İSTANBUL TECHNICAL UNIVERSITY « INSTITUTE OF SCIENCE AND TECHNOLOGY

DEVELOPMENT OF MODEL SUPPORT SYSTEM FOR RURAL AREA NON-POINT SOURCE MODELING: KÖYCEĞİZ-DALYAN WATERSHED CASE STUDY

Ph.D. Thesis by

Kızıltan YÜCEİL, M.Sc.

(501982403)

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Supervisor (Chairman) : **Prof. Dr. Ethem GÖNENÇ (İTÜ)**

Members of the Examining Committee **Prof. Dr. Orhan YENİGÜN (BÜ)**

Assoc. Prof. Dr. Turgut ONAY (BÜ)

Prof. Dr. Cumali KINACI (İTÜ)

Prof. Dr. Ayşegül TANIK (İTÜ)

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KIRSAL ALANLARDA YAYILI KAYNAK MODELLEMESİ İÇİN MODEL DESTEK SİSTEMİ GELİŞTİRİLMESİ : KÖYCEĞİZ-DALYAN HAVZASI ÖRNEK ÇALIŞMASI

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Y. Müh. Kızıltan YÜCEİL

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Tez Danışmanı: **Prof. Dr. Ethem GÖNENÇ (İTÜ)**

Diğer Jüri Üyeleri **Prof. Dr. Orhan YENİGÜN (BÜ)**

Doç. Dr. Turgut ONAY (BÜ)

Prof. Dr. Cumali KINACI (İTÜ)

Prof. Dr. Ayşegül TANIK (İTÜ)

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FOREWORD

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January, 2005 Kızıltan Yüceil, MSc

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ABBREVIATIONS

AGNPS	: Agricultural Non-Point Source Pollution Model
ANSWERS	: Areal Nonpoint Source Watershed Environment Response Simulation
ARM	: Agricultural Runoff Management
ATM	: Atmospheric Transport Model
BASINS	: Better Assessment Science Integrating Point and Nonpoint Sources
BMP	: Best Management Practice
BOD	: Biochemical Oxygen Demand
CREAMS	: Chemicals, Runoff, and Erosion from Agricultural Management Systems
CSO	: Combined Sewer Overflows
DEM	: Digital Elevation Model
DHI	: The Danish Hydraulic Institute
DO	: Dissolved Oxygen
DR3M-QUAL	: Distributed Routing Rainfall Runoff Model - Quality
ET	: Evapotranspiration
FHWA	: US Federal Highway Administration
HEC	: Hydraulic Engineering Center of US Army Corps of Engineers
HEC-1	: HEC Model 1
HSPF	: Hydrological Simulation Program FORTRAN
IDF	: Intensity Duration and Frequency
ILLUDAS	: The Illinois Urban Drainage Area Simulator
ILS	: Impervious Land Segment
ITU	: İstanbul Technical University
GIS	: Geographical Information Systems
GLEAMS	: Groundwater Loading Effects of Agricultural Management Systems
MOUSE	: Modeling of Urban Sewers
MSS	: Model Support System
NPS	: Non-Point Source
PDRO	: Potential Direct Runoff
PET	: Potential Evapotranspiration
PLS	: Pervious Land Segment
PRZM	: Pesticide Root Zone Model
PRS	: Pesticide Runoff Simulator
RUNQUAL	: Runoff Quality Model
RUSTIC	: Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations
SCS	: US Department of Agriculture Soil Conservation Service
STORM	: Storage Treatment Overflow Runoff Model
SWM	: Stanford Watershed Model
SWMM	: Storm Water Management Model

SWRRB : Simulator for Water Resources in Rural Basins
TAFGCM : Turkish Armed Forces General Command of Mapping
TEHM : The Terrestrial Ecology and Hydrology Model
TMDL : Total Maximum Daily Load
TR : Turkish Republic
TRDC : Turkey Research and Development Center, TAGEM
TRGDEWA : TR General Directorate of Electrical Works Administration (EİE)
TRGDRA : General Directorate of Rural Affairs of the Turkish Republic
TRGDRA-NIC : TRGDRA National Information Centre
TRGDMRE : TR General Directorate of Mineral Research and Exploration
TRSHW : Turkish Republic State Hydraulic Works (DSİ)
TRSMW : Turkish Republic State Meteorology Works
TÜBİTAK : The Scientific and Technical Research Council of Turkey
US : United States
USDA **:** United States Department of Agriculture
USEPA : US Environmental Protection Agency
USGS : US Geological Survey
USLE : Universal Soil Loss Equation
UTM-TOX : Unified Transport Model for Toxic Materials
WDM : Watershed Data Management
WHTM : Wisconsin Hydrologic Transport Model
WMS : Watershed Modeling System 6.1
WWTP : Wastewater treatment plant
YDABÇAG : TUBITAK Land Ocean Air Sciences and Environmental Research Group

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SUMMARY

"Non-Point Source" (NPS) pollution modeling systems are essentially supportive to sustainable management and conservation of natural resources in a rural watershed. These systems could be characterized by their highly sophisticated structure and the vast amount of diversified data they require. Especially in developing countries, where data sources might be; scarce, of shorter history, questionably reliable, distributed, or not well-publicized, data gathering process might be as challenging as the modeling itself. Furthermore, lack of a systematical approach to gather, analyze and prepare these data as inputs to the model, might threaten the success of the modeling efforts, if not totally annulling it. Hence, the primary aim of this study is to develop a systematic approach to undertake all these predecessor tasks of modeling, namely the Model Support System (MSS). A secondary intention is to provide a detailed guidance on setting up a watershed modeling system in Turkey, by introducing this approach to a case study on Köyceğiz-Dalyan Watershed.

The scope of the study extends from the conceptual information on the Rural Area NPS MSS, to local execution of the tasks defined under these concepts. However, the extent of the study "does not" intend to state any prescription for the Köyceğiz-Dalyan Watershed NPS pollution risks, but rather addresses the systematic approach, difficulties, and workarounds bound to local conditions, to establish a proper rural MSS for the region. Nevertheless, the MSS developed by this approach, shall in fact be leading those with the necessary resources and investment, to succeed in forming that pursued prescription.

A full documentation on how to initiate and proceed a project for "rural area non-point source modeling" is made available for use of decision makers, researchers and modelers in Turkey. Thus, the primary and secondary targets of the study are highly fulfilled. Moreover, some additional effort is given to execute the HSPF (Hydrological Simulation Program - FORTRAN) model by the gathered and derived data, which produced acceptably positive results. Hence, a hydrological model basis for Köyceğiz-Dalyan Watershed is developed with HSPF, which became one of the very rare applications of this model in Turkey.

In summary, the study serves as a guideline for scientists in Turkey to do research in a similar framework, and aims to provide them the expertise that would back up their efforts and intensify their studies. Although the quantified modeling outputs of this study should be considered as preliminary, they also act as a reliable and timesaving initial step towards a much broader evaluation of the non-point sources in this rural watershed. Given that developing an integrated approach for watershed management is quite a fertile and a rather young concept, this study shall act as a guiding tool for the possible implementation of holistic environmental management plans in Turkey, and assist the NPS modeling process in a "realistic" manner.

KIRSAL ALANLARDA YAYILI KAYNAK MODELLEMESİ İÇİN MODEL DESTEK SİSTEMİ GELİŞTİRİLMESİ : KÖYCEĞIZ-DALYAN HAVZASI ÖRNEK ÇALIŞMASI

ÖZET

Yayılı Kaynak Kirliliği (YKK) modelleme sistemi, kırsal havzalarda doğal kaynakların korunması ve sürdürülebilir yönetimi için, temel bir destekleyici unsurdur. Bu sistemler, yüksek sayı ve çeşitlilikteki veri ihtiyaçları ile hayli sofistike yapılarıyla karakterize edilebilirler. Özellikle gelişmekte olan ülkelerde veri kaynaklarının; sayı, kayıt geçmişi, güvenilirlik, dağılmışlık veya kamusallık bağlamlarında sorun içermeleri, veri derlemeyi modellemenin kendisi kadar zorlu hale getirebilmektedir. Dahası, modele girdi verilerinin derlenmesi, analizi ve hazırlanması için sistematik yaklaşım eksikliği, modelleme çabalarının başarısının tehlikeye düşmesini ve hatta bütün olarak sonuçsuz kalmasını beraberinde getirebilir. Bu nedenle, bu çalışmanın ana gayesi, modellemeden önce gelen tüm adımların yerine getirilebilmesi için Model Destek Sistemi (MDS) adı verilen sistematik bir yaklaşım geliştirmektedir. Çalışmanın ikinci amacı ise, Türkiye'de bir havza modelleme sistemi kurulabilmesi için detaylı bir yönlendirme sağlayabilmek üzere, bu yaklaşımın Köyceğiz-Dalyan havzasında bir örnek çalışma olarak uygulanmasıdır.

Çalışmanın kapsamı, kırsal yayılı kaynaklarda MDS kavramsal bilgilerinden, bir yerel çalışmada bu kavramlara dair adımların uygulanmasına kadar uzanmaktadır. Ancak, çalışmada Köyceğiz-Dalyan Havzası için yayılı kaynak kirlilik risklerine yönelik detaylı bir reçetenin hazırlanmasına teşebbüs edildiği "düşünülmemelidir". Zira hedeflenen, bölgede kırsal kesime özel düzgün bir MDS kurmak için gereken sistematik yaklaşımı tanımlamak, uygulama esnasında karşılaşılabilecek olası güçlükleri belirlemek ve bunların yerel şartlarda telafi yöntemlerini geliştirmektir. Yine de, bahsedilen yaklaşımla geliştirilmiş olan bu MDS ile, arzu edilen reçetenin hazırlanabilmesi için gerekli yatırım ve kaynağa sahip olanlar, yeterince yönlendirilebilmiş olacaktır.

Karar vericiler, araştırmacılar ve modelleme uzmanlarının kullanımı için Türkiye'de Kırsal alanlarda yayılı kaynakların modellenmesi için projelerin nasıl başlatılması ve sürdürülmesi gerektiğini konu edinen tam kapsamlı bir dokümantasyon oluşturulmuştur. Böylelikle, birincil ve ikincil hedeflerde büyük ölçüde başarı sağlanmıştır. Öte yandan, ek çalışmalarla derlenen ve işlenen veriler kullanılarak, HSPF (Hydrological Simulation Program - FORTRAN) modeli çalıştırılmış ve kabul edilebilir derecede olumlu sonuçlar üretilmiştir. Bu sayede, Türkiye'de çok az örneği bulunan bir HSPF modeli uygulaması ile Köyceğiz-Dalyan Havzası için bir temel hidrolojik model de oluşturulmuştur.

Özetle bu çalışma, benzer çerçevede Türkiye'de araştırmalar yapmak isteyecek bilimadamları için bir kılavuz işlevi taşımakta olup, bu çabaları takviye etmek ve derinleştirebilmek üzere gerekli uzmanlığı temin etme hedefindedir. Bu çalışmanın sayısal hale getirilmiş sonuçları, ön bilgi olarak ele alınmaları gerekmesine karşın, kırsal havzalarda yayılı kaynakların rolünün daha kapsamlı olarak değerlendirilebilmesi için zaman kazandırıcı ve güvenilebilir bir ilk adım olmaları açısından yine de önemlidir. Havza yönetiminde bütünleşmiş bir yaklaşımın geliştirilmesi nispeten genç ve verimli bir kavram olması da dikkate alındığında, bu çalışma, Türkiye'de çevre yönetim sistemlerinin bütünü esas alan olası uygulamalarında bir araç olarak kullanılabilecek ve yayılı kaynak modelleme sürecine gerçekçi bir destek sağlayacaktır.

1. INTRODUCTION

1.1 Aims and Scope

“Non-Point Source” (NPS) pollution modeling systems are essentially supportive to sustainable management and conservation of natural resources in a rural watershed. These systems could be characterized by their highly sophisticated structure and the vast amount of diversified data they require. Especially in developing countries, where data sources might be; scarce, of shorter history, questionably reliable, distributed, or not well-publicized, data gathering process might be as challenging as the modeling itself. Furthermore, lack of a systematical approach to gather, analyze and prepare these data as inputs to the model, might threaten the success of the modeling efforts, if not totally annulling it. Hence, the primary aim of this study is to develop a systematic approach to undertake all these predecessor tasks of modeling, namely the Model Support System (MSS). A secondary intention is to provide a detailed guidance on setting up a watershed modeling system in Turkey, by introducing this approach to a case study on Köyceğiz-Dalyan Watershed, a vulnerable natural protection zone in southwestern Anatolia with vast rural and agricultural zones.

The scope of the study extends from the conceptual information on the Rural Area NPS MSS, to a systematic and local implementation of these concepts within the case study. However, the extent of the study “does not” intend to state an extensive prescription for the Köyceğiz-Dalyan Watershed NPS pollution risks, but rather addresses the systematic approach, difficulties, and workarounds to establish a proper rural MSS for the region.

1.2 Significance

NPS modeling on rural areas requires a wide scale of multidisciplinary collaboration. Data collection, analysis and assessment on land-based sources in a rural watershed necessitate data, information and expertise from environmental, hydraulic, geodesy, photogrammetry, soils, and meteorology disciplines. Furthermore, in Turkey, data with regard to all of these different disciplines are hold by a variety of governmental and non-governmental organizations through their central, provincial, or regional authorities. Thus coordination of the data gathering process as well as the consulted collaborators requires know-how and systematical approach. Otherwise failure in gathering, analysis or preparation of input data, might threaten the success of the modeling efforts, if not totally annulling it. Hence, this study, which pursues to create a reference on how to initiate and proceed a rural area NPS modeling project in Turkey, undertakes a mission, yet not challenged.

The study defines every aspect of the data gathering process and locates the necessary information distributed along a wide number of authorities in Turkey. It also eases the way for future researchers by introducing an approach to define, formulate, organize, analyze and assess the problems of rural watershed.

Moreover, some additional effort is given to execute the HSPF (Hydrological Simulation Program - FORTRAN) model by the gathered and derived data, which produced acceptably positive results. Hence, a hydrological model basis for Köyceğiz-Dalyan Watershed is developed with HSPF, which became one of the very rare applications of this model in Turkey. This is another significant mission of the study.

The study serves as a guideline for scientists in Turkey to do research in a similar framework, and aims to provide them the expertise that would back up their efforts and intensify their studies. Although the quantified modeling outputs of this study should be considered as preliminary, they also act as a reliable and timesaving initial step towards a much broader evaluation of the non-point sources in this rural watershed. Given that developing an integrated approach for watershed management is quite a fertile and a rather young concept, this study shall act as a guiding tool for the possible implementation of holistic environmental management plans in Turkey, and assist the NPS modeling process in a “realistic” manner.

2. RURAL AREA NON-POINT SOURCE MODEL SUPPORT SYSTEM

This chapter primarily highlights the significant purposes of utilizing NPS modeling on rural areas, and then it introduces the commonly used NPS models as tools for rural watershed management practices. Finally, the systematic methodology to adopt a MSS within a rural watershed is provided in the chapter, for the selected NPS model, HSPF.

2.1 Significance

The aim of a watershed planning strategy must be to maintain the conservation of natural resources, to bring the environment to a self-renewing state, and to manage the vulnerable and sensitive resources in a sustainable manner (ESCAP-UN, 1997; EPA, 2002). The detailed identification of the prevailing situation of a watershed is of utmost importance to develop scenarios regarding sustainable management and development (Şeker *et al*, 2002a). Hence, modeling, which enables to quantify the impacts of ongoing, possible, and prospective natural and human generated activities, is an essential tool to address the functions and conflicts in a watershed. In terms of modeling of pollutants and thereby evaluating the environmental risks in a watershed, the types of models required would mainly differ on whether the pollutant fluxes are from point sources or from non-point (diffused) sources. With the achievements in the past 50 years, it is now much easier to allocate contribution of waste loads from point sources. However, non-point sources are still a challenge to assess because of the sophisticated process and mechanisms they undergo. On the other hand, there is an impetus on developing new techniques to better identify these sources and therefore it becomes critical to immediately employ them to be able to enact necessary measures for conservation of natural resources.

2.1.1 Non-point sources modeling

NPS Modeling, as an essential component of watershed modeling, is a vital tool in water quality research and management with the rapid advancement in computer and information technologies. NPS Modeling was originally utilized for estimation of water quantities in engineering applications such as flood forecasting, urban storm management, and many other water resources planning activities like, reservoir design and water supply (Chen, 2001). However, the impetus in computer and computational technology allowed for much more sophisticated modeling tasks to be synchronously executed and hence it did become possible to introduce; fate and transport of pollutants and sediments, chemical and biochemical reactions and biological growth mechanisms into a single integrated modeling framework. Thus, it is getting increasingly possible to converge to accurate simulation results on land and soil contamination and their impacts on aquatic environment via overland and subsurface fluxes.

Point sources of pollutants originating from wastewater treatment plants (WWTP) and industrial plants are directly discharged into the receiving media, i.e. end-of-pipe, whereas non-point (diffused) emissions are caused from various pathways, such as;

- direct input on the water surface by atmospheric deposition,
- nutrient input into the river streams by surface runoff,
- nutrient input via interflow which represents a fast subsurface flow component,
- and nutrient input via groundwater realized by the slow flow component.

The quantification of the input of substances via natural interflow and tile drainage is particularly complex (Chen, 2001). Parallel to the complexity of the latter, it is yet another challenge to provide substantial amount of data required for execution, calibration, and verification of NPS models. Therefore, a clear understanding of NPS concept and thereby precise addressing of the problems in the watershed is vital for a MSS to be achievable.

2.1.2 Integrated watershed management on rural areas

Many watersheds in the world that even slightly interact with anthropogenic activities encounter threads against their ecosystem and natural capital. Increasing human activities make these dynamic and productive ecosystems sensitive and vulnerable. Integrated watershed management, involves the adoption of a coherent management system for land and water, which can ameliorate the adverse impacts of either natural disasters or man-driven activities, and help to achieve the sustainable use of natural resources within a watershed. Accordingly, integrated watershed management targets the coordinated use and management of land and water to ensure minimal impact to water yield and environmental quality (Tanık *et al.*, 2003).

The key philosophy proposed within the integrated watershed management is 'permission to use the watershed in accordance with the tendencies of the society in a controlled manner, while protecting the quality of the watershed, and to assure continuing control by implementing economic and technical sanctions'. Watershed management decision-making must therefore depend on the assessment of the potential of the land and water resources (Gürel *et al.*, 2005). However, it is just very recently that making use of integrated models and GIS as tools in land use planning and management is initiated. Hence, there exists a need to improve integrated models to deal with land-water interaction and to convey their outputs to decision makers for implementation (Şeker *et al*, 2002b).

The integration of land sources with the aquatic environment could only be established by non-point and point sources modeling in tandem. On the other hand, parameters traced in water and those from either of the sources on soil should be compatible in order to judge the complete fate of parameters modeled. GIS would also ease the efforts to geographically associate the diffused sources with the waterbodies. For instance, the results of a NPS modeling study could provide a spatial and temporal distribution of unit fluxes and these fluxes along the banks of a stream and these could be compared with the measured concentrations in the stream. Thus, GIS is generally preferred in this kind of studies, as it is distinctive with its ability to incorporate, manage, and analyze spatial data and to answer spatial questions (Burrough and McDonell, 1998).

However, especially rural NPS modeling require a multidisciplinary expertise. Data collection and assessment on land-based sources in an rural watershed might necessitate collaboration of environmental, hydraulic, geodesy, photogrammetry, soils, and meteorology engineers or experts. As integrated watershed management is a decision making task, mapping and further analyses of land and water quality parameters through GIS would aid better presentation and understanding of the current situation in the watershed. Hence, the findings of the NPS modeling studies could be assessed under the related regulations, to establish pollution scenarios, and to make queries as a basis for a sustainable management strategy. Without such detailed interdisciplinary investigations, scientists might fail to depict an integrated approach and modeling studies may not lead to sustainable management practices (Şeker *et al*, 2002b).

Another crucial role of NPS modeling in rural watershed management is that it enables to view the level of nutrient and toxic pollutant loads from agricultural activities. Agriculture with overuse and/or misuse of pesticides and fertilizers, uncontrolled livestock breeding, irrigation and stormwater are named as the major sources of NPS pollution in most watersheds. Among these sources, agricultural fertilizers were for a long time considered as the main sources of nutrients worldwide on a global scale (Novotny, 1999). The difficulty in identifying such sources both qualitatively and quantitatively is that they are highly governed by natural conditions such as spatial (topography, location, incidence of surface runoff) and temporal (precipitation, evaporation) factors, soil characteristics (texture, structure, permeability), and land management (land use, cultivation trends, fertilizer application considering time and frequency, irrigation requirements) (Heathwaite and Sharpley, 1999). This, therefore, verifies that NPS models need to be fully dynamic, should be capable to define soil characteristics and mechanisms in detail and that fine resolution time series of input data together with various quantified soil characteristics should be maintained from site measurements. Besides, regarding the need to associate the land and water components of a watershed with agricultural land use patterns, sustainable management could be attained if; excess nutrient loads would be estimated and monitored in the waterbody against possible eutrophication problems (Tanık *et al.*, 2001).

Pesticide losses from application areas and contamination of non-target sites represent a monetary loss to the farmer as well as a threat to the environment. Thus, careful management of pesticides in order to avoid environmental contamination is desired by both farmers and by the public. Regarding the soil and aquatic environment, it is necessary to investigate the behavior and fate of a pesticide in both soil and aquatic systems, and in particular, how it is distributed and how it degrades (Tanık *et al.*, 2000). The soil properties that are needed to determine the amount of pesticides that leach to the ground and/or join surface water through surface run-off or other fluxes are briefly; soil structure and composition, bulk density, pH, permeability, moisture content, water depth, soil water holding capacity and infiltration rate parameters (Gürel *et al.*, 2003).

2.2 Rural Area Non-Point Source Modeling

Non-point source modeling on rural areas could be characterized with its technical difficulties arising from sophisticated flow and fate mechanisms, vast number of long term and high resolution data requirements, numerous parameters with many measurement problems and generally large areal coverage. However, these problems are often multiplied by non-technical factors such as the need to gather an interdisciplinary project team, data availability and reliability, financial limitations, regulatory constraints, public expectations and the priorities of the decision-makers, which may be from different and generally competing jurisdictional parties. Thus, it is yet another challenge to address the non-technical issues, as well as it is already a challenge considering the scientific burden. The following sections will provide a guideline for the modeling process as a whole and will introduce the essential tools for nonpoint source modeling on rural areas.

2.2.1 Modeling process

Although the role of NPS modeling over integrated watershed management practices is vital, it is a critical issue to launch the modeling program, which would comply with the environmental requirements, public benefits and policies of the decision makers themselves, as well. Thus, the questions to be answered prior to the commencement of a modeling study are not entirely technical or scientific but also depend on social, financial and governmental factors. The following sections aim to brief the steps of modeling process within this widened point of view.

2.2.1.1 Modeling purpose and extent

A model is a useful tool for decision-making because it provides for a better understanding of the elements, mechanisms, kinetic processes and capabilities of the systems being modeled. Modeling allows for integrated interpretation of input scenarios by varying the existing parameters to the desired future condition as well as to analyze costs and benefits of each of the outcomes they have input (Terwilliger and Wolflin, 2005). Despite its merits as a tool for decision making process, addressing the purpose and extent of modeling is a very critical issue. Any specific detail, which might have been disregarded within the planning stage of modeling may result in incomplete or misleading interpretation of the current and forecasted status. Thus;

- clarity in defining and addressing the problem, functions, demands and objectives
- precise analysis of data requirement, quality and availability
- technical adequacy and
- allocation of financial reserves

are inevitable for a successful, functional, effective and feasible modeling project. There are four major issues to deal with within the preliminary phase of modeling:

- Definition of the demands (functions): The need for non-point source modeling in rural areas especially arise due to the diversified functions demanded by the users of the ecosystem. It is the main mission of the decision makers to find a sustainable solution to harmonize demands with each other and the environmental quality whilst targeting an acceptable development plan. Therefore, a recent and foreseeable list of these demands as well as desired development pattern and quantifiable environmental quality parameters must be prepared.
- Definition of the problems (conflicts): As the parties or components of environmental system that demand functions from the ecosystem designate their priorities regarding their own activities or state of being, these functions

tend to create resource conflicts. A very typical example of these conflicts takes place between the natural capital and tourism functions. Countries like Turkey with significant natural capital become appealing for tourism purposes. However, as tourism functions intensify in a particular ecosystem, natural capital tends to deteriorate. This deterioration feeds back a decline in tourism facilities. Unfortunately, unless an integrated management approach is initiated, the habitat eventually looses both of its functions. As a result, to develop an integrated approach towards decision making process all recent and possible prospective conflicts should be extensively addressed.

- Definition of the mechanisms and processes (concepts): As modeling is scientific tool for understanding the nature and its interactions with anthropogenic activities, the mechanisms and processes specific to the ecosystem to be modeled must be examined in full detail so as to establish a justifiable basis for simulations. However, the level of technical detail to be resolved is not entirely a technical issue. Every single parameter required by a model necessitates a set of sufficient number of reliable data. The availability of such data is dependent on the condition of recent data archives, technical, financial and temporal suitability of activities required to gather and/or to measure these data. Any failure to actualize the necessary conditions for specific data requirements might dictate to eliminate or neglect some of the mechanisms or processes to be modeled. In order to avoid a misalignment towards the targets of the project, these prioritization decisions are mission critical and require high expertise and interdisciplinary involvement as well as decision makers' advisement, if necessary. On the other hand, should the scientific analysis prove that modeling of some of observable processes and mechanisms in the ecosystem is inevitable in order to develop reasonable outputs, then the project might need to be reengineered to supplement financial or technical resources to incorporate these processes and mechanisms into the project.
- Definition of the objectives (purposes): Given the demands, problems, and structure of the system it would then be possible to determine the objectives of the project. The objectives should be achievable, feasible, effective, sustainable and flexible in terms of future reconsiderations.

Once all of the four definitions of integrated watershed management stated above are finalized, the appropriate modeling tool could be selected.

Specifically for watershed models the objectives of the modeling study may be such as the following:

1. Runoff quantity and quality could be characterized with temporal and spatial detail in terms of concentration/load ranges, etc.
2. The output of the study could provide input to a receiving water quality analysis, e.g., a receiving water quality model.
3. Effects, magnitudes, locations, combinations, etc. of control options could be determined.
4. Frequency analysis on quality parameters, e.g., to determine return periods of concentrations/loads could be performed.
5. The output of the study could provide input to cost/benefit analyses.

Objectives 1 and 2 characterize the magnitude of the problem, and objectives 2 through 5 are related to the analysis and solution of the problem (Donigian and Huber, 1991).

2.2.1.2 Model selection

Consecutive to defining the purpose and extent of the modeling study, the first task is to form a set of model implementation alternatives. This model selection process comprises three major steps:

- Determining the alternative models:
    - All the available models technically appropriate for modeling purposes and extent should be surveyed
    - Data sets required for implementation of each model should be listed
    - Data sets and procedures required for calibration, validation and verification of the models should be examined
    - Checklists should be prepared to match the data available and data required by each model.
- Data gathering for comparative analysis of model options:

    - Input data requirements and accessibility of literature citations for the model options should be examined and compared for equally reliable and technically satisfactory outputs
    - Expertise and personnel necessitated by each modeling option for; data gathering, field studies, modeling, monitoring, analysis, assessments, and project management should be brought to light. This should then be compared to the human resources available.
    - Phased and complete project duration should be determined for each modeling option together with a study of timely consumption of human resources for each phase. The availability of human resource allocation required for each option should also be evaluated.
    - Services and data supplies and other contributions required from third parties and possible collaboration alternatives should be studied for each model option.
    - Financial budget requirement to fulfill data, expertise, time, and outsourcing demands should be estimated for every modeling alternative.
    - Available and possible funding opportunities should be investigated.
- Comparative analysis for model selection:
    - The selection of the most suitable and applicable model requires a preferably quantifiable comparison to be made among the options. Priorities and optimal performance on the following aspects would impact on the ranking of each option:
        - Likelihood to fulfill the purposes of the project in its targeted extent
        - Constraints on available technological or scientific practices such as equipments, laboratories or special methods
        - Feasibility and funding constraints due to high quantity of data, costly data, need for external service and/or technology supplies from third parties

        - Durational constraints in case of emerging action needed to be taken, i.e. some options may provide best efficient results due to a longer period of study whereas some other alternative may provide relatively less precise results in a shorter time
        - Personnel constraints, in other words, the total number of unique team members required during the project life span
        - Expertise constraints such as interdisciplinary contribution and specialists usage and availability of these resources
    - The selection of the most applicable model should be completed regarding the above listed criteria
    - The results of analysis for the selected model is used as a guide for team formation, project management, and data gathering during the model implementation process

2.2.1.3 Model implementation

Because of improvements in software development and hardware capabilities, there is an increasing trend towards incorporating many different processes and mechanisms into an integrated, dynamic, multidimensional and modular simulation framework. Hence majority of available NPS models today have a modular structure, by which the model users have the flexibility to simulate only certain processes, mechanisms, or parameters – if they are relevant – according to their preferences. This modular structure also allows for a systematic implementation of the model, where the model is initiated with fundamental mechanisms and then expanded to a more sophisticated network of equations. Therefore, it becomes more possible to analyze the system sensitivity and realign the model implementation tasks by such as development of alternative monitoring programs if found justifiable by this systematic approach. Thus, it is the foremost task to select the processes and mechanisms of concern to start with and to determine the modules and their requirements to run this core model.

The second task for model implementation for NPS models in particular, is to determine the hydraulic, hydrological and quality parameters subject to the objectives of the study. These parameters may similarly be diversified in time, parallel to the development of the model structure from a core to the final version as a part of the sensitivity, calibration and verification processes as well as availability of data.

The third fundamental issue is to form the temporal and spatial structure of the model. This encompasses determination of geographical coverage, streams, basins, subcatchments, land cover, segmentation, compartmental or linear network of these spatial elements, soil layers, boundary conditions, initial conditions, simulation period, targeted output frequency, etc.

As the location and timeline of simulation is resolved, input data sets could be prepared. In terms of its origin, any data could be classified under two groups: real data and estimated data. Since reliability of data is a prerequisite for the validity of the results measurement or observational data should be provided from reliable resources and if possible, be analyzed through some statistical methods against error risks. For estimated data, an extensive literary survey or expertise must be brought in. In either of the cases data format and units conversion is another compulsory step for model implementation.

