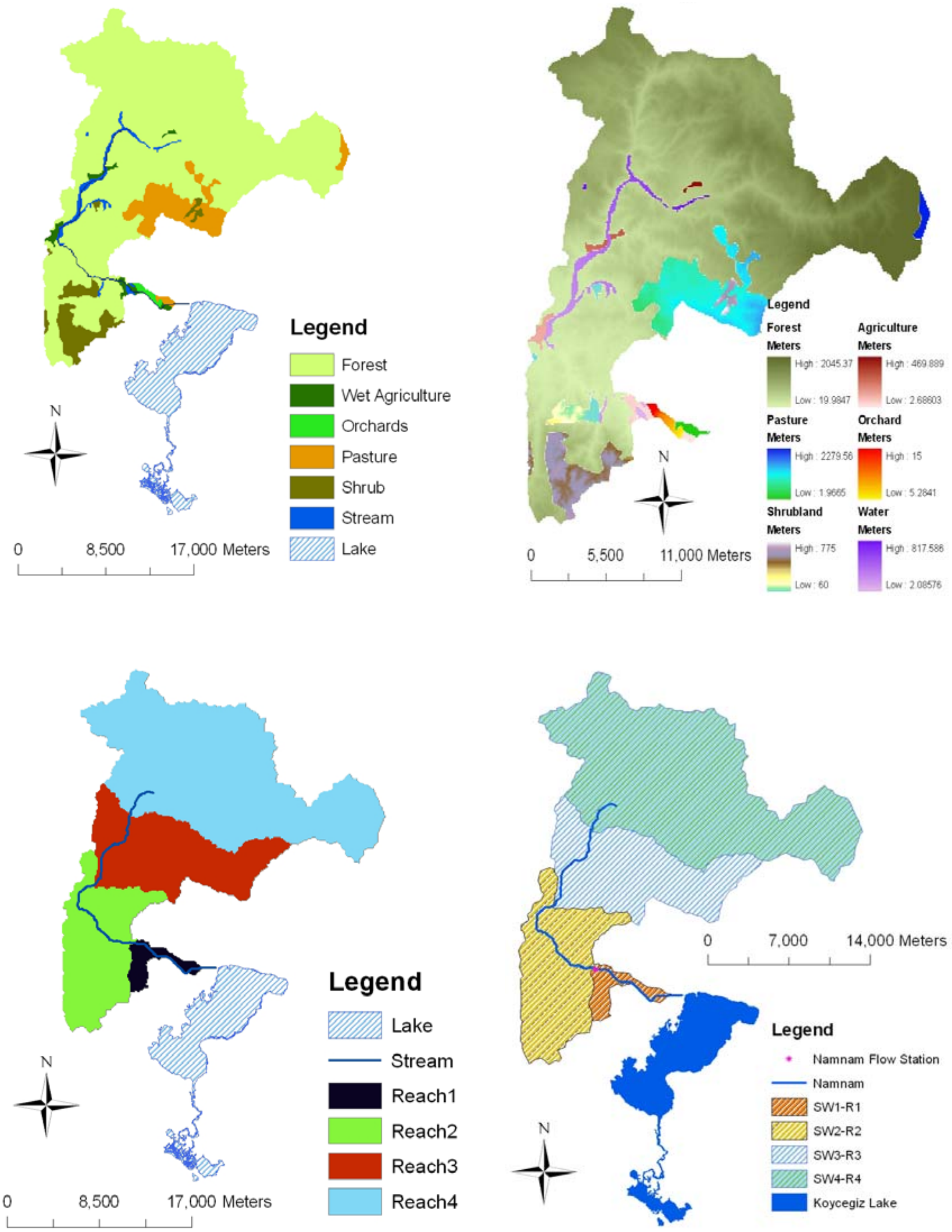

Figure 7.3: Characterization of Namnam Sub-watershed: Clockwise from top left a) Land Cover b) Land Segment Elevations c) Model Setup and d) Delineated Namnam sub-watershed

The automatic watershed delineation tool within BASINS provides this increased workability based on a threshold value of contributing area and location of reach outlets for the definition of reach segments and sub watersheds. The definition of systme boundaries in the absence of such a tool within HSPF requires manual modifications in the UCI file providing an unfriendly user interface, extremely sensitive to incorrect input formats resulting in loss of efficiency.

Figures 7.1 – 7. 3 provide the basic configuration of the watershed system that was used for the simulation of hydrology and NPS pollution using HSPF. It defines the major components of the system in the form of reach segments, sub watersheds and land uses for subsequent modeling processes. This configuration is a function of availability of data and the quality of available data mainly in terms of coverage and resolution. For the Koycegiz watershed calibration data is only available for the Namnam stream therefore extending the boundaries of the system beyond Namnam sub watershed would have added to the complexity of the modeling process and thus the uncertainty in the model generated results. Therefore under prevalent conditions of data avialbility it can be said that the system configuration shown in Figure 7.3 d fullfills the requirments of the modeling objectives.

7.2 Model Calibration and Validation Results

Observed flow data for Namnam stream was available from October 1, 1990 to September 30, 1999. Considering the availability of observed flow data, a calibration period of January 1, 1995 to September 30, 1999 was selected for simulation of watershed hydrology. The land use/land cover maps were obtained for year 2000 and owing to its temporal proximity, 1995-1999 was selected for calibration purposes. The hydrologic model was validated using flow data of the Namnam stream for the period October 1, 1990 to December 31, 1994. Furthermore, the model was also run for the period of available data. The result of a model calibration is a set of parameters that produce the best overall agreement between simulated and observed values during the calibration period, based on a predefined set of criteria (Donigian, 2002). The following section presents a discussion on the calibration and validation results for the hydrological model of the Namnam stream in the case study watershed.

The assessment of model performance based on the linear correlation coefficient is presented in Table 7.1. The model performance varies from poor to fair based on the criteria discussed earlier. These results show that the model performance on predicting daily flows has not been at the same level with its ability to predict the monthly flows. However, just one set of criteria is selected for the evaluation of model performance. To ascertain the acceptibility of model results, other criteria discussed in Chapter 5 should also be evaluated.

Table 7.1: Model Performance based on Correlation Coefficient

	Calibration Period 1995-1999		**Validation Period 1990-19994**		**Entire Period Oct. 1990- Sep. 1999**	
	Mean Daily	Mean Monthly	Mean Daily	Mean Monthly	Mean Daily	Mean Monthly
R	0.634	0.847	0.761	0.843	0.638	0.838
Status	Poor	Fair	Fair	Fair	Poor	Fair

Another criteria for the evaluation of calibration results is generated using HSPEXP. The results of calibration of the hydrologic model for the Namnam stream in the Koycegiz watershed based on the HSPEXP criteria are presented in Table 7.2.

Table 7.2: Model Calibration Performance Results compared to findings of Donigian (2002)

Flow Component (units)	**Simulated**	**Observed**	**% Error**	**Criteria**	**Status**
Total Runoff (in)	118.90	122.692	-3.1	10 %	Very Good
Total of Highest 10% Flows (in)	54.29	56.667	-4.2	15 %	Very Good
Total of Lowest 50% flows (in)	6.080	9.448	-35.6	10 %	Poor
Evapotranspiration, (in)	11.020	11.130	1.0	10 %	Very Good
Total storm volume (in)	27.120	33.260	-18.46	10 %	Fair
Average of storm peaks (cfs)	1967.731	2420.667	-18.7	15 %	Fair
Summer Flow Volume (in)	1.750	5.940	-70.53	10 %	Poor
Winter Flow Volume (in)	72.640	67.727	7.25	10 %	Good
Summer Storm Volume(in)	0.00	0.00	0.00	15 %	--
Base Flow Recession rate (ratio)	0.930	0.920	0.01	0.01	Good
Total Interflow(in)	19.290	---	--	---	---
Total Surface Runoff (in)	4.260	---	---	---	---

Based on the HSPEXP criteria model, performance in predicting summer flow volumes and total of 50% of flows is poor where as it has been succesful in representing the actual total run off , total of highest 10% flows and evapotranspiration. Based on these results, it might be argued that a lower correlation coefficient for mean daily flows might be associated with under-representation of summer flows by the model. However, in order to further ascertain the evaluation of model performance, graphical tests may be

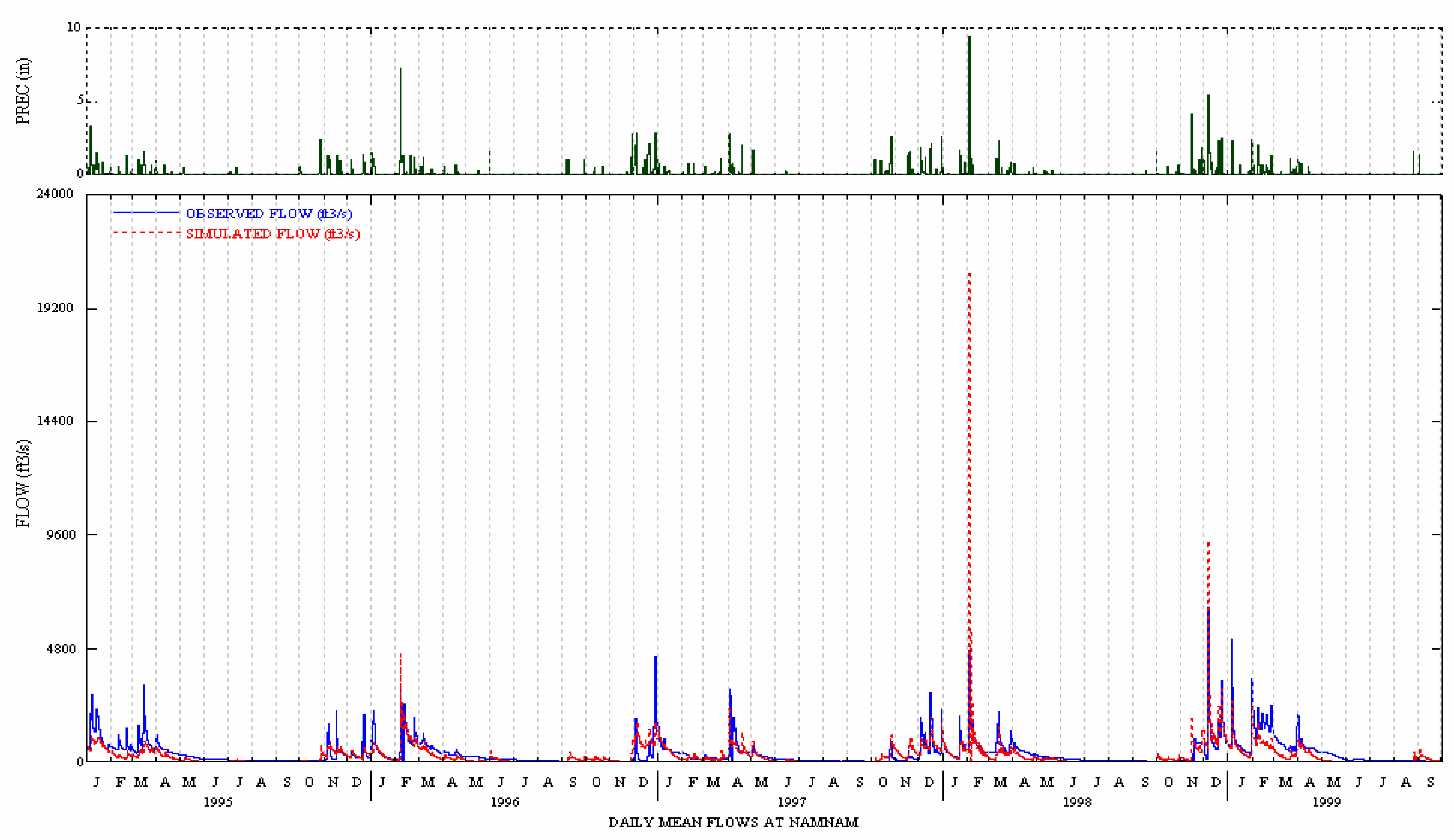

Figure 7.4: Calibration-Standard Plots for Observed and Simulated Daily Flows at Namnam (1995-1999)

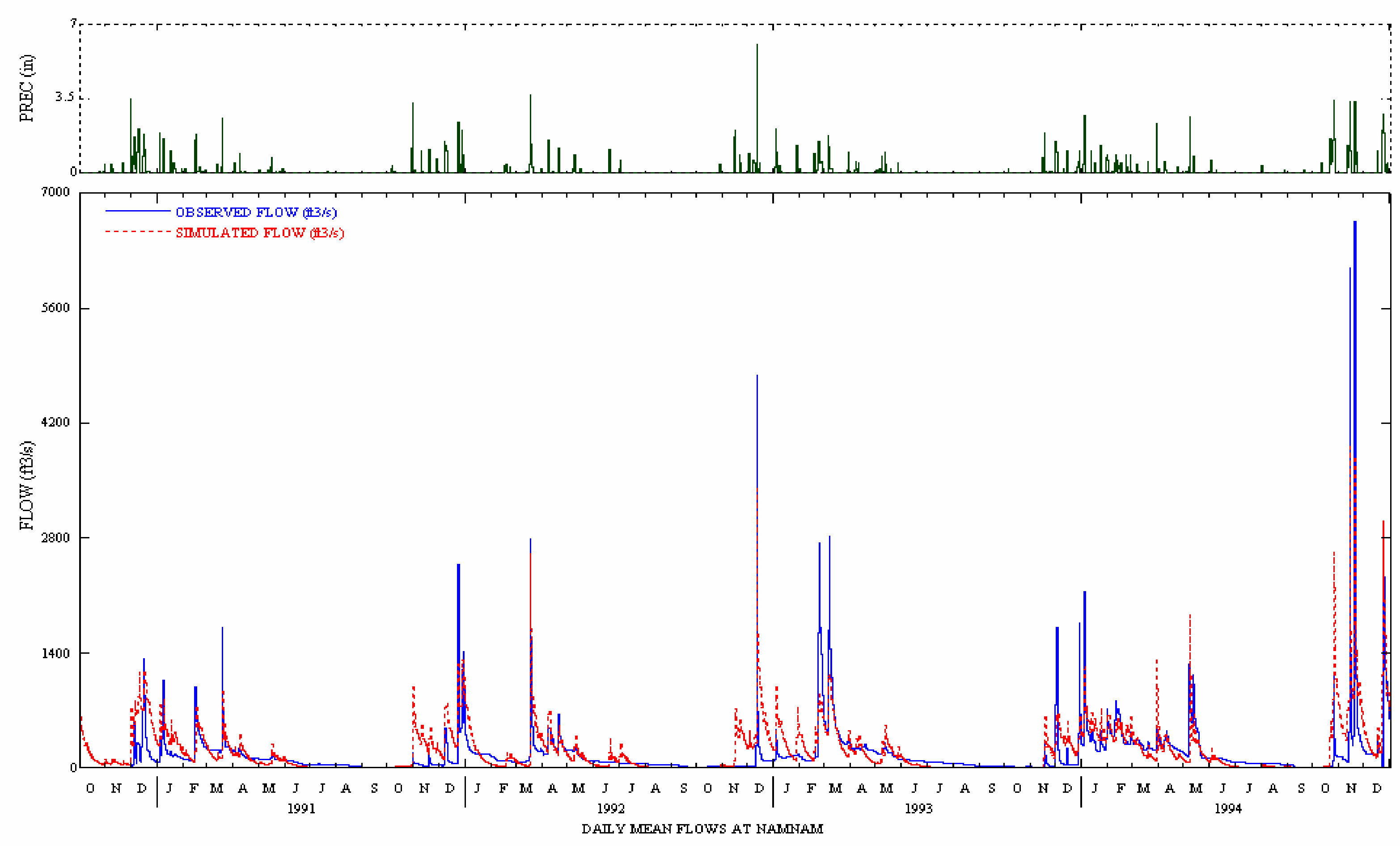

Figure 7.5: Validation-Standard Plots for Observed and Simulated Daily Flows at Namnam (1990-1994)

conducted. As discussed in the previous sections, these tests involve comparison of standard plots of simulated and observed flows, scatter plots and flow duration curves for simulated and observed flows.

Figures 7.4 and 7.5 present the standard plots for observed and simulated daily mean flows at Namnam station for the calibration and validation period of available flow data, respectively.The calibration and validation standard plots show consistent trends in simulated flows following the observed flows.The standard plots of daily mean flows for observed and simulated flows show considerable consistency in identifying the storm events, however, the simulated results lack consistency in showing base flows. However, model generated flows under extreme precipitation events are much higher than the observed flows for the same events. The storm event in February 1998 was caused by a 24 hours precipitation of 9.4 inches (239.2 mm) per day. This value is higher than the expected 100 years period storm of 8.4 inches (214.9 mm) per day. The differences in daily flows can be explained by the differences in the actual precipitation patterns and the measurements in the Metereological Station. The precipitation data available for the entire watershed is obtained from only one metereological station lying in the relatively flatter part of the watershed; therefore, lacking the coverage representing the areas of watershed that are higher in elevation.

The comparison of the monthly mean flows and the total monthly flows also shows lower summer flows predicted by the model as compared to the observed. Figure 7.6 present standard plots for observed and simulated total monthly flows. However, total annual flows for observed and simulated flows are consistent as shown in Figure 7.7.