Sometimes the format of the available data may not be suitable to the necessities of the module simulated. This is the general case for data presented in time series. The electronic file format as well as the temporal resolution of the available data might not match with the system. Under these conditions, file formats and time resolution of the data sets could be altered with additional labor or support software. The lack of hourly data could be compensated by estimating an annual average of hourly trend for each daily data. Or as for the US Watershed Data Management (WDM) format, which is a standard binary file structure for storing and manipulating time series, needs a long series of operations to be converted from Turkish Republic State Meteorology Works (TRSMW) daily meteorology data sets, which are supplied in ASCII file format and as cross tables. As for the input data sets, output data sets should also be studied to generate results available for calibration. Thus, similar conversion operations might be required for output data, as well.

Software technologies used for mathematical modeling has a much longer history of many software applications commonly used in daily life has. Eventually, numerous public or open source models of today still use their relatively unchanged core applications in comparison to the rapid change of computational technology over these decades. Starting from the 1990s, however, especially for commercialized modeling software usage of Graphical User Interfaces (GUI) before these old core applications and enabling a much more user friendly modeling environment, became an increasing trend. On the other hand, because of a wide variety of structural differences in terms of input data requirement by the core applications, the methods of introducing input parameters and data sets into the models are still diversified. Hence, modelers need to overcome this issue by preparation of input files for direct input to the model or by making use of auxiliary software applications for this purpose.

Apart from these operational issues, one of the most important tasks is to do a literature survey on the input parameters in order to make sure that the content of the input files reflect a reasonable representation of the actual system. Without such a study, it might take years to converge output results suitable for calibration. Thus, the selection of the initial input parameters is a very critical duty and requires a good understanding of the processes and mechanisms that actually take place in the watershed. When this understanding is accompanied by intense knowledge about the simulated concepts, representative meanings of input parameters and their roles in these concepts, it would then be possible to achieve a successful initial execution of the model.

2.2.1.4 Calibration, validation and verification

Calibration process is simply reiteration of the model by modifying relevant selective input parameters or structure until an output with acceptably high level of correspondence with the calibration data is attained. The scale of time and effort dedicated for calibration has strict dependence on the reliability of the input and calibration data. However, although these parameters might be reliable the idealizations on system network definitions might not be representative enough to reflect actual conditions. If the modeler is confident with all of these conditions then the input parameters should be calibrated by rerun of the model until an optimal agreement between the model and the targeted results are reached.

Whenever the calibration process is due, a rerun of the model is beneficial by a new set of data wherein only time dependent parameters are replaced in accordance to a different simulation period. This process, called validation, goals to understand whether the calibrated system parameters are both representative and durable to the actual system structure. If the validation results perform in a consistent manner using the new data set, then it would be confident to make forecasts on system behavior under various scenarios. Still, the modeler should be aware that the results of these scenarios could only be dependable unless there is a means of change in system structure.

If the calibration and/or validation processes fail to produce optimal acceptable outputs with reserved confidence on input and observation data and system metrics, verification process could be initiated. Verification is an examination of the numerical technique in the computer code to ascertain that it truly represents the conceptual model and that there are no inherent numerical problems (Neilson, 2000).

For NPS modeling the calibration priority is as follows:

1. Hydrology: The water budget is the first and foremost calibration argument, as there is no relevance to calibrate quality if water fluxes and mass balance are unrepresentative.
2. Sediment: After a trustable definition of the system hydrology is attained sediments need to be calibrated as sediments convey the quality constituents as well as host many physical, chemical and biochemical processes.
3. Water quality: A final touch on the water quality input parameters might still be necessary if optimal accuracy is not yet achieved although the rest of the system produces favorable results.

The modeler should follow the below check list for model testing:

- Is the water balance representative?
- Do the resulting time series show a parallel trend to the observed data sets?
- Do total flows from single storm event reflect the actual conditions?
- Are monthly and seasonal totals in the order of measured data?
- Is the annual total accounted for?
- Is the computed frequency duration curve justifiable?
- Is the pollutant balance reasonable?

2.2.1.5 Scenario analysis

The validated model could be used to present the impacts of recent, forecasted or synthetic conditions within the system. Long-term impacts of the existing system could be estimated with this approach. Hence, the decision makers could be warned about the threats before they actually worsen until an irreversible threshold. Development of worst/best case scenarios could highlight risks and limits of environmental progress in the watershed. The worst case scenarios could be used to forecast the immediate and gradual impacts of environmental catastrophes. For NPS modeling one of the most typical catastrophe scenarios is to estimate a storm event with minimal frequencies. Via such a scenario, the NPS model could alert the immediate build up of pollutants due to overland flow and if assisted by a water quality model running within the receiving waters the environmental burden of such an event could be estimated.

With regard to the applications of NPS models on rural areas, scenario analyses are even more functional for use of decision makers. The overall significance of agricultural pollution in the watershed, environmental performance of pesticide usage, irrigation, crop types and zone planning could be quantified with such scenario analysis. Once the watershed model is established and validated, it becomes possible to analyze long-term impacts of functional rearrangements in the watershed. However, dependability of these analyses could only and only be claimed if all three levels of validation are attained. Here are some of the typical questions that could be answered directly or with some extra exercise, after the latter is achieved:

- Are the applications of various pesticides threats to the environment?
- What kind of agricultural application modifications serve well for the sake of environment?
- What are acute risks of a storm event with a period of 100 years? Is there a risk of mass fatality for certain species in the watershed?
- Is NPS pollution a significant contamination resource in comparison to point sources? If so, what kind of infrastructure precautions should be implemented to point and/or non-point sources?

- How long could the receiving waters survive eutrophication if no action is taken right now?
- Which alternative crops could be applied in the agricultural zones for better environmental impact performance?
- What is the maximum land cover that the agricultural zones could expand as is without additional environmental infrastructure requirements?
- It takes 1 Million US Dollars to launch a pesticide control and ecological agriculture promotion program. If a financial model were attached to the watershed model, would it be possible to offset this environmental quality enhancement investment due to a probable increase in ecological tourism?

2.2.2 Rural non-point source models

As the capabilities and applicability of the models are highly important criteria in model selection, this section presents concise information on the NPS model alternatives available for applications on rural areas.

Chen (2001) divides the background of watershed and NPS modeling into three stages:

- During the mid and last 1960s, hydraulic computations and conceptual water balance algorithms on a digital platform was implemented. The classical and long-lasting models like “Stanford Watershed Model” (SWM), “the Hydraulic Engineering Center of United States (US) Army Corps of Engineers (HEC) Model 1” (HEC-1), and “Storm Water Management Model” (SWMM) laid down the theoretical and technical basis for constructing conceptual hydrological models, which became important tools for watershed management and non-point source pollution control planning.
- Together with the rapid advancement of personal computers and modeling techniques becoming more sophisticated, numerous watershed modeling systems were developed through the 1980s. “The Hydrological Simulation Program-FORTRAN” (HSPF), “Chemicals, Runoff, and Erosion from Agricultural Management Systems” (CREAMS), “Groundwater Loading Effects of Agricultural Management Systems” (GLEAMS), “Agricultural

Non-Point Source Pollution Model" (AGNPS), and "Areal Nonpoint Source Watershed Environment Response Simulation" (ANSWERS) in US, and "Système Hydrologique Européen" (SHE) and "Topmodel" in Europe could be cited as examples.

- Since the early 1990s, the third stage was signified by the increasing emphasis on the development of computer interfaces and application of GIS techniques.

Especially with the third stage of NPS models, there is a growing trend to develop modeling software with the ability to run separate modules for urban and rural sources in a synchronous manner. This gives the modelers to have an integrated basin-scale view of all fluxes with their temporal and especially spatial variations if GIS association is available. However, there is still a distinction among models regarding their capabilities under urban and rural conditions.

As with the urban models, a wide range of nonpoint models appropriate for rural areas are available and have been used for many different types of land categories. The available models also cover a large range of complexity depending on the extent to which hydrologic, sediment erosion, and chemical/biological processes are modeled in a mechanistic manner or based on empirical procedures. Similar to urban modeling, many of the same simple procedures and assumptions used in the loading functions are also incorporated into a number of simulation models, e.g., USLE, SCS Curve Number, constant pollutant concentration. The following sections provide brief summaries of a number of the more widely used and "operational" non-urban models, along with a brief discussion of their relative strengths and weaknesses (Donigian and Huber, 1991).

2.2.2.1 HSPF

HSPF is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF incorporates the watershed scale Agricultural Runoff Management (ARM) and NPS models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is the only comprehensive model for watershed hydrology and water quality, which allows the integrated simulation of land and soil contaminant runoff processes with instream hydraulic, water temperature, sediment transport, nutrient, and sediment-chemical interactions. The runoff quality capabilities include both simple relationships (i.e. empirical buildup/washoff, constant concentrations) and detailed soil process options (i.e., leaching, sorption, soil attenuation and soil nutrient transformations).

The result of this simulation is a time-history of the runoff flow rate, sediment load, nutrient, pesticide, and/or user-specified pollutant concentrations, along with a time-history of water quantity and quality at any point in a watershed. HSPF simulates three sediment types (sand, silt, and clay) in addition to a single organic chemical and transformation products of that chemical. The instream nutrient processes include DO, BOD, nitrogen and phosphorus reactions, pH, phytoplankton, zooplankton, and benthic algae.

The organic chemical transfer and reaction processes included are hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption. Sorption is modeled as a first order kinetic process, in which the user must specify a desorption rate and an equilibrium partition coefficient for each of the three solid types. Resuspension and settling of silts and clays (cohesive solids) are defined in terms of shear stress at the sediment-water interface. For sands, the capacity of the system to transport sand at a particular flow is calculated and resuspension or settling is defined by the difference between the sand in suspension and the capacity. Calibration of the model requires data for each of the three solids types. Benthic exchange is modeled as sorption/desorption and desorption/scour with surficial benthic sediments. Underlying sediment and pore water, are not modeled.

2.2.2.2 CREAMS

CREAMS was developed by the US Department of Agriculture, Agricultural Research Service (Knisel, 1980; Leonard and Ferreira, 1984) for the analysis of agricultural best management practices (BMP) for pollution control. CREAMS is a field scale model that uses separate hydrology, erosion, and chemistry submodels connected together by pass files.

Runoff volume, peak flow, infiltration, evapotranspiration, soil water content, and percolation are computed on a daily basis. If detailed precipitation data are available then infiltration is calculated at histogram breakpoints. Daily erosion and sediment yield, including particle size distribution, are estimated at the edge of the field. Plant nutrients and pesticides are simulated and storm load and average concentrations of sediment-associated and dissolved chemicals are determined in the runoff, sediment, and percolation through the root zone (Leonard and Knisel, 1984).

User defined management activities can be simulated by CREAMS. These activities include aerial spraying (foliar or soil directed) or soil incorporation of pesticides, animal waste management, and agricultural BMPs (minimum tillage, terracing, etc.).

Calibration is not specifically required for CREAMS simulation, but is usually desirable. The model provides accurate representation of the various soil processes. Most of the CREAMS parameter values are physically measurable. The model has the capability of simulating 20 pesticides at one time.

2.2.2.3 GLEAMS

GLEAMS was developed by the US Department of Agriculture, Agriculture Research Service (Leonard *et al.*, 1987) to utilize the management oriented physically based CREAMS model (Knisel, 1980) and incorporate a component for vertical flux of pesticides. GLEAMS is the vadose zone component of the CREAMS model.

GLEAMS consists of three major components namely hydrology, erosion/sediment yield, and pesticides. Precipitation is partitioned between surface runoff and infiltration and water balance computations are done on a daily basis. Surface runoff is estimated using the SCS Curve Number Method as modified by Williams and Nicks in 1982, (Donigian and Huber, 1991). The soil is divided into various layers, with a minimum of 3 and a maximum of 12 layers of variable thickness are used for water and pesticide routing (Knisel et al., 1989).

2.2.2.4 ANSWERS

ANSWERS was developed at the Agricultural Engineering Department of Purdue University (Beasley and Huggins, 1981). It is an event based, distributed parameter model capable of predicting the hydrologic and erosion response of agricultural watersheds. Application of ANSWERS requires that the watershed to be subdivided into a grid of square elements. Each element must be small enough so that all important parameter values within its boundaries are uniform. For a practical application, element sizes range from one to four hectares. Within each element, the model simulates the processes of interception, infiltration, surface storage, surface flow, subsurface drainage, and drainage, detachment, transport, and deposition of sediments. The output from one element then becomes a source of input to an adjacent element.

As the model is based on a modular program structure, it allows easier modification of existing program code and/or addition of user supplied algorithms. Model parameter values are allowed to vary between elements; thus, any degree of spatial variability within the watershed is easily represented.

Nutrients (nitrogen and phosphorus) are simulated using correlation relationships between chemical concentrations, sediment yield and runoff volume. A research version (Amin-Sichani, 1982) of the model uses “clay enrichment” information and a very descriptive phosphorus fate model to predict total, particulate, and soluble phosphorus yields.

2.2.2.5 AGNPS

AGNPS was developed by the US Department of Agriculture - Agriculture Research Service (Young *et al.*, 1986) to obtain uniform and accurate estimates of runoff quality with primary emphasis on nutrients and sediments and to compare the effects of various pollution control practices that could be incorporated into the management of watersheds.

The AGNPS model simulates sediments and nutrients from agricultural watersheds for a single storm event or for continuous simulation. Watersheds examined by AGNPS must be divided into square working areas called cells. Cell grouping results in the formation of subwatersheds, which can be individually examined. The output from the model can be used to compare the watershed examined against other watersheds to point sources of water quality problems, and to investigate possible solutions to these problems.

AGNPS is also capable of handling point source inputs from feedlots, WWTP discharges, and stream bank and gully erosion (user specified). In the model, pollutants are routed from the top of the watershed to the outlet in a series of steps so that flow and water quality at any point in the watershed may be examined. The Modified ‘Universal Soil Loss Equation’ (USLE) is used for predicting soil erosion, and a unit hydrograph approach used for the flow in the watershed. Erosion is predicted in five different particle sizes namely sand, silt, clay, small aggregates, and large aggregates.

The pollutant transport portion is subdivided into one part handling soluble pollutants and another part handling sediment attached pollutants. The methods used to predict nitrogen and phosphorus yields from the watershed and individual cells were developed by Frere *et al.* (1980) and are also used in CREAMS (Knisel, 1980). The nitrogen and phosphorus calculations are performed using relationships between chemical concentration, sediment yield and runoff volume.

Data needed for the model can be classified into two categories: watershed data and cell data. Watershed data includes information applying to the entire watershed which would include watershed size, number of cells in the watershed, and if running for a single storm event then the storm intensity. The cell data includes information on the parameters based on the land practices in the cell.

Additional model components that are under development are unsaturated/saturated zone routines, economic analysis, and linkage to GIS.

2.2.2.6 PRZM

Pesticide Root Zone Model (PRZM) was developed at the USEPA Environmental Research Laboratory in Athens, Georgia by Carsel *et al.* (1984). It is a one-dimensional, dynamic, compartmental model that can be used to simulate chemical movement in unsaturated zone within and immediately below the plant root zone. The model is divided into two major components namely, the hydrology (and hydraulics) and chemical transport. The hydrology component, which calculates runoff and erosion, is based upon the SCS curve number procedure and the USLE respectively. Evapotranspiration (ET) is estimated directly from pan evaporation or by an empirical formula if pan evaporation data is not available. Soil-water capacity terms including field capacity, wilting point, and saturation water content are used for simulating water movement within the unsaturated zone. Irrigation application is also within model capabilities.

Pesticide applications on soil or on the plant foliage are considered in the chemical transport simulation. Dissolved, adsorbed, and vapor-phase concentrations in the soil are estimated by simultaneously considering the processes of pesticide uptake by plants, surface runoff, erosion, decay, volatilization, foliar washoff, advection, dispersion, and retardation. The user has two options to solve the transport equations using the original backward difference implicit scheme or the method of characteristics (Dean *et al.*, 1989). As the model is dynamic, it allows considerations of pulse loads.

PRZM is an integral part of an unsaturated/saturated zone model called “Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations” (RUSTIC) (Dean *et al.*, 1989). RUSTIC links three subordinate models in order to predict pesticide fate and transport through the crop root zone, and saturated zone to drinking water wells through PRZM, VADOFT, and SAFTMOD.

VADOFT is a one-dimensional finite element model that solves Richard’s equation for water flow in the unsaturated zone. VADOFT can also simulate the fate and transport of two parent and two daughter products. SAFTMOD is a two-dimensional finite element model, which simulates flow and transports in the saturated zone in either an X-Y or X-Z configuration. The three codes PRZM, VADOFT, and SAFTMOD are linked together through an execution supervisor, which allows users to build models for site-specific situation. In order to perform exposure assessments, the code is equipped with a Monte Carlo pre and post processor (Dean *et al.*, 1989).

2.2.2.7 SWRRB

“Simulator for Water Resources in Rural Basins” (SWRRB) was developed by Williams *et al.* (1985) and Arnold *et al.* (1989) for evaluating basin-scale water quality. SWRRB operates on a daily time step and simulates weather, hydrology, crop growth, and sedimentation together with nitrogen, phosphorous, and pesticide movement. The model was developed by modifying the CREAMS (Knisel, 1980) daily rainfall hydrology model for application to large, complex, rural basins.

Surface runoff is calculated using the SCS Curve Number technique. Sediment yield is computed for each basin by using the Modified USLE (Williams and Berndt, 1977). The channel and floodplain sediment routing model is composed of two components operating simultaneously (deposition and degradation). Degradation is based on Bagnold’s stream power concept and deposition is based on the fall velocity of the sediment particles (Arnold *et al.*, 1989).

Return flow is calculated as a function of soil water content and travel time of the return flow. The percolation component uses a storage routing model combined with a crack flow model to predict the flow through the root zone. The crop growth model (Arnold *et al.*, 1989) computes total biomass each day during the growing season as a function of solar radiation and leaf area index.

The pollutant transport portion is subdivided into one part handling soluble pollutants and another part handling sediment attached pollutants. The methods used to predict nitrogen and phosphorus yields from the rural basins are adopted from CREAMS (Knisel, 1980). The nitrogen and phosphorus calculations are performed using relationships between chemical concentration, sediment yield and runoff volume. The nutrient capabilities are still undergoing testing and validation at this time.

The pesticide component is directly taken from Holst and Kutney (1989) and is a modification of the CREAMS (Smith and Williams, 1980) pesticide model. The amount of pesticide reaching the ground or plants is based on a pesticide application efficiency factor. Empirical equations are used for calculating pesticide washoff, which are based on threshold rainfall amount. Pesticide decay from the plants and the soil are predicted using exponential functions based on the decay constant for pesticide in the soil, and half-life of pesticide on foliar residue.

The Pesticide Runoff Simulator (PRS) was developed for the USEPA Office of Pesticide and Toxic Substances by Computer Sciences Corporation in 1980 to simulate pesticide runoff and adsorption into the soil on small agricultural watersheds. PRS is based on SWRRB. Thus, the PRS hydrology and sediment simulation is based on the USDA CREAMS model, and the SCS curve number technique is used to predict surface runoff. Sediment yield is simulated using a modified version of the USLE and a sediment routing model.

The pesticide component of PRS is a modified version of the CREAMS pesticide model. Pesticide application (foliar and soil applied) can be removed by atmospheric loss, wash off by rainfall, and leaching into the soil. Pesticide yield is divided into a soluble fraction and an adsorbed phase based on an enrichment ratio.

The model includes a built in weather generator based on temperature, solar radiation, and precipitation statistics. Calibration is not specifically required, but is usually desirable.

2.2.2.8 UTM-TOX

Unified Transport Model for Toxic Materials (UTM-TOX) was developed by Oak Ridge National Laboratory for the U.S. EPA Office of Pesticides and Toxic Substances, Washington, D.C. (Patterson ***et al.***, 1983). UTM-TOX is a multimedia model that combines hydrologic, atmospheric, and sediment transport in one computer code. The model calculates rates of flux of a chemical from release to the atmosphere, through deposition on a watershed, infiltration, and runoff from the soil, to flow in a stream channel and associated sediment transport. From these calculations mass balances can be established, chemical budgets made, and concentrations in the environment estimated. The atmospheric transport model (ATM) portion of UTM-TOX is a Gaussian plume model that calculates dispersion of pollutants emitted from point (stack), area, or line sources. ATM operates on a monthly time step, which is longer than the hydrologic portion of the model and results in the use of an average chemical deposition falling on the watershed.

The Terrestrial Ecology and Hydrology Model (TEHM) describes soil-plant water fluxes, interception, infiltration, and storm and groundwater flow. The hydrologic portion of the model is from the Wisconsin Hydrologic Transport Model (WHTM), which is a modified version of the SWM. WHTM includes all of the hydrologic processes of the SWM and also simulates soluble chemical movement, litter and vegetation interception of the chemical, erosion of sorbed chemical, chemical degradation in soil and litter, and sorption in top layers of the soil. Stream transport includes transfer between three sediment components (suspended, bed, and resident bed).

2.2.3 Frontier and future of NPS modeling

There is an increasing demand to integrate all of the modeling efforts within a single framework, wherein spatial and temporal data could be input, processed, analyzed and presented on and via a GIS interface. This approach dictates to incorporate universal conventions within the urban and non-urban NPS models, as well as other component models to enable dynamic transfer of input data and processed output information. Hence, it would be reasonable to suppose a decline in the attractiveness of standalone models and reversely to envision an increase in development of modeling frameworks, which would enable integrated and synchronized use of numerous models with full GIS and database compatibility. Parallel to this trend, the following two sections will provide information on the most promising breakthrough in the watershed management and modeling cited in the last 10 years and its prospective expansions.

2.2.3.1 BASINS

In 1994, Tetra Tech began efforts on the development of USEPA's "Better Assessment Science Integrating Point and Nonpoint Sources" (BASINS) modeling system (Lahlou *et al.*, 1998). The BASINS system combines environmental databases, models, assessment tools, pre- and post-processing utilities, and report generating software to provide the range of tools needed for performing watershed and water quality analyses. HSPF was incorporated into BASINS as the core watershed model. A graphical representation of the current BASINS components (Version 3.0) and their operating platform is provided in Figure 2.1 (Donigian and Imhoff, 2002).

The BASINS physiographic data, monitoring data, and associated assessment tools, are integrated in a customized GIS environment. The GIS used is ARCView 3.2 developed by Environmental Systems Research Institute, Inc. The simulation models are integrated into this GIS environment through a dynamic link in which the data required to build the input files are generated in the ARCView environment and then passed directly to the models. The models themselves run in either a Windows or a DOS environment. The results of the simulation models can also be displayed visually and can be used to perform further analysis and interpretation (Donigian and Imhoff, 2002).

Supporting the conclusions of Gönenç and Wolflin (2005) emphasizing the need of collaboration among multidisciplinary parties for integrated assessment and management of watersheds, similar collectivity is experienced on HSPF/BASINS between USEPA and the USGS since 1998, for cooperation and integration of watershed modeling and model support activities (Donigian and Imhoff, 2002).

2.2.3.2 Prospective advancements

As for many other scientific researches, advancements in NPS and comprehensive watershed modeling would not be driven only by a technical achievements, but also by persistent governmental concerns for nonpoint source issues and problems accompanied by legislative endorsement and enforcement on related parties. So far, the comprehensive nature of HSPF, and its flexibility in allowing consideration of the combined impacts of both point and nonpoint source pollutants at the watershed scale, has led to unprecedented interest in model applications (Donigian and Imhoff, 2002). As the decision-maker interest is a prerequisite, on the other hand, improvements in process algorithms, enhanced and broadened capabilities to interact with a wide variety of environmental data, and more powerful user interaction will all be required for BASINS and other possible similar frameworks to appeal sustainable endorsements. Hence as an example to these improvements, Donigian and Imhoff (2002) reported some of such prospective advancements within BASINS:

- <u>Important environmental state variables and processes:</u> In order to provide the basis for multi-stressor analysis of whole-ecosystem effects, many chemical and biological state variables and processes must be represented. While the majority of these state variables are already considered in the model, HSPF might be enhanced to include the following additional state variables:
    - Selected additional biological variables (herbivorous fish, predatory fish))
    - Selected habitat variables (% pools and riffles, streambank vegetation and shading, substrate character, turbidity)
    - Selected ecosystem variables (elemental dynamics, energy dynamics, trophic dynamics, biodiversity, critical species (presence/abundance), genetic diversity, dispersal and migration, natural disturbance, ecosystem development)
- <u>Man-made effects on environmental state variables and processes:</u> In addition to representing natural processes, modeling systems such as HSPF must provide process algorithms that represent the effects of man-induced sources or processes on environmental state variables. Models must include algorithms that can be used to represent any environmental disturbance that could influence the behavior of the natural watershed system. Examples of such phenomena include nutrient and pesticide application, tillage practices, crop harvest and residue practices, tile drainage, livestock grazing, feedlot runoff, highway drainage, urban development, stormwater detention structures, stream channelization,

combined sewers, construction practices, mine drainage, silvicultural practices, municipal and industrial discharges, etc. Many of these effects can be represented by adjusting values for parameters contained in existing HSPF algorithms; others may require development of enhanced algorithms. This may be the most critical area of model development activity as it directly affects the ability to use models like HSPF for environmental management and decision-making.

- <u>Process algorithms that utilize available data:</u> HSPF was developed before the proliferation of a new generation of data and data generation techniques that offer refined spatial detail for a number of parameters critical to watershed modeling. In some cases, these new data are best used to support existing process algorithms that are solved for a higher resolution grid. However, the potential also exists to replace or enhance certain process algorithms to improve the simulation of natural processes by taking advantage of new data. For example, satellite data, GIS and digital elevation models (DEMs) made it possible to compute the aspect (i.e., the direction toward which a slope faces) for watersheds or watershed segments at a high level of detail. The availability of techniques to reliably compute aspect invites the incorporation of improved process algorithms for snowmelt, soil temperature, and water temperature in areas of significant topographical relief. The remote sensing data available from current and future satellites offer an opportunity to develop new process algorithms that could offer improved representation of precipitation, surface runoff, soil moisture, groundwater, and water quality variables including thermal pollution, erosion, sediment load, and trophic state of receiving waters. An immediate need of watershed-scale models is algorithms using radar-imaging data to represent thunderstorms.

- <u>Future modeling research areas:</u> Below are a few of the areas that deserve attention in future model research and development:
    - Wetlands: The beneficial effects of wetlands on flood retention, sediment filtration, and nutrient and toxics processing are well known, but not adequately understood. Despite some attempts on HSPF Version 12 to approximate the impacts of wetlands, these were found inadequate due to lack of resources and alternative models. Coordinated data collection and modeling research efforts (i.e. algorithm development) are needed to

improve our ability to represent the complex water quality impacts of wetlands on the watershed system.

- Fish: Fish share all zooplankton processes including growth, respiration, death, and predation; additional important processes for fish include exposure to environmental stresses such as high temperatures, low dissolved oxygen, toxic chemicals, and sedimentation. Models of various fish species exist, but few are appropriate for inclusion within a comprehensive watershed modeling framework.
- Habitat Suitability: As a group, habitat state variables (e.g., velocity, channel gradient, flow, depth, % pools and riffles, stream bank vegetation and shading, substrate character, turbidity, salinity, pH, temperature, dissolved oxygen) characterize the physical or chemical setting in which biotic communities live. The physical state variables are tied to considerations of topographical relief, runoff, erosion, sedimentation, channel characteristics, and thermal inputs. Largely, the habitat state variables that characterize the chemical setting need to be modeled irrespective of whether modeling goals include habitat analysis. A watershed modeling system, like HSPF, is ideally suited to include assessment of habitat variables.
- Ecosystem Modeling: The goal of ecological modeling is to determine self-sustainability. To do this, modeling may focus on system elements or components (i.e., species), system structure/organization, system function (based on physical, chemical, and/or biological principles), system dynamics (material and energy transport), or the integration of one or more of these system characteristics, habitat features, and biotic communities. Relative to the other categories described above, habitat and ecological modeling are in their infancies; consequently, it is not possible to identify the important processes in a rigid manner. However, the need exists to integrate these areas into the watershed modeling arena to allow consideration of the full extent of human impacts on the watershed system and its component ecosystems.

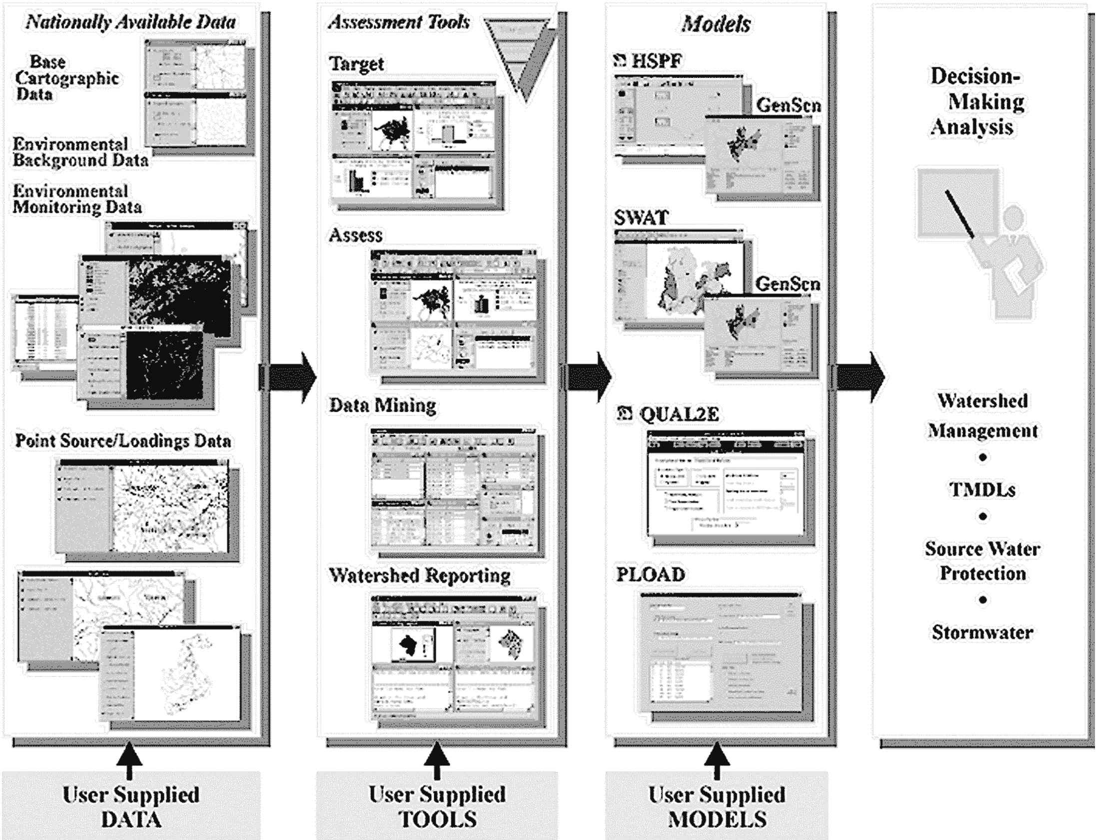


Figure 2.1 BASINS 3.0 Modeling System Overview

2.3 HSPF Modeling Techniques

This section provides information on hydrological and quality modeling structure and techniques of the HSPF model, which was selected for the case study application among a set of available rural models.

2.3.1 Hydrological model

HSPF segments pervious and impervious areas and allows different "modules" (PERLND and IMPLND modules respectively) for their computation. The following two sections will examine the hydrological models for HSPF impervious and pervious land segments. However, it should be born in mind that this study is focused on rural area applications of NPS models, which predominantly are characterized by pervious soil structure.

2.3.1.1 Impervious land segments

The “Impervious Land Segments” (ILS) in HSPF do not comprise infiltration processes, i.e., the overland flow of water and sediments is substantially higher than what would have generated over a “Pervious Land Segment” (PLS). Reversely, an ILS accounts for no subsurface flows and thus should be utilized only for widely paved urban land segments where infiltration would be negligible. As horizontal velocity of overland flow is much greater than subsurface flows, time elapsing to transfer unit amounts of water and sediment is much shorter over an ILS compared to a PLS. Thus on general terms, ILS necessitates a lower level of complexity regarding the mechanisms it undergoes. Figure 2.2 presents execution structure of the IWATER, the hydrological subroutine under IMPLND Module of HSPF, which simulates the retention, routing, and evaporation of water from an ILS (Bicknell *et al.*, 2001).

Moisture (SUPY) is supplied by precipitation, or under snow conditions, it is supplied by the rain falling on areas with no snowpack plus the water yielded by the snowpack. This moisture is available for retention computed by the RETN subroutine. Lateral surface inflow (SURLI) may also be retained as an option to the user by the flag RTLIFG. Unless this option is used, retention inflow (RETI) equals SUPY. Moisture exceeding the retention capacity overflows the storage and is available for runoff. HSPF allows for a monthly variable retention capacity, which can be used to designate any retention of moisture that does not reach the overland flow plane, e.g. roof top catchments, asphalt wetting, urban vegetation, improper drainage, etc. Water held in retention storage is removed by evaporation (IMPEV). While evaporation is determined via subroutine EVRETN, potential evaporation is an input time series. Retention outflow (RETO) is combined with any lateral inflow when flag RTLIFG is zero, producing the total inflow to the detention storage (SURI). Water remaining in the detention storage plus any inflow is considered the moisture supply. Thereby the moisture supply is available to route from the land surface in subroutine IROUTE which is identical to pervious runoff routing subroutine PROUTE.

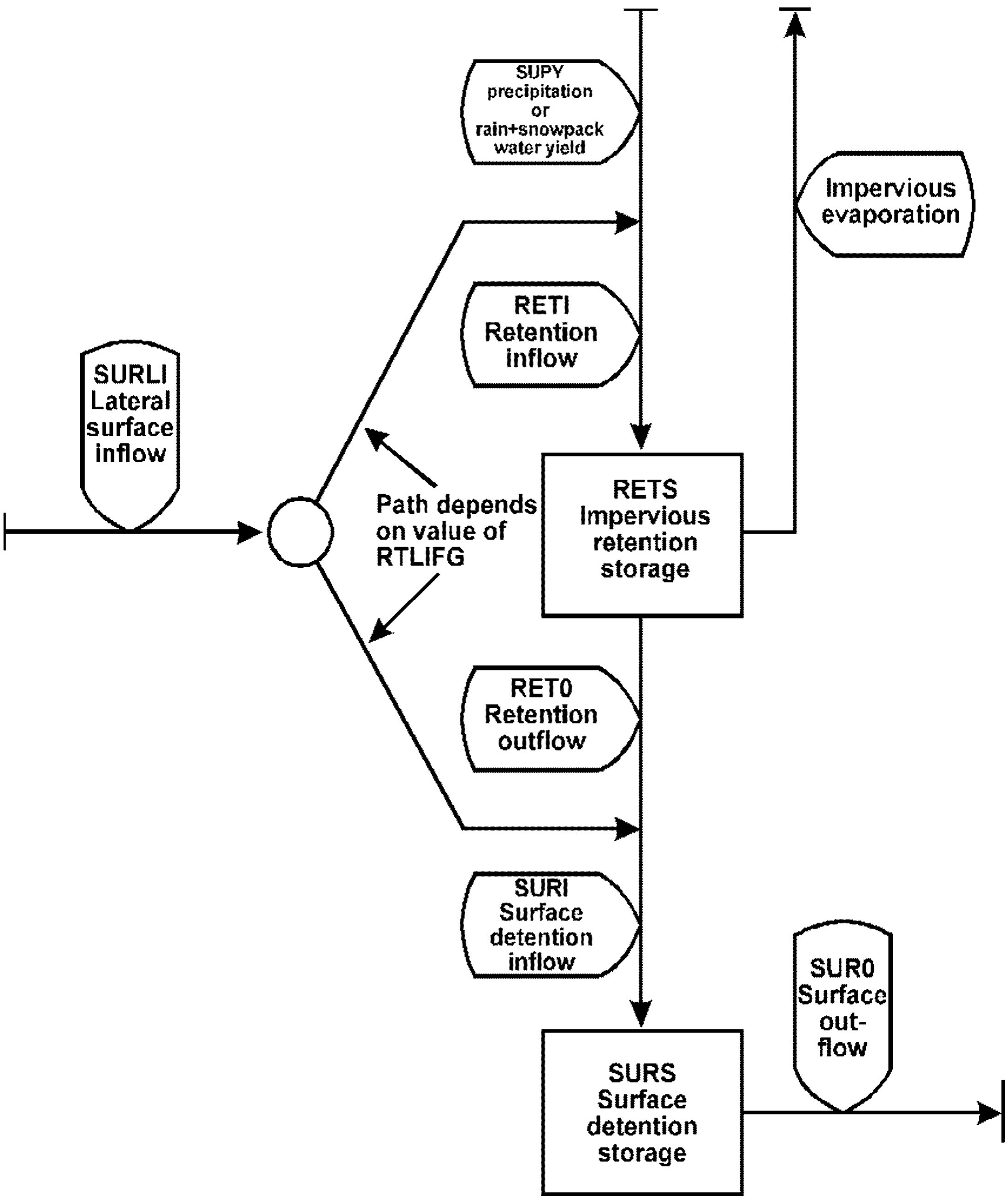


Figure 2.2 Hydrological Processes of HSPF on an ILS

The purpose of subroutine PROUTE is to determine how much potential surface detention runs off in one simulation interval. Overland flow is treated as a turbulent flow process and is simulated using the Chezy-Manning equation along with an empirical expression, which relates outflow depth to detention storage (Bicknell *et al.*, 2001).

The rate of overland flow discharge is determined by conditional Equation 2.1:

$$SURO = \begin{cases} SURSM < SURSE \Rightarrow & \dfrac{DELT60 \cdot SRC \cdot \left(SURSM \cdot \left(1.0 + 0.6 \cdot \left(\dfrac{SURSM}{SURSE} \right)^3 \right) \right)^{1.67}}{} \\ SURSM \geq SURSE \Rightarrow & DELT60 \cdot SRC \cdot \left((SURSM \cdot 1.6)^{1.67} \right) \end{cases} \tag{2.1}$$

where;

SURO = surface outflow (mm/interval),

DELT60 = DELT (time step) /60.0 (hr/interval),

SRC = routing variable,

SURSM = mean surface detention storage over the time interval (mm), and

SURSE = equilibrium surface detention storage (mm) for current supply rate.

DELT60 makes the equations applicable to a range of time steps (DELT). The first condition of Equation 2.1 represents the case where the overland flow rate is increasing and the second case where the surface is at equilibrium or receding. Equilibrium surface detention storage is calculated by:

$$SURSE = DEC \cdot SSUPR^{0.6} \tag{2.2}$$

where;

DEC = calculated routing variable and

SSUPR = rate of moisture supply to the overland flow surface.

There are two optional ways of determining SSUPR and SURSM. One option estimates SSUPR by mm/interval units through subtracting the surface storage at the start of the interval (SURS) from the potential surface detention (PSUR), which was determined in subroutine DISPOS and SURSM is estimated as the mean of SURS and PSUR. The other option estimates SSUPR by the same method except that the result is divided by DELT60 to obtain a value with units of mm/hr. SURSM, in this option, is set equal to SURS. The latter option is dimensionally consistent for any time step.

The variables DEC and SRC are calculated daily in subroutine SURFAC, but their equations will be given here since they pertain to routing (Bicknell *et al.*, 2001). They are:

$$DEC = 0.00982 \cdot \left(NSUR \cdot LSUR \cdot \sqrt{SLSUR} \right)^{0.6} \tag{2.3}$$

$$SRC = 1020.0 \cdot \left(\frac{\sqrt{SLSUR}}{NSUR \cdot LSUR} \right) \tag{2.4}$$

where;

NSUR = Manning's n for the overland flow plane (monthly variable if desired),

LSUR = length of the overland flow plane (m), and

SLSUR = slope of the overland flow plane (m/m).

2.3.1.2 Pervious land segments

In HSPF, core hydrological subroutine deriving the water budget on pervious land segments is PWATER within the PERLND section. PWATER is used to calculate the components of the water budget, primarily to predict the total runoff from a pervious area (Bicknell *et al.*, 2001). The hydrologic processes that are modeled by PWATER, which initially originated from the LANDS subprogram of the SWM IV (Crawford and Linsley, 1966), are illustrated in Figure 2.3.

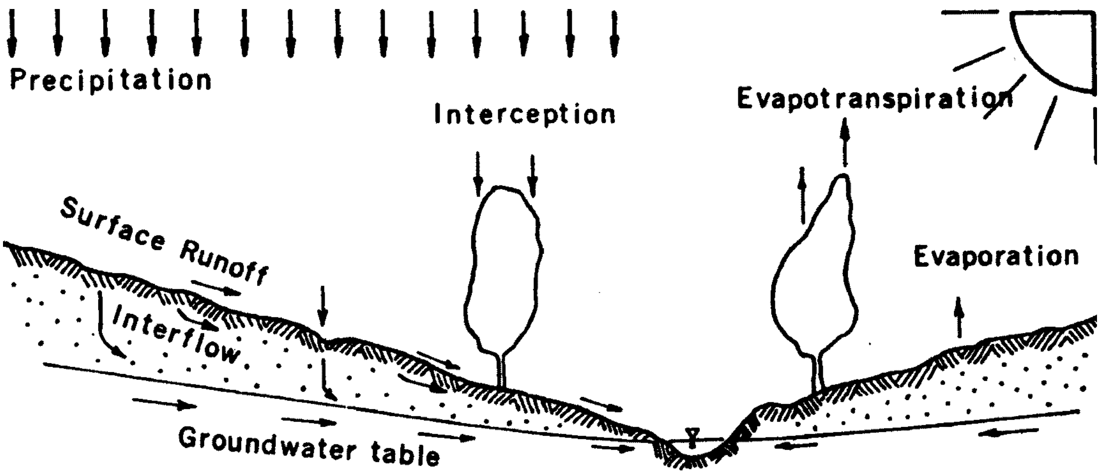


Figure 2.3 Hydrologic Processes in HSPF

The number of time series required by module section PWATER, depends on whether snow accumulation and melt are considered. When such conditions are not considered, only potential evapotranspiration and precipitation are required. However, when snow conditions are considered, air temperature, rainfall, snow cover, water yield, and ice content of the snowpack are also required. Modeling of snow conditions require the SNOW subroutine to be run. Snow accumulation and melt processes are sketched in Figure 2.4 (Bicknell *et al.*, 2001).

The evaporation data need to be adjusted when snow is considered. The input evaporation values are reduced to account for the fraction of the land segment covered by the snowpack (determined from the generated time series for snow cover), with an allowance for the fraction of area covered by coniferous forest which, it is assumed, can transpire through any snow cover. Furthermore, “potential evapotranspiration” (PET) is reduced to zero when air temperature is below the parameter PETMIN. If air temperature is below PETMAX but above PETMIN, PET will be reduced to 50% of the input value, unless the first adjustment already reduced it to less than this amount. The estimated potential evapotranspiration (PET) is used to calculate actual ET in subroutine group EVAPT. Figure 2.5 represents the process flow of PWATER section by fluxes and storages simulated (Bicknell *et al.*, 2001).

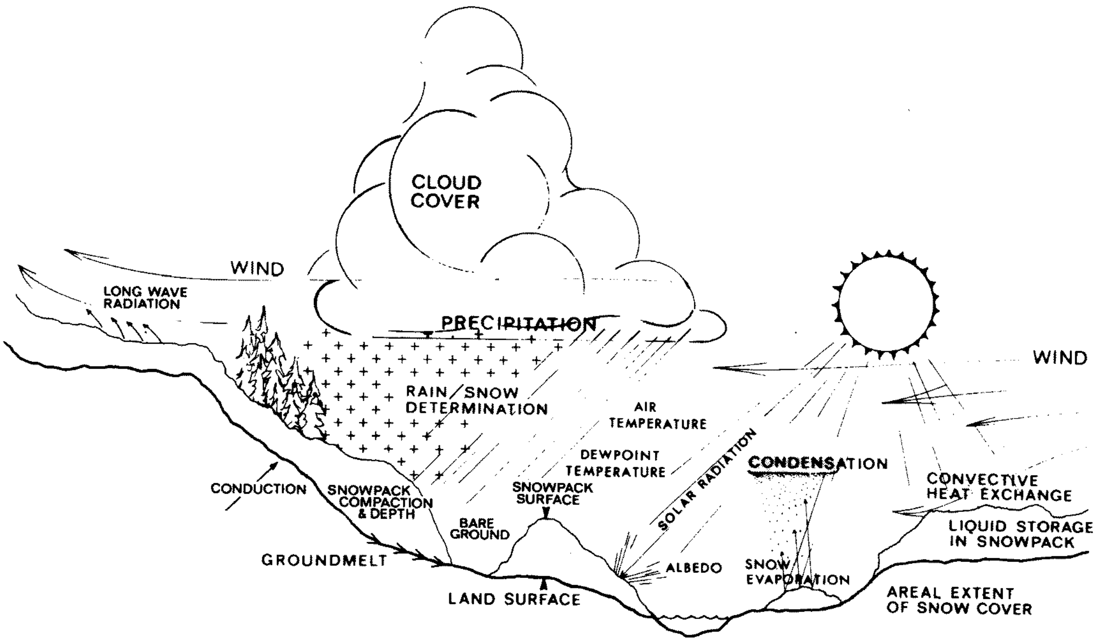


Figure 2.4 Snow Accumulation and Melt Processes

Unless snow conditions are considered, SUPY represents moisture supplied to the land segment essentially from rain; otherwise, it also comprises the additional water from the snowpack. SUPY is then available for interception, which includes water retained by any storage above the overland flow plane. For pervious areas, interception storage is mostly on vegetation. Any overflow from interception storage is added to the optionally supplied time series of surface external lateral inflow to produce the total inflow into the surface detention storage. Inflow to the surface detention storage is added to existing storage to make up the water available for infiltration and runoff. Moisture, which directly infiltrates moves to the lower zone and groundwater storages. Other water may add up to the upper zone storage, may start to flow as runoff from surface detention or interflow storage, or may stay on the overland flow plane, from which it runs off or infiltrates later (Bicknell *et al.*, 2001).

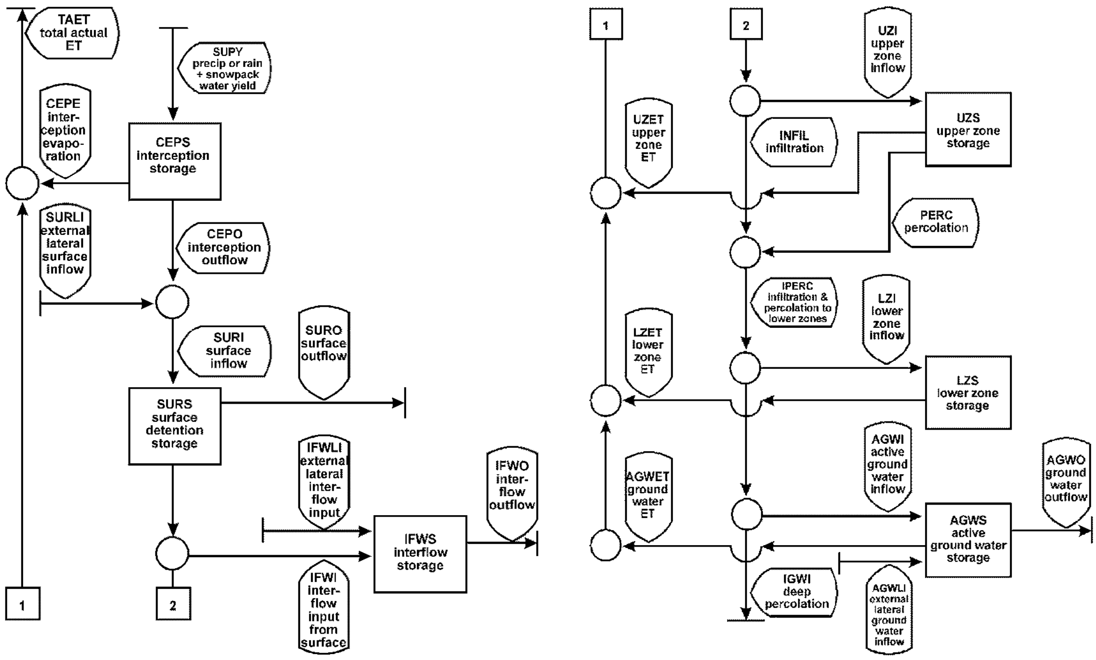


Figure 2.5 Pervious Hydrology Process Flow in HSPF

The processes of infiltration and overland flow interact and occur simultaneously in nature. Surface conditions such as heavy turf on mild slopes restrict the velocity of overland flow and reduce the total quantity of runoff by allowing more time for infiltration. Increased soil moisture due to prolonged infiltration, will gradually reduce the infiltration rate producing more overland flow. Surface detention will also modify flow. For example, high intensity rainfall is attenuated by storage and the maximum outflow rate is reduced. The water in the surface detention may also later infiltrate reoccurring as interflow, or it can be contained in upper zone storage (Johansson *et al.*, 1984).

Water infiltrating through the surface and percolating from the upper zone storage may become stored within the lower zone storage, flow to active groundwater storage, or may be lost by deep percolation. The water that reaches the lower zone is subject to evapotranspiration. Active groundwater eventually reappears as baseflow, and may be subject to evapotranspiration, but deep percolation is considered lost from the simulated system (Johansson ***et al.***, 1997).

Lateral external inflows to interflow, upper zone, lower zone, and active groundwater storages are also possible in section PWATER. One may wish to use this option if an upslope land segment is significantly different to merit separating it from a downslope land segment and no channel exists between them (Bicknell ***et al.***, 2001).

Not only are flows important in the simulation of the water budget, but also are storages. As stated, soil storage affects infiltration. The water holding capacity of the two soil storages, upper zone and lower zone, in module section PERLND is defined in terms of nominal capacities. Nominal, rather than absolute capacities, serve the purpose of smoothing any abrupt change that would occur if an absolute capacity is reached. Such capacities permit a smooth transition in hydrologic performance as the water content fluctuates. Storages also affect evapotranspiration loss. Evapotranspiration can be simulated from interception storage, upper and lower zone storages, active groundwater storage, and directly from baseflow.

Storages and flows can also be instrumental in the transformation and movement of chemicals simulated in the agrochemical module sections of HSPF. Soil moisture levels affect the adsorption and transformations of pesticides and nutrients. Soil moisture contents may vary greatly over a land segment. Therefore, a more detailed representation of the moisture contents and fluxes may be needed to simulate the transport and reaction of agricultural chemicals (Johansson ***et al.***, 1984).

Subroutine SURFAC deals with the distribution of water available on the surface of a PLS for infiltration and runoff. The algorithms, which simulate infiltration, represent both the continuous variation of infiltration rate with time as a function of soil moisture and the areal variation of infiltration over the land segment. The equations representing the dependence of infiltration on soil moisture are based on the work of Philips (1957) and are derived in detail in the previously cited reports.

The infiltration capacity, the maximum rate at which soil will accept infiltration, is a function of both the fixed and variable characteristics of the watershed. Fixed characteristics include primarily soil permeability and land slopes, while variables are soil surface conditions and soil moisture content. Fixed and variable characteristics vary spatially over the land segment. A linear probability density function is used to account for areal variation. Figure 2.6 represents the distribution function of section PWATER for infiltration/interflow/surface runoff (Bicknell *et al.*, 2001).

The infiltration distribution is focused around the two lines, which separate the moisture available to the land surface (MSUPY) into what infiltrates and what goes to interflow. A number of the variables that are used to determine the location of lines I and II (see Figure 2.6) are calculated in subroutine SURFAC through Equations 2.5-2.8.

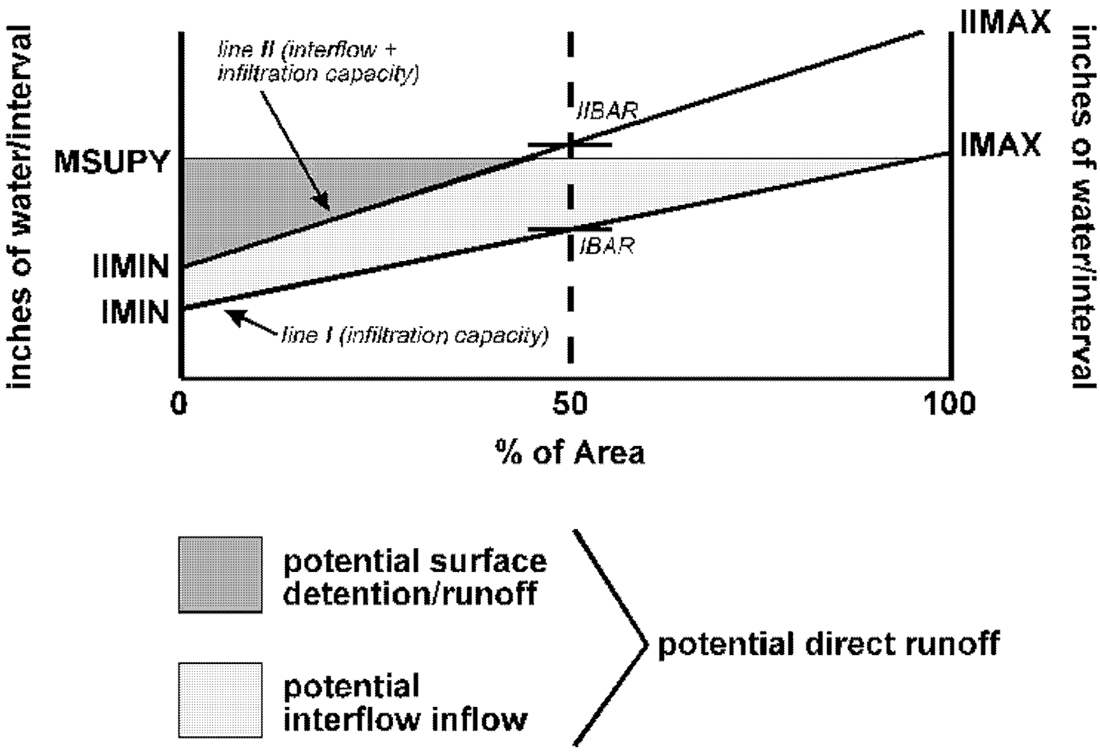


Figure 2.6 Determination of Infiltration and Interflow Inflow in HSPF

$$IBAR = \left(\frac{INFILT}{\left(\frac{LZS}{LZSN} \right)^{INFEXP}} \right) \cdot INFFAC \qquad (2.5)$$

$$IMAX = INFILD \cdot IBAR \qquad (2.6)$$

$$IMIN = IBAR - (IMAX - IBAR) \qquad (2.7)$$

$$RATIO = INTFW \cdot \left(2.0^{\left(\frac{LZS}{LZSN} \right)} \right) \tag{2.8}$$

where;

IBAR = mean infiltration capacity over the land segment (in/interval)

INFILT = infiltration parameter (in/interval)

LZS = lower zone storage (inches)

LZSN = parameter for lower zone nominal storage (inches)

INFEXP = exponent parameter greater than one

INFFAC = factor to account for frozen ground effects, if applicable

IMAX = maximum infiltration capacity (in/interval)

INFILD = parameter giving the ratio of maximum to mean infiltration capacity over the land segment

IMIN = minimum infiltration capacity (in/interval)

RATIO = ratio of the ordinates of line II to line I, and

INTFW = interflow inflow parameter.

The parameter INTFW can be input on a monthly basis to allow for variation throughout the year. The factor that reduces infiltration (and also upper zone percolation) to account for the freezing of the ground surface (INFFAC) is calculated by either from the water equivalent of ice in the snowpack if snow is considered or according to the soil temperature in the lower layer. Given the latter, if temperature is less than 0 degrees C, then INFFAC is set to a parameter called FZGL; otherwise it is set to 1.0. However, this second method can only be used if section PSTEMP, which handles vertical variation of temperature through the soil layers, is active.

The subroutine DISPOS calls a series of subordinate routines to determine the quantity of infiltration and runoff. The amount under Line I in Figure 2.6 shows infiltration. The amount over this line but under the MSUPY line (the entire shaded portion) is the potential direct runoff (PDRO), which is the combined increment to interflow, and upper zone storage plus the quantities which will stay on the surface and run off. PDRO is subdivided by Line II. The ordinates of line II are found by multiplying the ordinates of line I by RATIO (Equation 2.8). The quantity underneath both line II and the MSUPY line but above Line I, is called potential interflow inflow. This consists of actual interflow plus an increment to upper zone storage. Any amount above line II but below the MSUPY (potential surface detention/runoff) is, that portion of the moisture supply, which stays on the surface and is available for overland flow routing, plus a further increment to upper zone storage. The fractions of the potential interflow inflow and potential surface detention/runoff, which are combined to compose the upper zone inflow, are determined in subroutine UZINF.

Further information on conventional HSPF processes; inflow to upper zone (subroutine UZINF), interflow (subroutine INTFLW), upper zone behavior (subroutine UZONE), lower zone behavior (subroutine LZONE), groundwater behavior (subroutine GWATER), and evapotranspiration (subroutine EVAPT), are presented in full detail in Johansson *et al.* (1984) and Bicknell *et al.* (2001). New PLS hydrology features of HSPF brought within Version 12 such as wetland hydrology (pervious, high water table and low gradient) and irrigation, are also provided in Bicknell *et al.* (2001).

2.3.2 Quality model

HSPF PERLND is one of the most detailed, operational models of agricultural runoff quality (Donigian and Huber, 1991). The model simulates runoff and erosion from field size areas, using different methods. It also simulates land surface and soil profile chemical/biological processes (using similar methods) that determine the fate and transport of pesticides and nutrients. Figure 2.7 shows the structure of the various subroutines that comprise the HSPF PERLND module (Bicknell *et al.*, 2001). Agrichemical Modules of PERLND perform the simulation of chemical/biological soil processes. Figure 2.8 presents the conceptual structure and processes simulated for pesticides and nutrients in the ARM model, which was the basis for the HSPF Agrichemical Modules (Donigian and Huber, 1991).

HSPF PERLND was derived from the Stanford Watershed Model (SWM), which was subsequently used as the basis for the HSP, ARM, and NPS models forming the predecessor components for HSPF. This model development effort originated in the hydrologic research community with emphasis on not only runoff modeling but also on watershed scale modeling, including both runoff and hydraulic routing needed for large watersheds and river basins.

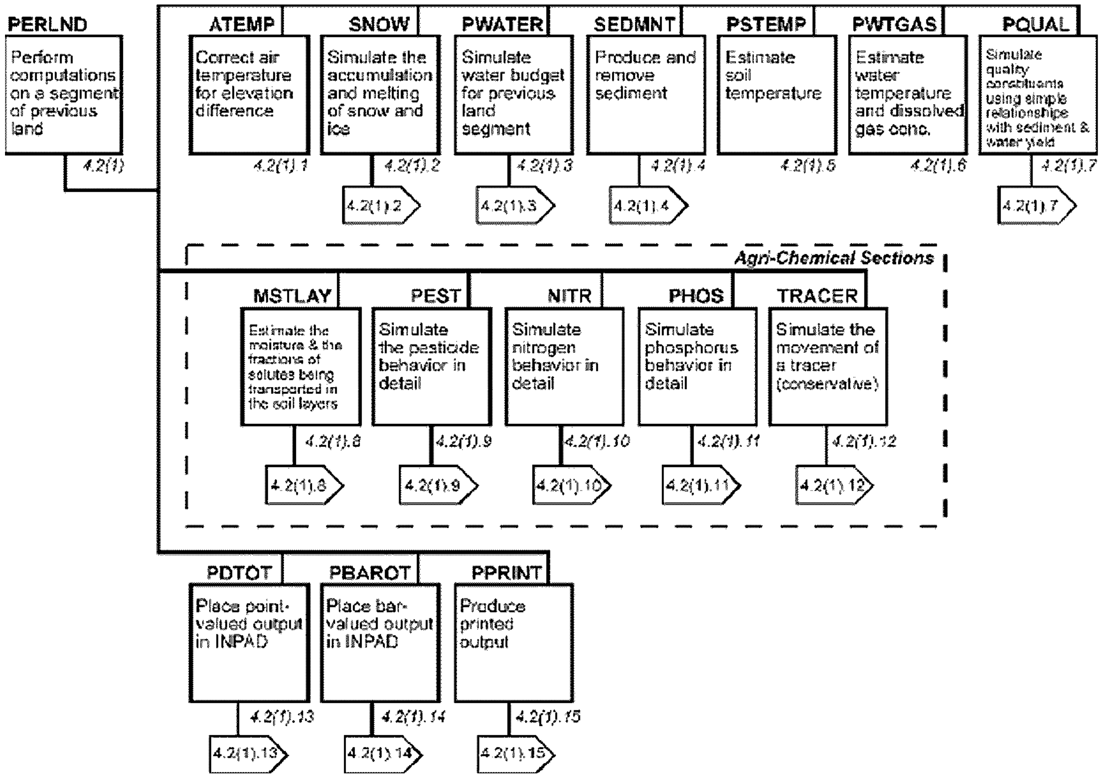


Figure 2.7 HSPF PERLND Modules

When USEPA selected SWM as the basis for modeling nonpoint pollutant runoff, their ultimate goal was to be able to evaluate the downstream water quality impacts of pesticide and nutrient runoff from agricultural lands. Consequently, HSPF considers all streamflow components; surface runoff, interflow, baseflow and their pollutant contributions (as shown in Figure 2.7), and then allows direct linkage of these contributions to an instream water quality model.

2.4 Model Support System

MSS is a series of technical and management tasks, which are essential to the model implementation and post-implementation processes. MSS acts as an assistant within the modeling project mechanism and performs the coordination, gathering and supply of all preliminary and preparatory data and services to model implementation process. The following sections describe the key inputs of the MSS into the modeling project.