An analysis of relationships between flow duration curves (FDCs) for the simulated and observed flows can provide some insight into the performance of a model in representing the movement of water in a watershed. Figure 7.8 presents the flow duration curve for the observed and simulated flows based on the simulation of the entire data period. Flow duration analysis typically uses daily average discharge rates, which are sorted from the highest value to the lowest plotted against percent of time the values have been met or exceeded. Flow duration intervals are expressed in percentages, with zero corresponding to the highest stream discharge in the record (i.e. infrequent

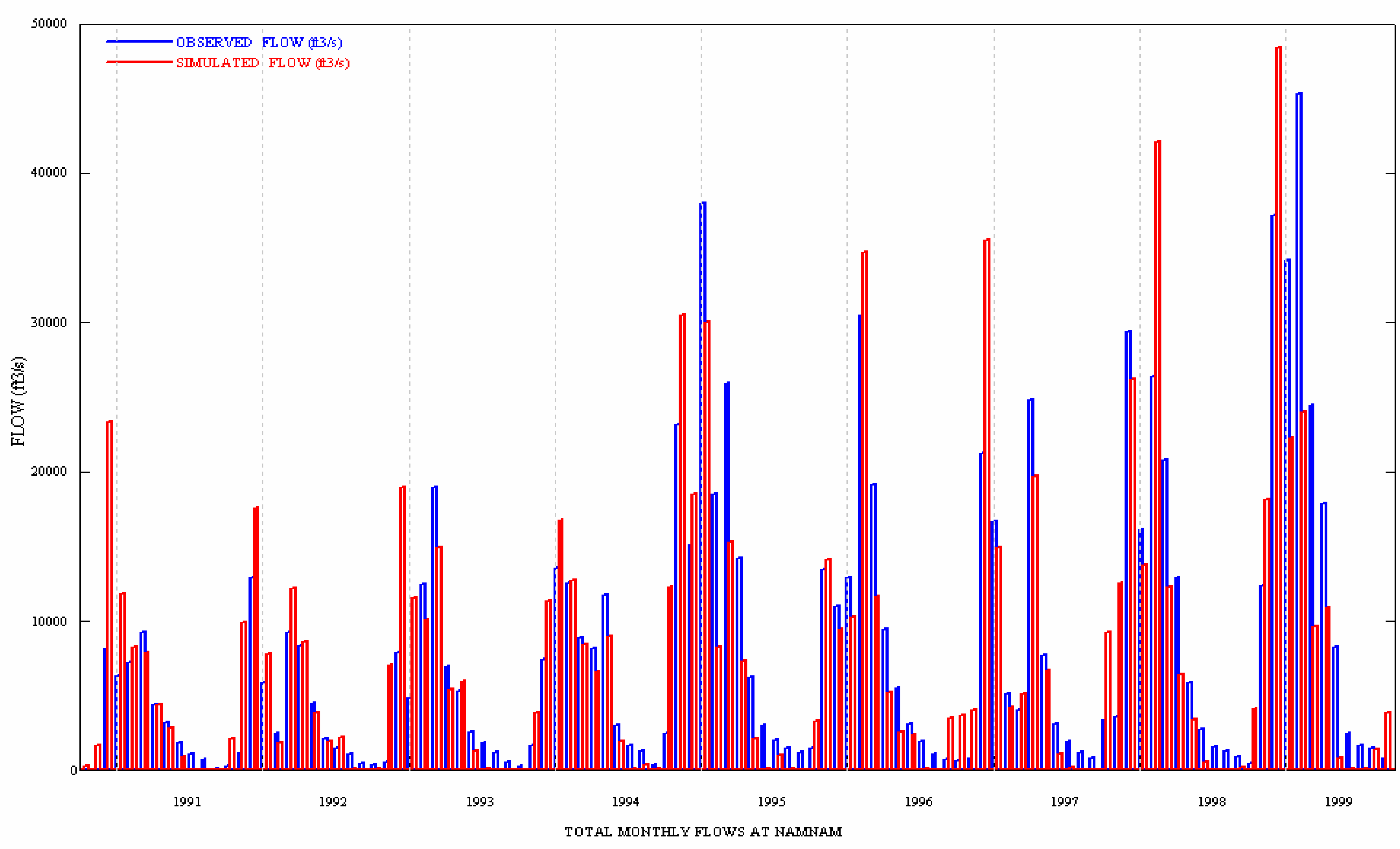

Figure 7.6: Observed and Simulated Total Monthly Flows at Namnam (1990-1999)

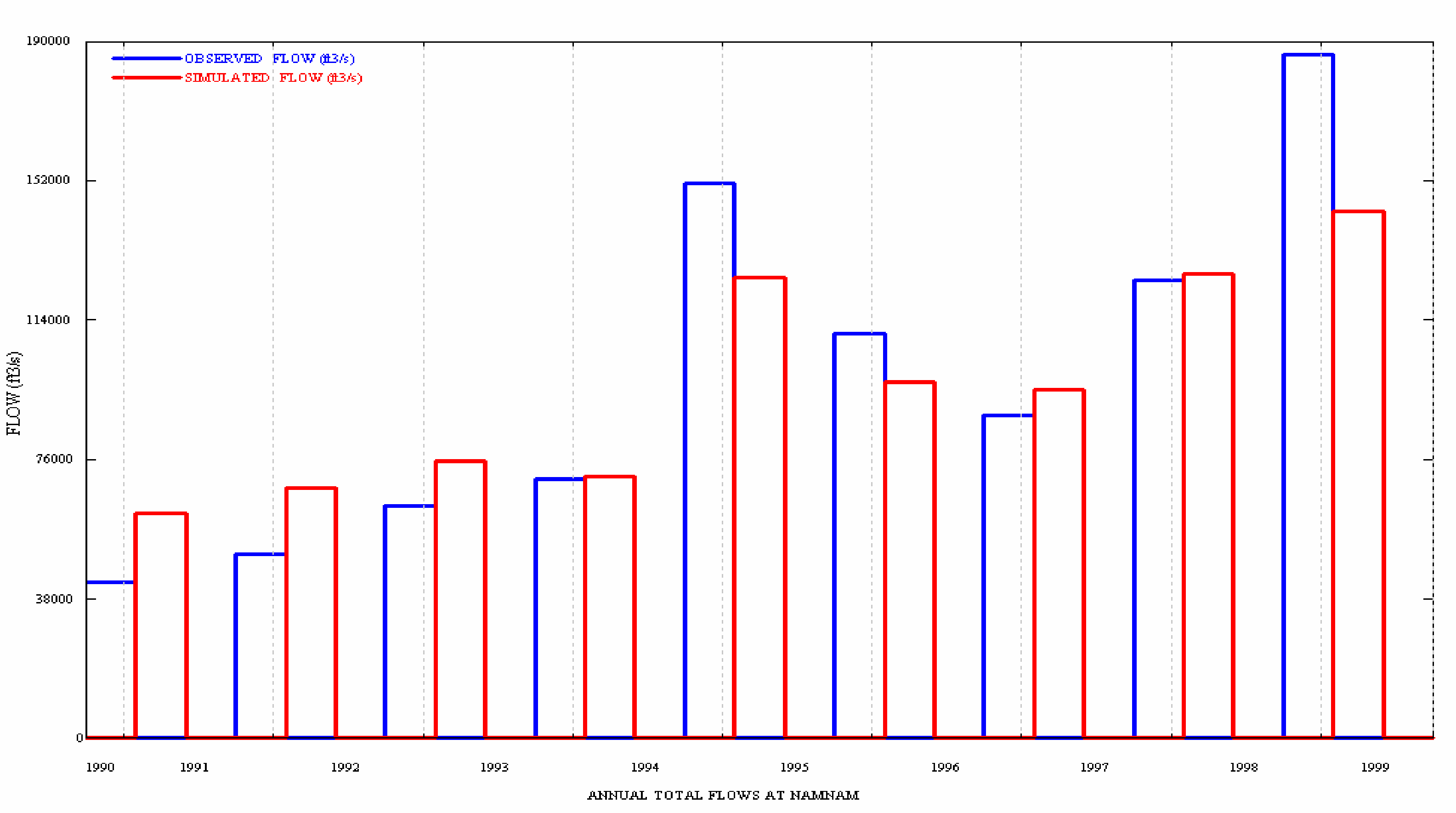

Figure 7.7: Observed and Simulated Total Annual Flows at Namnam (1990-1999)

exceedence, flood conditions) and 100 to the lowest (i.e. most frequent exceedence, drought conditions). The FDCs have been divided into 5 zones after Cleland (2003). The scatter plots and flow distribution curves for the individual calibration and validation runs are presented in Appendix A. Similarly, standard plots based on the average monthly flows and scatter plots based on average monthly flows are also presented in Appendix A.

The shape of the simulated FDC for the first three zones of higher flows, moist conditions and mid- range flows follow an approximately similar shape and slope to that of observed FDC, thereby representing the hydrologic regime in the watershed for approximately 60 % of the flows. This fact is evident in the consecutive flow duration curves for calibration, validation (Appendix A), and the entire period where simulated and observed flows present similar probabilities for higher flows, however, at low flow conditions, the simulated and observed flows vary drastically.

However, as seen from the calibration and validation results, FDC for simulated flows in the dry conditions and lower flow zones do not exhibit similar properties to that of observed FDC. Steeper slope for the simulated flows in the dry conditions represent a highly variable system with stream flow largely driven by direct runoff with limited groundwater storage capacity. Considering the typical Mediterranean climatic conditions and lack of data for exact representation of soil infiltration characteristics and groundwater interactions in the watershed, this irregularity in simulated flows may be credited to high evaporation and infiltration rates during the summer months, which is also evident from the lack of sustained base flow shown in the observed flows of FDC.

Furthermore, considering the objectives of the study and the pollution sources within the watershed, the representation of low flows may not be an important factor in simulated flows. Nonpoint sources are typically associated with runoff events in the mid-range, moist and higher flow conditions. On the other hand, dry conditions may be critical for point source discharges into the stream. Due to lack of point sources in the watershed, the inappropriateness of low flows in the model results does not pose any serious contradiction against the study objectives.

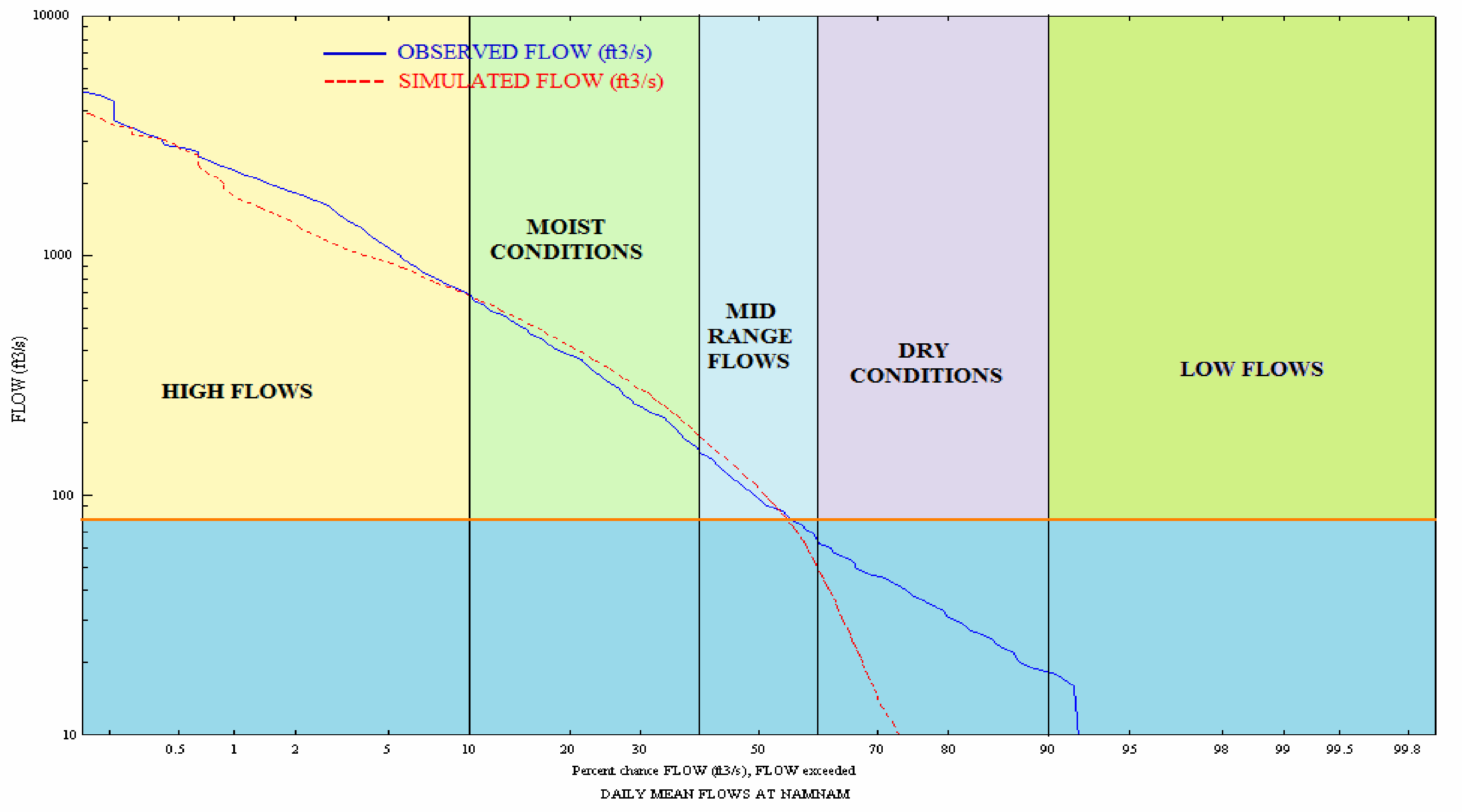

Figure 7.8: Flow Duration Curves for Observed and Simulated Flows

7.3 Determination of NPS Pollutant Loads

The major land use/land cover for the watershed is forests which constitute 81% of the total land. Figure 7.9 shows the land use distribution in the watershed.

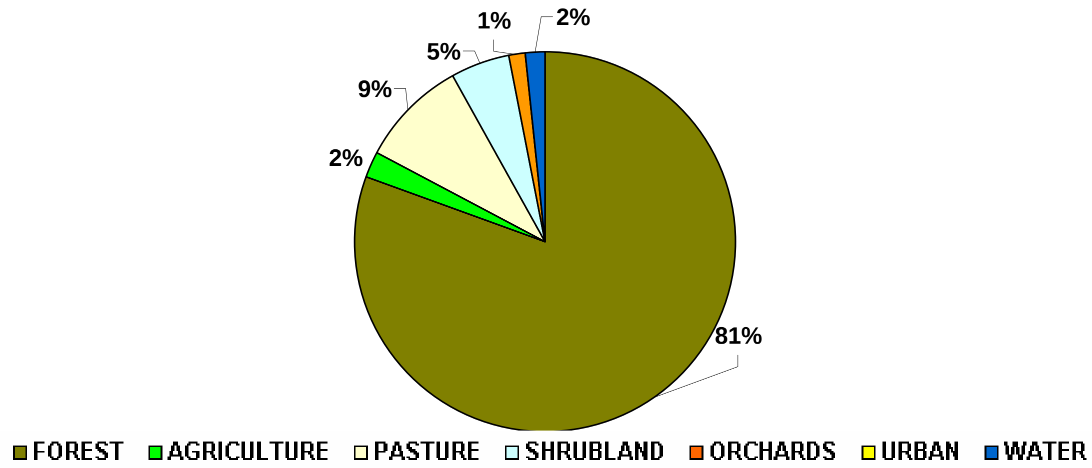

Figure 7.9: Distribution of land uses in the watershed

The sediment production and removal was simulated for each land use under the current conditions. The daily, monthly and annual mean values of sediment production for different land uses were determined. Similarly, nitrate-N, orthophosphate-P and BOD fluxes and total annual loads were determined from each land use and the entire watershed. Due to lack of calibration data, the results of NPS pollution loading could not be calibrated. Therefore, a holistic approach towards assessment of loadings, only average annual and total annual sediment loads is considered based on the relative loadings arising from different land uses. Table 7.3 lists the sediment flux and the total annual sediment loading contributions of the individual land uses.

Table 7.3: Distribution of sediment release from different land uses

Land Use Category	Area	Sediment Loads	
	Acre	Ton/ac/yr	Ton/yr
FOREST	97024	0.000120125	11.65501
AGRICULTURE	2725	0.000272	0.7412
PASTURE	10732	0.000331	3.552292
SHRUBLAND	6284	0.000264625	1.662904
ORCHARDS	1411	0.000467	0.658937
Total	118176		18.27034

Figure 7.10 shows the distribution of mean annual flux of sediment, nitrate-N, orthophosphate-P and BOD from different land uses.

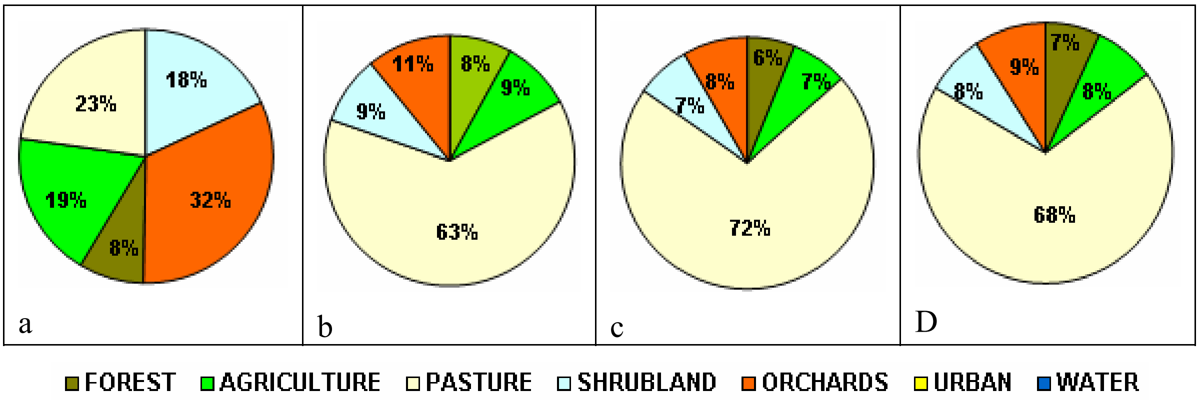

Figure 7.10: Annual NPS Pollutant Flux Distribution among different land uses a) Sediment b) Nitrate-N c) Orthophosphate-P and d) BOD

Table 7.4 lists the distribution of mean annual fluxes of nitrate-N, orthophosphate-P and BOD based on land use.

Table 7.4: Distribution of mean annual fluxes of pollutants

LAND USE	AREA	NITRATE-N	ORTHO-P	BOD
	acres	lbs/ac.year	lbs/ac.year	lbs/ac.year
FOREST	97024	2.8175	0.0315625	6.26125
AGRICULTURE	2725	3.28375	0.03575	7.125
PASTURE	10732	22.2125	0.362125	62.2
SHRUBLAND	6284	3.1125	0.0364625	6.9625
ORCHARDS	1411	3.785	0.0417625	8.2375

Figure 7.11 shows the distribution of the mean annual total loads of sediment, nitrate-N, orthophosphate-P and BOD based on land uses. Table 7.5 on the other hand, lists the distribution of the total mean annual loads of Nitrate-N, Orthophosphate-P and BOD.

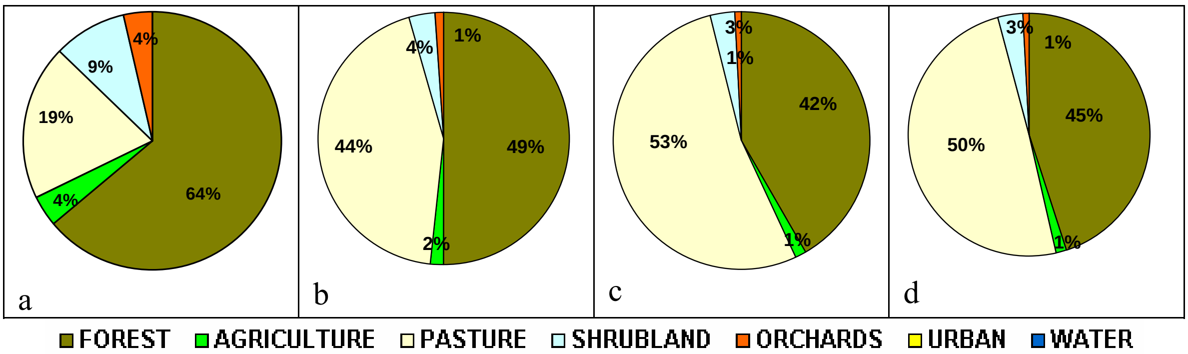

Figure 7.11: Total Annual NPS Pollutant Load Distribution based on Land Uses a) Sediment b) Nitrate-N c) Orthophosphate-P and d) BOD

Table 7.5: Distributions of Total Mean Annual Loads of Pollutants

LAND USE	NITRATE-N	ORTHO-P	BOD
	lbs/year	lbs/year	lbs/year
FOREST	273365.12	3062.32	607491.52
AGRICULTURE	8948.21875	97.41875	19415.625
PASTURE	238384.55	3886.3255	667530.4
SHRUBLAND	19558.95	229.13035	43752.35
ORCHARDS	5340.635	58.9268875	11623.113

The sediment flux arising from the watershed has an approximately even distribution among different land uses of agriculture, pasture and shrub land ;however, it was the highest from the Orchards with forested land generating the least percent of mean annual flux. The orchards are 1% of the total area, but contribute 4% of total sediment load and 32% of mean annual flux. The Forests cover 81% of the total land area; however, contribute to 64% of the total annual sediment load, and 8% of mean annual flux. The total mean annual sediment flux was highest in the year of1998 and was the least in year1993 within the simulated period of 1991-1998.

The pollutants flux from pasture was 63, 72 and 68% for nitrates-N, orthophosphates-P and BOD, whereas it was approximately evenly distributed from rest of the land uses in the watershed. The pasture contributed to 44%, 53% and 50% of total nitrate-N, orthophosphate-P and BOD loads, respectively whereas it constitutes only 9% of total land. The higher pollutant loads from pasture can be attributed to livestock breeding.

7.4 Scenario Analysis

The results of different scenarios were analyzed in terms of the effects of land use and climate change on hydrological regime of the watershed, and the total annual loads of sediment and simulated pollutants. The results of the scenario analysis are discussed below reflecting the effects on NPS pollutant loadings and on the hydrologic regime. Furthermore, the implications of the scenarios analysis results are discussed.