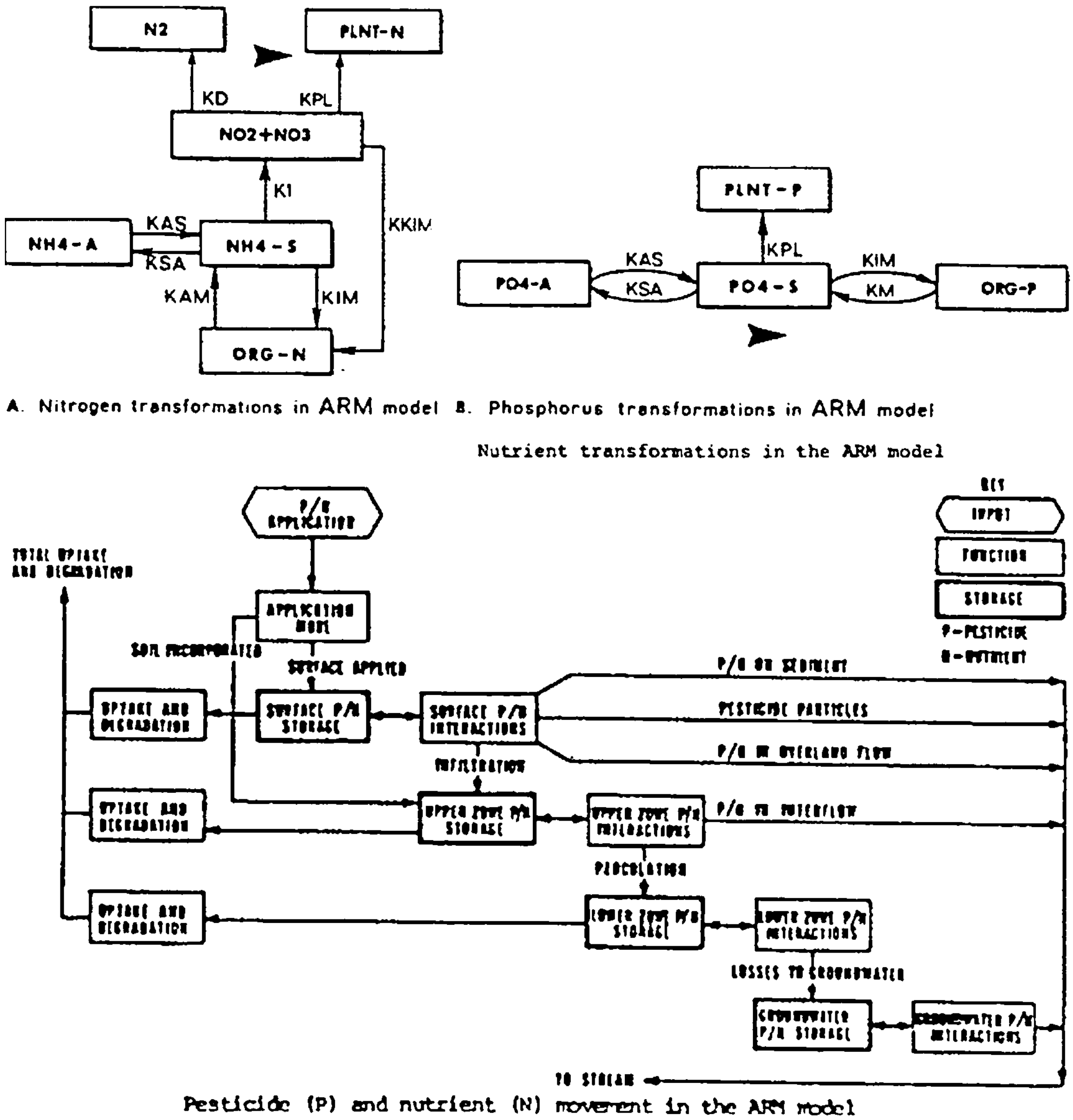


Figure 2.8 Pesticides and Nutrient Transformation and Movement in the HSPF Predecessor ARM Model

2.4.1 Modeling project management

A modeling project as a whole, aims to develop a tool for decision making process in order to provide guidance for watershed management and planning on a scientific basis. Modeling and the model support system are the two major processes, which operate in tandem throughout the modeling project management. Modeling project management is composed of a circular sequence of tasks and interim decisions. Figure 2.9 shows a diagram describing modeling project management cycle.

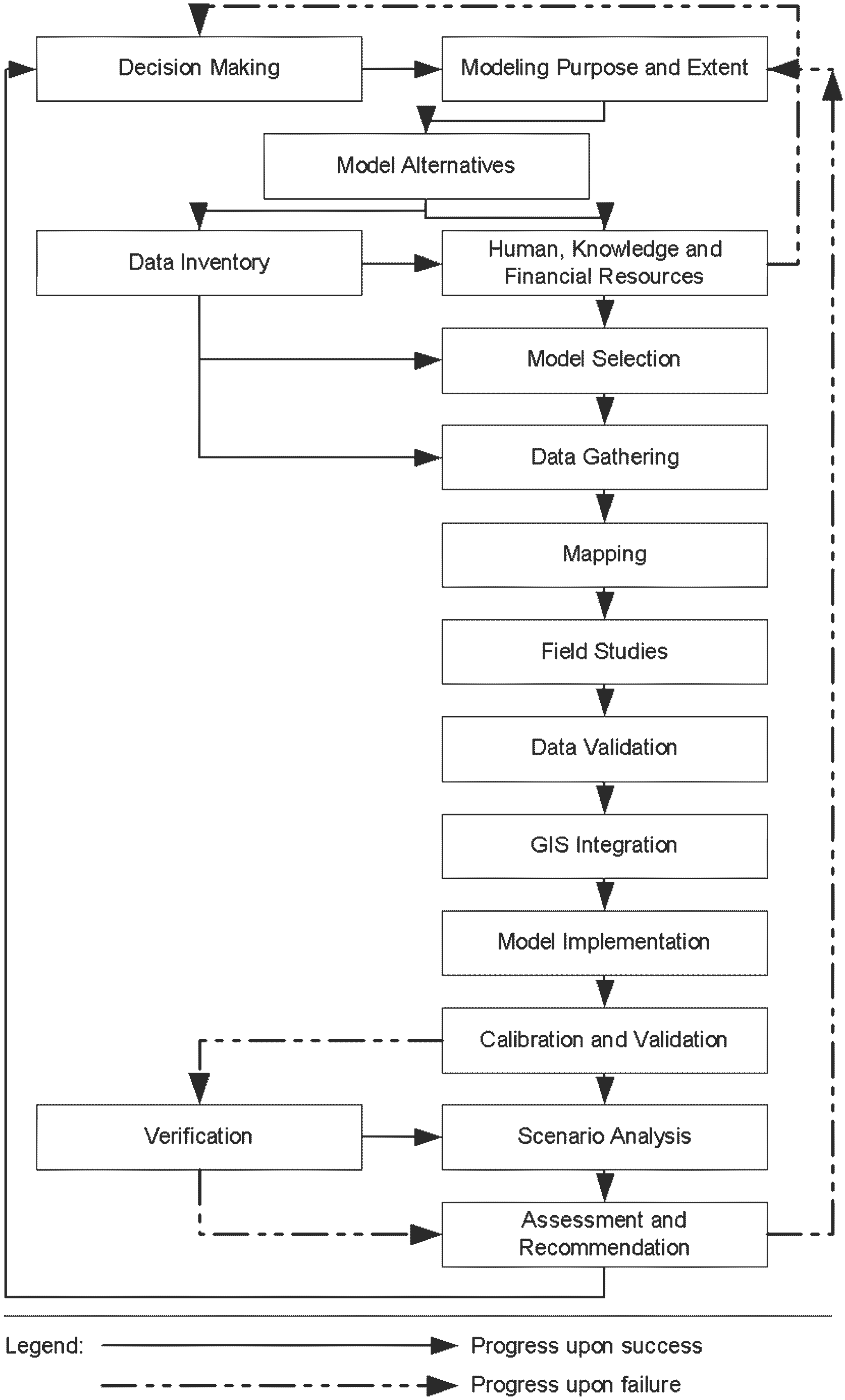


Figure 2.9 Modeling Project Management Cycle

The first decision made by decision maker is to examine the relevance and feasibility of a modeling project. Hence, parties decision makers, modeling and model support teams gather for a conceptual exercise to determine the purposes and extent of the proposed modeling study. As discussed earlier, in accordance with the given context, members of the modeling group forms a list of available model options. Modeling and model support groups identify the data and resource requirements of each option and examines the data inventory and availability of human, knowledge and financial resources for modeling and data acquirement. The results of this study bring the proposed selected model, methods, benefits and cost of the project to light. However, even though the results of the study prove that the modeling objectives could technically be achievable, financial and other factors may inhibit the decision maker and/or the modeling team to proceed. Hence, either the project targets are reconsidered for a more applicable solutions or the project is terminated with "no action" decision. On the other hand, if the decision maker and the modeling groups are convinced to overcome these obstacles the modeling project commences. All of these takes up to this point are grouped as "preliminary phase".

The preliminary phase is followed by "data processing phase" which comprises all necessary tasks required for "model implementation". Data processing phase starts with the gathering of data for the selected model, through using the existing data inventory and acquiring new data from other resources if required. Prior to the field studies thematic site maps should be gathered. The site maps are later used for GIS integration, as well. Field studies may provide data sets for calibration of the model or also validation of site-specific data gathered from less reliable, imprecise or low-resolution data resources. Finally, all gathered data is stored in a database and preferably within a GIS environment for ease of use and capability to make spatial queries. Hence, the previously discussed modeling process could be initiated.

Should modeling implementation, calibration and validation processes attain satisfactory results with regard to modeling objectives, a series of scenarios could be developed in order to materialize solid answers to the decision-making considerations. Otherwise, the causes of substandard modeling performance could be sought within the verification process. If verification works enhance the quality of simulations to an acceptable level then scenario analysis could initiate. If not, the verification process should ensue a negative comment for the success of the project, which will be proceeded by a decision to reinitiate the entire project or to abandon it. On the other hand, the verification process could also be followed for improving the sensitivity of the validated model. Provided that there exist no critical problems with the reliable functionality of the model, scenario studies would outcome valuable information for making assessments on the objectives pursued and developing recommendations as the final product of the modeling project. Yet, the ultimate task would be carried by the decision maker, which is to launch an action plan for or despite the concluded recommendations and assessments.

The modeling project management cycle is fully applicable for HSPF modeling projects and this study aims to provide a case study on this matter.

2.4.2 Data processing

Data processing is the main task of the MSS. Especially in developing countries it is generally a more challenging task to find and preprocess the relevant information rather than the modeling exercise itself. However, this process becomes a lighter burden if governmental agencies are more considerate about storing centralized data as well as organizing them with eased accessibility, through interactive and public domain data channels. One of the most developed services related to this issue is provided by USEPA, which gives totally free access for digital thematic maps and long term modeling measurement data over the Internet or via mail express in CDs if delivery costs are covered.

2.4.2.1 Data inventory

Forming the data inventory could start during the preliminary phase of the modeling project while the model alternatives are tested for presence of data they require. The checklists formed in this process could then be used as a core for the inventory. In particular, HSPF provides a rich spectrum of documentation available on the Internet for its input parameters and time series requirements. These requirements are also categorized by the modules and subroutines used in the model. In the general perspective, the data inventory should be formed according to the requirements of the selected model due to the defined modeling purposes and extent. HSPF data inventory would consist of the following:

- Digital and analog maps with appropriate scales or grids.
- Site-specific experimental data on water quality, soil analysis, etc. gathered from literature, publications of related academic institutions, or local/national administrations
- Measurement data based on long term time-series such as meteorology, stream hydraulics, hydrogeology and so on
- Purpose specific data such as agricultural applications in the region, pesticide use, nutrient loadings, previous reports or citations from earlier studies in the watershed or watersheds with similar characteristics
- Socioeconomic data regarding; demography, statistical information, surveys, questionnaires, historical information, natural and cultural assets, economy, etc.

2.4.2.2 Data gathering

Data gathering task involves investigations to locate the required data sets. The level of difficulty for this task depends on the nature of national policies or lack of policies to provide public centralized data. This difficulty could be multiplied by the sophistication of the processes targeted to model. The following issues and data sets should be investigated during the for a typical NPS models and in particular HSPF data gathering process:

- Research on data resources
- Preferably hourly resolution of meteorological time series for precipitation, evaporation, temperature, wind, solar radiation, cloudiness, humidity, snow cover, etc.
- Soil characteristics regarding available land use, soil types, physical and chemical characteristics and layer depths
- Geological and hydrogeological data, especially water depth and flow measurements or estimations
- Soil hydrology parameters such as infiltration rate, water content, wilting point, etc.

- Flow measurements from streams, irrigation use, outflows, wells, pumps, etc.
- Water quality data for the targeted quality parameters to be modeled
- Runoff and groundwater quality data for quality parameters to be modeled through soil layers
- Watershed and basin delineation

2.4.2.3 Mapping

Watershed scale modeling necessitates maximum use of geographical data. Geographical information make it possible, to plan the on-site works, to minimize field experimentation by readily made thematic maps, to make estimation and analysis on flow routes and patterns, to be able to guess soil characteristics as well as the possible location of resources. It would generally be much more efficient to handle mapping tasks with guidance or collaboration of experts from geodesy and photogrammetry discipline. Mapping tasks could be summarized as follows:

- Administrative tasks
    - Investigation of public and classified base maps
    - Authorization requests for maps of limited access
- Incorporation of gathered data with their geographical coordinates where possible
- Development of custom thematic maps with coordinated preferably digital data
- Formation of a preliminary GIS platform wherein all digital geographical data gained can be stored
- Coordinate system conversions of digital maps where necessary
- Testing, debugging and elimination of digital errors on the thematic maps

2.4.2.4 Field studies

Without a good understanding of the soil structure in a watershed, it would not be reasonable to expect reliable results from a hydrological model. The dominant characteristics and critical exceptions of the soil structure should be determined and located. The field studies for NPS modeling are put into practice for two essential purposes. The first is to gain data by field measurements and the second is to validate the readily available location based data for use with modeling. During the field studies, it might be possible to make surveys regarding agricultural applications should it be within concern. The field studies comprise all kind of experimentation and observation on soil characteristics as well hydrogeological parameters. However, the design and exercise of the monitoring program requires contribution from soil engineer experts. Besides, field experimentation for on-site infiltration rate measurements necessitate special soil engineering equipments. Other experimentation such as determination of the soil type and chemical characteristics require laboratorial work. Field study tasks are listed below:

- Administrative tasks
    - Arrangement of collaborative contribution for soil engineering expertise
    - Funding arrangement for monitoring program
- Field study system design
    - On-site investigations
    - Use of mapping and preliminary GIS facilities to locate monitoring stations
    - Planning a detailed field study schedule
    - Preparation of experimentation documents and database
- Implementation of field study
- Results and evaluation
- Compilation of data for use within the GIS database

2.4.2.5 Data validation

Data gained from field studies are then used to validate the digital map data and legends. If there might be any inconsistency between the observed conditions and recorded values, this could be due to two main reasons. The first of which is that thematic maps may not be up-to-date so there might be partial mismatches between the gained data and the as is situation. The second is that there might be individual digital entry errors on the thematic map data tables, resulting in a different misrepresentation of the actual soil patterns. Data validation tasks are listed below:

- Validation of data gathered with data gained from field studies
- Evaluation of invalidated data if any
- Repetition of field analysis if required

2.4.2.6 GIS integration

All location-based information should be standardized using a common coordinate system and be incorporated to a GIS database. This would allow access to data via spatial queries. Latest advanced GIS tools have the capability to develop areal distribution estimations based on point data. Hence, given rather stabile parameters and adequate number of equidistant sampling stations, i.e. smaller grids, it is yet much more easier to estimate areal distribution of soil parameters. This advancement could be used as a cost reduction factor for future reanalysis of soil structure. Typical GIS integration activities are below:

- Digitization of analog maps
- Scale and coordinate conversions of digital maps
- Design of a GIS database
- Data migration from distributed sources to the database
- Integration of all thematic maps and attributes to the GIS system
- Simple and cross queries at spatial level

2.4.3 Assessment and recommendations

Assessments and recommendations are developed at the end of the modeling project for the possible following purposes:

- To present an evaluation of the entire modeling project through a fully scientific and objective perspective,
- Development of recommendations towards the use of the decision maker for the watershed depending on the results of the evaluation

- To address the findings as outputs of a systematical scientific study and to avoid exerting pressure on the decision maker rather than presenting the results with conclusive remarks,
- Development of recommendations to enhance the capabilities of further modeling studies
- Analysis of successful or weak results and/or conditions in the project period

3. PRELIMINARY PHASE OF KÖYCEĞİZ-DALYAN WATERSHED CASE STUDY

Sections 3, 4 and 5 provides the full details of an attempt to implement the introduced concepts, modeling process, MSS, and modeling project management cycle, within a case study. This attempt however should not be perceived as a sound complete exercise of integrated watershed management, but should be addressed as guidance for implementation of a new systematic approach blended with the local expertise gained through the study. Hence, the outcome of this study would be this expertise for prospective researchers in Turkey to do research in this globally new arena. This guideline therefore, shall accelerate successive efforts and present a basis to intensify those studies. Nonetheless, the quantified outputs of this study should still be considered as a reliable and timesaving initial step towards a much broader evaluation of the NPS modeling in the critical rural case study area, Köyceğiz-Dalyan Watershed. Yet, this study introduces a potential to initiate NPS modeling as a tool for implementing the holistic environmental management approach for other watersheds in Turkey.

From Section 3 to Section 5, the modeling project management cycle will be implemented systematically, for the Köyceğiz-Dalyan Rural Watershed Case Study, using the NPS model, HSPF, as a tool for use of decision support system towards sustainable management of the watershed. The modeling project management cycle as defined in Section 2 consists of three consequent groups of tasks, namely, preliminary, data processing and modeling phases.

Section 3 basically deals with the description of the site, the formulation of the problem, investigation of solution tools, i.e. models, and availability of resources. The preliminary phase of the modeling project management cycle encompasses the conceptual exercise to determine the purposes and extent of the proposed modeling study, to prepare a list of technically available model options for these purposes and extent, and to assess the data and resources they would require. The results of this exercise will provide a basis for the selection of the applicable model. Hence, foremost an introduction is to be made for better understanding selected the case study area, Köyceğiz-Dalyan Watershed.

3.1 Case Study Area

The watershed of Köyceğiz-Dalyan Watershed, with an approximate surface area of 1200 km², is situated at the southwest of Turkey within the province of Muğla, where the Köyceğiz Lake joins the Dalyan Lagoon and the Lagoon joins the Mediterranean Sea. The area is also one of the sensitive and vulnerable coastal regions of the country in terms of endangered and endemic species. Caretta-caretta sea turtles, one of the rare species in the Mediterranean region, utilize the area as their nesting and breeding sites. The region is also enriched with Lycian archeological monuments lasting more than two millennia.

Noticing the ecological significance, the majority of the area was declared as a part of Köyceğiz-Dalyan Special Protection Region by the Government Decree Ref: 88/13019 dated 12th of June, 1988, which was put in force due to the issue of the Official Gazette Ref: 19863 dated 5th of July 1988. The coverage of the region was then enlarged by the Government Decree Ref: 90/77 dated 2nd of March 1990, with the issue of Official Gazette Ref: 20449 dated the same day.

The watershed hosts a population of almost 45 000 capita mainly dealing with agriculture, tourism and fishery, but there is no significant industrial activity in the region. Ortaca, Dalyan, and Köyceğiz are the major settlements and point sources of pollutants in the region. The location of the watershed in Turkey is presented in Figure 3.1, which was produced by 3D Digital Elevation Model (DEM) (Gönenç ***et al.***, 2002a).

3.2 Modeling Purpose and Extent

Studies on Turkish Legislation suggest that any particular area may be designated as a special protection region for one or more of the following reasons (Gürel, 2000):

1. It is a good sample of an important ecosystem or habitat type.
2. It is distinct by a high diversity of species.
3. It is situated on an area with intense biological activity.

4. It provides a critical habitat for a particular or a group of species.

5. It hosts special cultural values, such as historical or recreational sites.

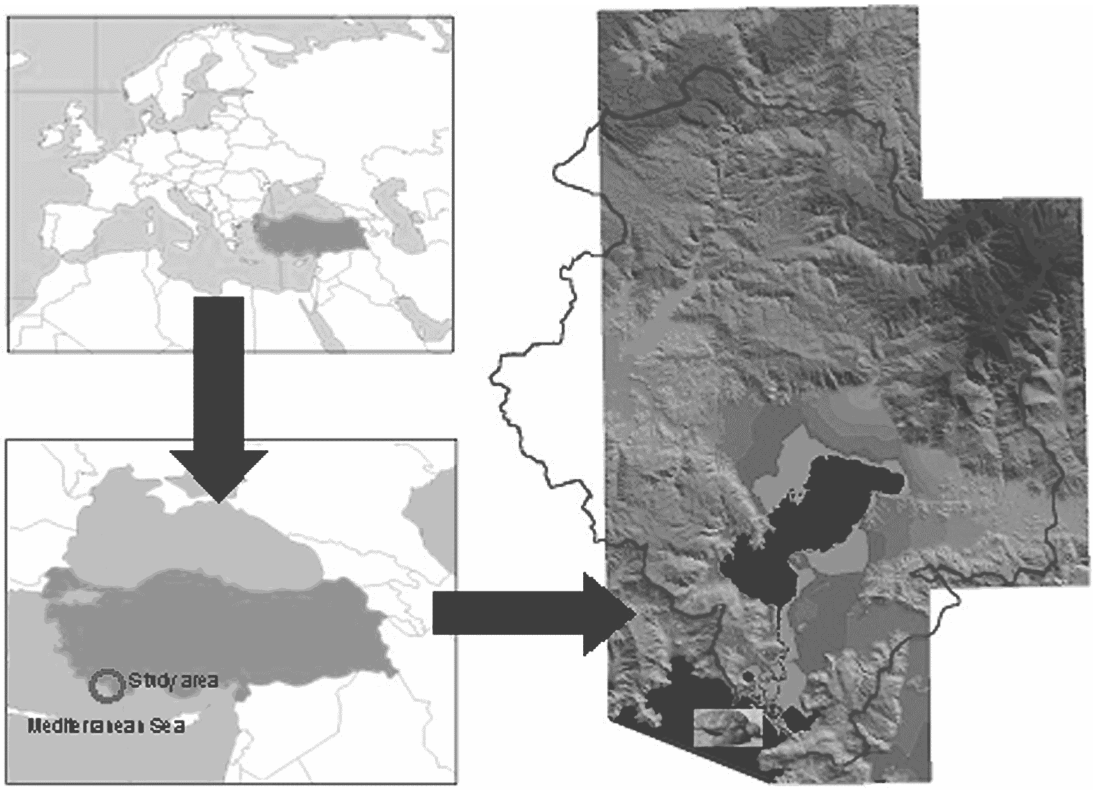


Figure 3.1 Location of the Case Study Area

Köyceğiz-Dalyan Special Protection Region complies with all of the cases mentioned above. It is a unique area with special ecological, historical and recreational characteristics. Besides the environmental and cultural importance, the lagoon system and the Köyceğiz Lake have very significant scientific value because of; the stratified saline and fresh water flows along the lagoon channels in reverse directions, the wetland habitat alongside the banks of the channels, Mediterranean saline water permanently trapped at the bottom of Köyceğiz Lake and hot mud springs in Sultaniye.

Another important factor why this area was selected as a Case Study area is that there is an ongoing implementation of an environmental protection program in the area. The protection program allows for tertiary treatment of municipal wastewaters and minimizing the pollution risks from point sources. The project also goals to protect groundwater resources which has been exploited for domestic water supply purposes as well as wastewater discharge for many years. Thus, there are efforts by the local authorities to complete the wastewater collection and water supply infrastructure systems. Hence as these entire studies target to control eutrophication risks in the lake it is yet another question raised by the decision makers whether point sources are the only threat against lake water quality or other actions should be taken to control agricultural NPS contamination.

Following this question was raised by the local authorities it was decided that a NPS modeling study should be launched to assess the potential NPS contribution into the lake system. For this purpose in order to determine the extent of the project and better understand the watershed, the case study area was evaluated in terms of functions, conflicts, concepts and purposes; as described in the Model Process discussion:

- Functions:
    - 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, where 42 different types of pesticides are regularly applied (Güvensoy, 2000).
    - There are also natural and cultural functions originating from a sensitive and vulnerable lagoon system with endemic and endangered species, as well as an attractive environment.
    - The cultural and historical reserves are another function that increases the significance and value of the area.
- Conflicts:
    - Agricultural and tourism functions conflict with fishery function due to the boat traffic along the channels where the fishery takes place and agricultural activities on the fertile wetlands 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 increase in tourism functions cause promote pollution in the

    waterbody and deteriorate the pristine regions of the environment as well as the living habitat.

    - Public awareness on environment develops with economic growth, however economic growth tends to increase pollution sources.
    - Economic functions of the watershed mainly originate from agricultural activities, which might threaten the environment with uncontrolled chemical applications.
    - High investments are due to control point source pollution from the residential land use, however efficiency of the treatment systems will be in question until a clear understanding of NPS is attained.

- Concepts:
    - At least 85% of the area is covered with forests. Scattered residential zones are spatially insignificant. Thus, the entire basin has pervious land characteristics and rural land use patterns.
    - Previous citations prove malpractice of pesticides and irrigation within agricultural activities, thus this fact puts forward a need for understanding NPS loadings.
    - Tertiary wastewater treatment plant is discharged into the Köyceğiz to minimize eutrophication risks in the lake, however this might never be possible if a significant NPS loading of nutrients exist. Thus, if such a threat does actually exist, it would be vital to amend the regulations in force to lessen the use of agricultural chemicals.
- Purpose:
    - In order to better understand the scale of NPS pollution loads a watershed-scale rural modeling study should be implemented.
    - Using a reliable model as a tool, assessments could then be made whether particular functions need to be addressed for preventive action.
    - Decision makers may use these assessments as arguments for amendment of the current watershed management plan.

Given this purpose, possible technically available mathematical models were investigated in order to form a list of options for comparison.

3.3 Model Alternatives and Selection Process

Seven NPS models available for use on rural areas were chosen as alternatives for comparison and final model selection. These models were tested for firstly on technical performance towards the needs of the project and the complexity of the watershed, secondly on the data resources, which were already present, and those that may possibly be made available. Finally, a third filter is the financial and human resources the project would require for each option.

3.3.1 Technical issues

The seven candidate NPS models were AGNPS, ANSWERS, CREAMS, HSPF, PRZM, SWRRB and UTMTOX. In addition to this seven, although mostly preferred for urban conditions, SWMM is also discussed comparatively because of its functional merits. These models as discussed briefly in the previous sections do not represent all of the options available for NPS modeling, but they are certainly the most notable, widely used and operational. Thus, selection from among these models is often based on user requirements, in addition to needed model capabilities. For models like STORM and DR3M-QUAL that are developed regarding specific projects or groups, technical support may not be available to some other independent researches. CREAMS has been used most extensively for field-scale agricultural runoff modeling because of its agricultural origins and ties to the agricultural research community. Therefore, the needs and scope of the project should clearly be addressed, and applicability of the model for those purposes should be carefully examined (Donigian and Huber, 1991).

HSPF and SWMM are probably the most versatile and most widely applicable of the models, with the nod to SWMM if the urban hydrology and hydraulics must be simulated in detail. On the other hand, the water quality routines in HSPF for sediment erosion, pollutant interaction and groundwater quality are superior, and the capability to efficiently handle all types of land uses and pollutant sources, (including urban and agriculture, point and non-point), is a definite advantage when needed for large complex basins. Both models appear somewhat overwhelming in terms of size to the novice user, but only the components of interest of either model need be used in a given study, and the catchment schematization can often be coarse for purposes of simulation of water quality at the outlet. The several quality modeling options within SWMM permit simple conceptual water quality simulation using constant concentration and rating curves as well as the more formidable buildup-washoff methods. Similarly for HSPF, the ability to use the simple SWMM-type formulations for urban and non-agricultural areas, and detailed soil/runoff process simulation for agricultural areas provides the user with great flexibility in representing the watershed system.

Continuing model development and testing within the agricultural research community will likely lead to further enhancements and development of many of the agricultural models, like CREAMS, SWRRB, and AGNPS. The SWRRB development effort appears to be focusing in on a middle ground (in terms of complexity) between HSPF and the detailed field-scale models which are limited to small areas; its use of daily rainfall, as opposed to smaller time interval measurements (usually hourly is needed for HSPF) is seen as a definite advantage by many users. However, most of these efforts still focus primarily on agricultural areas, with limited abilities to be used in large, complex multi-land use basins. A comparative summary of the attributes of above stated rural models is provided in Table 3.1.

The table reflects the clearly seen technical superiority of HSPF over other urban runoff quality models. The model supports both single storm event and continuous simulations. Rainfall/runoff analysis, erosion modeling, pesticides, nutrients, soil processes are expressed using fully detailed mechanisms. Pervious and Impervious land segments used in the model could be re-categorized according to their land uses (agricultural applications, land cover, etc.). HSPF enables to analyze the mechanisms within different subsurface zones. Overland flow, interflow, upper zone deposition, lower zone deposition, active groundwater layer and deep percolation are concepts, which provide a clear understanding of water and sediment transport in pervious land segments. Thus, vertical distribution of all of the quality constituents including pesticides is traced along a timeline of the given simulation period. Other than subsurface modeling, instream modeling could also be performed with HSPF. The model supplies the advantage of defining the characteristics of rural canal structures.

However, as the overall complexity of the model is high, especially data requirement becomes a critical issue to discuss prior to selecting this model. Even though, the need for collecting and assuming a vast amount of data is an important problem to overcome, public domain data for worldwide applications of the model, EPA databases and numerous citations eases the preliminary studies with the model. Hence, HSPF is found to be the technically most appropriate model software for the purposes of this study.

Table 3.1 Comparisons of Rural Model Attributes

Attribute[(1)]	**AGNPS**	**ANSWERS**	**CREAMS**	**HSPF**	**PRZM**	**SWRRB**	**UTMTOX**
Sponsoring Agency	USDA	Purdue	USDA	EPA	EPA	USDA	ORNL & EPA
Simulation type	C, SE	SE	C, SE	C, SE	C	C	C, SE
Rainfall/Runoff Analysis	Y	Y	Y	Y	Y	Y	Y
Erosion Modeling	Y	Y	Y	Y	Y	Y	Y
Pesticides	Y	N	Y	Y	Y	Y	N
Nutrients	Y	Y	Y	Y	N	Y	N
User-Defined Constituents	N	N	N	Y	N	N	Y
Soil Processes							
Pesticides	N	N	Y	Y	Y	Y	N
Nutrients	N	N	Y	Y	N	Y	N
Multiple Land Type	Y	Y	N	Y	N	Y	Y
Instream Water Quality	N	N	N	Y	N	N	Y
PC Availability	Y	Y	Y	Y	Y	Y	N
Data/Personnel Requirements	M	M/H	H	H	M	M	H
Overall Model Complexity	M	M	H	H	M	M/H	H

1) Y = yes, N = no, M = Moderate, H = High, C = Continuous, SE = Storm Event

3.3.2 Data resources

During the model selection of this study, only very few and analog maps were available. Yet, there were no topographical maps readily present by any means.

Thus, it was impossible to delineate the major watershed boundaries as well as the drainage basins. Therefore, one of the prior and essential needs of the study was to gain preferably digital maps as much as possible.

Also a comprehensive one-year project on water quality monitoring program for the Dalyan lagoon system were initiated by Gürel (2000). As one of the collaborators of the latter was İstanbul Technical University Environmental Engineering Department as it is to this particular study, the data produced for that study was entirely accessible. Hence, meteorological data for years 1991, 1992 and 1998 from three stations (Köyceğiz, Marmaris, and Dalaman), which are within, and neighboring the watershed, were present as a data resource gained from that study. However, these data were quite limited and for long-term analysis of the meteorological conditions a wider scope of data sets were compulsory.

Due to rich academic research potential of the region, many earlier citations on various aspects of the watershed were available. Still, none of them was related to NPS modeling and only very few regarded the hydrological issues.

As a result, the initial site-specific present data inventory was seriously limited. Thus, it became obvious that seeking and establishing collaborative research opportunities were inevitable. Otherwise, it would not have been possible to gather sufficient quantity and quality of site-specific data for any of the alternative modeling software, which would be capable of achieving the objectives of the modeling project purposes.

With regard to the model specific data, literature data for HSPF input parameters and implementation citations, such as training course materials, parameter databases, e-mailing lists and project reports, were mostly public domain and available on the Internet. Although similar opportunities for other alternative models were also present, HSPF as the seemingly leading NPS model for USEPA were rather more advantageous in terms of literature resources availability.

3.3.3 Financial, knowledge and human resources

Prior to the commencement of the project, there were no readily available financial resources. However, there were possibilities of gaining several research grants from ITU Research Fund and The Scientific and Technical Research Council of Turkey

(TUBITAK). Thus, it would be possible to finance meteorological data sets, digital maps and some experimental fieldwork through these new resources.

The project would require not only environmental engineering background but also expertise from hydrology, meteorology, GIS, and soil engineering fields. It was decided that available personnel were adequate for hydrology and meteorology inputs. Yet, the project would still require external support from geodesy and photogrammetry and soil engineering parties. Fortunately, there was a possible chance to assign the GIS personnel through a collaborative study with ITU Geodesy and Photogrammetry Department. On the other hand, it would be also be possible to provide collaborative assistance from several related governmental institutions as consultants to the ITU Environmental Engineering Department, financed through the expected new research grants.

Finally, support from Department team was taken into account for all other personnel requirements.

3.3.4 Model selection and project extent

As the technical comparative analysis showed, HSPF was the most appropriate model for the purposes of the study. Although the overall complexity of the model was high, and thus learning procedure and model implementation were expected to last longer, in return, HSPF would be capable of providing integrated answers to integrated questions, which was basically the main purpose of the project.

In spite of the fact that HSPF was a competent tool to develop assessments for decision makers on NPS pollution issues, the extent of the outputs of the project was seriously dependent on the site-specific data resources. Although there were some possible personnel and expertise inputs, homogenous data gathering for the entire watershed was still a critical question. For a proper watershed scale modeling study, hydrological parameters such as; stream flow rates and groundwater layer levels should be fulfilled with long-term time series of daily measurement results. Furthermore, these data sets should be made available for every drainage basin and major catchments. Unfortunately, these critical data were not available and possibility to acquire them was relatively less.

On the other hand, the project itself was in a new but fertile scientific arena and Internet researches on HSPF implementation citations out of the US, showed only limited number of countries such as, South Africa, Germany, Australia and Canada. Nevertheless, given the scarcity of watershed NPS modeling projects in Turkey, it would be a significant attempt to open a new pathway for systematic and integrated approach for this particular scientific practice. Moreover, the study would introduce an important experience especially for the environmental engineers in Turkey by providing them a guideline on MSS so that they would be able;

- to locate and utilize the multidisciplinary data resources,
- to work around possible problems in data gathering, and
- to process site-specific and literature data for use with a complex NPS model.

Hence, in 1997, the project initiated with the purpose and extent of establishing a hydrological model using the HSPF software and to evaluate the total runoff and pollution loads from NPS within Köyceğiz-Dalyan Watershed.

4. DATA PROCESSING PHASE

The project commencement is also the beginning of data processing phase, which comprises all the necessary data supply tasks for the model implementation. These are the questions to be answered in the data processing phase, which are subjects to Section 4:

- What are the data required?
- Which of these data are absent?
- Where could the absent data be found?
- How could the data be validated?
- How should all the data be combined?
- In which form shall the data be used in the model?
- What are the tools or methods required to transform the data?
- How shall the data be transformed?
- What should be done if data requirement could not be fulfilled?

The following sections provide the information about the practices of the case study on these critical issues.

4.1 Data Inventory

The data inventory study, which was launched during the model selection process, was intensified due to the precise needs of the HSPF model for farthest possible extent of project. Hence, the entire data requirements and their respective uses were listed by the year 1998 to finalize the data inventory as presented in Table 4.1.

Table 4.1 HSPF Data Inventory

Data Set	**Use and Description**
Meteorology	
Stations	Analysis required selecting representative meteorology stations among five available stations within and surrounding the watershed. Station elevation data also required for temperature correction over the land segment (ATEMP).
Rainfall	Long-term time series of total rainfall data in preferably hourly, acceptably daily resolutions. Required for the basis of hydrological water budget in the watershed (PWATER).
Snow	Long-term time series of all snow precipitation and accumulation data in daily resolution. Optional unless snow packing is significant (SNOW).
Pan Evaporation and/or PET	Long-term time series of total measured pan evaporation data in preferably hourly, acceptably daily resolutions. Required for the calculation of PET unless it is provided as a separate time series. Basic element of hydrological water budget in the watershed (PWATER). Ready for 3 stations and for 3 years.
Air temperature	Long-term time series of maximum, minimum and average data in preferably hourly, acceptably daily resolutions. Required for the calculation of PET unless it is provided as a separate time series (WDMUtil). Also required for estimating soil layer temperature (PSTEMP) and optional for instream water temperature calculations unless instream water quality routing is not practiced (RQUAL). Beneficial in analyzing the general meteorological characteristics. Ready for 3 stations and for 3 years.

Table 4.1 HSPF Data Inventory (Continued)

Data Set	**Use and Description**
Solar Radiation	Long-term time series of average daily data. Required for the calculation of PET unless it is provided as a separate time series (WDMUtil). Required for instream water plankton growth calculations if instream water quality routing is practiced (RQUAL).
Cloudiness	Long-term time series of average daily data. Required for the calculation of PET unless it is provided as a separate time series (WDMUtil).
Humidity	Long-term time series of average daily data. Optional for some of the empirical PET calculation methods unless it is provided as a separate time series (WDMUtil). Ready for 3 stations and for 3 years.
Wind	Long-term time series of average daily vector data with speed and magnitude. Optional for some of the empirical PET calculation methods unless it is provided as a separate time series (WDMUtil). Optional for instream water quality routing unless it is practiced (RQUAL).
Watershed delineation	
Digital base maps	At least 1:25 000 scale digital topographical maps for delineation of the watershed, stream basins and catchments of stream tributaries. Also used as the base maps for the GIS.
Thematic maps	Thematic digital geographical maps in the same coordinate system and scale with the base maps such as; land use, soil information (structure, type and classes), geology, erosion, cultivability, crop types, streams and other surface waterbodies, administrative boundaries, settlements, natural reserves, roads, etc. Required for basin segmentation, by agricultural applications, soil types and land use. To be used as GIS layers for further spatial data storage and analysis.

Table 4.1 HSPF Data Inventory (Continued)

Data Set	Use and Description
Basin geometry	Required for dimensional parameters such as land coverage, average slope, elevation, width, length of basins and streams (PERLND, RCHRES).
Hydrology	
Stream flows	Long-term time series of outlet flow rate data in preferably hourly, acceptably daily resolutions, for every catchment of concern preferably by multiple stations. Required for the calibration and validation of hydrological water budget in the watershed (RCHRES).
Water and flows	Long-term time series of water level and flow measurements or estimations in daily resolutions, for every PLS of concern. Required for the input parameters, calibration and validation of hydrological water budget in the watershed (PERLND).
Land based data	
Structure and type	Soil texture (clay, silt, lime) and layer depths, experimental data from selected monitoring locations, required for validation of data retrieved from thematic GIS maps and optional for use in defining soil structure (PERLND).
Land use	Land cover and crop types, observational and survey information at selected monitoring locations, required for validation of data retrieved from thematic GIS maps and optional for segmentation (PERLND).
Infiltration rate	On-site measurement data with special apparatus at selected monitoring locations, beneficial for determining input parameters and optional for use in defining soil structure (PERLND).

Table 4.1 HSPF Data Inventory (Continued)

Data Set	**Use and Description**
Chemistry	Salinity, pH, $CaCO_3$, P_2O_5, NO_3, total N and total organics, experimental data from selected monitoring locations, required for use in quality routing through soil layers (PERLND).
Physics	Water saturation, field capacity and wilting point, experimental data from selected monitoring locations, beneficial for determining input parameters and optional for use in defining soil structure (PERLND).
Soil temperature	Experimental data from selected monitoring locations, beneficial for determining input parameters (PSTEMP).
Agricultural application survey	Cultivation patterns, irrigation methods and pesticide application, survey data obtained from the farmers at selected monitoring locations, required for validation of data retrieved from thematic GIS maps and for validation of the use of environmentally critical pesticides reported in the region earlier by other researchers (Güvensoy, 2000)
Pesticides	Experimental data from selected monitoring locations for selected environmentally critical pesticides, required for use in quality routing through of pesticides in soil layers (PEST).
Other Watershed Data	
Surface water quality data	Already provided by Gürel (2000) for the Köyceğiz/Dalyan Lagoon System, but missing for Köyceğiz Lake. A one year period monitoring program within the Köyceğiz/Dalyan channel system, the lakes and their catchments. Numerous samples taken to reflect the spatial and seasonal variations of many water quality parameters some of which are also applicable for HSPF such as, nutrients, BOD and TOC. An optional data set which could be used for correlating the concentration of quality constituents instream and the receiving waters. Beneficial if the NPS model (PERLND) is extended by an instream quality model (RCHRES-RQUAL).

4.2 Data Gathering

A nationwide extensive research was launched on locating providers of the items data inventory immediately after it was completed. As administrative communication was ongoing with the data providers, financial support investigations were also initiated. Hence, three separate research funds were actualized during years 1999 and 2000:

- TÜBİTAK - Land Ocean Air Sciences and Environmental Research Group (YDABÇAG) Project № 100Y047: "Ecosystem Modeling for Sustainable Management of Lagoons" (Gönenç *et al.*, 2002b)
- İTÜ Research Fund: "Modeling and Planning of Köyceğiz/Dalyan Lagoon and Its Watershed" Project (Gönenç *et al.*, 2002a)
- İTÜ Research Fund: "Hydrological Modeling of Non-Point Sources in Köyceğiz-Dalyan Lagoon System" Yüceil, K. PhD Thesis Project

The following sections will provide information on where and how items in the data inventory were attempted to gather.

4.2.1 Meteorology

In the year 2000, Meteorological time series were purchased from TRSMW for up to 51 years term and for five stations within and surrounding the watershed, namely Köyceğiz, Dalaman, Muğla, Marmaris and Fethiye. Qualifications of the data gathered from the related task in the data inventory, are as follows:

- Stations: Data from the targeted five stations were received together with elevation and coordinate values.
- Rainfall: Up to 51 years of daily total rainfall data and their 07:00, 14:00 and 21:00 updates were received for each of five stations. In addition, the annual maximum observed rainfall and durations data set were retrieved for use in Intensity-Duration-Frequency (IDF) analysis.
- Snow: Given Mediterranean climate regime, on-site observations and the average elevation of the watershed, snow mechanisms were initially included in the data gathering process. However, final consideration on this issue was

postponed until the data processing in which meteorological data would intensely be analyzed.

- Pan Evaporation and/or PET: PET values were not received as a time series but up to 18 years of daily total pan evaporation data and their 07:00, 14:00 and 21:00 updates were received for each of five stations. Nevertheless, because of the measurement technique used by the TRSMW, these data lacked winter season evaporation values for each year.
- Air temperature: Up to 25 years of daily average temperature data and their 07:00, 14:00 and 21:00 updates were received for each of five stations. Monthly averages of daily maximum and minimum temperatures for a 35-year term were also received.
- Solar Radiation: Up to 7 years of monthly averages were received.
- Cloudiness: Up to 25 years of monthly averages were received.
- Humidity: Up to 25 years of monthly averages were received.
- Wind: Up to 25 years of daily average wind speed and direction as well as their 07:00, 14:00 and 21:00 updates were received for each of five stations. Up to 25 years of monthly averages and directions were also received.

4.2.2 Watershed Delineation

Data gathering for watershed delineation and GIS was provided from various parties:

- Digital base maps:
    - The only authority in Turkey to develop and distribute digital topographical base maps is the Turkish Armed Forces General Command of Mapping (TAFGCM). These maps are of 1:25 000 scale and are developed using photogrammetry techniques. Because of the budget available in the year 2000 and a tendency to limit the geographical extent of the study by the lagoon system and its catchments, the first base maps gathered were only four plates covering the near vicinity of Köyceğiz Lake and the lagoon system. These plates, which are presented in the Figure 4.1, were O21-a1, O21-a2, O21-a4 and O21-a3.

- The rest of the plates, which cover most of the entire watershed, were gathered in 2002, when new financial resources were actualized. However, access to two of the required plates, which are located westward to the longitude 28º30' and cover the western edge of the watershed boundaries, were not authorized by the TAFGCM due to military security issues. Hence, operations that take place over these two plates were based on estimations rather than possible actual geographical characteristics.

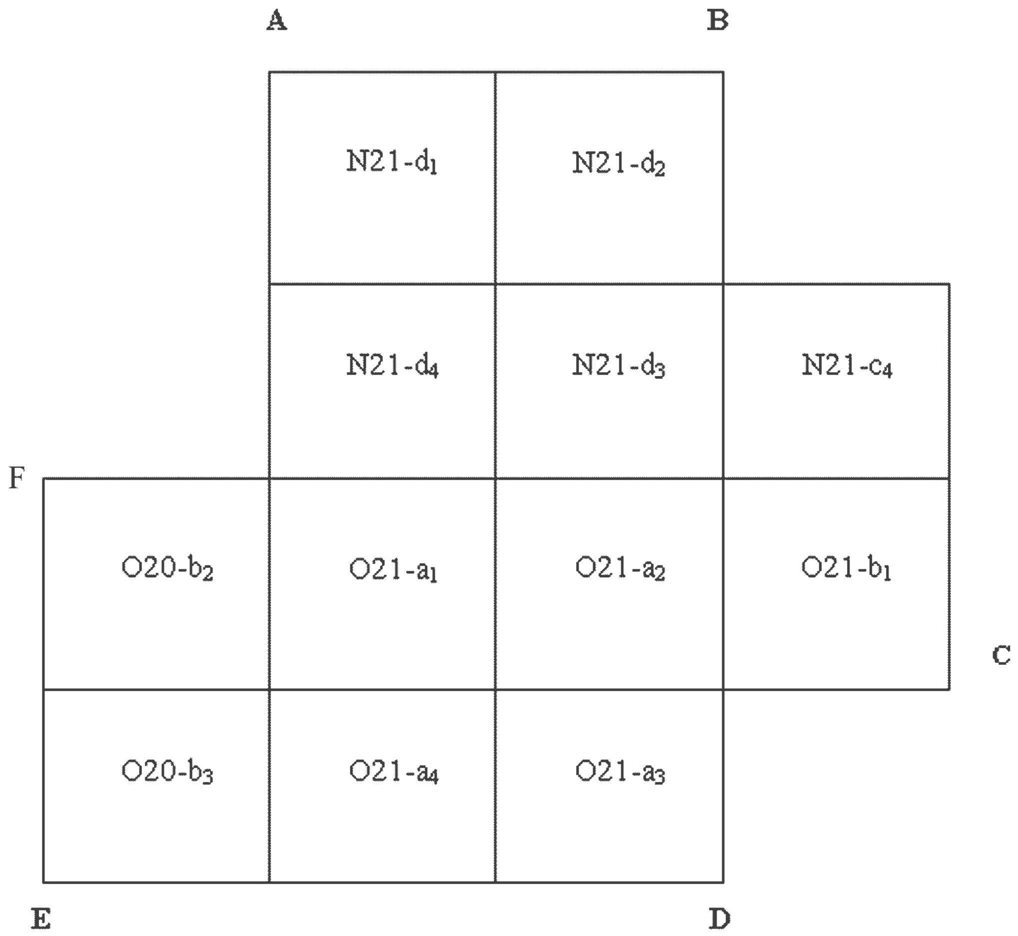
- Thematic maps:
  - Soils thematic maps, which were crucial for hydrological modeling, were purchased from the National Information Center (NIC) of the General Directorate of Rural Affairs of the Turkish Republic (TRGDRA) in 2001. These maps were originally digitized over the base maps of TAFGCM. Thus, the scale and coordinate system of the soil maps were fully compatible with the digital base maps gained. The maps contained attribute tables containing legend information and were designed using polygonal segmentation.
  - Stream and creek beds map of the watershed was also received from TRGDRA-NIC. The plates were originally produced by the State Hydraulic Works of Turkish Republic (TRSHW). The scale used 1:100000 and is delimited by the administrative boundaries of Muğla, the province in which the entirety of the watershed resides.
  - The socio-demographic data is another layer that shows the current status of population distribution in the watershed. These data were acquired in the year 2001 from public domain resources made available by Turkey Research and Development Center (TRDC). However the coordinate system was different from the base maps and therefore, until the coordinate transformation support were maintained from the Department of Geodesy and Photogrammetry, these maps were to be analyzed separately without superimposition over the base maps.

- Basin geometry: Stream cross-sections were required for use in stream flow model. However, no record could be found for this purpose. Some on-site observations could be made available during the field studies in year 2003, but these were quite limited. Only, some information on the basin dimensions was gained due to the processing of base maps with appropriate software, which are discussed within the following sections.

4.2.3 Hydrology

Data gathering for hydrological issues was not as successful as it relatively was for other major data groups:

- Stream flows:
  - Three years of studies for gathering stream flow data during the years 2000 and 2002 started with investigations on the records of local authorities. Face to face queries in İzmir Menemen Research Institute, as the only authorized institution for soil surveys in the case study area, and the phone conversations with the TRSHW regional office did not achieve to locate any flow measurement records for any of the streams in the watershed.
  - Fortunately in 2003, flow measurements for the two major streams discharging into the Köyceğiz Lake, namely Namnam and Yuvarlakçay were provided from State Hydraulic Works office in Ankara. Yet, data sets were not continuous and Yuvarlakçay measurements were considerably out-of-date (1960s).
- Water and flows: Some information about the hot springs in the southwestern zone of the watershed were made available, however quantified resources on the water remained critically missing. Furthermore, the hot springs data was insignificant and unrepresentative. Thus, data requirement for both quantity and quality of groundwater sources left unfulfilled, apart from the fact that some ranges from literature were made available.



Geographical coordinates of the bounding corners:

Corner	Latitude (φ)	Longitude (λ)
A	37°15'00"	28°30'00"
B	37°15'00"	28°45'00"
C	36°52'00"	28°52'30"
D	36°45'00"	28°45'00"
E	36°45'00"	28°22'30"
F	37°00'00"	28°22'30"

Figure 4.1 Base Maps

4.2.4 Land based data

In addition to the data from the thematic maps on the GIS, some literature data on the soil structure of the watershed was also gathered in 2001 from Soil and Water Research Institute in Ankara. The study provides information on various soil type characteristics and their province based distribution in the region. A summary on these data is presented in Table 4.2 (Gönenç, 2002a). A comprehensive geology and soils research in the watershed dated back 1960s were found in Ankara, as another literature input to the study. Other progress on the data inventory was as follows:

- Structure and type: The experimental data, which was gathered through the field study, is described in full detail within the related section below.
- Land use: The land use validation of GIS data is also described in full detail within the related section below.
- Infiltration rate: It was anticipated to measure this parameter on site through the consulting agreement established with İzmir Menemen Research Institute as being the only official institution to perform soil surveys in the region. However, it had not been possible to measure this parameter firstly because of technical unavailability due to malfunction of special measurement equipment. Secondly, it was not possible to work this around using financial resources since; the stringent budget was already insufficient to cover the entire expenses of the soil analysis. Hence, field data supply for this parameter failed.
- Chemistry: Experimental data regarding soil chemistry was fulfilled to a modest extent for selected monitoring locations on site. The details are given in the related section below.
- Physics: Similar to chemical parameters, field study covered these issues and the details are described in the related section below.
- Soil temperature: This parameter was measured during the soil survey and provided rough information to verify with the average meteorological data sets.

- Agricultural application survey: As a part of the fieldwork in 2002, very brief interviews were made with the farmers who were available during the visit to the sampling locations, through a questionnaire form.
- Pesticides: A theoretical study was completed to minimize the number of critical pesticides to trace via modeling, by re-filtering the previously cited pesticides according to their persistence and common use. Moreover, a competent and authorized institution to perform the pesticide measurements in the soil was also found namely, İzmir Bornova Agricultural Research Center. Thus, it would have been possible to do pesticide investigation only on those sites, which the interview results would prove the application of that particular pesticide. However, due to the significantly high costs per experiments this project also failed.

Table 4.2 Sub-province Based Distributions of Major Soil Groups

Major soil groups	Köyceğiz		Ortaca		Ula		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Alluvial soils	4 133	2.62	10 141	35.70	1 787	4.20	16 061	7.00
Hydromorphic alluvial soils	1 100	0.70	1 194	4.20	162	0.38	2 456	1.00
Colluvial soils	8 610	5.30	1 147	4.00	5 017	11.70	14 774	6.30
Alluvial wetlands	50	0.03	-	-	-	-	50	0.02
Brown forest soils without lime	113 401	70.30	4 952	17.40	13 916	32.60	132 269	57.00
Mediterranean red-brown soils	23 380	14.50	10 402	36.60	20 628	48.30	54 410	23.40
Mediterranean red soils	-	-	-	-	432	1.00	432	0.20
Other soil groups	4 803	3.55	123	0.40	726	1.70	5 652	2.40
Waterbody	5 723		471	1.60	58	0.10	6 252	2.70
Total	161 200	100	28 430	100	42 726	100	232 356	100

4.2.5 Other watershed data

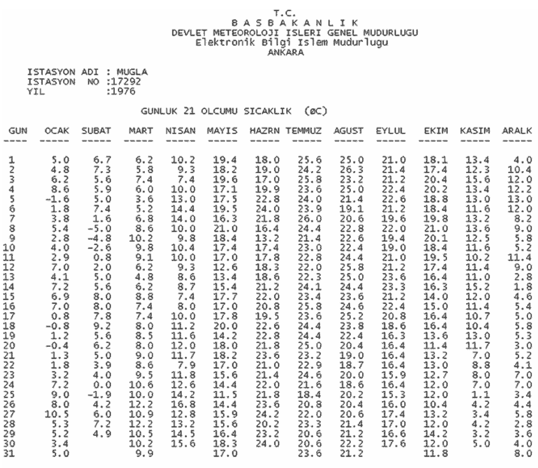
As even some of the essential data set needs was not fully complied, additional data sets could not be developed because of lack of resources, time, and effort.

4.3 Meteorological Analysis

Throughout the years from 2000 to 2002, very detailed meteorological analysis was performed and reported as parts of the related projects from TÜBİTAK (Gönenç *et al.*, 2002b) and İTU Research Fund (Gönenç *et al.*, 2002a). Hence, the following sections will describe only a concise summary of these studies, and yet the full details could be examined within these references.

4.3.1 Raw data processing

Data for all the parameters gained from TRSMW was provided in ASCII format 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. Despite its practical advantage of compact presentation of entire annual data in a single table, HSPF and other NPS models use a linear record based system. Thus, in order to transform these data sets into a linear data table 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 a Microsoft Access database wherein sophisticated spatial and temporal queries could be made. Hence, these queries were then used as powerful tool for meteorological analysis in watershed. Format samples for each of TRSMW and Microsoft Access data tables are presented for comparison in Figure 4.2.

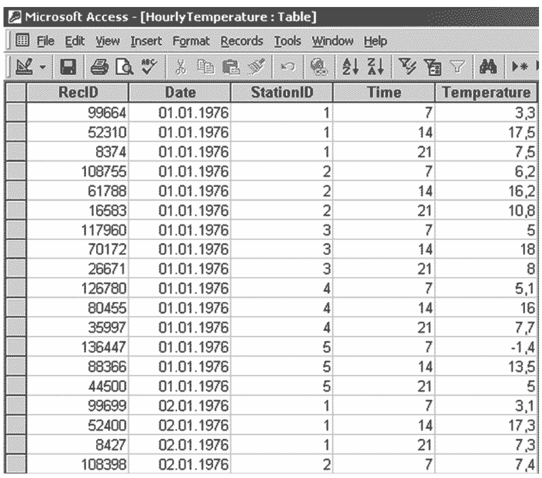


T.C.
B A S B A K A N L I K
DEVLET METEOROLOJI ISLERI GENEL MUDURLUGU
Elektronik Bilgi Islem Mudurlugu
ANKARA

ISTASYON ADI : MUGLA
ISTASYON NO :17292
YIL :1976

GUNLUK 21 OLCUMU SICAKLIK (ØC)

GUN	OCAK	SUBAT	MART	NISAN	MAYIS	HAZRN	TEMMUZ	AGUST	EYLUL	EKIM	KASIM	ARALK
1	5.0	6.7	6.2	10.2	19.4	18.0	25.6	25.0	21.0	18.1	13.4	4.0
2	4.8	7.3	5.8	9.3	18.2	19.0	24.2	26.3	21.4	17.4	12.3	10.4
3	6.2	5.6	7.4	7.4	19.6	17.0	25.8	23.2	21.2	20.4	15.6	12.0
4	8.6	5.9	6.0	10.0	17.1	19.9	23.6	25.0	22.4	20.2	13.4	12.2
5	-1.6	5.0	3.6	13.0	17.5	22.8	24.0	21.4	22.6	18.8	13.0	13.0
6	1.8	7.4	5.2	14.4	19.5	24.0	23.9	19.1	21.2	18.4	11.6	12.0
7	3.8	1.6	6.8	14.0	16.3	21.8	26.0	20.6	19.6	19.8	13.2	8.2
8	5.4	-5.0	8.6	10.0	21.0	16.4	24.4	22.8	22.0	21.0	13.6	9.0
9	2.8	-4.8	10.2	9.8	18.4	13.2	21.4	22.6	19.4	20.1	12.5	5.8
10	4.0	-2.6	9.8	10.4	17.4	17.4	23.0	22.4	19.0	18.4	11.6	5.2
11	2.9	0.8	9.1	10.0	17.0	17.8	22.8	24.4	21.0	19.5	10.2	11.4
12	7.0	2.0	6.2	9.3	12.6	18.3	22.0	25.8	21.2	17.4	11.4	9.0
13	4.1	5.0	4.8	8.6	13.4	18.6	22.3	25.0	23.6	16.4	11.0	2.8
14	7.2	5.6	6.2	8.7	15.4	21.2	24.1	24.4	23.3	16.3	15.2	1.8
15	6.9	8.0	8.8	7.4	17.7	22.0	23.4	23.6	21.2	14.0	12.0	4.6
16	7.0	8.0	7.4	8.0	17.0	20.8	25.8	24.6	22.4	15.0	11.4	5.4
17	0.8	7.8	7.4	10.0	17.8	19.5	23.6	25.2	20.8	16.4	10.7	5.0
18	-0.8	9.2	8.0	11.2	20.0	22.6	24.4	23.8	18.6	16.4	10.4	5.8
19	1.2	5.6	8.5	11.6	14.2	22.8	24.4	22.4	16.3	13.6	13.0	5.3
20	-0.4	6.2	8.0	12.0	18.0	21.8	25.0	20.4	16.4	11.4	11.7	3.0
21	1.3	5.0	9.0	11.7	18.2	23.6	23.2	19.0	16.4	13.2	7.0	5.2
22	1.8	3.9	8.6	7.9	17.0	21.0	22.9	18.7	16.4	13.0	8.8	4.1
23	3.2	4.0	9.5	11.8	15.6	21.4	24.6	20.0	15.9	12.7	8.0	7.0
24	7.2	0.0	10.6	12.6	14.4	22.0	21.6	18.6	16.4	12.0	7.0	7.0
25	9.0	-1.9	10.0	14.2	11.5	21.8	18.4	20.2	15.3	12.0	1.1	3.4
26	8.0	4.2	12.2	16.8	14.4	23.6	20.8	20.4	16.0	10.4	4.2	4.4
27	10.5	6.0	10.9	12.8	15.9	24.2	22.0	20.6	17.4	13.2	3.4	5.8
28	5.3	7.2	12.2	13.2	15.6	20.2	23.3	21.4	17.0	12.0	4.2	2.8
29	5.2	4.9	10.5	14.5	16.4	23.2	20.6	21.2	16.6	14.2	3.2	3.6
30	3.4		10.2	15.6	18.3	24.0	20.6	22.2	17.6	12.0	5.0	4.0
31	5.0		9.9		17.0		23.6	21.2		11.8		8.0



Microsoft Access - [HourlyTemperature : Table]
File Edit View Insert Format Records Tools Window Help

RecID	Date	StationID	Time	Temperature
99664	01.01.1976	1	7	3,3
52310	01.01.1976	1	14	17,5
8374	01.01.1976	1	21	7,5
108755	01.01.1976	2	7	6,2
61788	01.01.1976	2	14	16,2
16583	01.01.1976	2	21	10,8
117960	01.01.1976	3	7	5
70172	01.01.1976	3	14	18
26671	01.01.1976	3	21	8
126780	01.01.1976	4	7	5,1
80455	01.01.1976	4	14	16
35997	01.01.1976	4	21	7,7
136447	01.01.1976	5	7	-1,4
88366	01.01.1976	5	14	13,5
44500	01.01.1976	5	21	5
99699	02.01.1976	1	7	3,1
52400	02.01.1976	1	14	17,3
8427	02.01.1976	1	21	7,3
108398	02.01.1976	2	7	7,4

Figure 4.2 Transformation of SMW Cross Tables to Parameter Database

4.3.2 Characteristic meteorological station selection

The following criteria should be taken into consideration when selecting representative meteorological stations.