7.4.1 Effects on NPS Pollutant Loads

The total annual loads of sediment nitrate-N, orthophosphate-P, and BOD under different land use scenarios are presented in Figure 7.12. Figure 7.13 presents the annual total loads of nitrate-N, orthophosphate-P, BOD and sediment, respectively for the base scenario and climate change scenarios.

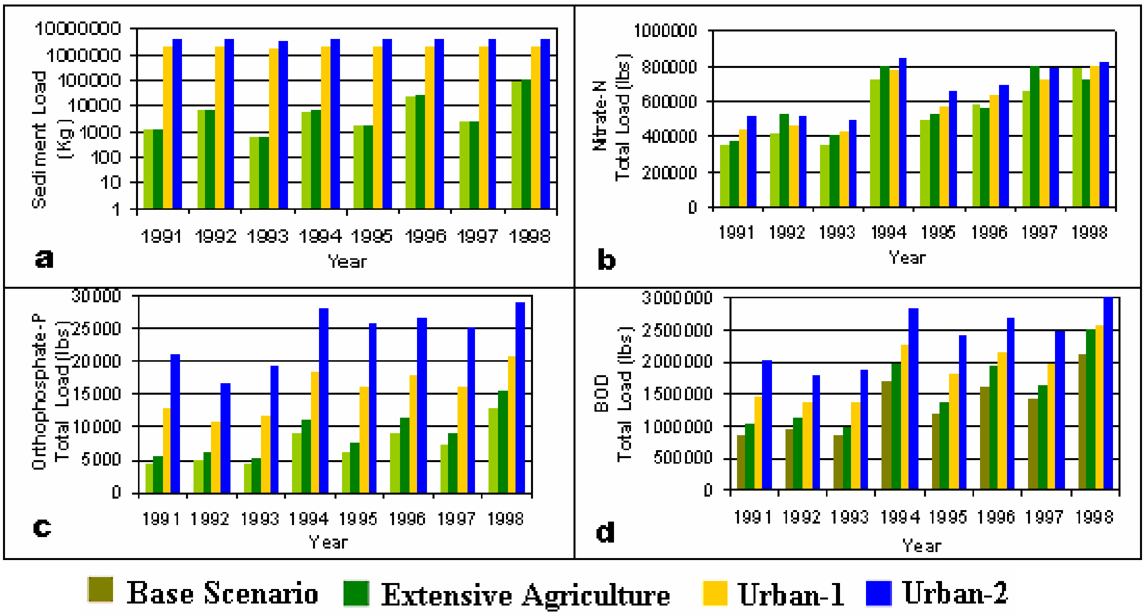

Figure 7.12: Annual variation of NPS Pollutant loads due to land use a) Sediment b) Nitrate-N c) Orthophosphate-P and d) Biochemical Oxygen Demand (BOD)

The total sediment loads increased with conversion of 25% forests to agricultural land; however, the total loads of sediment increased drastically by three orders of magnitudes due to urbanization. The variation in the total load of nitrates-N shows a general trend of higher loads for the case where 50% of forests are converted to impervious land. Conversion of 25% of forests to agricultural land produced highest loads for nitrates-N for three years, but remained lesser than the maximum urbanization scenario. For the entire simulation period, the mean annual nitrates-N loads increased by 8% for the extensive agriculture scenario and by 11 and 22% for the urbanization and extensive urbanization scenarios, respectively.

The total loads of orthophosphate-P increased with increase in urbanization. The effect of deforestation for agriculture, though, increased the annual total loads beyond base scenario; however, the loads remain much lower than converting the same amount of forests into urban area. The change in the mean annual loads was 23% for the extensive agriculture, while for the urban and extensive urban scenarios, the change increased significantly to 113 and 227 %, respectively.

BOD shows higher loads with decreased forests and an increase in agriculture and urban areas, but increase in impervious land produces higher loads of BOD for the same amount of area changed to agricultural land. The changes in mean annual loads were 17% for the extensive agriculture scenario, and 39 and 78% for the urbanization and extensive urbanization scenarios, respectively.

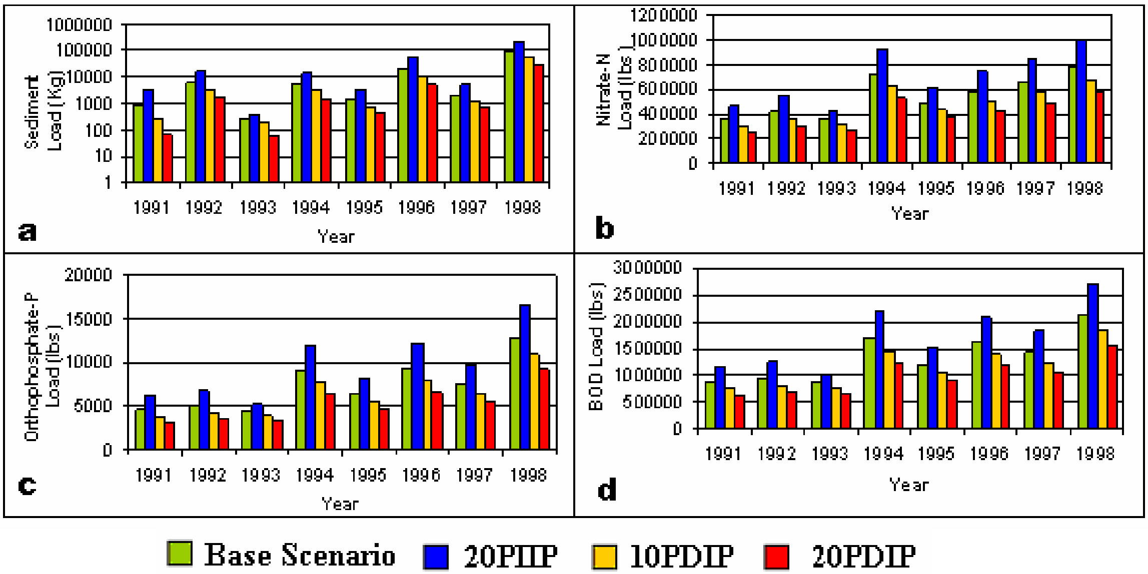

Figure 7.13: Annual variation of NPS Pollutant loads due to climate change a) sediment b) nitrate-N c) orthophosphate-P and d) biochemical oxygen demand (BOD)

The effect of climate change, i.e. change in the precipitation on sediment and pollutants loads, is similar following a uniform increase with increase in precipitation and decrease in loadings with a decrease in precipitation. An interesting trend was obtained as a result of simulating NPS pollutant loads for different precipitation scenarios. A 10% decrease or increase caused a corresponding 13% decrease or increase in the nitrate-N, 14% in orthophosphate-P, and 13% in BOD loadings, respectively. The sediment loads did not show a uniform trend: the loads increased by approximately136% for a 20% increase in precipitation. Similarly, a 20% decrease in precipitation caused a reduction of 70% sediment loads.

7.4.2 Effects on Hydrologic Regime

The alterations in the hydrologic regime of the watershed were analyzed using the IHA method by performing an individual analysis on the flow results of each simulation. The analysis period covered years 1991-1998 of the simulated results for the reach number 2 of the watershed model network. Table 7.6 lists the parameters for the indicators of hydrologic alteration (IHA) for the base scenario and different simulated land-use scenarios, whereas Table 7.7 lists the IHA parameters for the base scenario and the simulated climate change scenarios.

The mean annual flow increased with deforestation. However, increase in urbanization induced a more significant increase in the flow. The same cannot be said for the monthly average flows, except for the extensive agriculture scenario.

The increase in urbanization did not increase the relative average monthly flows. The extreme low flow conditions were similar for all land use scenarios. However, the 30- days and 90- days minimum values decreased with increase in deforestation. The extreme high flow conditions increased with rises in deforestation. The timing of the annual extreme flows were similar for the base scenario and extensive agriculture scenario; however, the timings shifted from mid July for base scenario and agriculture, to beginning and mid of January for urbanization scenarios.

The urbanization scenarios were characterized with higher numbers of high and low pulse flows having short durations, whereas the base scenario and extensive agriculture scenarios have fewer numbers of low and high pulse flows with longer durations.

The IHA analysis of changes in precipitation conditions indicates a direct relationship between different flow conditions and precipitation magnitudes. It shows an increase in annual flows with increase in precipitation and vice versa. However, it is important to note the extensive changes in the duration of low pulse for different precipitation condition scenarios. The decrease in precipitation drastically increases the duration of the low pulses, which might be a critical flow condition for water availability in the stream.

The modification of hydrologic regime of the Namnam stream have extreme implications for the aquatic ecosystems in the stream and Koycegiz lake. The water conditions define many functions of these very fragile ecosystems and non availability of water may severely damage these ecosysytems causing an imbalance in the functions of the Koycegiz Lake as a source of fishery. It can be seen that urbanization induces the worst impacts on the hydrologic regime where one day maximum values increased from 14 to 27% as a result of 25 to 50% increase in urbanization. Similarly, the 90 days minimum and maximum values show profound variation as a result of increased urbanization ranging between 20 to 47% reduction for the 90 days minimum and 24.4 to 59% increase for the maximum for 25% and 50 % urbanization scenarios, respectively. The variation due to increase in agriculture were 14% reduction for the 90 days minimum and 3.8% increase for the 90 days maximum flows.

The climate change scenarios however, do not show very abrupt changes in the 90 days minimum and maximum values based precipitation change scenarios. The 90 days minimum flow increased by approximately 23% and the 90 days maximum flow increased by 24.7% as a result of an increase in precipitation by 20%. The 90 days minimum and 90 days maximum decreased by approximately 12% for a decrease in precipitation by 10%. Similarly, the 90 days minimum and maximum decreased by 25% as a result of decrease in precipitation by 20%.

7.4.3 Decision Support Imperatives

Keeping in view the scenario analysis results, decision support imperatives for a specific scenario may be presented as a decision support matrix, listing a hierarchy of decision imperatives. It is assumed that the priority in this case is to sustain a viable water quality for fulfillment of watershed functions of tourism, agriculture, and fisheries. Therefore, only four decision imperatives, namely agricultural pattern, erosion control, nutrient management, and habitat conservation, have been considered. The decision support imperatives have been assigned a relative score from one to five for a corresponding importance of least to very important. The ranking of decision support imperatives for different scenarios is listed in Table 7.8.

The decision support imperatives provide an important guideline for decision makers to consider for the prioritization of resources and mitigation of adverse effects. A shift towards tourism (more hotels, resorts, etc.) will increase impervious surfaces in the watershed. To mitigate with the adverse effects on fisheries and ecologic health of the stream and the lake–lagoon system, decision makers must provide resources for erosion control, nutrient management, and habitat conservation in the watershed. Similarly, under drought conditions, the crop patterns may be modified according to the hydrologic regime characteristics to prevent water shortages for the integrity of stream and lake-lagoon ecosystems.

Table 7.6: IHA Parameters for Land Use Scenarios

IHA Parameter Group	BASE	Agriculture	Urban-1	Urban-2
Mean Annual Flow (ft^3/sec)	262	271.1	328.8	421.3
Parameter Group #1	**Magnitude Of Average Monthly Flows (ft^3/sec)**			
January	383	385.5	246.5	177
February	281.8	291.5	211	133.8
March	275.5	275	190	117
April	184	190.8	149	102.4
May	109	110.5	86.5	60.8
June	27.38	25.23	20.7	13.25
July	2.5	2	1.9	1.25
August	0	0	0	0
September	0	0	0	0
October	19.25	20.55	14.65	9.5
November	331.8	339.5	228.8	161.5
December	432	443.5	342	231.5
Parameter Group #2	**Mag. and Dur. of Ann. Extreme Flows (ft^3/sec)**			
1-day minimum	0	0	0	0
3-days minimum	0	0	0	0
7-days minimum	0	0	0	0
30-days minimum	0	0	0	0
90-days minimum	1.158	0.9917	0.9261	0.615
1-day maximum	3470	3310	8325	13150
3-days maximum	2222	2280	3890	5748
7-days maximum	1507	1578	2338	3370
30-days maximum	926	960.2	1121	1454
90-days maximum	564.3	586.2	702.3	898
Number of zero days	56.5	57	70	81
Base flow index	0	0	0	0
Parameter Group #3	**Timing of Annual Extreme Flows (Julian Day)**			
Date of minimum	218.5	218	14	5
Date of maximum	19.5	19.5	366	366
Parameter Group #4	**Frequency and Duration of High and Low Pulses**			
Low pulse count	1.5	1.5	16	27.5
Low pulse duration	51.75	56.25	1	1
High pulse count	12	12.5	39.5	46.5
High pulse duration	2	3	1	1
Parameter Group #5	**Rate and Frequency of Flow Changes**			
Rise rate	29.5	36.75	118	120.4
Fall rate	-17	-18.5	-39.75	-33.28
Number of reversals	138.5	144.5	210	204.5

Table 7.7: IHA Parameters for Climate Change Scenarios

IHA Parameter Group	BASE	20PIIP	10PDIP	20PDIP
Mean Annual Flow	262	327.5	229.2	197.3
Parameter Group #1	**Magnitude Of Average Monthly Flows (ft^3/sec)**			
January	383	457.5	351.5	316.5
February	281.8	338.8	254.5	228
March	275.5	333.5	247	223
April	184	216.3	174	155.3
May	109	128.5	98.15	84.15
June	27.38	33.7	24.25	21.63
July	2.5	3.1	2.25	1.95
August	0	0	0	0
September	0	0	0	0
October	19.25	35	14.35	8.9
November	331.8	398.3	295.5	257.8
December	432	593.5	373	328.5
Parameter Group #2	**Mag. and Dur. of Ann. Extreme Flows (ft^3/sec)**			
1-day minimum	0	0	0	0
3-days minimum	0	0	0	0
7-days minimum	0	0	0	0
30-days minimum	0	0	0	0
90-days minimum	1.158	1.433	1.016	0.8639
1-day maximum	3470	5630	2450	1780
3-days maximum	2222	3220	1730	1349
7-days maximum	1507	2195	1241	1030
30-days maximum	926	1158	811.4	699.1
90-days maximum	564.3	703.7	495.6	427.5
Number of zero days	56.5	53.5	57.5	58.5
Base flow index	0	0	0	0
Parameter Group #3	**Timing of Annual Extreme Flows (Julian Day)**			
Date of minimum	218.5	219.5	217.5	216.5
Date of maximum	19.5	19.5	19.5	19.5
Parameter Group #4	**Frequency and Duration of High and Low Pulses**			
Low pulse count	1.5	2	1	1
Low pulse duration	51.75	42.25	71.5	70
High pulse count	12	14.5	12	11
High pulse duration	2	2	2	3
Parameter Group #5	**Rate and Frequency of Flow Changes**			
Rise rate	29.5	41.05	33.35	38.9
Fall rate	-17	-18.4	-14.55	-11.75
Number of reversals	138.5	158	133.5	129.5

20PIIP: 20% Increase in Precipitation
10PDIP: 10% Decrease in Precipitation
20PDIP: 20% Decrease in Precipitation

Table 7.8: Decision Support Matrix for Koycegiz Watershed

Decision Scenario	Decision Support Imperatives for Water Quality			
	Agricultural Pattern	Erosion Control	Nutrient Management	Habitat Conservation
Extensive Agriculture	5	3	5	2
Urbanization	1	5	4	5
Extensive Urbanization	1	5	5	5
Wet Conditions	3	4	3	1
Drought Conditions	5	2	1	2

7.4.4 Error Discussion

The hydrology and NPS pollutant loads in the Namnam subwatershed of the Koycegiz drainage basin under different scenarios of climate and land use change were simulated using HSPF . The results of the hydrologic calibration can be termed satisfactory based on different criteria discussed above. However the following sources of error and uncertainty may be kept in mind while considering the acceptibility of simulation results.

As has been discussed in prior sections the apart from the inherent uncertainities in the model formulations the major incongruities arise from the data sources. The main forcing datasets for the hydrologic simulation are metereologic data which are obtained from on metereologic station that lies ouside the Namnam sub watershed within the greater Koycegiz drainage basin. The higher regions of the watershe din the north are not represented by this metereologic station which might be a cause of error in the results of the simulation.

The parametrization of the model was carried out using HSPEXP by assuming initial parameter values from HSPF parameter databse based on similarities between the climatic and land use conditions of Namnam watershed and one of the watersheds in the database. This creates yet another source of possible error due to lack of comprehensive data on the geomorphology of the watershed. However considering the semi physically based nature or the model the error generated may be of lesser significance than the uncertainty produced by the quality of the forcing data .

In a nutshell despite the the inferior quality of model forcing data, the results of the hydrologic calibration are appropriate for the determination of the diffuse pollution loads in the Namnam watershed.

7.5 Applicability Analysis

The Cost and Data categories of the Koycegiz watershed were analyzed and based on observed evidence, following results are presented.

A watershed model even at its best is still a mathematical formulation of watershed and the processes within it; therefore, the simplification of a complex watershed process into a mathematical formulation has an inherent uncertainty in predicting the behavior of the system and its processes. This inherent uncertainty means that the model will never be able to predict a 100% actual effect of an event. This fact is further strengthened by the uncertainty in data used for the application of watershed model. In other words, in terms of model performance, a correlation of 1.0 may not be achievable no matter how refined and representative the date may be. Similarly, there will always be some correlation between model generated and actual data due to parameterization of the model. The relationship between model performance and data can be represented by a curve shown in Figure 7.12. The minimum and maximum achievable model performance is shown as points ‘a’ and ‘b’ on the Model Performance-Data curve. The value of correlation attained by a model calibration between the minimum and maximum achievable level is dictated by the amount and quality of data. For each modeling application, there exists a value of correlation between observed and simulated data corresponding to an absolute minimum amount and quality of data and an acceptable model performance lying between the points ‘a’ and ‘b’ on the curve.

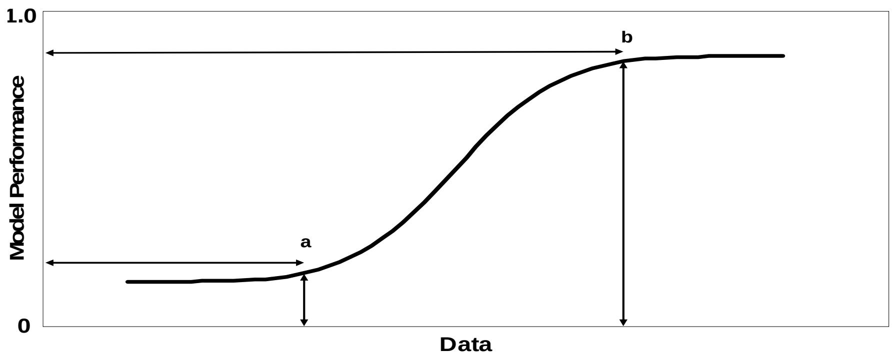

Figure 7.14: Model Performance–Data Curve

The acquisition of the quantity and quality of data for watershed modeling can be related to costs incurred is directly related to the cost of obtaining that specific amount data. At zero cost, one may have some data available in the form of simulated data for a specific watershed; however, it may not be of the desired quality and representative of the actual watershed. Furthermore, a reasonable amount of data may be obtained at a relatively reasonable cost; however, acquisition of data will require relatively higher cost with lesser data per unit cost incurred. The relationship between data acquisition and cost is represented by Data–Cost curve shown in Figure 7.15. For a cost of X, Y amount of data may be acquired; however, a further cost of X will only provide Z amount of data where Z is relatively 1/3 of Y. This is explained by the fact that initial data required is of general type like topographic data, land use/land cover data, precipitation, flow etc., which in most of the cases may be obtained through some agency or organization. Further data means more specific data which may not be available and thus require higher cost to obtain. The specific data may be infiltration capacities of soil, agricultural practices, etc.