- The station should preferably be within the boundaries of the basin
- Location of the station should represent the average topographical characteristics of the region, due to its possible impacts on local climate
- The selected station should provide data for all considered meteorological parameters with significant quantity and reliability
- In case of diverse topographical conditions, the station should provide values, which are not distinct from the actual spatial average.

As the core parameter of the hydrological model is the rainfall, the basis of trend and comparative analysis was based on this parameter. The logic of the comparative analysis is to test the likeliness and ability of the station record sets to represent the watershed as whole, and to avoid extremely low or high and widely fluctuating measurements which could be misleading. Thus, several station performance comparison graphs, which are discussed in full detail within Gönenç (2002a), are presented in the following paragraphs.

Köyceğiz, Muğla, Fethiye, Marmaris and Dalaman stations, the five stations with and surrounding the Köyceğiz/Dalyan Watershed are presented on map in Figure 4.3 and their geographical attributes in Table 4.3. Figure 4.4 shows annual rainfall history in these five meteorological stations. General data characteristics show that Marmaris station show higher and Fethiye show lower annual values when compared to Köyceğiz station with a middling trend among the five stations.

Table 4.3 Meteorological Stations

Station	Latitude	Longitude	Altitude
Muğla	37°13’	28°22’	+646
Marmaris	36°51’	28°16’	+19
Fethiye	36°37’	29°07’	+3
Dalaman	36°45’	28°47’	+13
Köyceğiz	36°48’	28°41’	+24

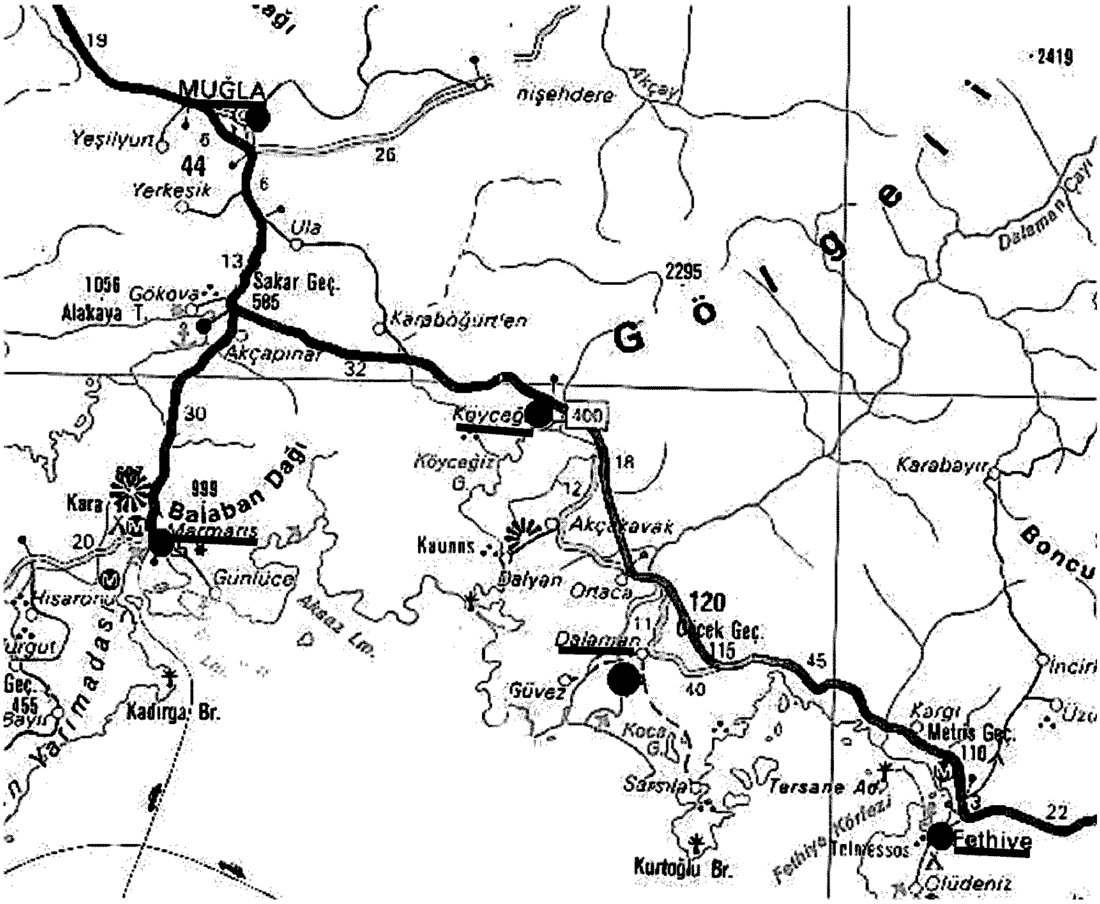


Figure 4.3 Meteorological Stations

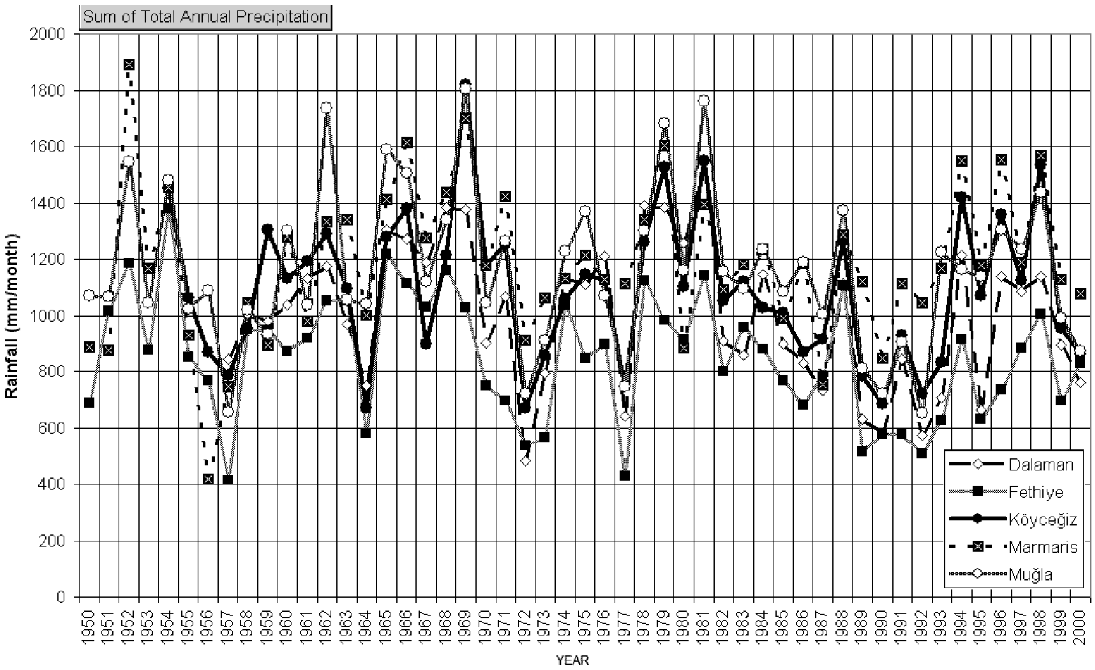


Figure 4.4 Comparison of Annual Rainfall in Five Meteorological Stations

Figure 4.5 presents monthly averages of daily rainfall, which are calculated by the division of monthly average rainfall to the number of days in that month. The averages are based on approximately 50 years of data.

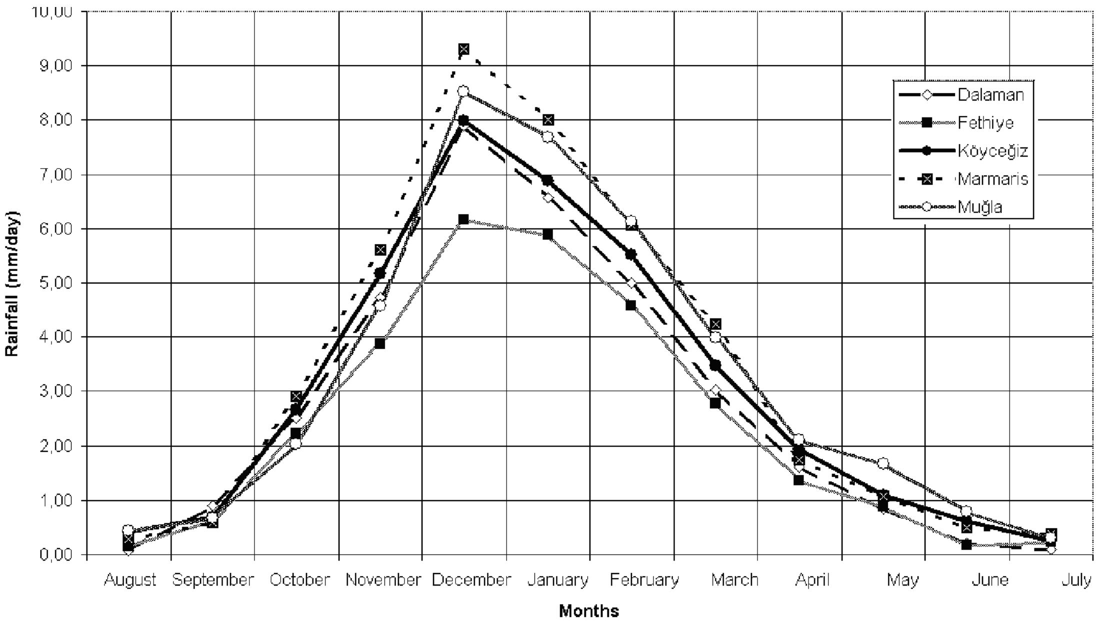


Figure 4.5 Comparison of Daily Rainfall in Five Meteorological Stations

In general, a similar ranking trend to annual rainfall is preserved in Figure 4.5, where Köyceğiz and Dalaman stations show similar values closer to the average of five stations whereas Marmaris and Fethiye stations are rather distinct. All stations, however, show a common fact that the first two rainiest months of the year are December and January, and on other hand, the driest two moths are July and August. Table 4.4 presents a summary of rainfall data history and Table 4.5 shows a comparison of average rainfall regime among all stations.

Table 4.4 Rainfall Data History of Five Stations

Meteorological Station	Measurement History	Number of Years	Number of Rainy Days (>0.1 mm)
Muğla	January, 1950	51	5011
Marmaris	January, 1950	51	3972
Fethiye	January, 1950	51	3950
Dalaman	October, 1956	44+	3382
Köyceğiz	April, 1953	47+	3902

Table 4.5 Average Rainfall Regime in Five Stations

Rain Event Recurrence Period (days)						Daily Probability of a Rain Event (%)				
Months	**Dalaman**	**Fethiye**	**Köyceğiz**	**Marmaris**	**Muğla**	**Dalaman**	**Fethiye**	**Köyceğiz**	**Marmaris**	**Muğla**
January	2.3	2.3	2.3	2.2	2.0	44%	44%	44%	46%	49%
February	2.6	2.4	2.4	2.4	2.2	39%	41%	41%	41%	46%
March	3.3	3.3	3.1	3.1	2.7	31%	31%	32%	32%	37%
April	4.2	4.0	3.8	4.2	3.2	24%	25%	26%	24%	31%
May	6.5	6.7	5.4	6.5	3.8	15%	15%	18%	15%	26%
June	16.5	14.5	10.7	13.0	7.9	6%	7%	9%	8%	13%
July	23.7	24.4	17.6	24.1	12.9	4%	4%	6%	4%	8%
August	23.3	22.1	20.1	27.9	14.3	4%	5%	5%	4%	7%
September	13.0	12.9	11.4	12.6	9.4	8%	8%	9%	8%	11%
October	5.9	5.2	5.2	5.5	4.5	17%	19%	19%	18%	22%
November	3.5	3.4	3.4	3.3	2.9	28%	29%	29%	30%	35%
December	2.3	2.3	2.3	2.2	2.0	43%	44%	44%	45%	49%
Average	4.6	4.5	4.3	4.4	3.6	22%	22%	24%	23%	28%

As expected, the movement of average recurrence periods and frequencies are parallel to total rainfall statistics. Given the 50 years of data the calculated average values for Muğla stations is relatively distinct to the other four stations. The higher frequency of rainfall events in Muğla versus higher total rainfall measurements in Marmaris shows that the rainfall regime in these two stations reflects different patterns. It is suggested that with its significantly higher elevation Muğla station encounters more frequent storm events. However, due to its distance to the

Mediterranean shorelines the southerly clouds with potential precipitation drop some of this potential as it is conveyed to up north where the Muğla station is situated at +646 m. On the contrary, Marmaris station, in the midst of a plain near to the sea level by +19 m, is contoured by high mountains, which blockade the rain clouds to move further and force them to loose their precipitation potential. However, the typical warm climate of Mediterranean region do not allow for more frequent rainfall events but rather cause storm events with higher intensity and shorter durations. Muğla station in this sense is rather less effected by this regime.

On the other hand, as a whole Köyceğiz Station among the three other stations in Fethiye, Marmaris and Dalaman were selected as the more representative meteorological station in the region, due to the following reasons:

- Köyceğiz Station is within the boundaries of the watershed, whereas all of the others are situated distinctly behind them.
- Its rainfall time series is neither far off from other three stations, nor dissimilar to their spatial average.
- It is in the proximity of receiving waterbodies and basins, which are of major concern.
- Rainfall record history is 47 years and the station holds statistically acceptable number of data for other parameters, as well.
- Although it is situated on a lower elevation close to average of mean elevations of drainage basins, it also has capability to represent rainfall regimes of zones with higher elevation.

Yet, this distinct characteristic of Muğla station leads to another issue regarding the representation of the watershed. Considering the northern highlands in the watershed although the Muğla station is not in the proximity of the watershed, it might have had some representative value for the northern basins. Thus, a trend analysis for these two meteorological stations, Köyceğiz and Muğla, was carried out to investigate the representational performance of Köyceğiz station on the higher, northern and northwestern zone of the watershed. Figures 4.6 and 4.7 reflect the 50 year and 10 year trends of the two stations with respect to total annual rainfall parameter.

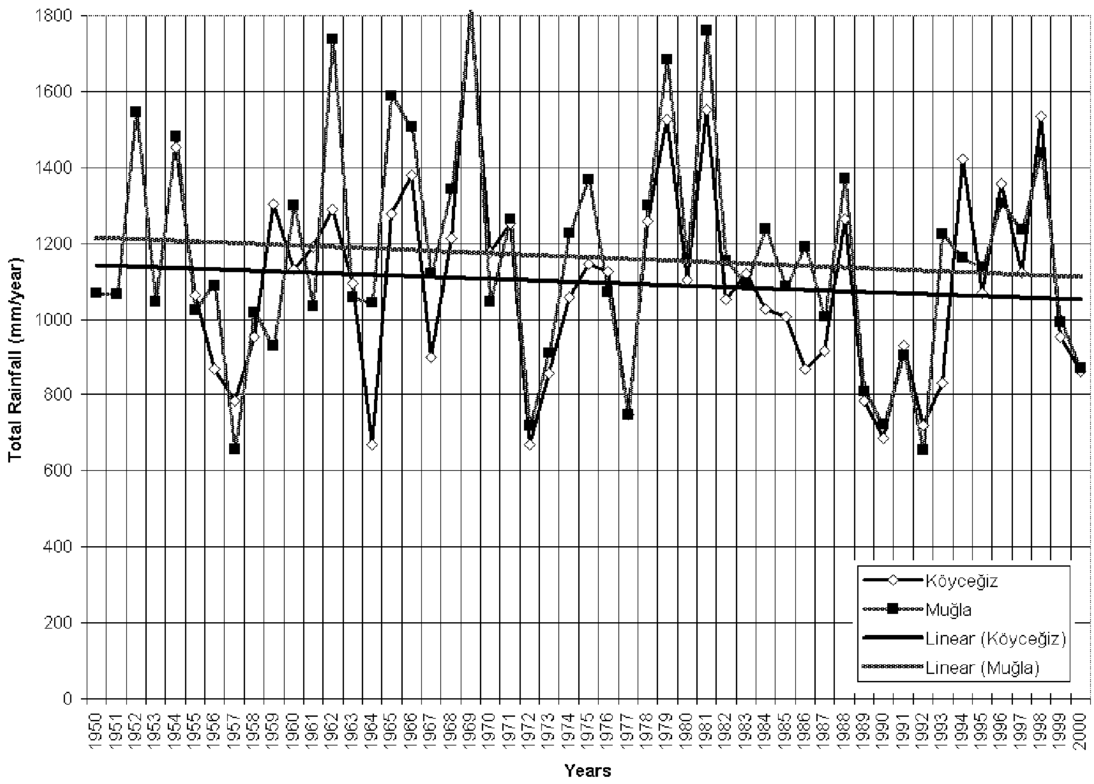


Figure 4.6 Trend Analysis by 50 Years Data for Muğla and Köyceğiz Stations

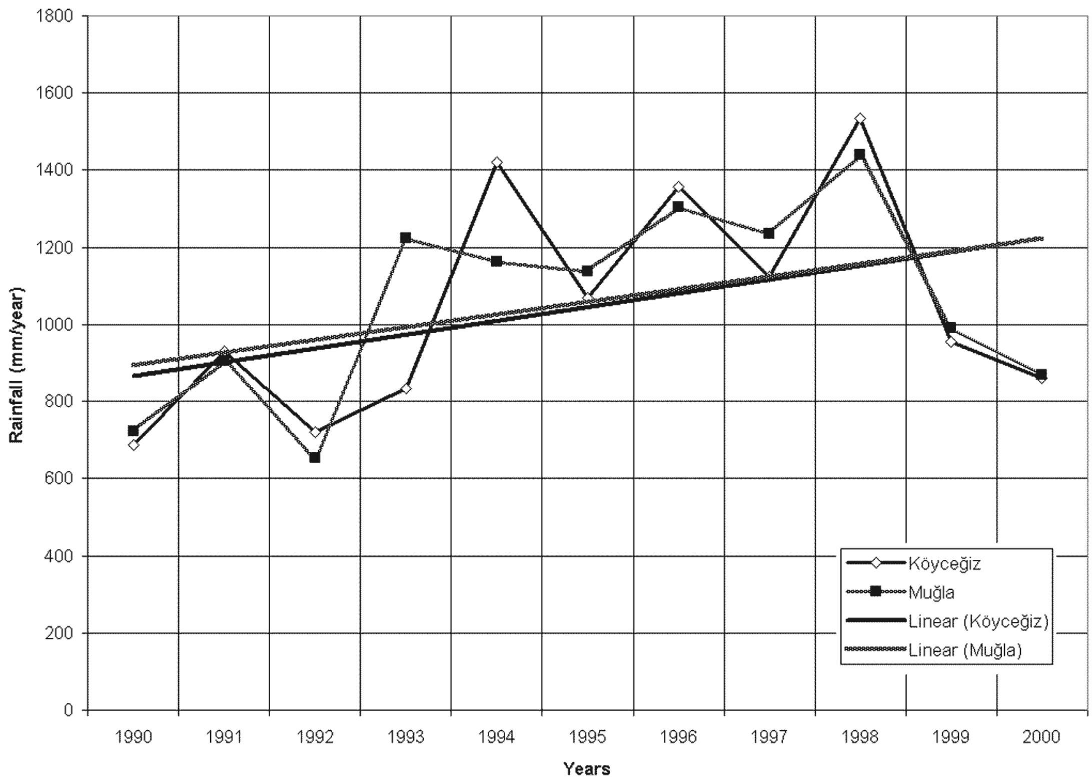


Figure 4.7 Trend Analysis by 10 Years Data for Muğla and Köyceğiz Stations

Figure 4.6 suggests that Muğla data set represents an approximately 90 mm higher linear regression trend almost parallel to Köyceğiz trend line but still, the difference gradually narrows. The figure also presents an overall decreasing trend of annual rainfall values. Figure 4.7 suggest a different trend when zoomed into the near history data from 1990 to 2000 (11 years). The linear tendency curves for both stations point up and diverge. As the global climate changes became observable in the last decade of the millennium, this segment of data and divergence noticed has some extra significance. However, it would not be scientifically correct to judge the increasing trends on these curves are predominantly dependent on the global warming. Moreover, since a similar tendency was observed between the 1954-1969 period for Köyceğiz station, it would be hard to deduce the driving factor behind the latest trends. The change could be because of a very long-term climatologic oscillation, some side effect of the global warming, or a local meteorological factor.

A final analysis for comparison of the stations is related to how the averages of long-term annual total rainfall results have changed. For this exercise, starting with statistically significant 30 years data set, i.e. data from 1954 to 1983 for both stations, average of total annual rainfall for the two stations, and the average of these averages are plotted together with their linear regression curves in Figure 4.8.

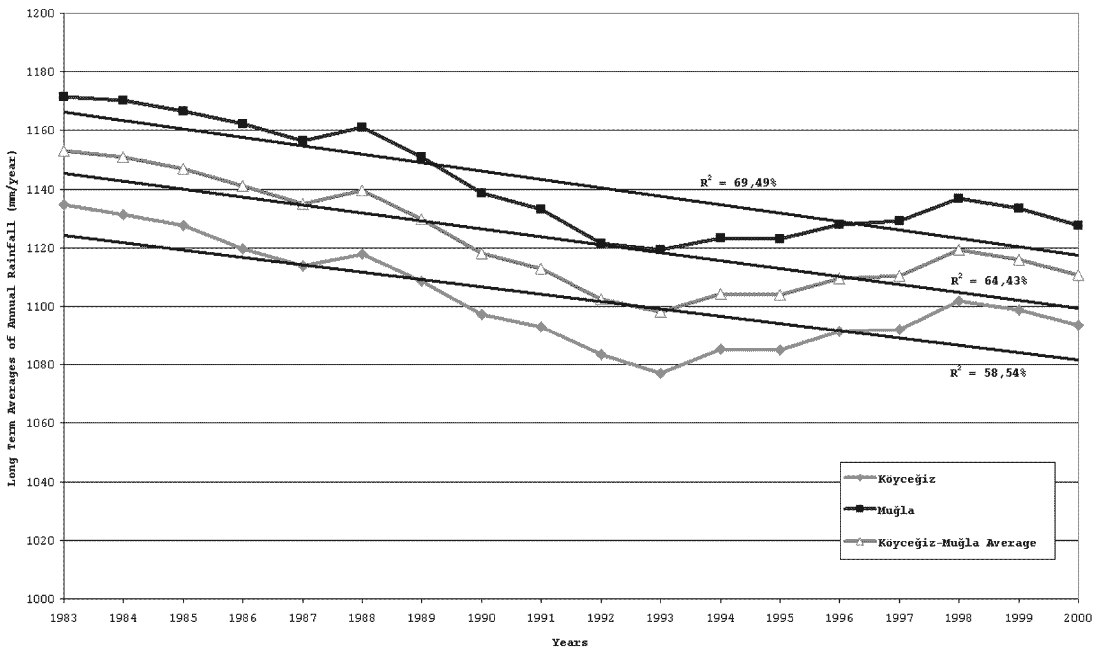


Figure 4.8 Progress of Long-Term Averages for Muğla and Köyceğiz Stations

The results show that there is a stable limited difference of approximately 40 mm between averages of the two stations. However, the significant difference in average rain probability statistics in Muğla station may cause critical errors in terms of the monthly distribution of the rainfall. On the other hand, this difference is in the order of 3.5% based on Köyceğiz Station values and therefore, is an acceptable difference to represent the entire watershed uniquely by this station, which happens to be the only station inside the boundaries of the watershed. Hence, it was suggested that Köyceğiz station should be the only station to be accounted for all meteorological data resembling the entirety of the watershed with its northern and southern zones.

Yet, considering the runoff and the hydrological cycle as a whole, northern mountainous zone of the watershed may partially encounter snowfall which might be rather be better represented by Muğla station values which is 622 m higher in elevation than the Köyceğiz station, where it is highly improbable to observe snow events. Therefore, with the model calibration process, this issue will be regarded as a criterion for possible error intrusion due to meteorological station selection.

Hence, the analysis for each of the meteorological parameters in the following sections will regard the data sets retrieved from Köyceğiz meteorological station.

4.3.3 Rainfall

Rainfall parameter is the main component of the hydrological cycle. In order to evaluate the rainfall parameter the methodology used by the TRSMW should be well understood. There are two instruments use to measure rainfall. One is the pluviometer with a 15.96 cm diameter and 200 cm² base area cylinder metal opening, through which rain, snow or other forms of precipitation is collected and transferred into a scaled cylinder of plastic, metal or glass material and measured as millimeters (mm). The second is the pluviograph with the same opening but equipped with a recording and plotting device by which the measurements could be read. However, pluviographs are not operational below 0°C and thus are used to verify the measurements from the pluviometers. The measurements are recorded in mm at 7:00h, 14:00h, and 21:00h daily. Every rainfall record represents the total volume of precipitation occurred until the time of recorded measurement from the previous. Thus, what a daily precipitation record represents is “not” the total volume of precipitation between the start of day at midnight, 12:00 AM, to the next. In stead, it is the sum of 14:00h and 21:00h readings of that day and the 7:00h reading of the next morning. Although this detail becomes negligible in an annual simulation period with daily data resolution, when working with higher resolutions and short simulation periods might be critical to address the simulation results with the factual timing.

The annual total rainfall statistics for Köyceğiz Station presented in Figure 4.6 show that values vary mostly between 900 mm and 1400 mm. The highest annual measurement since April 1954 to the year 2000, was recorded in 1969 by 1821 mm. The last ten years data (1991-2000) suggest a minimum of 700 mm precipitation at the station. However, this threshold was thrice outdated earlier in 1964 and 1972 by 670 mm, in 1990 by 685 mm. The average of 47 years values equals 1094 mm. Apart from the year 1969, when the maximum annual precipitation with a value 66% greater than the average was reported by the station, the fluctuation above and below the average did not exceed ±50%. On the other hand, the quarter deviation buffer of the average (±%25) is exceeded equally by 7 times on upper and lower directions. In other words, the ±%25 zone between 820 mm and 1367 mm was only passed by seven times for each threshold. These conditions suggest that there is a likely normal distribution in the occurrence of dry and rainy seasons.

Given the Köyceğiz station data in Figure 4.9 on monthly average distribution of total rainfall, arid season appears to be August and July (3 mm). On the other edge, the rainfall peak is observed on December (252 mm) and secondly in January (213 mm). The monthly distributions shows a symmetrical curve in which, the average rainfall does not drop below 210 mm, 150 mm and 50 mm during December-January, November-February, and October-April periods, respectively. Naturally, a similar case is also true for Figure 4.5, in which the peak rainfall in December shows an 8.0 mm/day average rainfall, whereas the lowest rainfall is in August by 0.1 mm/day, for Köyceğiz Station.

With the statistical parameter presented in Figure 4.5 it is assumed that there is a uniform distribution rain events among the entire days of the month. However, this is not the case in real terms, and storm events occur in an uncontrollable frequency. Thus, the actual rainfall in a day could only be averaged over the rainy days. Hence, such statistics are plotted in Figure 4.10 to represent the monthly change of average daily precipitations in expected average rainy days in each month.

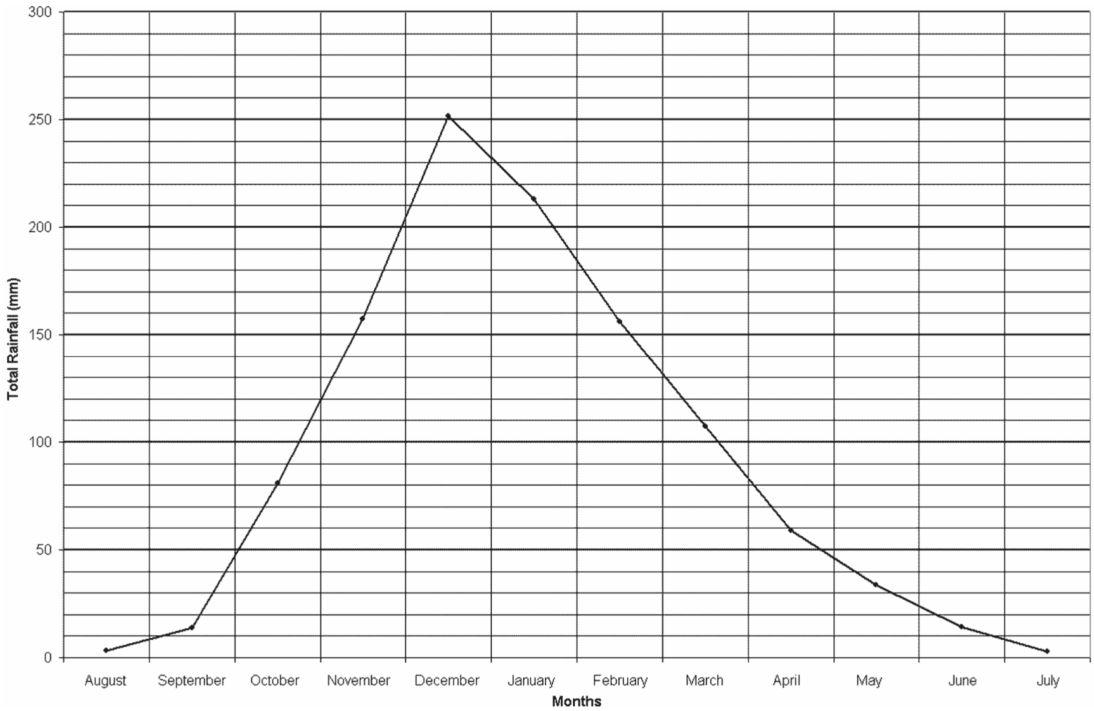


Figure 4.9 Monthly Variation of Rainfall at the Selected Station

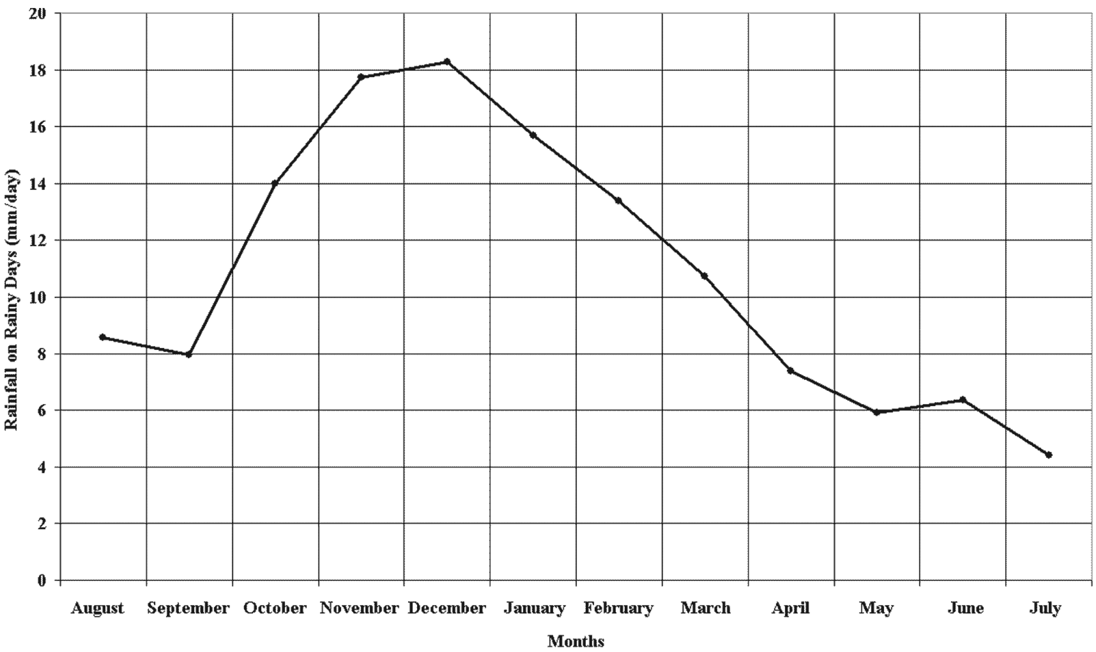


Figure 4.10 Monthly Variation of Daily Rainfall on Rainy Days

Although the general trend of the curve in Figure 4.10 is alike to the other monthly distribution charts presented above, there are also two slight differences. The general decreasing trend from December until August, is first broken in June, when 6.0 mm/day value of May rises to 6.6 mm/day, and for a second time in August, when 4.4 mm/day value of July increases drastically to 8.6 mm/day. The expected increasing trend, however, is not disturbed as the values reach the peak value of 18.1 mm in December without any drops in between. These two unconventional changes are probably due to the summer rains which are typical to Mediterranean climate and which could be characterized with high intensity and very short period of acute showering patterns. Despite the high intensity, these showers occur quite seldom. Therefore, as it is a known statistical fact, that as the number of occurrences decreases the stability of statistical trends is disturbed, this trend discrepancy should be interpreted in this manner. The number of average occurrences of precipitation events could be derived by multiplying the number of days in each month by the average occurrence probability given Table 4.5. The rounded results of this exercise are presented in Table 4.6.