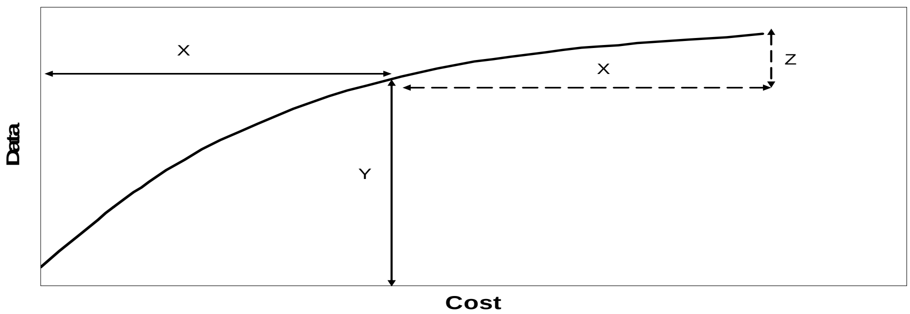

Figure 7.15: Data–Cost Curve

The cost incurred for the application of the model can be correlated with the performance of the model. Even without incurring any costs, an initial correlation may be obtained between the models generated results and observed data. The behavior may be represented by the model performance–cost curve shown in Figure 7.16. The model performance–cost curve represents minimum model performance corresponding to no cost while c represent maximum model performance at a high cost. B represents the situation where acceptable model performance is achieved at a relatively lower cost.

The relationship between data acquisition, cost and model performance can be used to define an optimization curve as shown in Figure 7.17. Data acquisition requires expenses in terms of costs to achieve results regarding model performance. Therefore, for each piece of data, a corresponding amount of money is spent to achieve a benefit in terms of model performance. However, based on the discussion presented above, at a certain point the amount of data obtained or money spent will start giving a decreasing value of model performance.

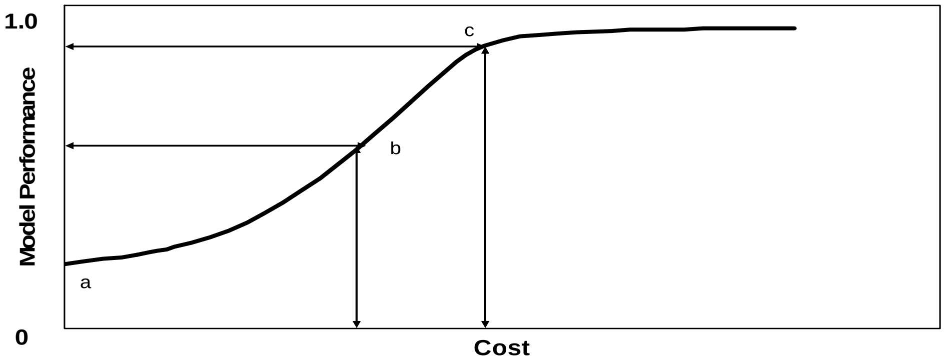

Figure 7.16: Model Performance–Cost Curve

The unit change in model performance per unit cost incurred may therefore be defined as the benefit. The relationship between benefit and cost can be represented by a normal curve as shown in Figure 7.17. The point of inflection obtained provides the amount of money spent or data acquired that will give the best model performance for the cost incurred.

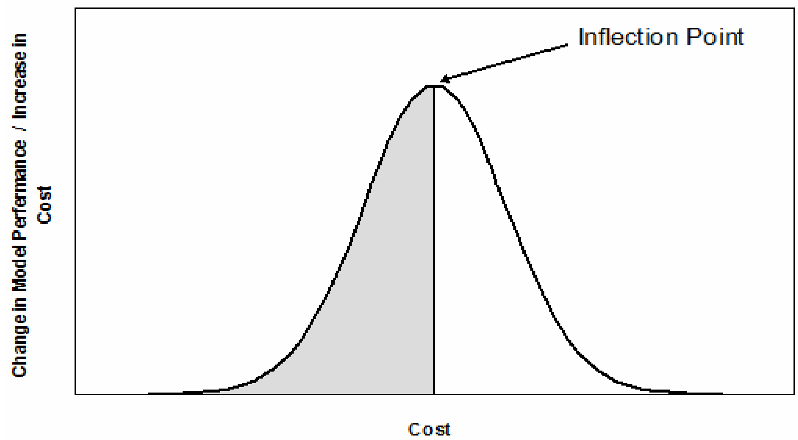

Figure 7.17: Cost Benefit Optimization Curve

7.5.1 Implications for model applicability in developing countries

The application of a watershed model in a developing country should lie in the rising limb of the Cost Benefit optimization curve, because acquisition of data and expenditure of costs beyond point of inflection does not provide the same amount of increase in model performance.

A researcher in a developing country should start with the minimum amount of data required by BASINS/HSPF for analyzing a specific watershed based on the objectives of the research. The absolute minimum amount of data required for hydrological modeling using BASINS/HSPF is presented in Figure 7.18. DEM and land use maps are required to perform the initial delineation and characterization of the watershed and the determination of the modeling system boundaries. These maps if availbe in a finer spatial resolution in the temporal window of the model simulation will generate best results. However if not available a coarser spatial resolution may be used to perform the aforementioned tasks. The temporal interval of precipitation and evaporation records is a key factor in obtaining accurate results in the simulation of hydrology and later on simulation of water quality. Normally hourly data is of best quality if not available at least daily records should be obtained to obtain satisfactory results from model simulation.

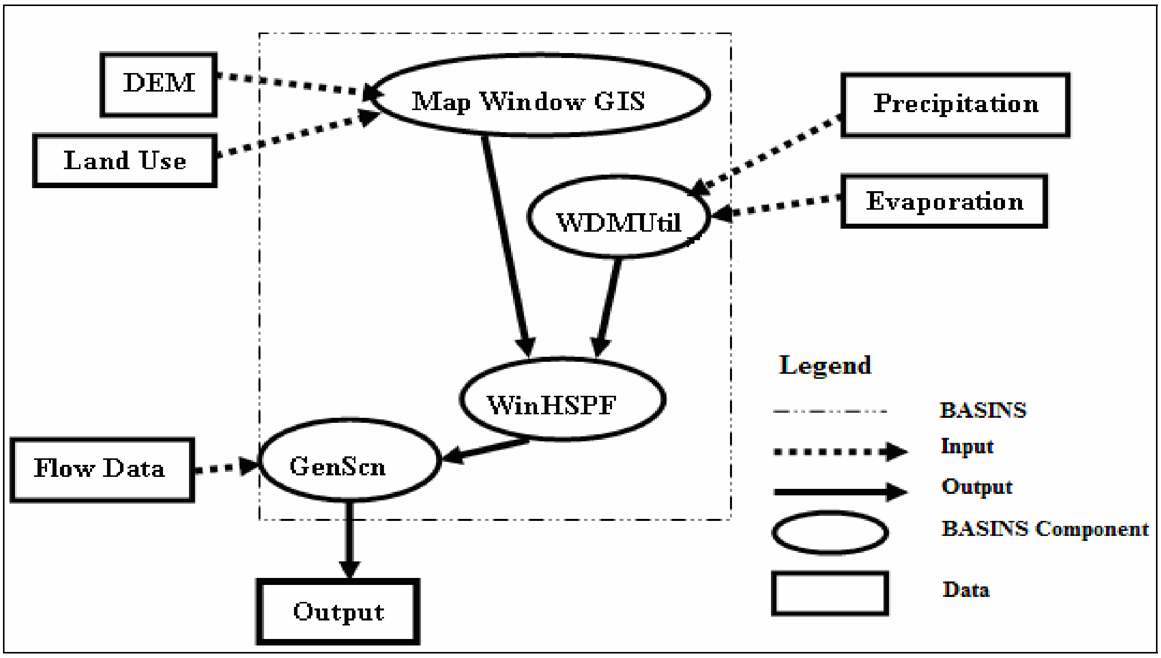

Figure 7.18: Absolute Minimum Data Requirement for Hydrological Modeling using BASINS/HSPF

The model verification data should be 3-5 years to check the performance of model under different conditions. In the case of the simulation of hydrology atleast daily stream flow data for a period of 2-3 years be available for calibration and validation of model results.

The next step based on available resources should be to acquire data required for enhancing the representation of the watershed in the model by improving parameterization. Data for parameter estimation may than be put on top of the priority list starting from the most sensitive parameter. Figure 7.19 shows the optimized model applicability pathway for a watershed modeling project in a limited data and costs scenario.

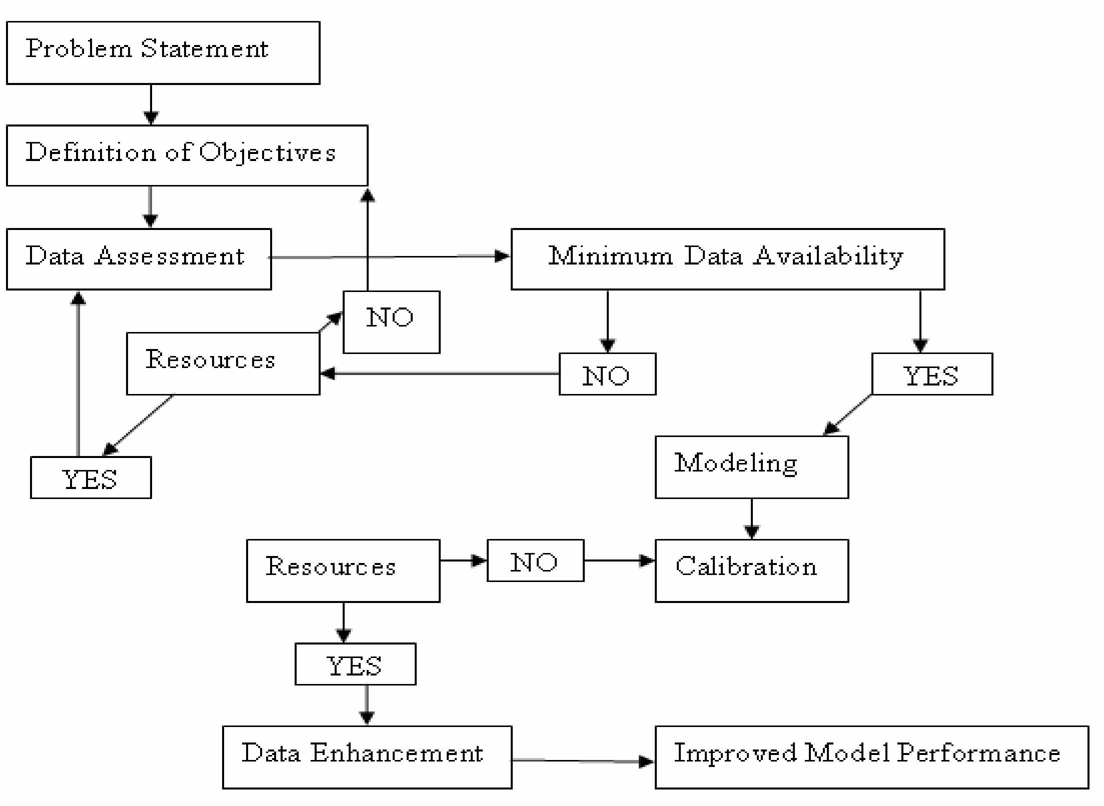

Figure 7.19: Optimized Model Applicability Pathway

8. CONCLUSIONS AND RECOMMENDATIONS

In this study, BASINS and its core watershed model HSPF were used for the analysis of climate and land use change impacts on NPS pollutant loads and hydrologica regime in the Koycegiz watershed located in Southern Turkey. This constitutes the first application of BASINS in Turkey. Despite the fact that the data download tool of the BASINS is only available for US watersheds, the application of BASINS for pre-processing of HSPF model setup for Koycegiz watershed enhanced the process of setting up the model network as compared to without its application for this purpose. Furthermore, it is believed that determination of physical characteristics of the individual reach segments, watershed segments and land cover types using BASINS improves the parameterization of HSPF model for calibration and validation. The model setup created using BASINS is physically more representative of the watershed due to advanced GIS capabilities of the program. BASINS provides broader room for experimentation with watershed model network for optimizing the number of sub watersheds and reaches for simplified modeling setup.

It is concluded that BASINS provides a strong toolkit for data preprocessing, watershed delineation, watershed characterization, model setup pre processing and visual representation of physical features of watershed once data compatibility issues are eliminated for watersheds outside USA.

The hydrological model for the Koycegiz watershed was calibrated using flow data from Namnam stream for a 5 years period covering 1995 to 1999. The model was validated using 5- years flow data of 1990-1994. Furthermore, the model was run for the entire period of available data 1990-1999. The model calibration and validation showed good to very good results in the comparison of total runoff, total storm volumes and total winter flow volumes. However, summer flow volumes were under represented by the model. Flow duration analysis of the observed and simulated flows further authenticated the calibration and validation results.

Considering inherent errors and uncertainties in the input data quality and lack of a single model performance criterion, the evidence from the statistical and graphical analysis, the performance of HSPF for hydrologic modeling of Koycegiz watershed may be termed as acceptable for water quality assessments, decision support analysis and regulatory purposes. However, it will be pertinent to mention that the results of the model can be improved by adopting a major data refinement exercise.

Sediment, nitrates-N, orthophosphates-P and BOD loadings arising from different land uses within the watershed were simulated and annual fluxes and total mean annual loads were determined. Due to lack of calibration and validation data, the results of the modeling efforts could only be considered for identification of critical land use practices with respect to nonpoint source pollutants. Therefore, magnitudes of the loads were used as a measure of comparison for different scenarios. On the basis of these results, Best Management Practices (BMPs) may be adopted for critical land uses to decrease nonpoint source pollutants.

The study analyzes the results of the land and climate change scenarios on NPS pollutant loads and the hydrologic regime of the watershed. The results put forth an example of watershed model simulation for quantification of changes in the hydrology and land uses within the watershed. This approach enables decision makers and natural resource managers to forecast the effects of potential changes in the watershed due to anthropogenic or natural activities.

The second part of the study analyzed the application of BASINS and HSPF for the case study watershed of Koycegiz in Turkey under data poor conditions as prevalent in most of the developing countries. It defines the relationships between data, cost of data and model performance based on a weight of evidence approach to define an optimized model applicability pathway for watershed modeling in developing countries. The following conclusions were derived based on the analysis of case study application;

- Watershed models may be applied in a data poor environment by optimizing the required data based on the priority of forcing data, model verification data and parametrization data and its corresponding costs with the objectives of the modeling project,
- The objective and scope of the modeling project must be carefully defined,

- All available databanks should be explored for any kind of data. This includes online sources of data made available by international organizations. United States Geological Services (USGS) and International Water Management Institute (IWMI) are examples of such organizations,
- A watershed modeling project may be carried out in phases proceeding from the simplest to the more complex with a corresponding data availability requirement. For most of the wtaershed models the simplest task involving least amount of data is the simulation of hydrology. The simulation of NPS loads requires additional time series of datasets, thus increasing the amount of data required. Modeling of the conventional pollutants in the stream will require additional number of datsets thus further increasing the data requirements for the modeling project. Simulation of the fate and transport of a specific pollutant will require further specific datsets. This compartmentalization in the model for the simulation of hydrology can be used to optimize modeling objective and data requirements. However there is always an absolute minimum data requirement for a specified modeling objective and an acceptable model performance, which must always be ensured,
- Calibration data must be made available for a meaningful and acceptable model application,
- A viable monitoring plan for collection of calibration data might be needed for most of the cases in developing countries. This must be kept in mind while calculating and assigning costs for a watershed modeling project,
- The analysis and results of the study present a preliminary qualitative and subjective theory of optimized watershed model applicability in developing countries. It presents a conceptual framework for prioritizing environmental monitoring for enhanced analysis of watershed processes by simulation tools such as BASINS and HSPF. It is believed that a detailed quantitative analysis may be carried out based on empirical data for data, cost and model performance from multiple applications to further improve the understanding of watershed model applicability optimization in developing countries.

8.1 Recommendations

The following recommendations are presented to help future studies in the development of integrated watershed management plans.

This study uses a widely applied modeling system for the simulation of hydrology and NPS pollutant loads in Koycegiz watershed. It provides a basic understanding of the hydrologic regime and pollution trends in the watershed. However to evolve quantitatively meaningful decision support implications, it is important to simulate the best management practice scenarios considering major sources of pollution identified in this study. A viable water quality monitoring plan should be implemented in the watershed to provide model verification data for water quality studies. Once absolute minimum data is available based on the objectives of the study, further analysis of stream water quality antecedents should be carried out.

Koycegiz Lake and Dalyan Lagoon carry special ecological status in maintaining the sustainability of watershed functions in the Koycegiz watershed. The next step of the modeling studies should be to connect the land based modeling efforts to the in stream water quality of Namnam river and water quality simulation of Koycegiz Lake. This step will complete the big picture of the water quality processes in the entire watershed by defining the relationship of different components of water quality determinants.

A GIS based water quality index may be developed based on the simulated water quality in the stream and lake to identify spatial hot spots for critical water quality conditions and analyze the sources for prevalent impaired water quality conditions.

The impacts of changes in hydrological regime on ecosystems may further be studied by interpreting the results of the impacts of climate and land use changes on hydrologic regime in relation to ecological stresses on vulnerable endemic species in the watershed. Furthermore climate change forecasts generated by GCMs at global scales should be downscaled to forecasts for the case study watershed. The downscaled forecast data should then be used for generating climate change scenarios. The simulation of such scenarios will be much more viable for the analysis of impacts on hydrologic regime and water quality in the watershed.

The relationships between data, cost and model performance may be investigated based on empirical data to further analyze the applicability of watershed models in developing countries and data poor conditions. This may involve empirical data collection from model users accross the world asking for their input on quality, quantity and cost of data they used for modeling studies and the results of these studies based on their professional judgement. This kind of an input may provide some empirical insights into the relationship of model applicability components defined in this study. This may involve a structural delphi process of collecting and distilling information from these experts to generate data for the quantification of data, cost and model performance relationships. However, it must be noted that even though this process will generate some empirical data , still it will be based on subjective personal professional judgment of the the participating experts .

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APPENDICES

Appendix A: Model Simulation Results

Appendix B: HSPF Hydrologic Model Inputs and Otputs

Appendix A: Model Simulation Results

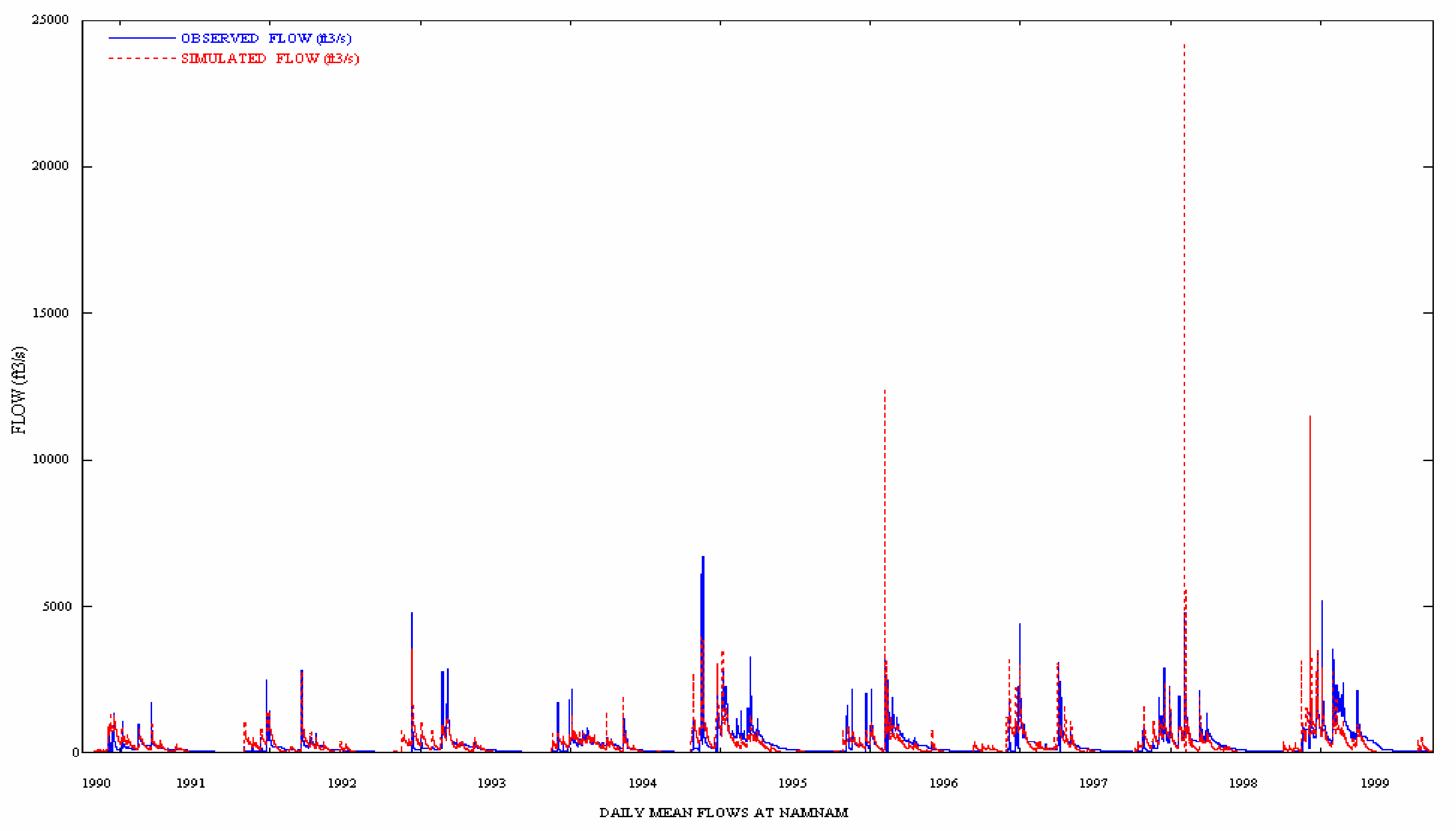

Figure A.1: Standard Plots for Observed and Simulated Daily Flows at Namnam (1990-1999)

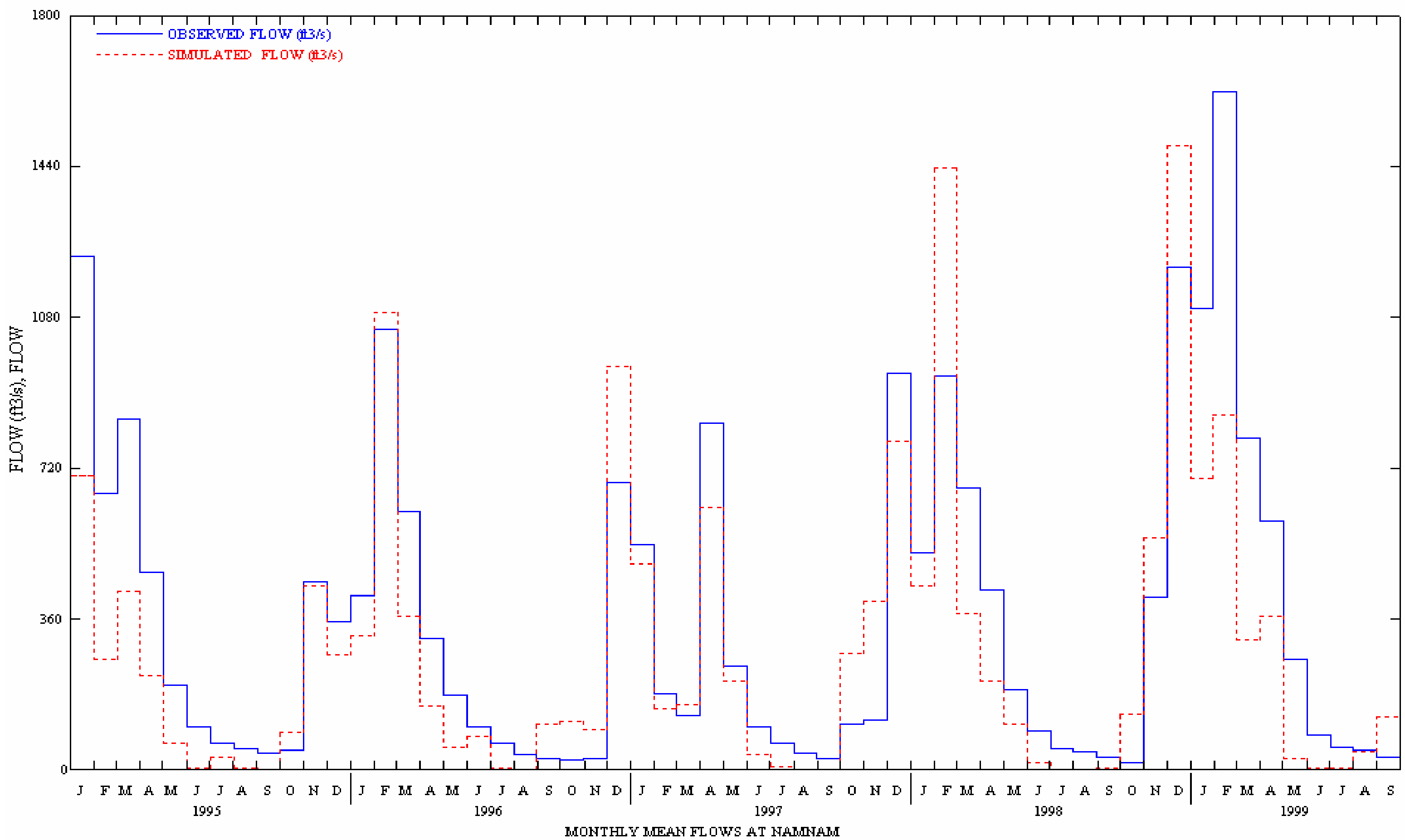

Figure A.2: Calibration-Standard Plots for Observed and Simulated Monthly Flows at Namnam (1995-1999)

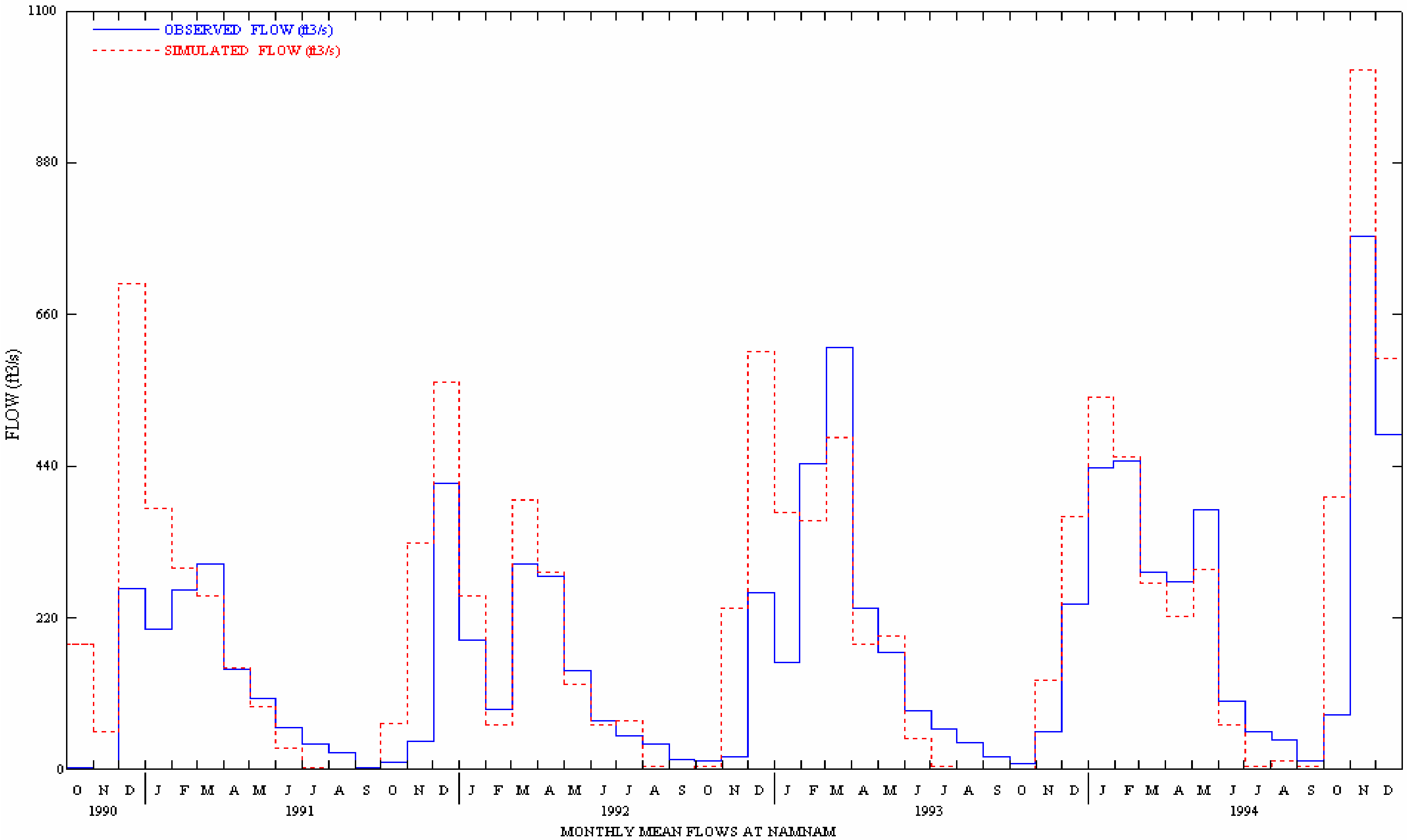

Figure A.3: Validation-Standard Plots for Observed and Simulated Monthly Flows at Namnam (1990-1994)

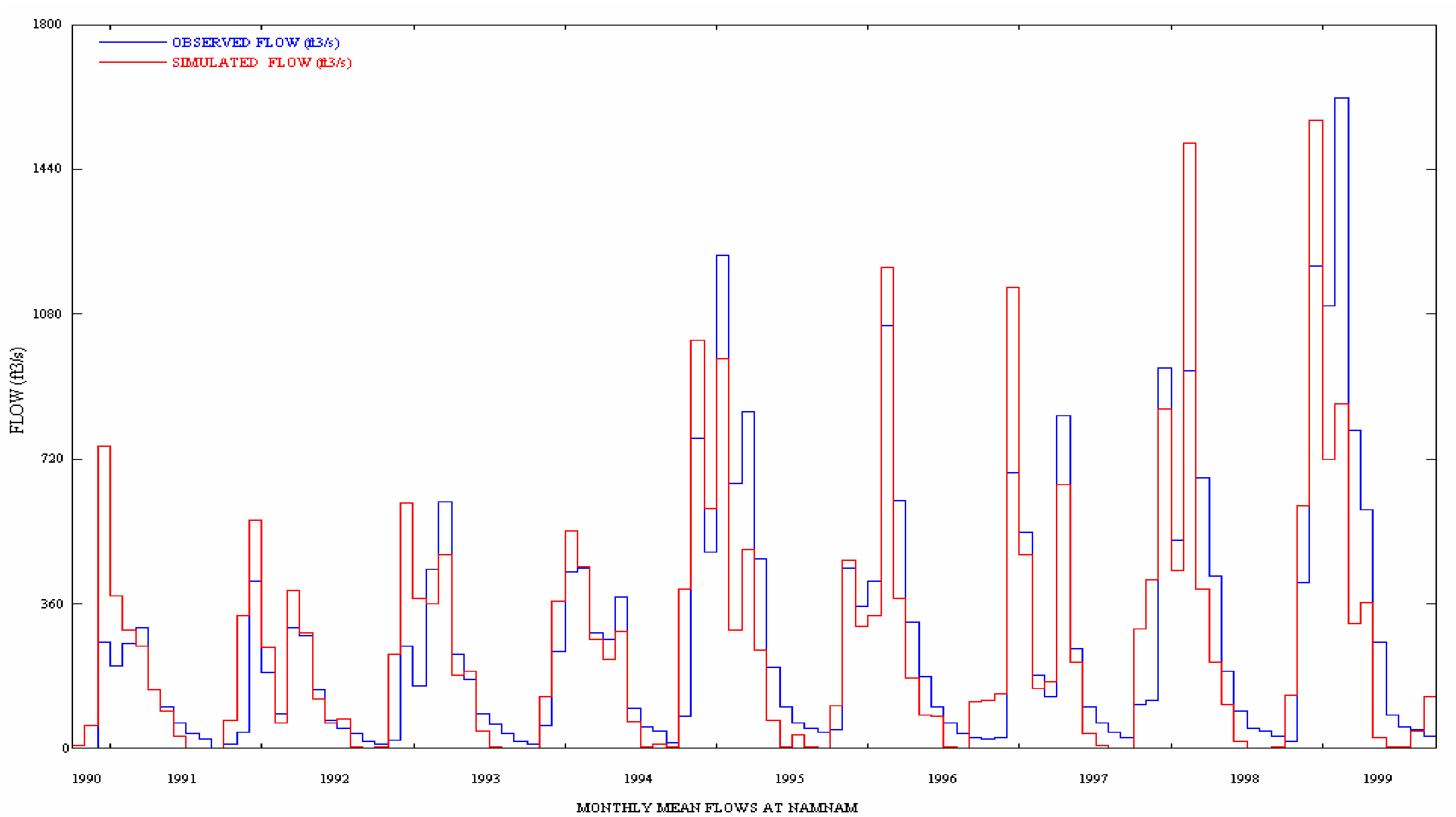

Figure A.4: Standard Plots for Observed and Simulated Monthly Flows at Namnam (1990-1999)

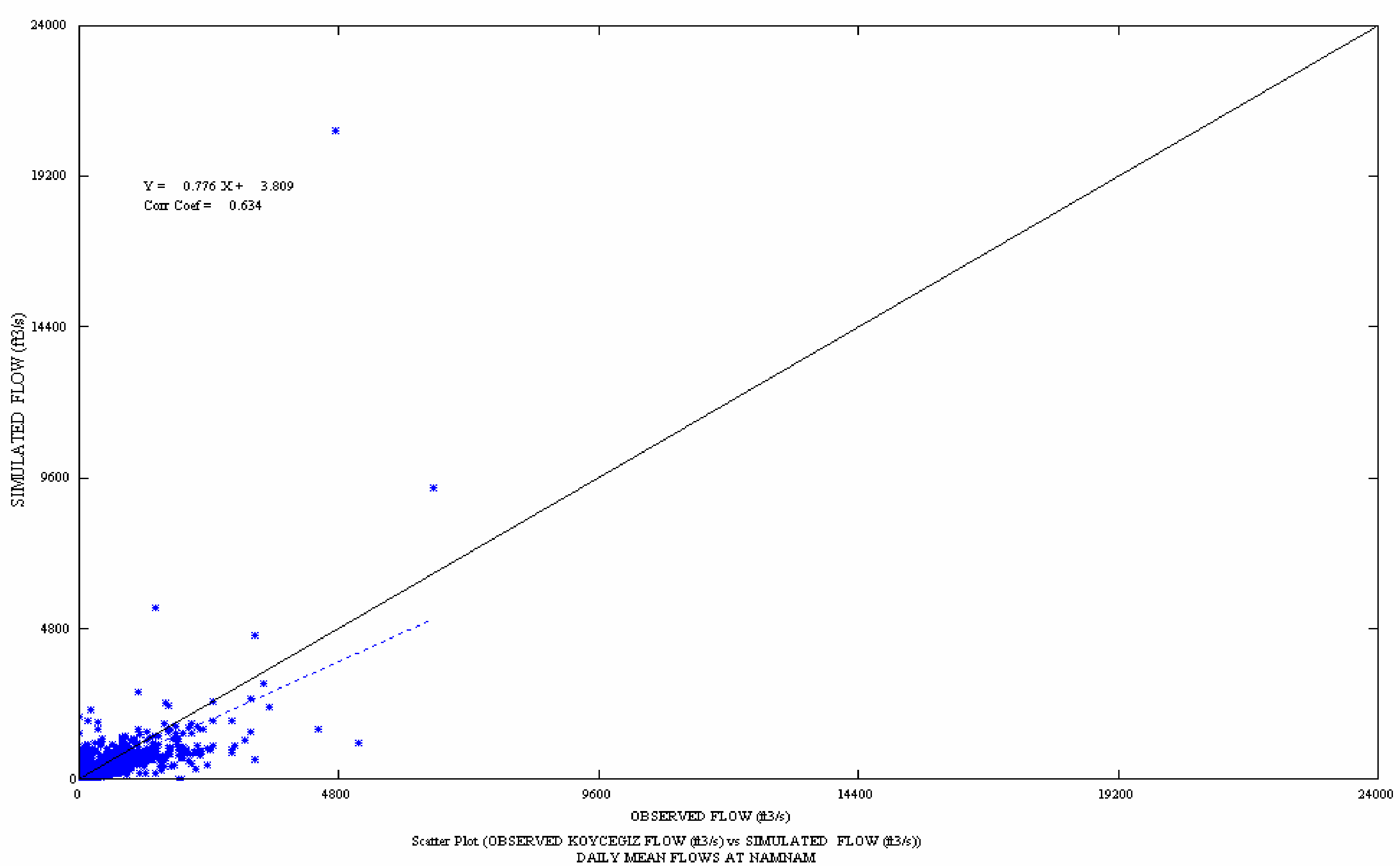

Figure A.5: Calibration-Scatter Plot for Observed and Simulated Daily Flows at Namnam (1995-1999)

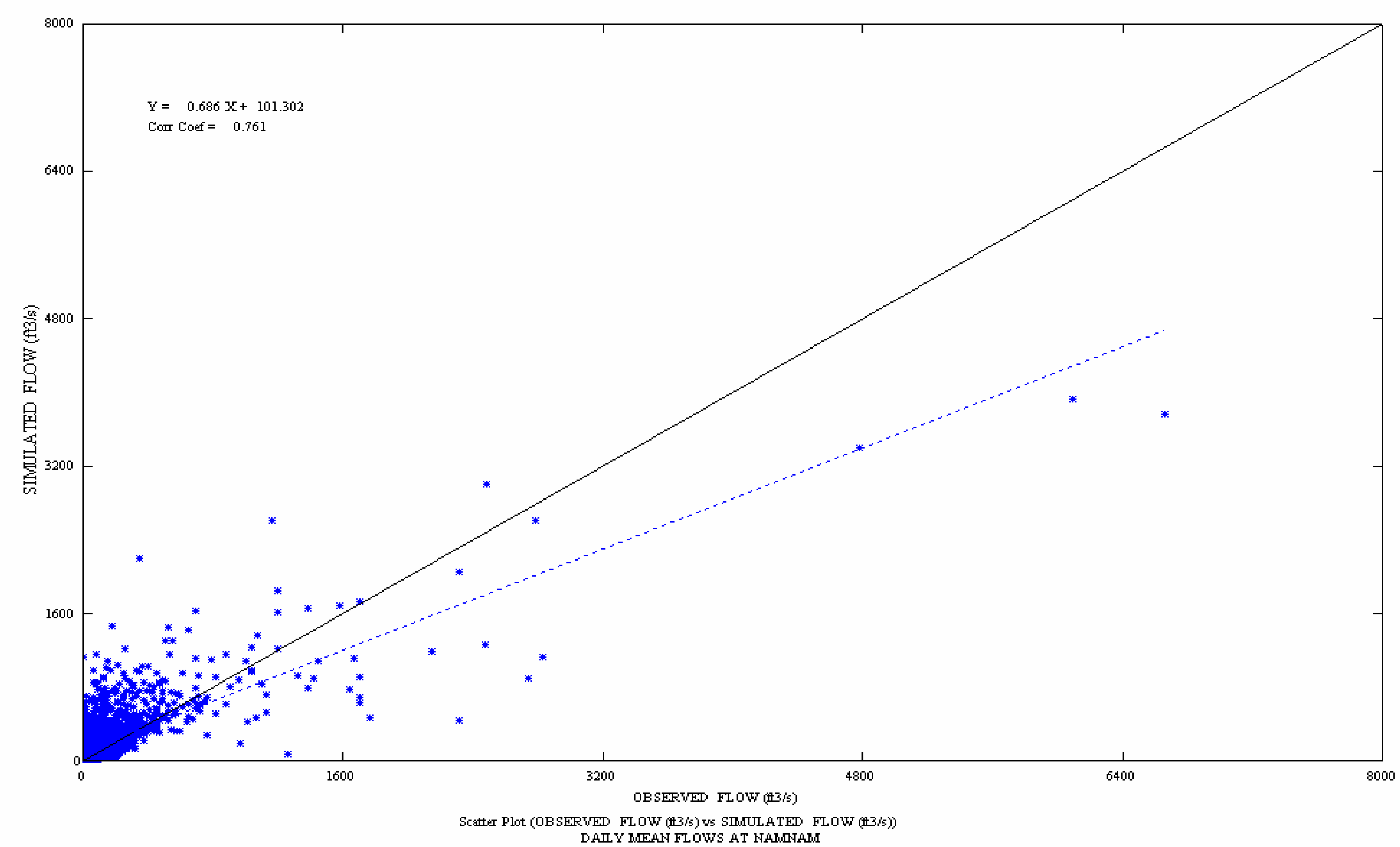

Figure A.6: Validation-Standard Plots for Observed and Simulated Daily Flows at Namnam (1990-1994)