Table 4.6 Rainfall Occurrences at the Selected Station

Months	Occurrence	Months	Occurrence
January	14	July	2
February	12	August	2
March	10	September	3
April	8	October	6
May	6	November	9
June	3	December	14

4.3.4 Evaporation

Evaporation is the second most important meteorological parameter in rural hydrology. Evaporation loss is the key sink to of a hydrological system. Evaporation as a meteorological parameter and evaporation as a concept of hydrological systems in a watershed have slight differences. Evaporation as a meteorological parameter refers to what is called as “pan evaporation”, which reflects the total of direct evaporation loss from the surface of a measurable water body. Thus, the pan evaporation parameter from a representative meteorological station would most precisely reflect the actual evaporation loss from a lake or a stream. However, in order to refer to the total of land and surface water based evaporation from a watershed; the “evapotranspiration” term is used which comprises the entire loss of water from; rivers and lakes, bare soil, and vegetative surfaces; within the leaves of plants (transpiration); and sublimation from ice and snow surfaces. Thus, as also presented in Figure 2.2 evapotranspiration, by definition, is a collective term for all processes by which water in the liquid or solid phase at or near the surface of earth becomes atmospheric water vapor.

Furthermore, when rural watershed modeling is concerned, the majority of the models use the potential evapotranspiration (PET) term as an input parameter. PET is the rate at which evapotranspiration would occur from a large area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water. This rate is assumed to be unaffected by micro-climatic processes such as advection or heat-storage effects. PET could be measured by the device presented in Figure 4.11 (HUJ, 2004) and called “lysimeter”, which is installed at the site and the loss of water from the natural soil prism is measured by the change in weight. Once PET is estimated, the soil water demand could be reduced and thus the actual evapotranspiration could be computed by the hydrological model.

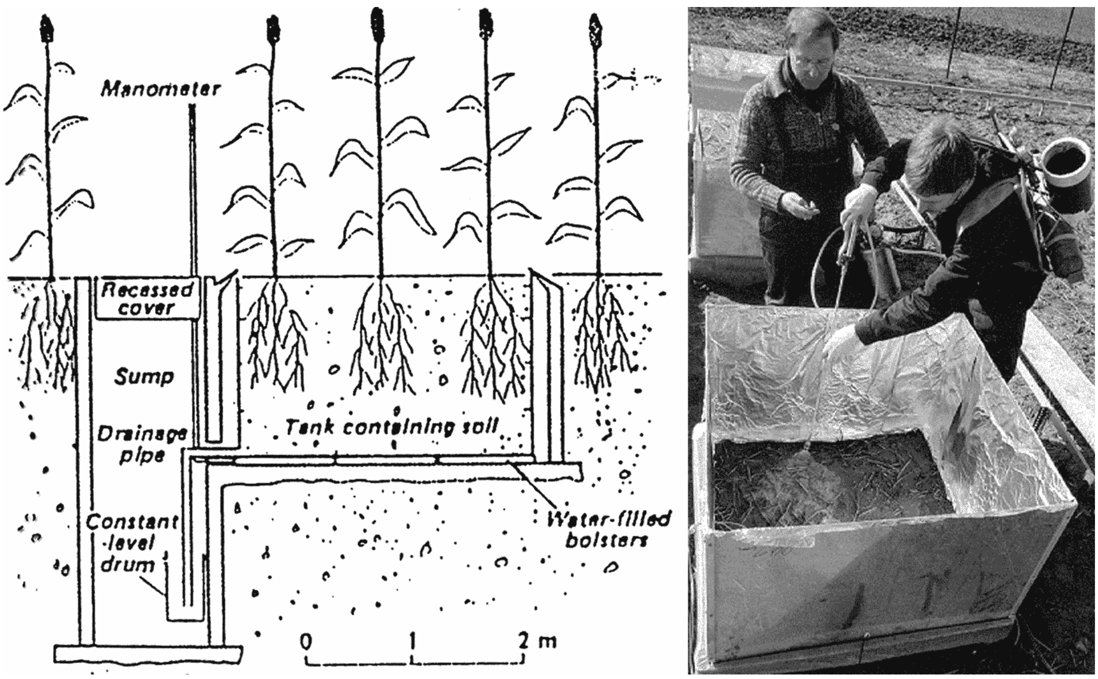


Figure 4.11 Lysimeter

As a result, as long as the entire watershed hydrology is of concern, the meteorological “pan evaporation” parameter could “not” directly be used for estimating the water budget in a basin. On the other hand, the meteorological parameter conserves its significance in terms of perceiving the water loss as a result of climatic conditions.

There are two methods of pan evaporation measurement practiced by the TRSMW. The first is called “in-trench evaporation” where evaporation is measured under containment and independent of the external factors such as, solar radiation, wind and precipitation. The second method is called open trench in which the evaporation pan is installed outdoors and exposed to the solar radiation and wind effects. Hence, the results would differ (Yıldırım and Özbilen, 2002). The evaporation pans are cylindrical water containers with a diameter of 112.9 cm, a base area of approximately 1 m^2, and a height of 25.4 cm (10 inches). An example for these pans used by TRSMW is shown in Figure 4.12 (TRSMW, 2003).

Figure 4.12 Evaporation pan

The in-trench and open trench evaporation pans used in the meteorological stations administered by TRSMW, are not functional when the air temperature is below 0°C. Thus, as the water contained in the pan is frozen it is no longer possible to measure evaporation. Therefore, the data sets of TRSMW do not include measurements starting from the first day when the measured water surface freezes, until the next April the 1st. However, as it is a known fact that evaporation could theoretically prevail below 0°C, this situation is a problem in determining the annual and monthly evaporation.

In particular, Köyceğiz station has a record history starting from 1983. On the other hand, due to the low temperatures in December the evaporation measurement equipment are taken out of service throughout the winter season until 1st of April. Hence, only the daily time series for the year 1984 is entirely continuous and complete, whereas measurements of all the other years are incomplete (Yıldırım and Özbilen, 2002). The monthly distribution of available measurements in the selected Köyceğiz station is given in Table 4.7.

Table 4.7 Evaporation Records Available at the Selected Station

Months	**Measurements**	**Years with Measurement**
January	29	1
February	29	1
March	31	1
April	535	18
May	558	18
June	540	18
July	558	18
August	558	18
September	540	18
October	550	18
November	483	17
December	223	11
	Total:4 634	Maximum: 18

The base of the statistics needs to be homogeneous for making reliable evaluations. Hence, due to its equal maximum number of complete measurements, April-October period was found to be the most appropriate term for this purpose. Thus, Figure 4.13 shows the change of average monthly pan evaporation during this term. In the figure, the averages for months not in the latter term, i.e averages based on less than 18 data points, are represented by single dots disconnected from the main curve.

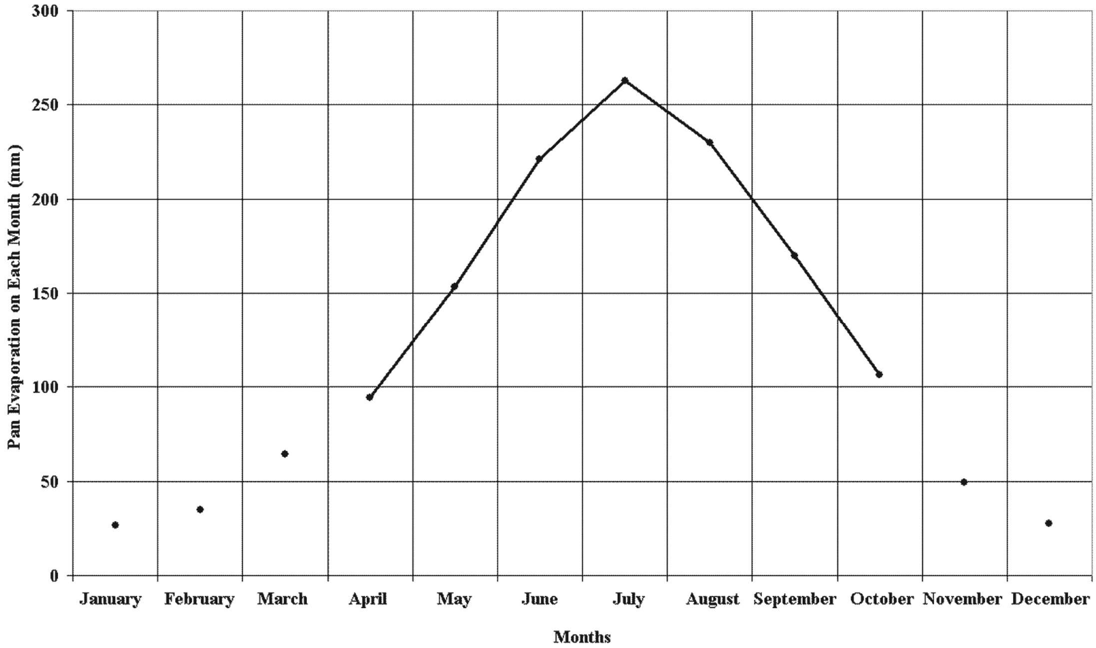


Figure 4.13 Monthly Variation of Evaporation at the Selected Station

Figure 4.13 presents almost a symmetrical curve considering that the value in April triples only in three months, when the annual peak is reached in July (263 mm). Then, the curve recedes to with almost the same but negative slope to its value in October. It is also suggested that given the trend in the April-October period, the values on January would be expected to vary between 0-10 mm. A better representation of monthly evaporation is provided in Figure 4.14 where errors arising from the unequal number of days of months are fixed by using daily evaporation averages instead of monthly totals.

July values in Figure 4.14 show an average of 8.5 mm/day. This evaporation loss decreases to 3.4 mm/day with the beginning of the raining season. Similarly, as the last storms of the spring end by April the 3.1 mm/day evaporation rate rapidly increases. Based on the obvious inversely proportional relationship between precipitation and evaporation, it would be reasonable to deduce a minimum evaporation rate in December or January.

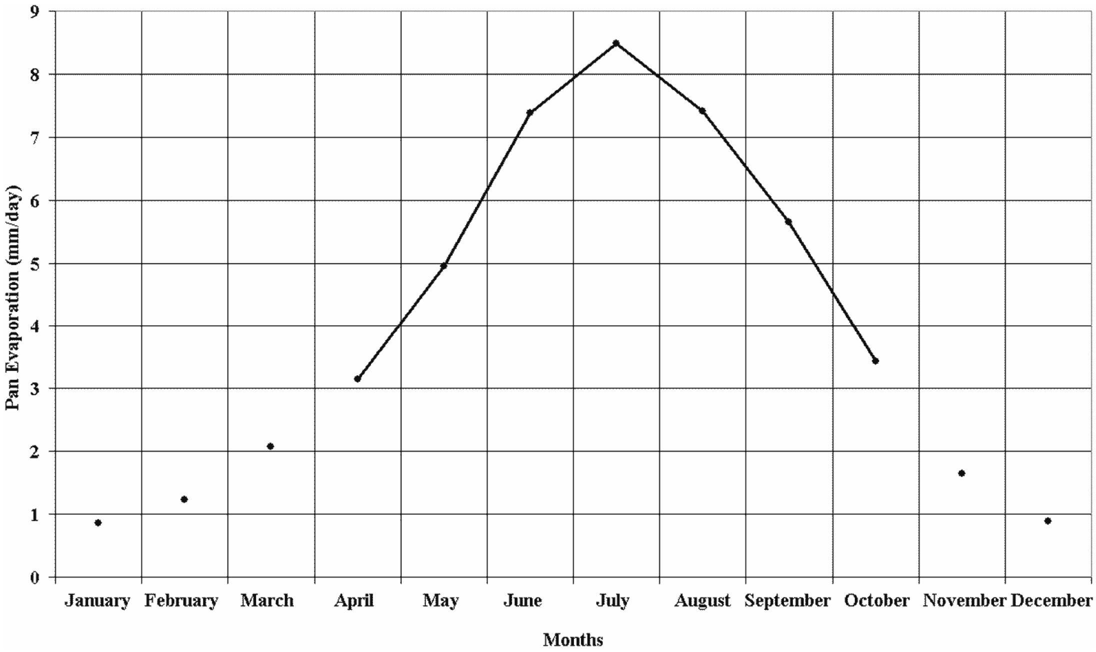


Figure 4.14 Monthly Variation of Daily Evaporation at the Selected Station

The discussions on the interrelationships between precipitation and evaporation, as well as computation of PET parameter will separately be provided in the further sections.

4.3.5 Temperature

Temperature is a major factor for many of the physical, chemical and biochemical processes in a watershed. In terms of watershed hydrology, it is the key indicator of the heat energy, which drives any water content to evaporate, thus controlling the dynamic of the hydrologic cycle.

The temperature data sets gathered from TRSMW contain triple measurements daily, and reflect a history of 25 years between 1976 and 2000. The readings are at 07:00h, 14:00 and 21:00h. In addition, summary tables for the 1953-1990 statistics were also gathered. Figure 4.15 represents the long-term trends of average 07:00h, 14:00h, and 21:00h values based on 1976-2000 data, Figure 4.16 shows monthly distribution of average 07:00h, 14:00h, and 21:00h values based the latter data set, and Figure 4.17 provides information on the change of minimum, average and maximum temperatures gathered from the records between 1953 and 1990.

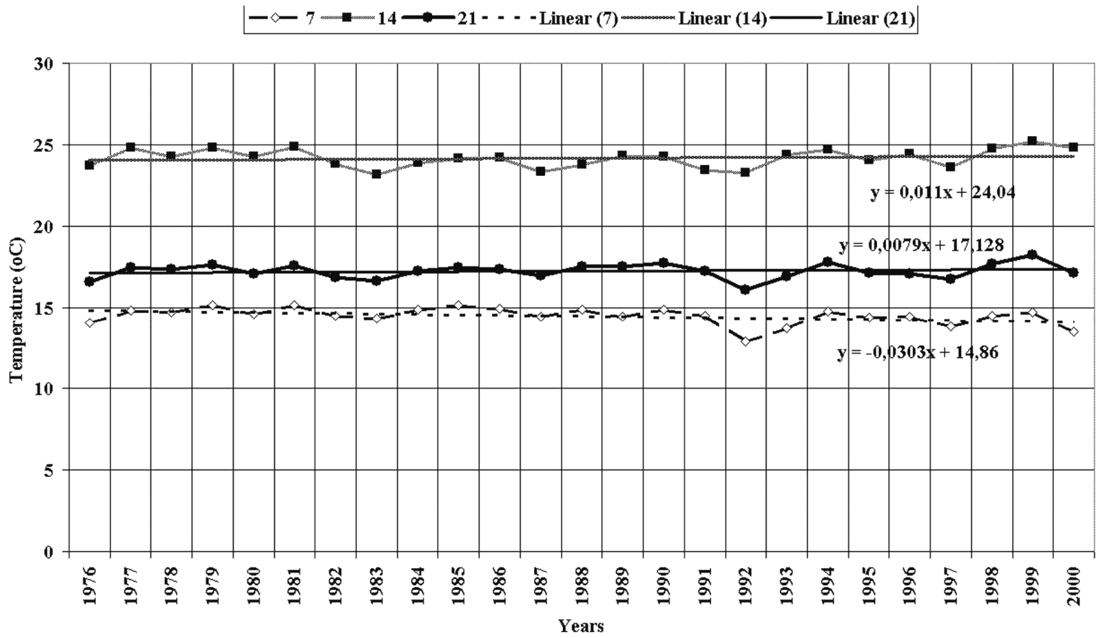


Figure 4.15 Long-Term Trends of 7:00h, 14:00h, and 21:00h Temperatures

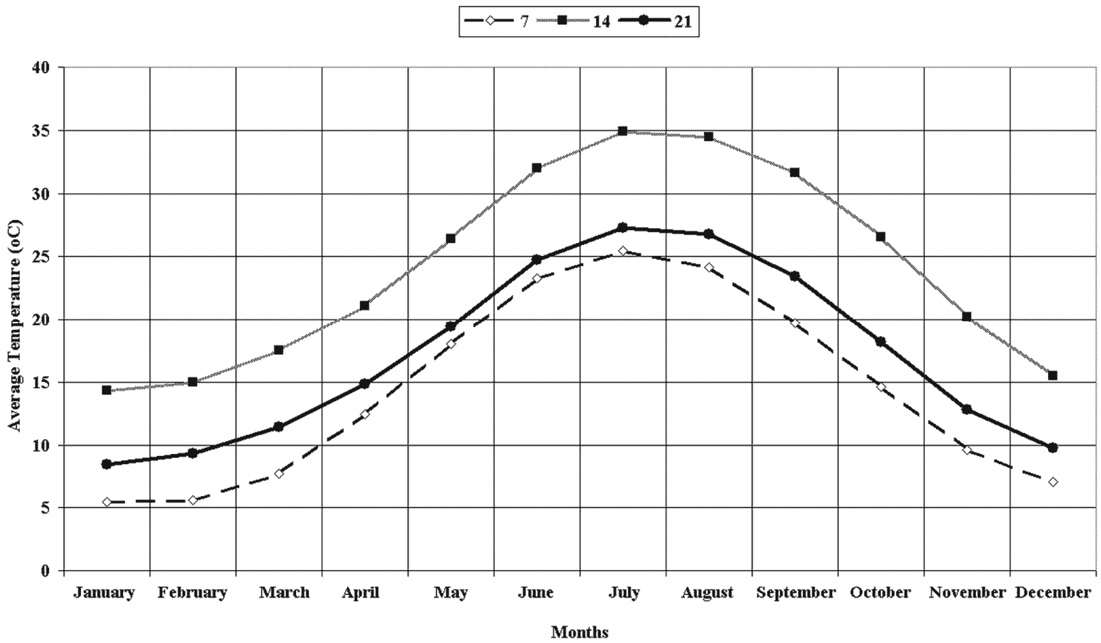


Figure 4.16 Monthly Averages of 7:00h, 14:00h, and 21:00h Temperatures on 1976-2000 Data Set

The timing of maximum and minimum temperatures during the day varies by seasonal, local, geographical and temporary conditions. Yet, analysis on the long-term temperature data show that, in summer, it is possible to expect maximum temperature values during 15:00h to 16:00h, whereas in winter, the maximum temperature should be expected between 13:30h and 15:00h. In another words, during the winter seasons it is likely to observe closeness between the 14:00h readings and the daily maximum temperature parameter. Still, for all seasons it is most probable to observe a peak of temperature shortly after 14:00h.

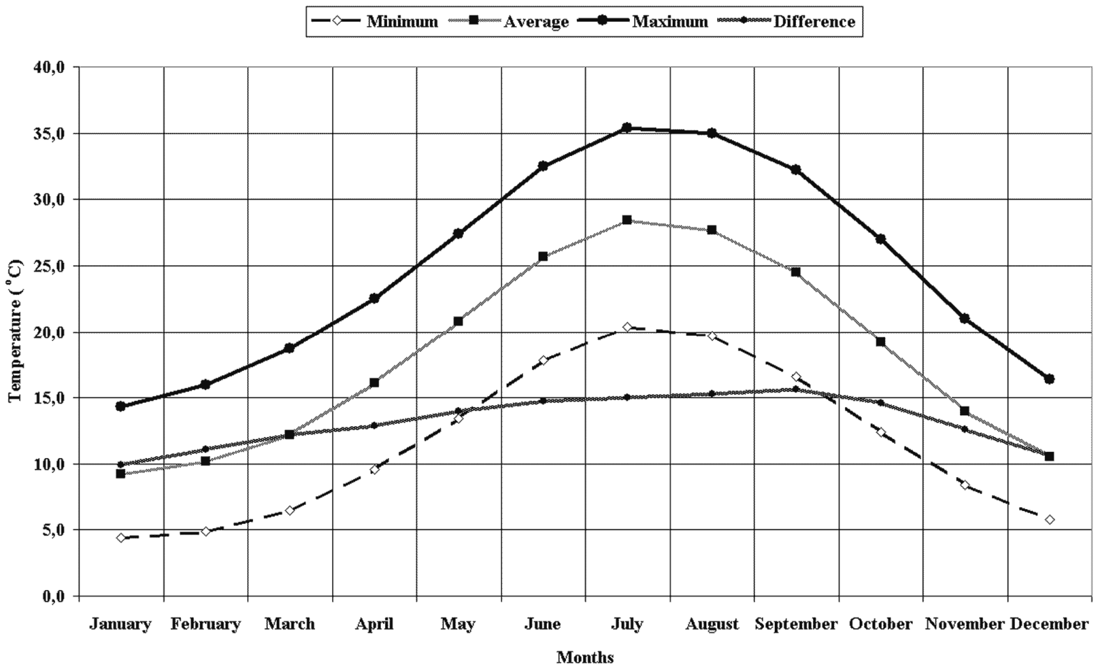


Figure 4.17 Minimum, Maximum and Average Temperatures on 1953-1990 Data Set

The trough of daily temperature curve is always met soon before the dawn. Hence, the minimal temperature values are observed from 04:00h to 05:00h during summers, whereas in the winter the decreasing temperature could last by 6:00h to 7:00h. As the solar radiation intensifies after the sunrise, the temperature rapidly increases by a few degrees Celsius. Therefore, there is a slight difference between the morning readings of temperature at 7:00h and the minimal temperature value.

However, meteorological issues by nature do not allow for accurate and steady generalizations. During the transition between the warm and cool atmospheric movements, heavy wind and storm conditions, thunder and lightning events under acute weather changes, temperatures may drastically change to higher or lower values. In fact, when a dominant and cool atmospheric wave approaches temperature gradually rises and immediately decreases due to its first contact. Such happenings may cause acute drops in temperatures as much as 5 to 10 °C even in the afternoon. Thus, the general trends may always be superseded by these kinds of exceptional occasions. The data investigation on Köyceğiz station shows that similar cases did also come into being in the history, where 7:00h readings were much above the 14:00h records.

According to the 1976-2000 data set, 7:00h, 14:00h, and 21:00h annual averages fluctuate in a narrow band with averages of 14.5°C, 24.2°C, and 17.2°C, respectively. In other words, there is a 70% increase of temperature from the morning to the afternoon. By the evening, the temperature falls to a value only 20% higher than the morning.

There is no significant evidence to deduce an effect of global warming over the data sets. As the 14:00h and 21:00h averages have a very slight increasing trend by 1% of slope, the 7:00h points down with a negative slope of 3%. Thus, it would not be scientific to interpret these evaluations as an indicator for a gradual and steady trend of climatic change.

From December to February the average temperature ranges from 5.5°C to 7.0°C at 7:00h, and is approximately 15.0°C at 14:00h and 9.0°C at 21:00h. This stable pattern increases through spring and becomes steady during July and August during when, the temperatures fluctuate around 25°C, 35°C, and 27°C in 7:00h, 14:00h and 21:00h measurements, respectively.

According to the 1963-1990 data maximum temperatures are expected in July and August period (35.0°C). The largest temperature difference is observed in September (15.6°C) and lowest in January (9.9°C).

4.3.6 Solar radiation

The solar radiation parameter is significant for evapotranspiration processes as well as the growth mechanisms of photosynthetic organisms. Solar radiation energy is derived by its intensity and duration. This parameter is measured by a device called actinograph, which plots the measured value of solar radiation in cal/cm² (Langley) unit on every minute. The minutely data are then cumulated to derive the hourly measurement. This operation is continuously applied from the sunrise to the sunset (Yıldırım and Özbilen, 2002).

However data acquired for this parameter is not rich and covers only a 6 years data set from 1985 to 1990 for solar duration and a 4 years data set between 1987 and 1990 for solar intensity parameter. These results are presented in Figure 4.18.

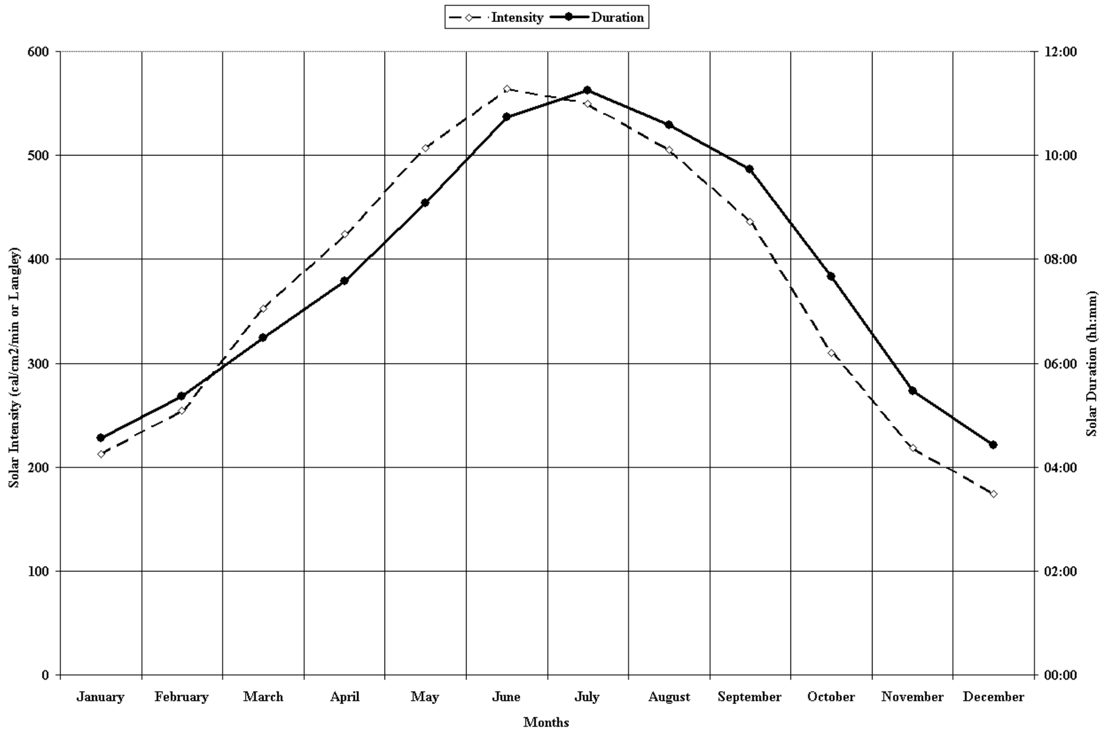


Figure 4.18 Solar Radiation

The intensity of solar radiation reaches its peak in June (564 Langleys), whereas its duration gets to its maximum at July (11 hours 15 minutes). Both components of the parameter recede to their lowest values in December by 175 Langleys of intensity and 4 hours and 25 minutes of duration. Thus, it is possible to formulate this trend by a gradual change of 3.3 times from winter season to the summer.

4.3.7 Cloudiness

Cloudiness is an important factor, which limits the solar radiation and thus controls photosynthetic growth accordingly. The data available for this parameter are the monthly averages derived from 1963-1990 statistics. Cloudiness is quantified by a scale of 0 to 10, where 0 shows clear air and 10 reflects an entirely clouded state. The distribution of the average cloudiness factor is presented in Figure 4.19. Naturally, cloudiness increases during the winter season because of the precipitation regime and vice versa in summer. Within the daily cycle, cloudiness decreases towards evenings and increases during afternoons. A typical evening in winter starts with a sky slightly covered with clouds, but clouds increasingly gather until the following day afternoon. It then decreases to its former state and completes a cycle. During the summer, the cloudiness is infrequent. Yet, after a clear night partial cloud activity might be observed for a short period during midday. Figure 4.20 reflects the occurrence of three segments of cloudiness factors. Regarding the average statistical data, it is not probably to observe a full cloudiness in the region. Despite the rainy climate, shaded weather conditions are only 30% of probability throughout the year.