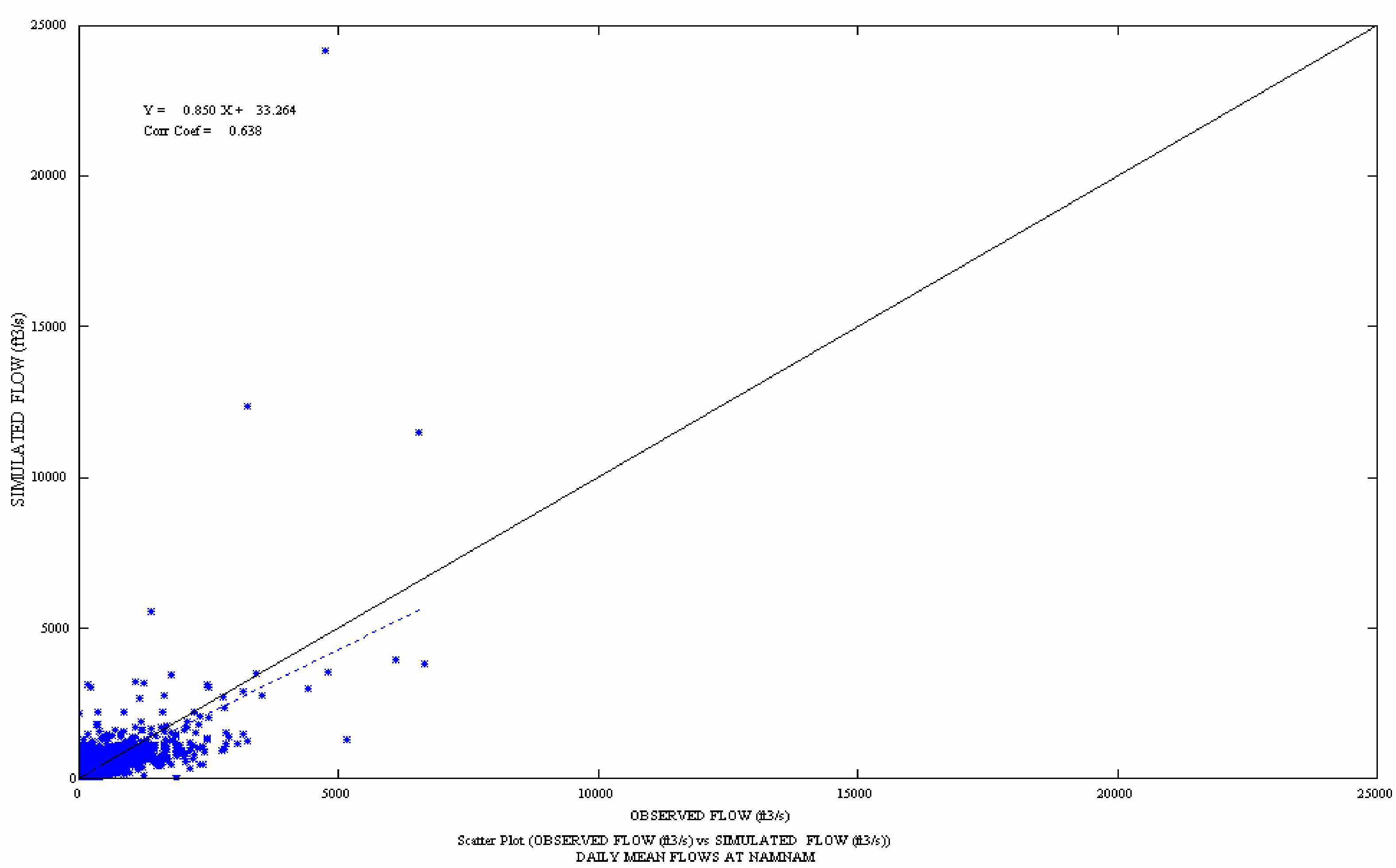

Figure A.7: Scatter Plot for Observed and Simulated Daily Flows at Namnam (1990-1999)

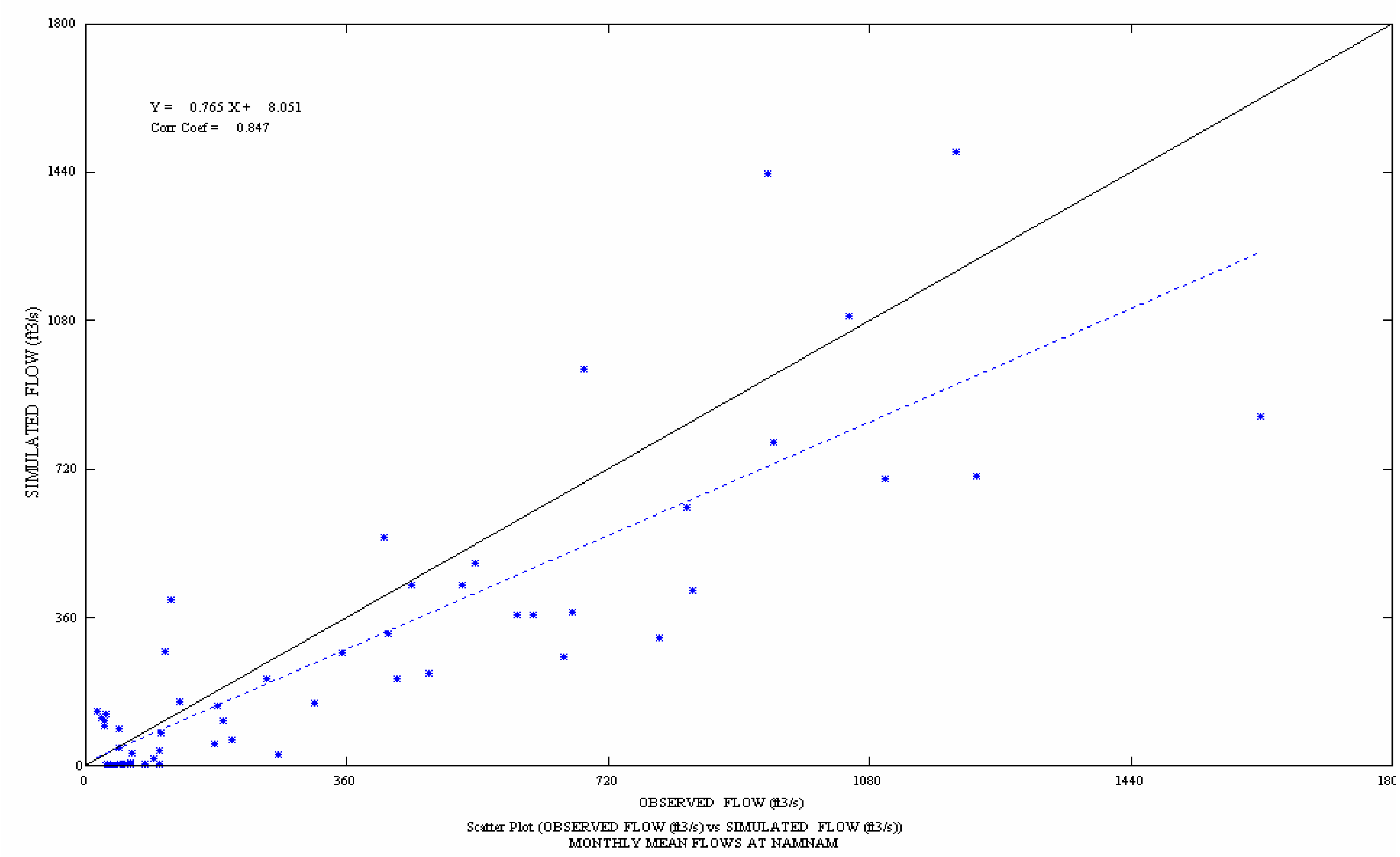

Figure A.8: Calibration-Scatter Plot for Observed and Simulated Monthly Flows at Namnam (1995-1999)

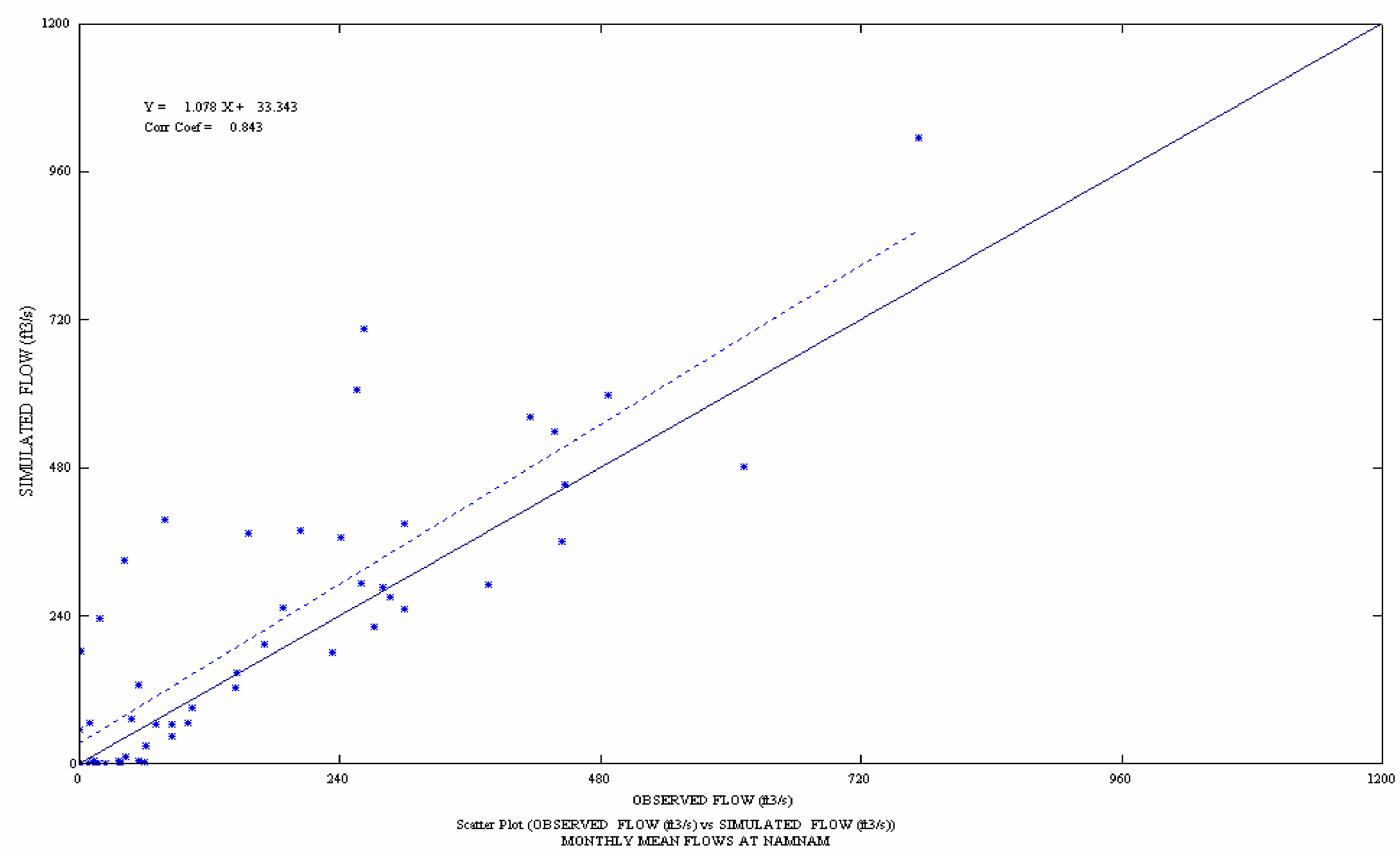

Figure A.9: Validation-Scatter Plot for Observed and Simulated Monthly Flows at Namnam (1990-1994)

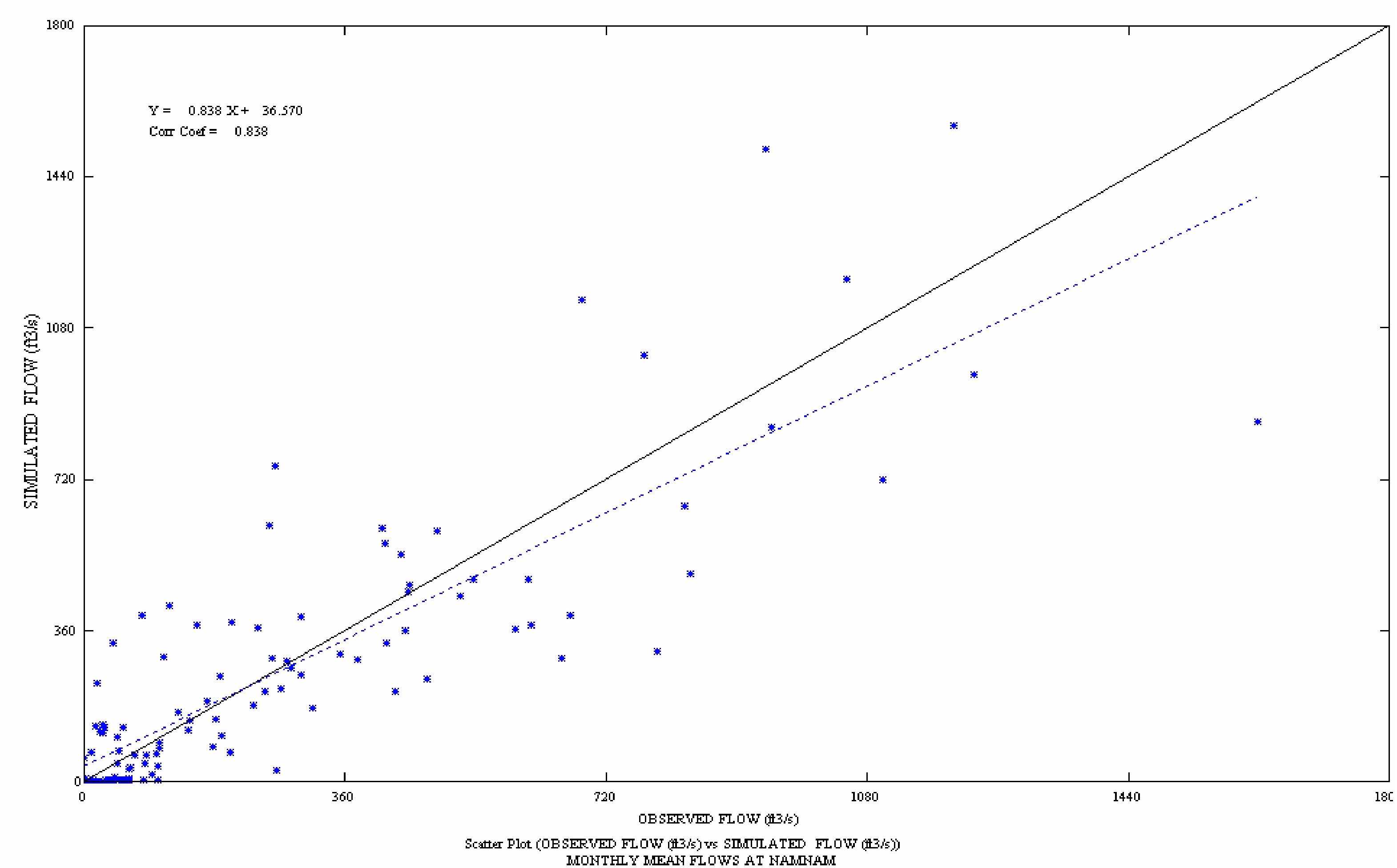

Figure A.10: Scatter Plot for Observed and Simulated Monthly Flows at Namnam (1990-1999)

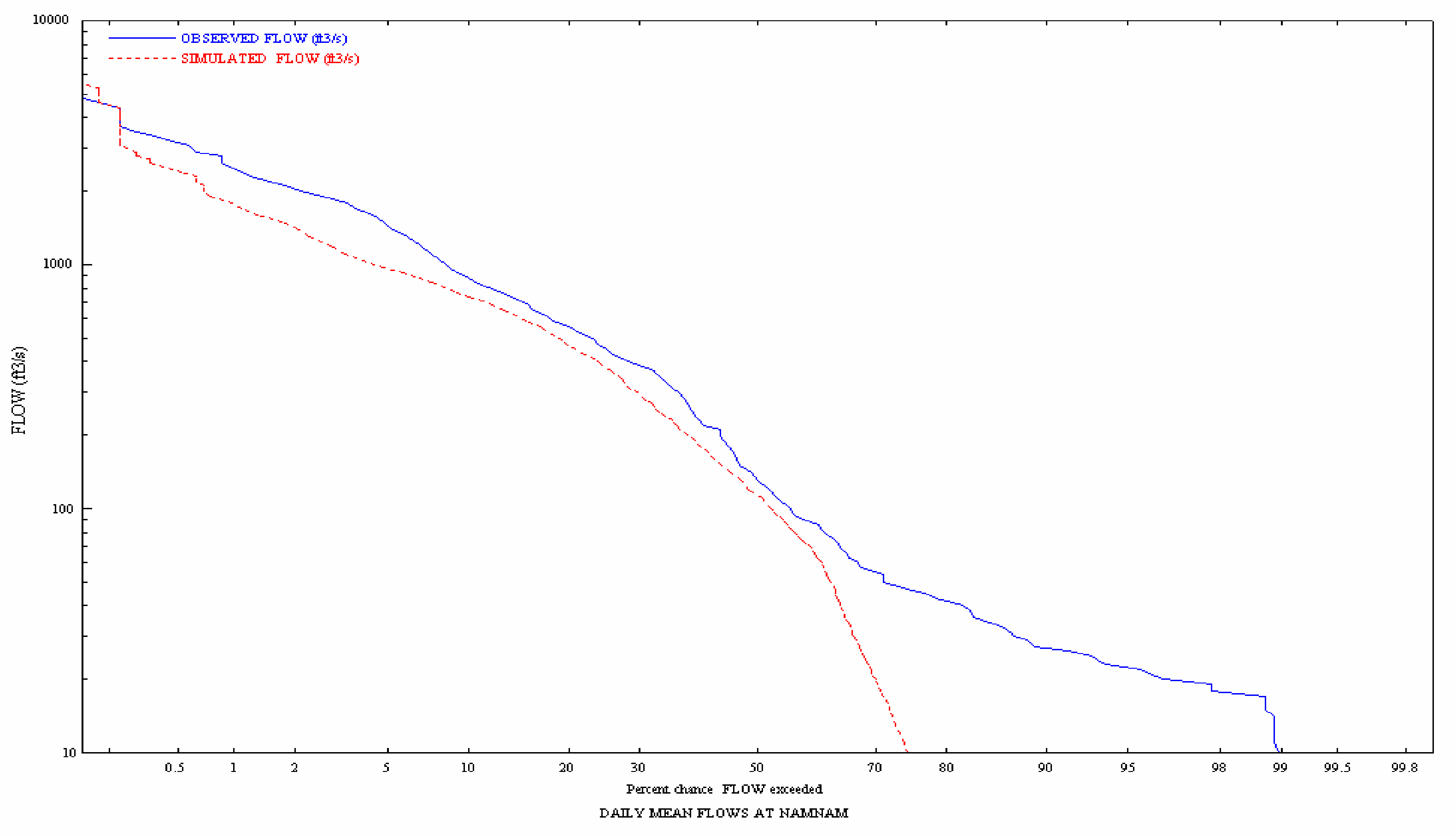

Figure A.11: Calibration-Plot of FDC for Observed and Simulated Daily Flows at Namnam (1995-1999)

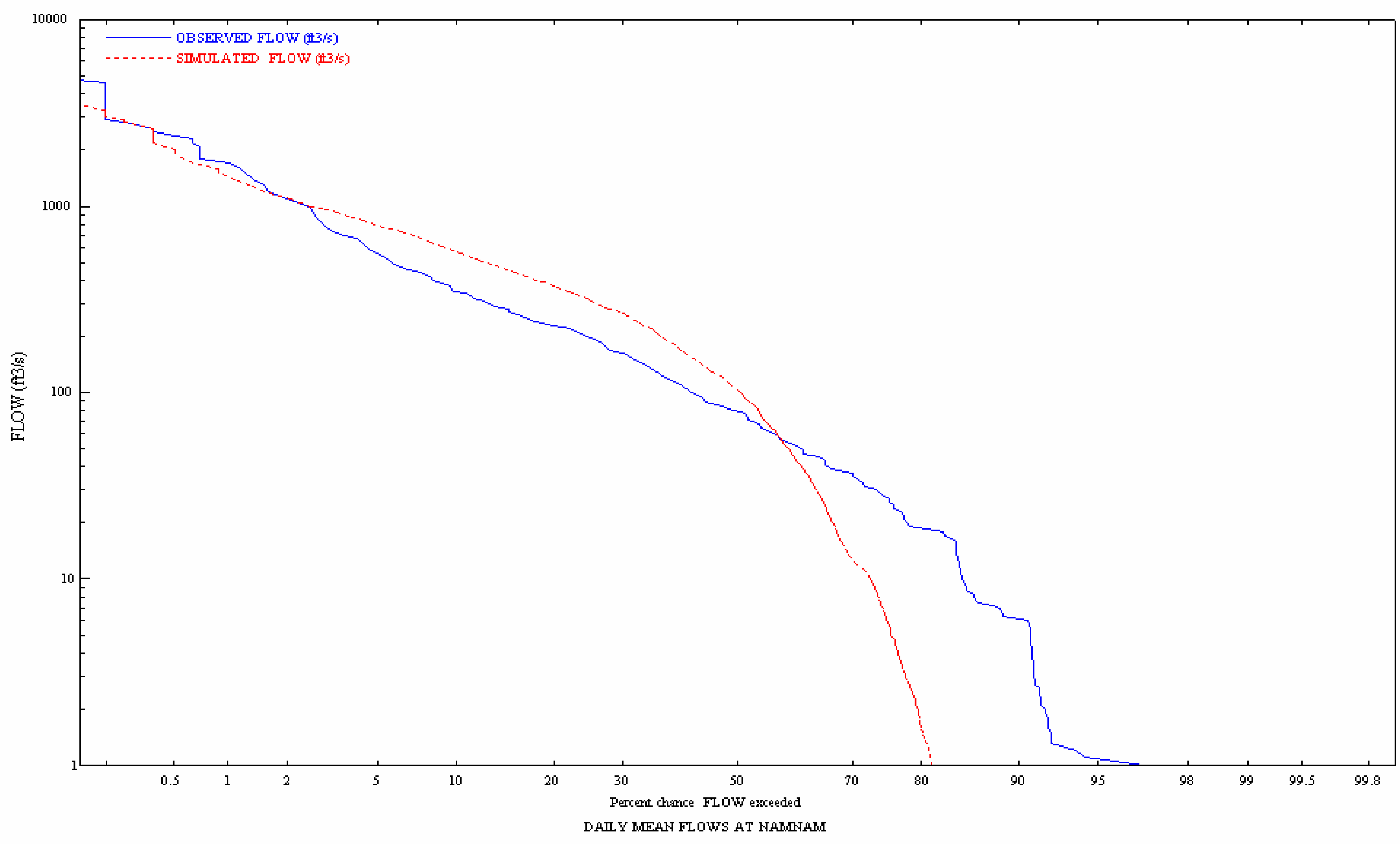

Figure A.12: Validation-Plot of FDC for Observed and Simulated Daily Flows at Namnam (1990-1994)

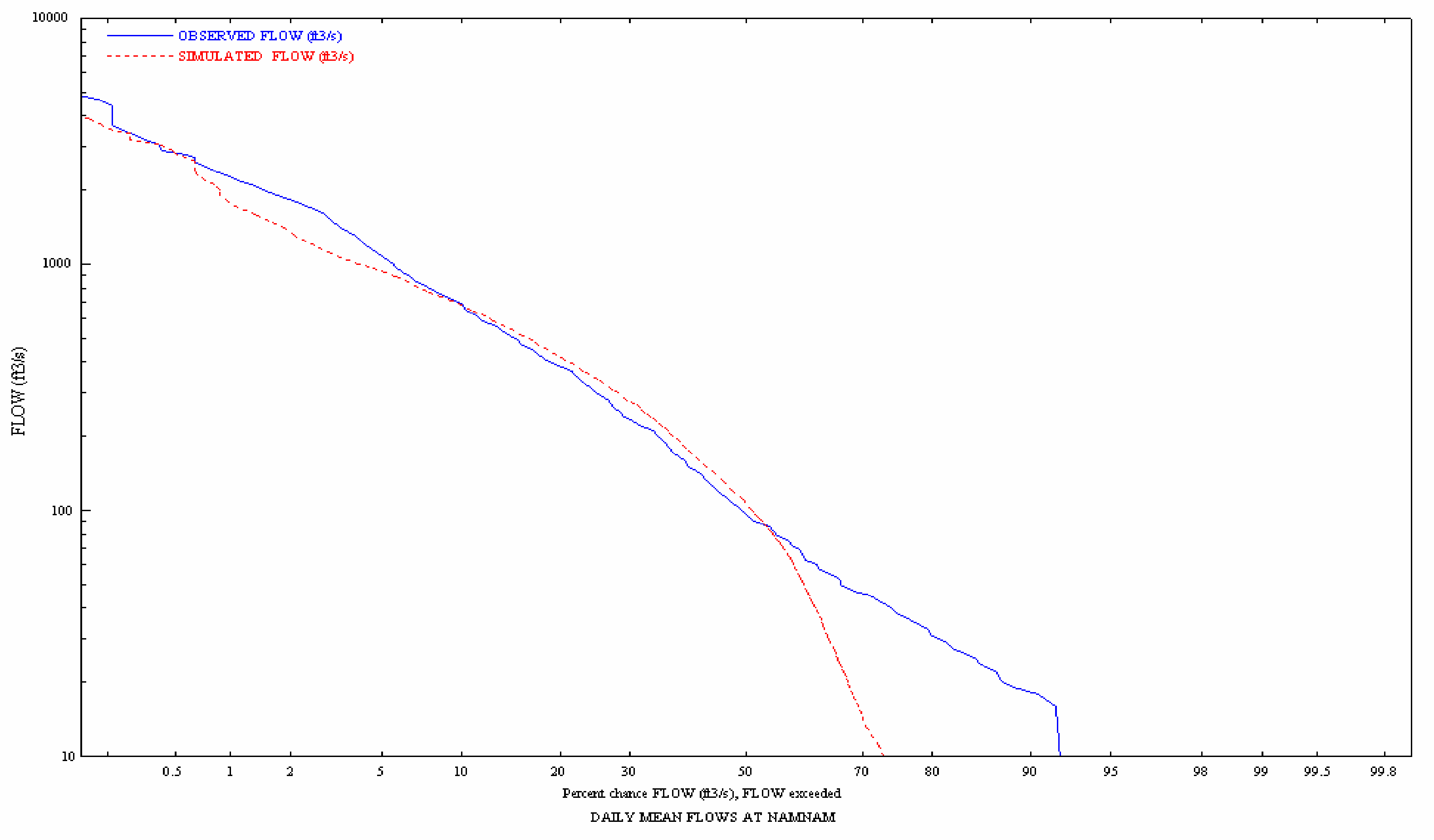

Figure A.13: FDC for Observed and Simulated Daily Flows at Namnam (1990-1999)

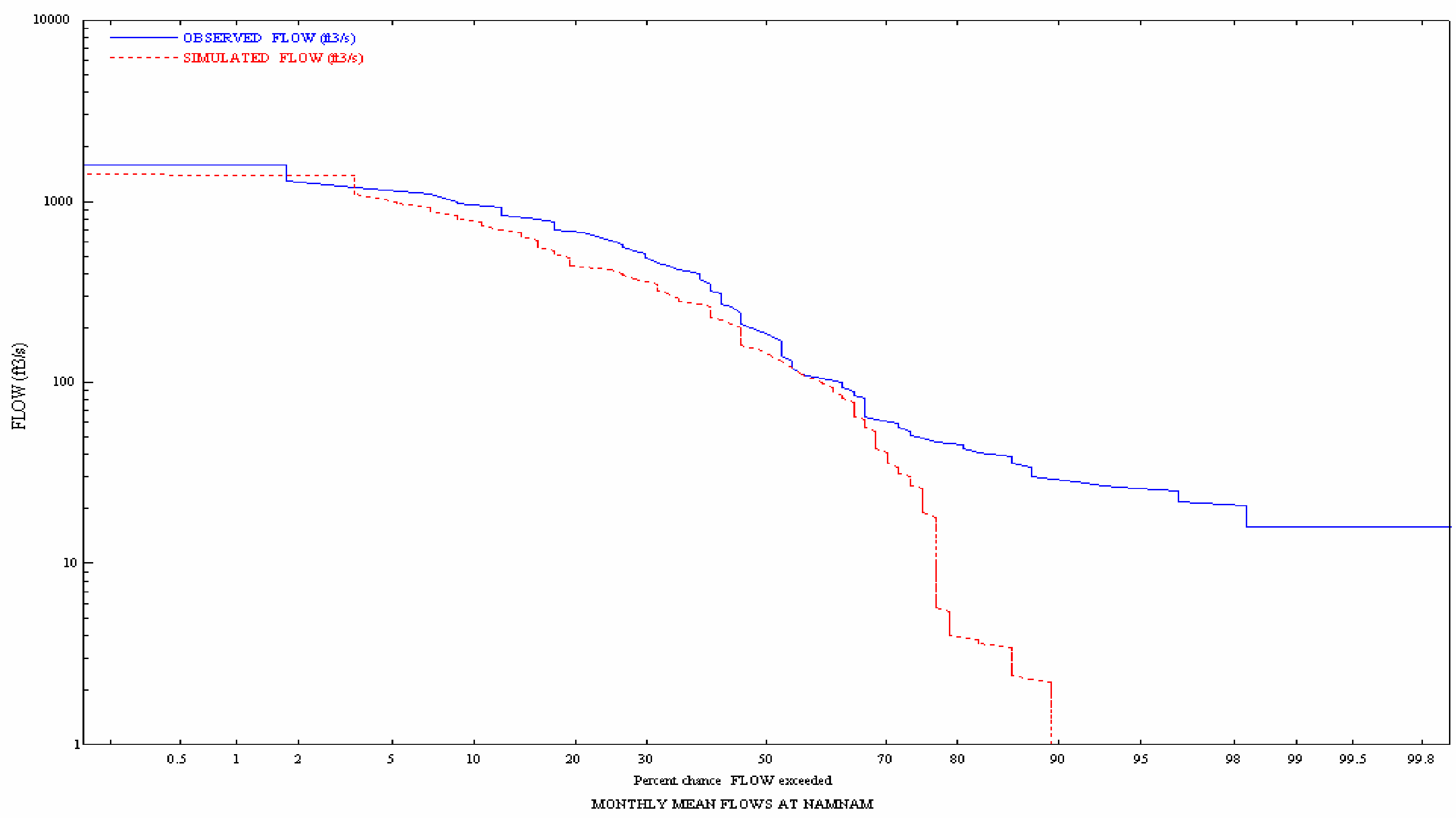

Figure A.14: Calibration-Plot of FDC for Observed and Simulated Monthly Flows at Namnam (1995-1999)

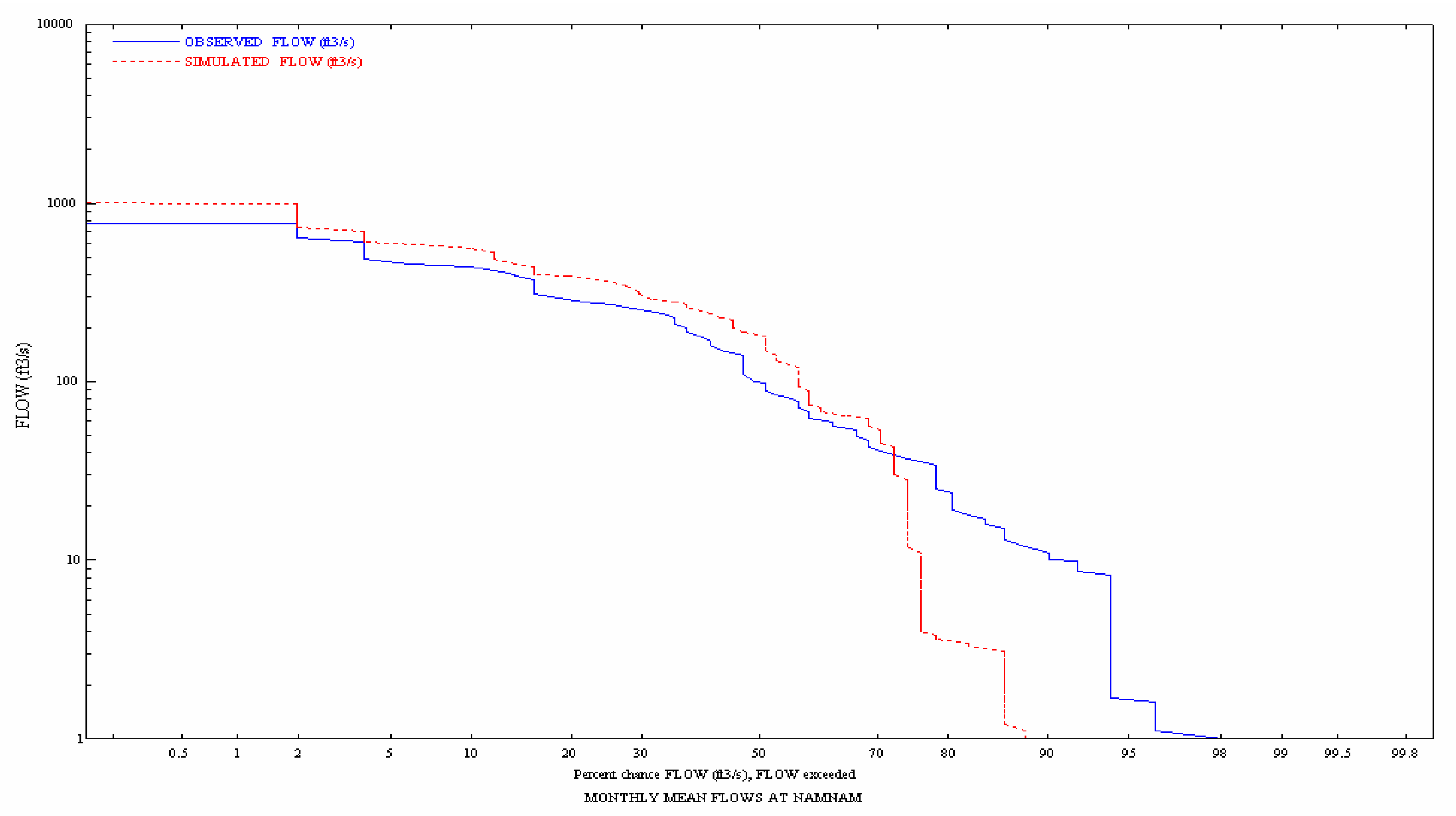

Figure A.15: Validation-Plot of FDC for Observed and Simulated Monthly Flows at Namnam (1990-1994)

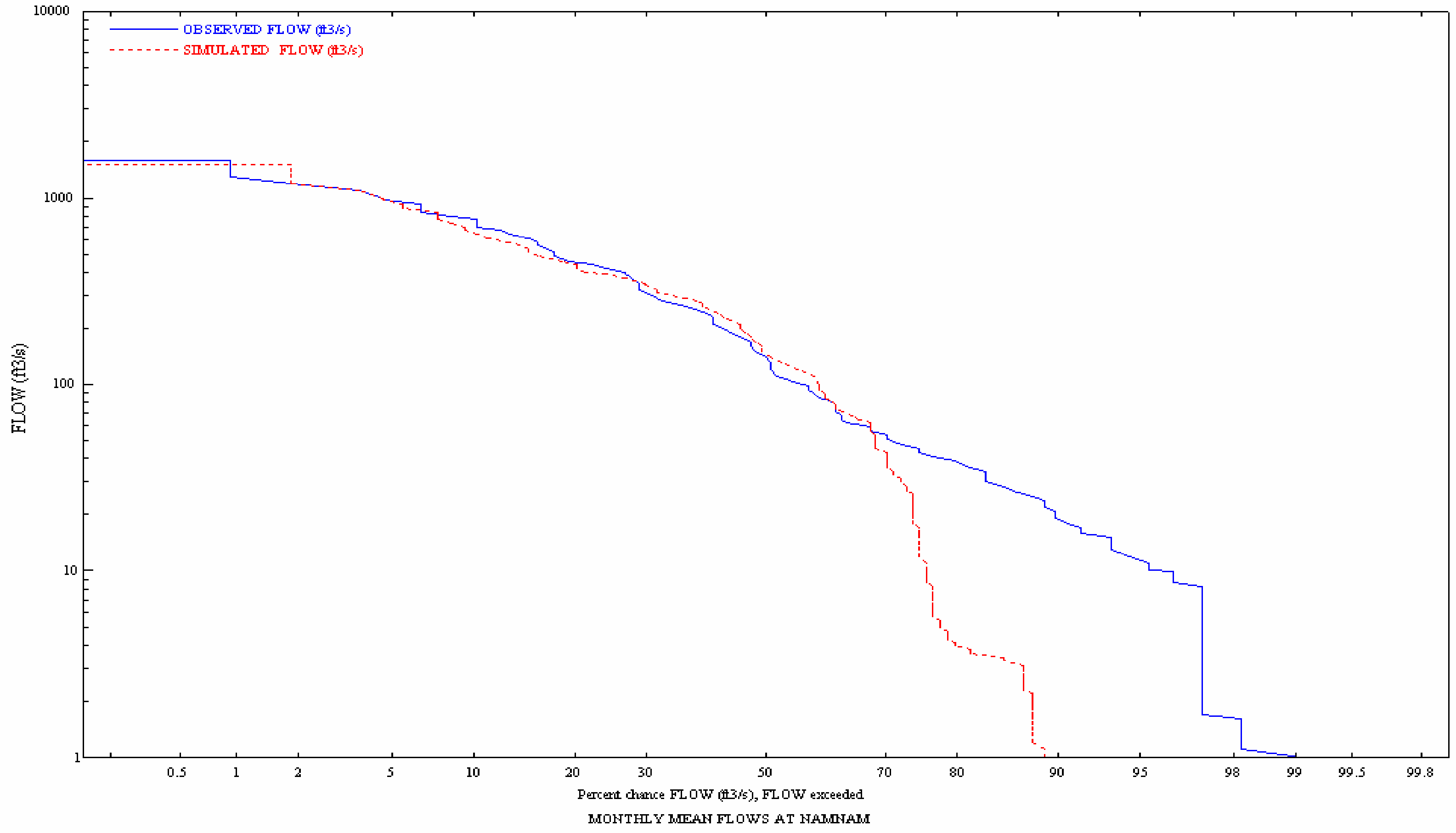

Figure A.16: FDC for Observed and Simulated Monthly Flows at Namnam (1990-1999)

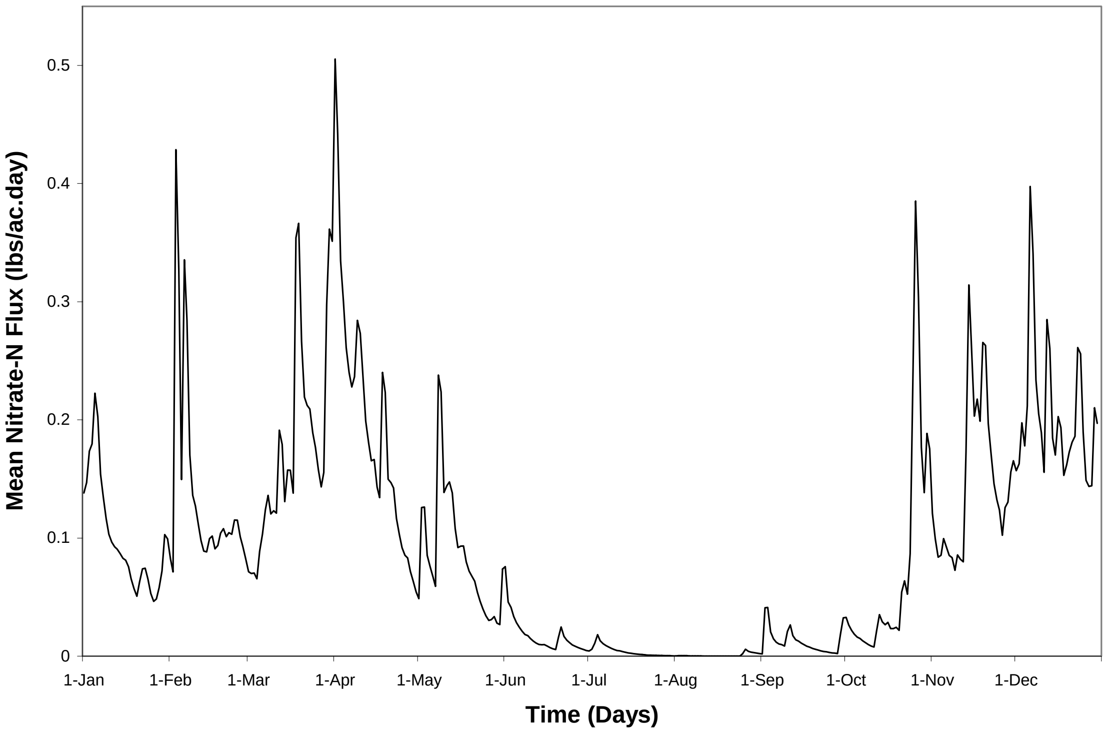

Figure A.17: Mean daily Nitarte-N flux

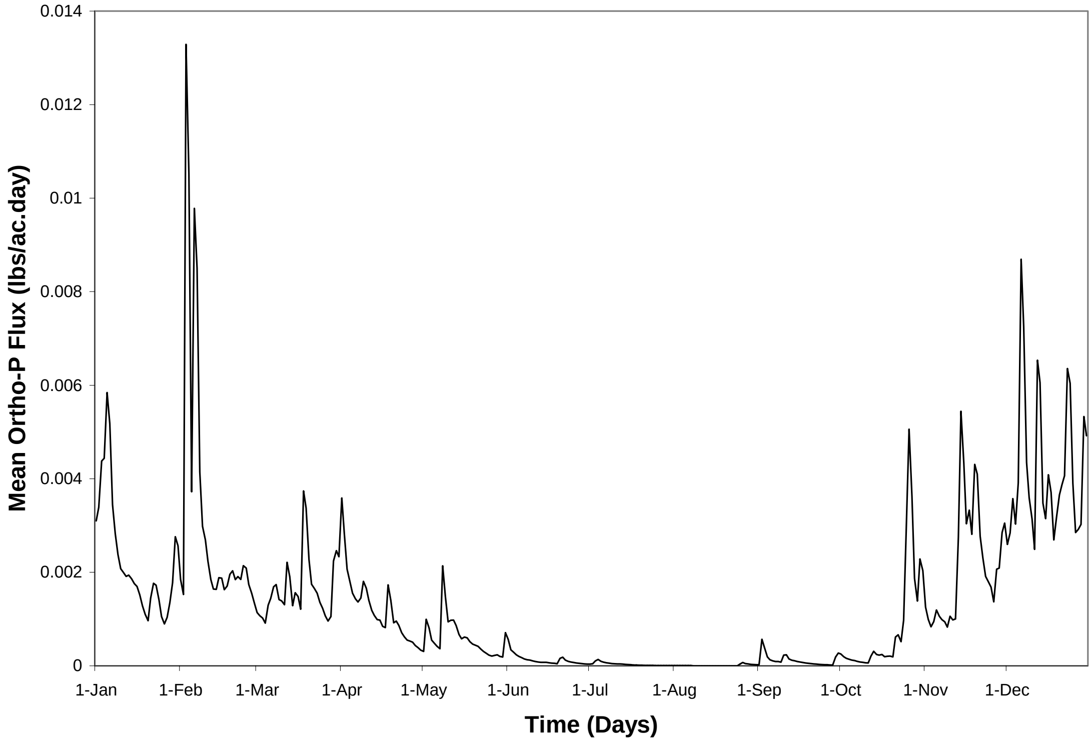

Figure A.18: Mean daily Orthophosphate-P flux

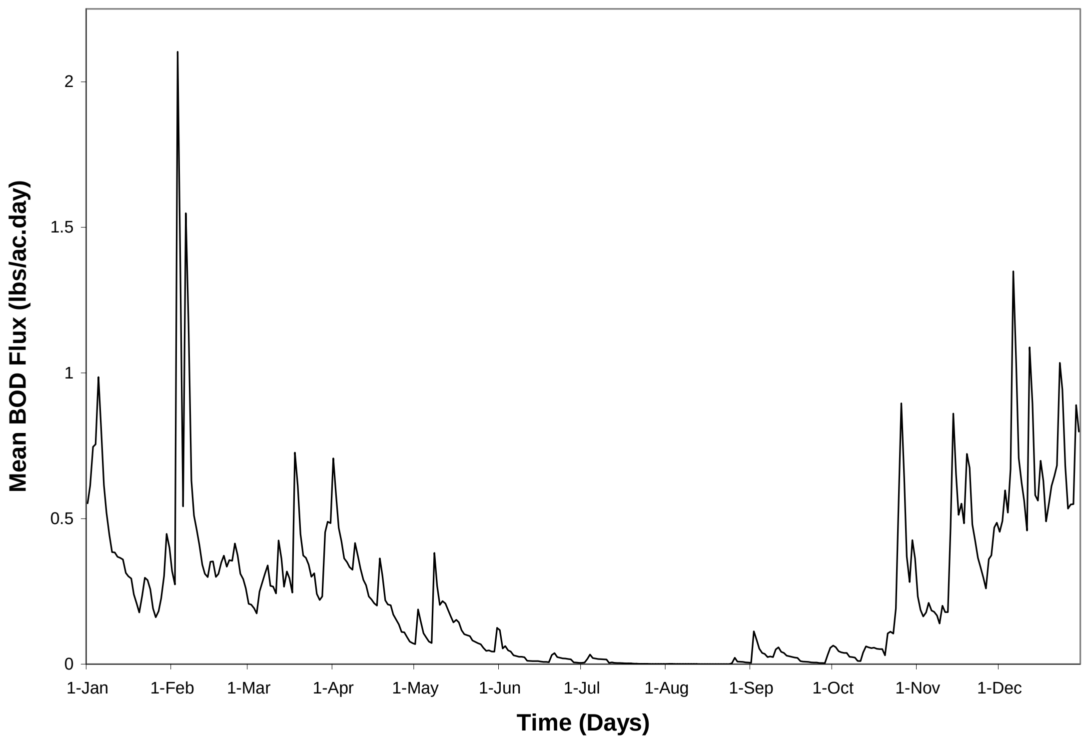

Figure A.19: Mean daily BOD flux

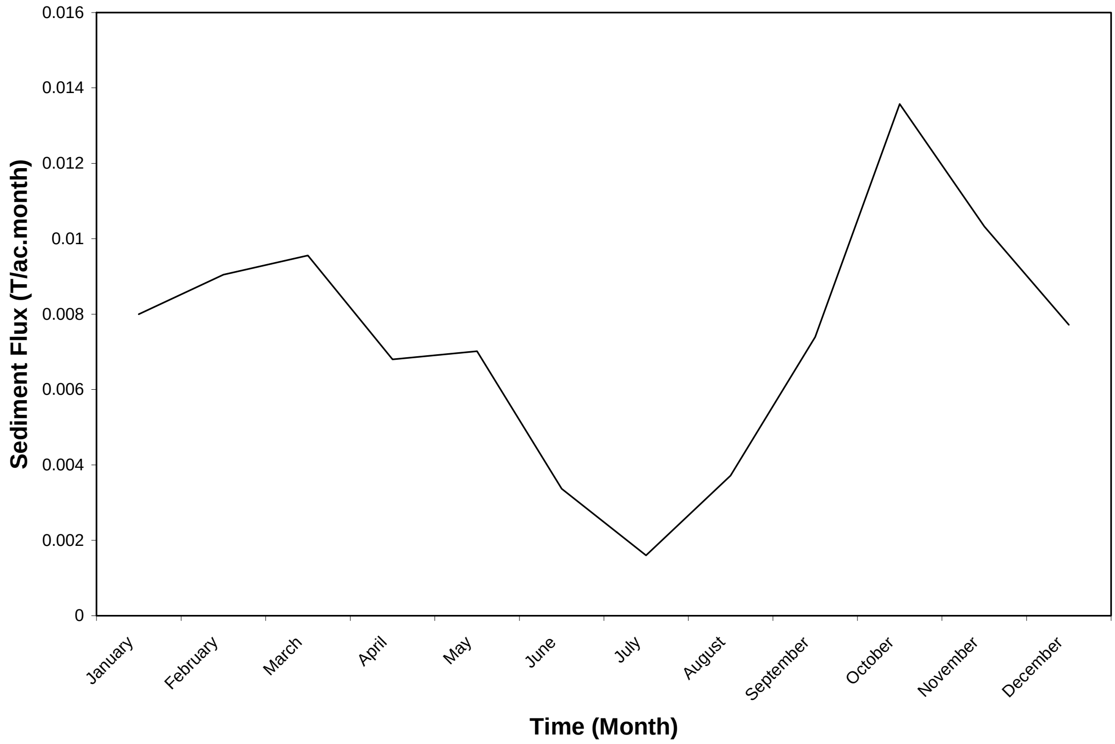

Figure A.20: Mean monthly sediment flux

Appendix B: HSPF Hydrologic Model Inputs and Otputs

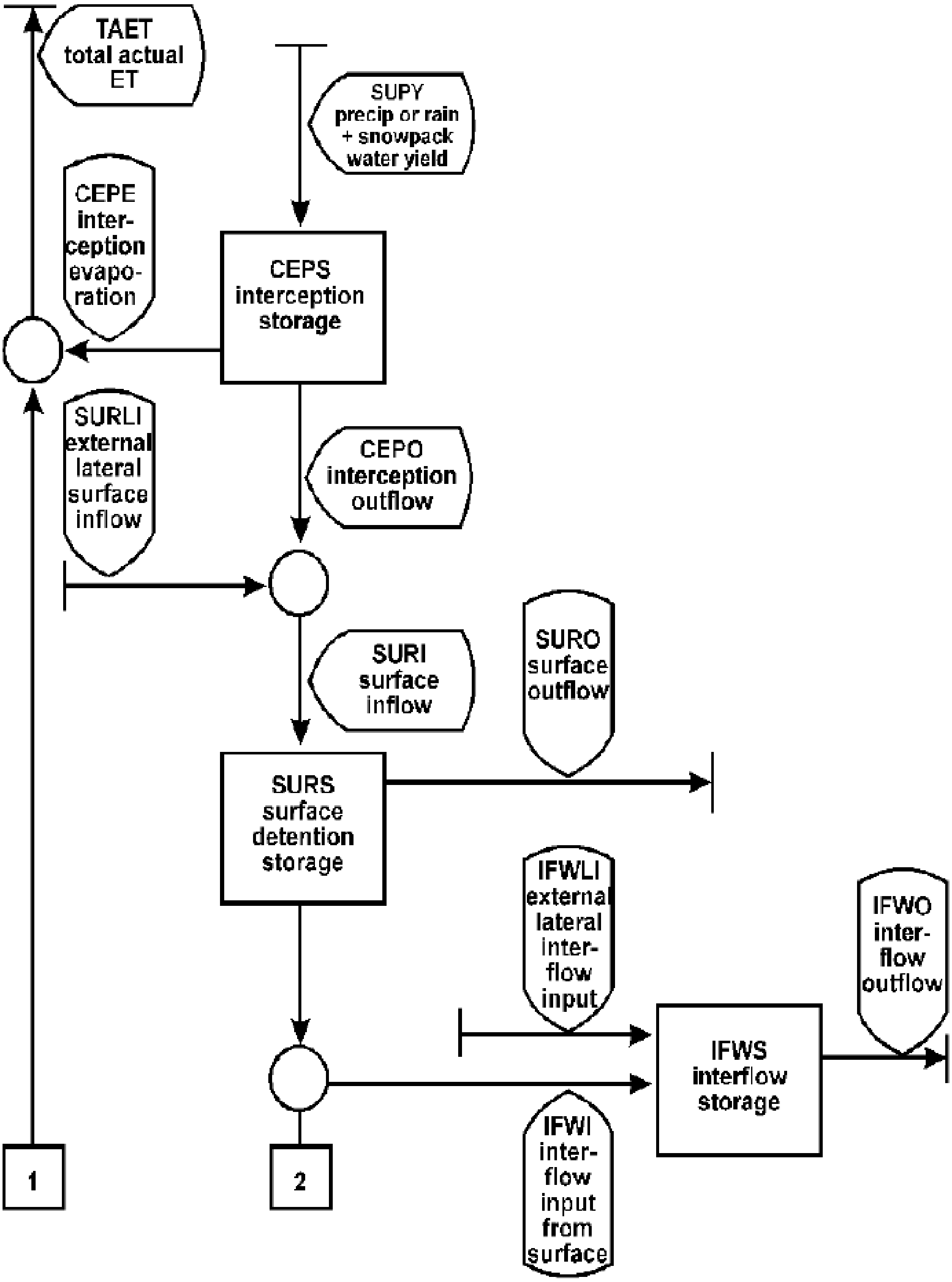

Figure B.1: Flow diagram of water inputs and outputs as modeled in PWATER application module of HSPF (part-1)

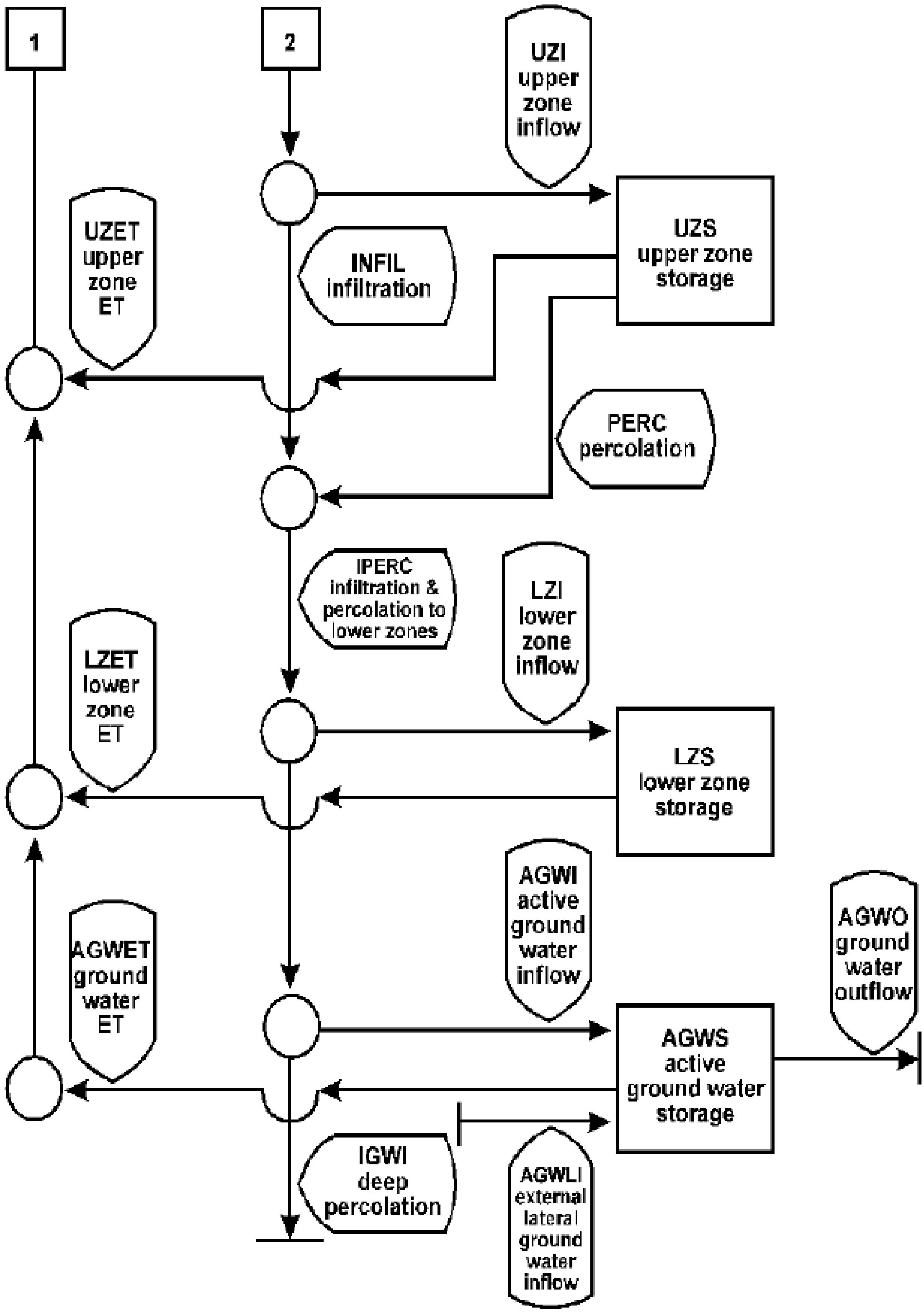

Figure B.2: Flow diagram of water inputs and outputs as modeled in PWATER application module of HSPF (part-2)

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- (In Prep) **Baloch, M.A**., Ames, D.P., Tanik A. "Climate and Land Use Change Impacts on Water Quality/Quantity in the Koycegiz Watershed, Turkey". For submission to: Hydrological Sciences Journal.
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- (In Prep) **Baloch, M.A**., Aburizaiza, A.O., Glenn F.N. "Application of Landsat imagery to water clarity assessment of the Koycegiz-Dalyan lake lagoon system in Turkey". For submission to: Environmental Monitoring and Assessment.
- (In Prep) **Baloch, M.A**., Ames, D.P. "A Geospatial Interpolation Approach to Water Quality Index Estimation for Koycegiz-Dalyan Lagoon, Turkey".