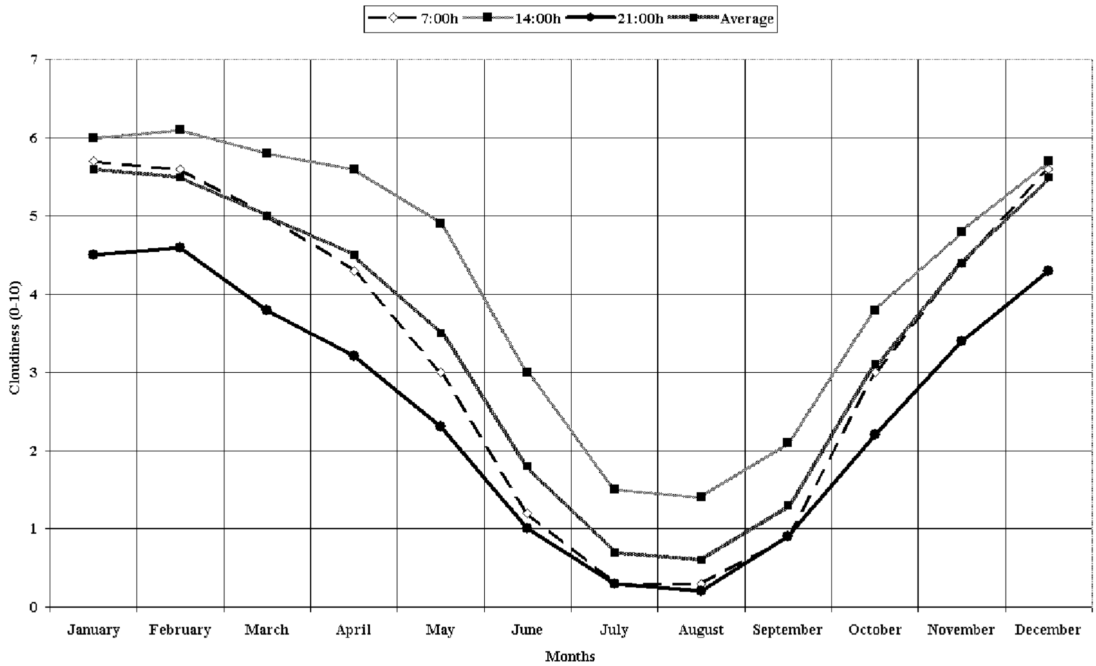


Figure 4.19 Cloudiness

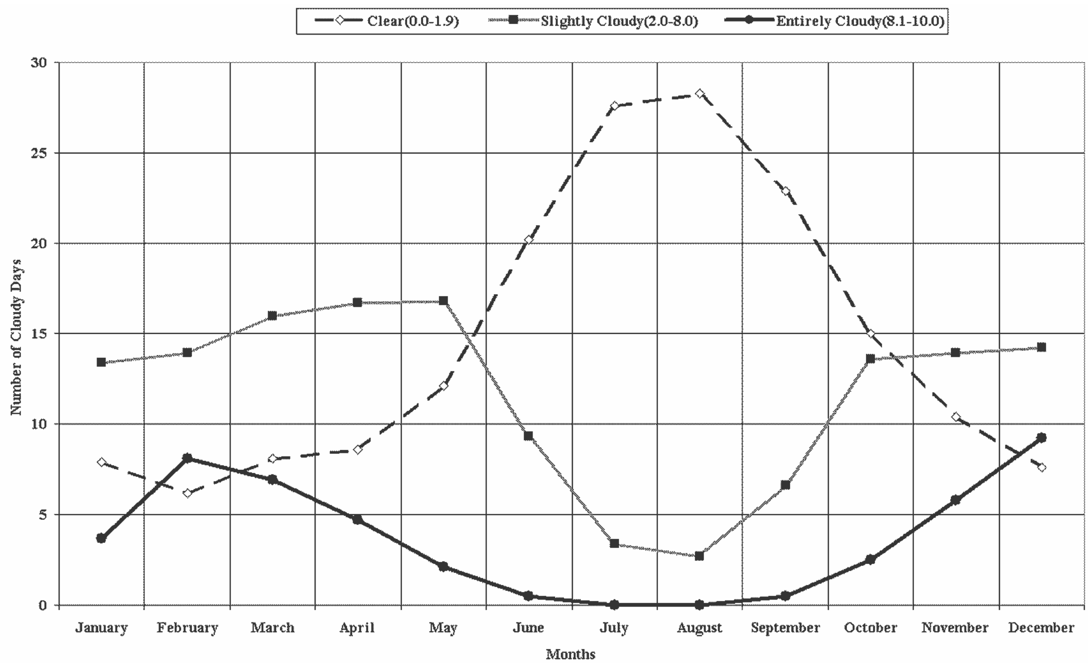


Figure 4.20 Cloudiness Occurrences

4.3.8 Wind

Wind speed is effective on surficial waters mixing mechanisms and evapotranspiration. Wind speed could be used as a time series to empirically derive evaporation with temperature and solar radiation.

Available data between 1969 and 1990 is presented in Figure 4.21. The dominant winds in the watershed range between WNW and SE directions. The highest wind occurrence is towards SSE with an average of 2323 times a year. Very closely, SSW winds blow 2303 times a year, on average. The strongest winds however, move towards NNW by 2.4 m/sec and to NNE by 2.3 m/sec. Both dominant and strong winds are WNW and SSE with a speed of 2.0 m/sec.

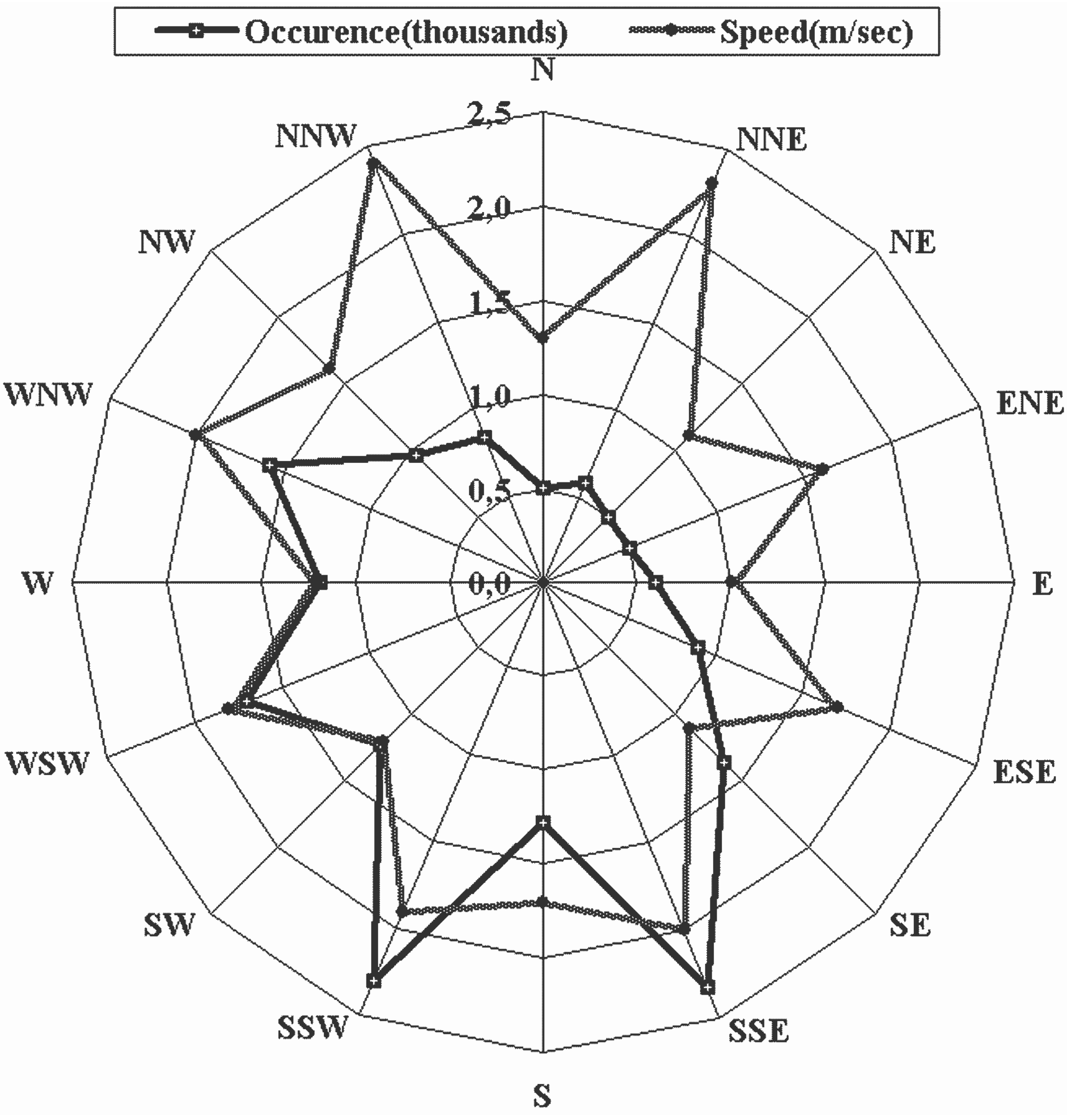


Figure 4.21 Wind

4.3.9 Humidity

Humidity might be used with wind speed in hydrological computations to estimate PET parameter. The gathered 1963-2000 data set for Köyceğiz station, was used to evaluate humidity. As seen in Figure 4.22, humidity is inversely proportional to the temperature. With higher temperatures the humidity drops and visa versa. The highest average humidity occurs in November (88%) whereas the lowest humidity is 60% in July. Finally the humidity parameter is always kept in a range of 40% to 90%.

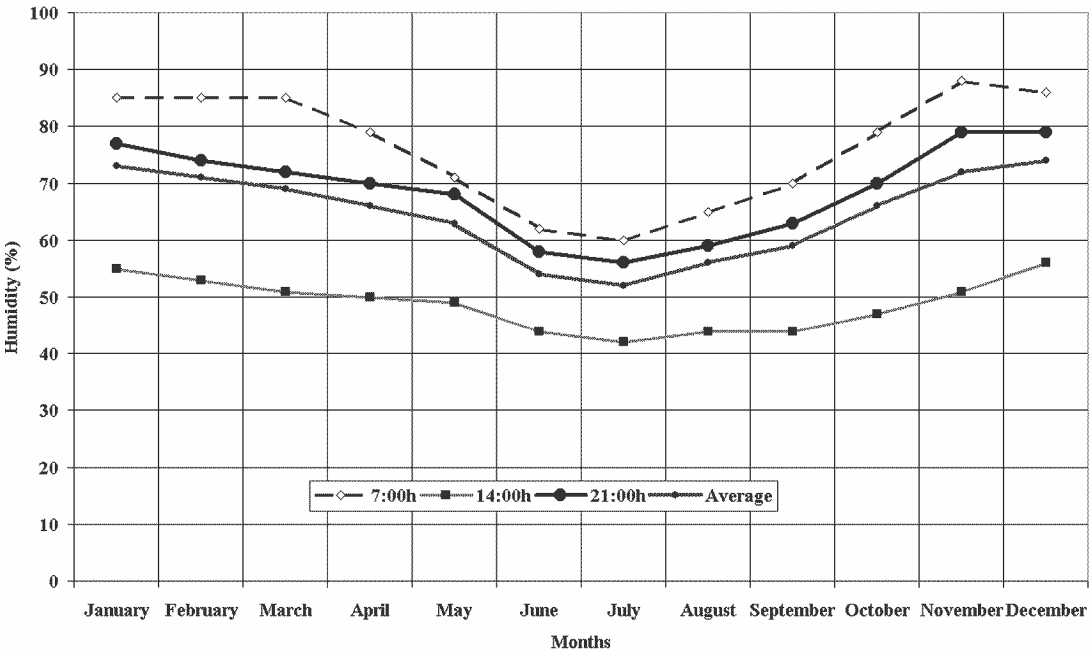
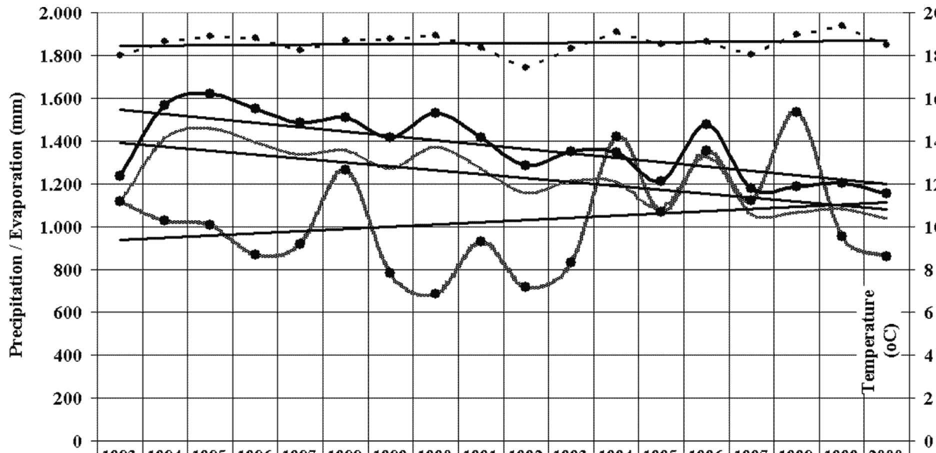


Figure 4.22 Humidity

4.3.10 Relationships among meteorological parameters

Precipitation and evaporation, as being the main source and sink respectively, and temperature, as being an indicator, are the three major parameters for rural watershed hydrology. The water budget for the watershed could only be attained, if these parameters are correctly evaluated.

As mentioned earlier there is a technical incapability to evaluate evaporation data for winter season. However, due to the highly season, it would be most beneficial to work around this problem. Appling the extrapolation technique on Figure 4.13 new synthetic average values were developed for the winter season. Then the total synthetic data to the actual 18 years averages were proportioned. Hence, the result shows that estimated synthetic winter evaporation loss (November-March) is 11% of the totals from the actual values (April-October). Therefore, it is then suggested that total of the 18 years data set for April-October period could be multiplied by 1.18 to estimate the entire pan evaporation of that year. Thus, a new data series were formed. Figure 4.23 shows the comparison of estimated evaporation, precipitation, and the average of 7:00h, 14:00h, and 21:00h temperature, data sets for the 1983-2000 term.



	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Precipitation	1120	1027	1007	869	917	1264	783	685	931	720	833	1421	1070	1357	1124	1534	954	862
Evaporation(Apr.-Oct.)	1115	1413	1459	1396	1340	1361	1274	1377	1275	1159	1218	1213	1091	1331	1062	1071	1085	1042
Evaporation (estimated)	1238	1568	1620	1550	1488	1510	1414	1529	1415	1286	1352	1347	1210	1477	1179	1189	1205	1157
Temperature	18,0	18,6	18,9	18,8	18,2	18,7	18,8	18,9	18,4	17,4	18,3	19,1	18,5	18,6	18,0	19,0	19,4	18,5

Figure 4.23 Long Term Comparison of Evaporation and Precipitation

Even though there is a positive trend line for the temperature indicator, the trend line for evaporation decreases and precipitation trend line has a positive slope. Hence based on these data, it would not be scientifically justifiable to state that temperature has a direct driving effect over the tendencies of the hydrologic system.

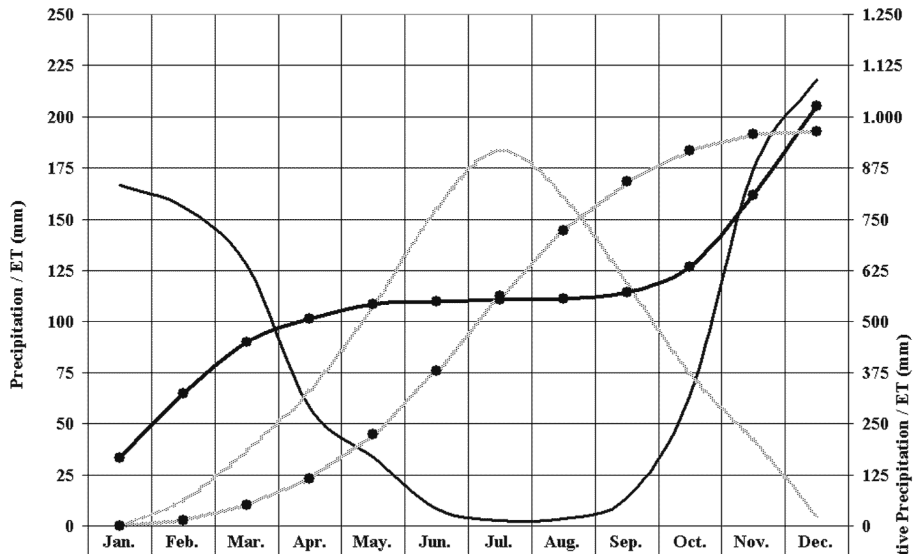
It is observed that during the 11 years term between 1983 and 1993 evaporation records always tend to be greater than the precipitation values. This would suggest that surface waters should have lost 529 mm (36% precipitation deficit) of water every year in this period. As the surface waters had not dried out yet or at the time, this would bring other resources into mind to compensate this deficit, such as groundwater inputs. Anyhow, the system seems to improve its condition since 1994 during which precipitation deficits are as low as 63 mm/year (5% precipitation deficit) on average basis, with even two years of precipitation surplus record in 1994 and 1998. Nonetheless, the 1983-1993 period might only be a result of a long wave climatologic oscillation, which might have forced the watershed to arid conditions for a while.

On the other hand, referring to the previous discussion over the concepts of pan evaporation and evapotranspiration it should be brought in mind that these pan evaporation data series must not be interpreted as a whole watershed scale loss but only a possible shortage over the surface waterbodies. Thus, as evaporation mechanisms would be much slower over and through the land segments, the overall evaporation, or in better phrasing, actual evapotranspiration, would be much less than what would be measured by the pan evaporators. If such have had been available, lysimeter recordings instead would be much more helpful to evaluate these concepts. Besides, the site visits also justified that evaporation loss in the region could not possibly be in this critical range but regarding the crop types and soil structure, the actual evapotranspiration is expected to be 30% less than what it is computed by extrapolation of gathered pan evaporation data from TRSMW. This 30% of reduction, which is based on expertise and site observations, is also justifiable by the literature where most citations traditionally report the use of 0.7 factor for calculating PET by pan evaporation data (PBS&J, 1999).

On the other hand, although data availability for precipitation is satisfactory quantity of evaporation records are not as fulfilling as precipitation data are. In addition, there might also be a slight contribution of snow melt processes arising from the northern and northwestern sections in the hydrological system, which Köyceğiz station might not be representing.

In order to harmonize these issues and revisit the watershed scale interpretation of evaporation and precipitation dynamics accordingly, the extrapolated evaporation values was reduced by 30% in order to reflect the estimated actual evapotranspiration situation and plotted on monthly basis together with precipitation data series, in Figure 4.24. As seen in this figure with the new data series, estimated actual situation of the watershed evapotranspiration are mostly compensated by precipitation. There exists an annual 63 mm surplus of precipitation. However, it should be noted that the watershed area does not cover the lake surface and hence, when the lake hydrology is studied in particular, pan evaporation data set should be regarded.

Precipitation and evapotranspiration equalizes in April and October. Cumulative balance is reached firstly on July and secondly on December. Simply, it could be stated that in the watershed, there is a cumulative balance of precipitation and evaporation every six months and in every beginning and end of the summer season, there happens a temporarily equal state of these hydrological parameters. However, all of these presumptions are to be reconsidered during the fieldwork and implementation of simulation calibration tasks.



	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Precipitation	166,66	156,13	127,65	58,08	33,54	8,54	2,76	3,54	13,87	63,57	173,98	218,26
Estimated ET	0,00	12,99	36,91	66,15	107,38	154,93	184,05	160,72	118,77	74,57	41,93	4,89
Cumulative Precipitation	166,66	322,78	450,43	508,52	542,06	550,60	553,36	556,90	570,77	634,33	808,32	1026,57
Cumulative Estimated ET	0,00	12,99	49,90	116,06	223,44	378,36	562,41	723,13	841,90	916,47	958,40	963,29

Figure 4.24 Water Budget Based on Meteorological Parameters

4.3.11 Average rainfall regime

In this section values previously presented in Table 4.5, are interpreted specifically for Köyceğiz station. The average probability and frequencies presented in the table show a statistical verification for seasonal changes. December-February period is distinct with high storm event recurrence period of 2 days, proving the winter season characteristics. March-May period shows a rapid but steady decrease in precipitation resembling the season spring. June-August term is typical with its dry summer weather, where daily storm probability is always below 10%. Finally, the September-November period presents a steady and increasing trend of precipitation showing autumn characteristics.

During the winter season, an average storm event of 16 mm/day is normally expected within every 2 days. On the other edge, it is only once or twice probable to observe a storm event during the dry summer weather. If that would happen, the expected intensity would have been 7 mm/day. Throughout the spring and autumn, there is an almost linear trend of rainfall with similar slopes in reverse directions.

These probability, frequency and intensity remarks on the average precipitation regime of the watershed, are further analyzed in terms of probable maximum flows and their statistical patterns in the following section.

4.3.12 IDF analysis

Apart from the essential functions to stream bed and canal improvements together with stormwater drainage system design, which protects the residential zones from flooding and other stormwater-flow related catastrophes; intensity, duration, and frequency analysis also guide to evaluate water quality risks and threats to the ecosystem by executing quality simulations on maximal flow conditions. This issue becomes even more critical for watersheds like Köyceğiz-Dalyan system given the dense agricultural activities and rural settlements. For instance, in order to assess the environmental impacts of a storm event with 100-year recurrence period, in terms of the acute pollution risks caused by total loads of nutrients, pesticides and heavy metals washed off and discharged via runoff, the intensity and duration of these storm events should be known. Thus, a third data set containing 26 years of maximum storms was received from TRSMW for this purpose. These data were then analyzed and tested through a series of statistical operations and eventually IDF curves were formed.

The history of maximum precipitation in Köyceğiz station starts in 1969 and until the year 2000, 26 successful recordings were made available. These records are presented in Table 4.8. The table consists of columns arranging different durations of storm events ranging from 5 minutes to 24 hours and rows listing the maximum intensity observed for each of these durations throughout a particular year stated at the first column of each row. In order to determine the most appropriate statistical distribution functions for each of the maximum storm data series with unique durations, the data series should be sorted in descending order. For each data sorted the corresponding percentiles of not exceeding that particular maximum storm value is also tabulated. However, for this purpose the data series was standardized by the Chegodaiev formula:

$$p = 1 - \frac{(n-0.3)}{(N+0.4)} \tag{3.1}$$

where;

p = probability of not exceeding the threshold value,

n = rank of the data from 1 being the minimum value and number of observations, being the maximum value, and

N = number of observations, i.e. maximum storm value observed by a stated duration.

Table 4.8 Maximum rainfall data

Year	Annually Observed Maximum Rainfall Events with Various Durations (mm)													
	5 m	10 m	15 m	30 m	1 h	2 h	3 h	4 h	5 h	6 h	8 h	12 h	18 h	24 h
2000	7.90	9.50	11.30	13.90	20.40	35.00	47.80	57.00	65.40	70.50	79.20	95.50	110.60	118.80
1999	17.90	20.50	26.10	34.10	35.80	36.80	39.20	39.30	39.40	39.40	39.40	39.50	39.60	39.60
1998	8.50	12.60	18.10	31.30	45.00	76.70	87.50	90.10	91.50	93.40	96.10	131.50	151.30	239.20
1997	6.40	9.90	14.60	21.00	27.90	33.00	36.80	37.50	39.60	45.30	54.00	71.90	81.60	88.10
1996														
1995	6.30	9.80	14.50	24.40	29.30	29.40	31.80	33.40	37.70	43.10	51.60	57.30	61.80	83.30
1994	9.40	13.20	17.50	34.20	59.20	78.80	109.80	118.60	125.40	125.70	126.60	126.90	127.00	127.00
1993	5.00	8.80	12.00	18.90	21.70	23.40	28.40	30.90	32.30	35.10	37.30	46.80	47.70	53.20
1992	9.20	14.20	16.50	17.00	20.80	27.80	27.80	30.40	31.30	35.80	35.80	50.10	50.10	53.10
1991	10.20	19.60	28.60	39.90	56.50	66.80	75.00	75.80	76.50	76.60	76.70	82.60	83.50	83.60
1990	8.50	12.10	13.10	21.80	33.70	43.40	46.20	55.50	68.60	79.30	87.10	87.40	87.40	88.70
1989	7.60	14.10	18.40	29.20	54.20	68.40	68.40	70.00	76.50	80.00	80.00	83.20	88.40	96.60
1988	6.50	7.60	10.30	13.50	19.40	20.80	29.30	37.30	48.20	56.70	66.70	77.90	88.60	92.40
1987														
1986														
1985	10.20	12.10	12.80	23.40	26.10	40.10	52.40	57.10	66.00	72.30	74.30	74.30	83.50	90.20
1984	4.20	5.20	9.20	15.60	22.10	40.60	44.00	44.40	45.20	49.40	52.20	59.40	64.30	65.30
1983	9.10	14.60	18.30	27.20	32.10	41.20	48.10	48.50	57.40	57.70	64.20	76.10	76.10	81.20
1982	13.80	18.00	22.30	30.30	40.50	43.60	43.90	47.90	48.50	48.90	50.20	78.70	78.70	116.80
1981														
1980														
1979	16.40	23.20	27.50	34.70	48.20	67.00	69.40	69.40	69.60	69.60	69.60	82.50	89.40	126.10
1978	11.50	13.10	15.30	19.20	32.80	39.80	39.60	39.80	39.80	39.80	39.80	45.40	58.70	83.50
1977														
1976	9.60	15.00	19.00	24.10	40.10	48.40	49.20	49.30	49.50	49.70	61.40	61.40	61.40	76.40
1975	12.20	19.20	20.90	33.10	38.20	41.80	41.90	43.30	47.90	53.60	55.70	57.60	73.70	75.80
1974	7.00	10.40	12.70	13.30	19.00	21.70	22.20	25.00	27.60	31.80	42.30	44.00	68.00	82.40
1973	11.00	14.10	14.50	16.70	24.00	44.00	51.70	64.40	72.10	75.20	75.90	78.50	85.30	85.30
1972	10.00	14.10	18.30	27.20	35.20	36.10	36.40	40.30	44.10	44.60	45.10	61.50	68.80	68.80
1971	8.00	15.00	20.00	23.10	25.70	32.90	39.40	49.60	59.50	69.30	83.00	110.10	115.50	115.50
1970	11.20	18.50	25.90	32.20	48.70	80.60	81.70	84.80	88.30	92.00	93.60	100.50	100.50	100.50
1969	9.30	15.40	22.30	33.90	40.80	49.80	59.60	67.70	69.60	71.00	71.40	71.40	83.40	112.30

As the probabilities of not exceeding the upper thresholds are determined for each data, these computed data series for each of the storm durations are tested for compatibility with Normal, Log-Normal, Gamma-II, Gumbel, Pearson-III and Log-Pearson-III statistical distribution functions. The required statistical parameters for each distribution function, such as, average, standard deviation, skewness, etc., are also calculated. For each of the storm durations these analyses are reexamined in terms of compatibility with the six statistical distribution functions. Hence, the most appropriate statistical distribution functions are determined by ranking their performance for each datasets of different durations. This ranking is decided upon a regression analysis for each of the durations between each distribution function results and targeted standardized observations for that duration. The rankings for each duration are then used for an overall interpretation of the performance of these statistical functions. Thus, the results of the study show that the compatibility of the distribution functions are in the sorted as; Log-Pearson-III, Log-Normal, Pearson-III, Gamma-II, Gumbel and Normal. Finally, these results were tested for a power function by which it would be possible to estimate the precipitation, dependent on the duration of the storm and the coefficients predetermined in accordance with the target recurrence period. The expression is as follows:

$$i = a \cdot t^{b} \tag{3.2}$$

where;

i = precipitation in mm,

t = storm duration, and

a,b = coefficients for a specific target recurrence period (2, 5, 10, 25, 50, and 100 years)

A typical critical flood analysis would require precipitation value estimation on a 100-year period storm event. Hence, as the results of the study show that the most appropriate statistical function is Log-Pearson III, the related formula would be:

$$i = 61.5897 \cdot t^{0.4178} \tag{3.3}$$

The results of the Log-Pearson III distribution for precipitation and intensity are presented in Tables 4.9 and 4.10 and plotted in Figure 4.25. Further numerical and graphical details for all statistical distributions are provided with high detail in Gönenç *et al.* (2002a).

Table 4.9 Rainfall Results of IDF Analysis on Log-Pearson III Distribution

Rainfall Duration	Rainfall (mm)											
	Standardized Observations						Formulated Rainfall (i = a·t^b)					
	2 years	5 years	10 years	25 years	50 years	100 years	2 years	5 years	10 years	25 years	50 years	100 years
5 min	9.09	11.93	13.68	15.78	17.28	18.72	11.02	14.41	16.42	18.73	20.32	21.81
10 min	13.74	17.53	19.47	21.45	22.65	23.67	14.38	18.87	21.59	24.78	27.02	29.14
15 min	16.99	21.92	24.99	28.70	31.35	33.92	16.79	22.09	25.34	29.19	31.91	34.51
30 min	24.41	31.66	35.85	40.60	43.80	46.74	21.89	28.93	33.32	38.62	42.42	46.10
1 h	32.48	43.66	51.03	60.31	67.23	74.14	28.55	37.87	43.80	51.09	56.39	61.59
2 h	41.60	57.67	68.65	82.88	93.71	104.79	37.22	49.58	57.59	67.59	74.96	82.28
3 h	45.81	64.16	77.38	95.35	109.69	124.78	43.47	58.04	67.59	79.61	88.54	97.46
4 h	49.63	68.66	82.21	100.46	114.92	130.04	48.54	64.91	75.73	89.41	99.65	109.91
5 h	54.20	74.26	87.99	105.81	119.41	133.34	52.87	70.79	82.70	97.84	109.21	120.65
6 h	57.80	77.83	91.36	108.74	121.89	135.28	56.69	75.99	88.87	105.32	117.70	130.20
8 h	62.45	82.35	95.14	110.96	122.55	133.97	63.29	84.98	99.56	118.29	132.46	146.83
12 h	71.57	93.40	107.33	124.47	136.98	149.27	73.92	99.48	116.85	139.33	156.46	173.93
18 h	78.69	100.99	114.73	131.19	142.87	154.11	86.33	116.46	137.14	164.11	184.82	206.04
24 h	86.85	117.40	138.98	167.82	190.51	214.19	96.39	130.24	153.64	184.32	207.99	232.35
						a	28.5456	37.8696	43.8035	51.0885	56.3875	61.5897
						b	0.3829	0.3887	0.3949	0.4037	0.4107	0.4178

Finally as a comparison of the average and maximum rainfall regimes it could be stated that a 5 minutes storm with a recurrence period of 100 years, could cause a rainfall intensity of 225 mm/hr which would correspond to the a scale 19 mm of rainfall which is 1 mm greater than the average rainiest December daily rainfall. On the other hand, a 24 hours storm with again a recurrence of 100 years could cause an

8 mm/hr rainfall intensity, which would almost equal the entire monthly rainfall in the rainiest December (215 mm). Hence, these conditions should be taken into consideration for prospective modeling efforts on risk assessment on agricultural runoff loads.

Table 4.10 Intensity Results of IDF Analysis on Log-Pearson III Distribution

Rainfall Duration	**Rainfall Intensity (mm/hr)**											
	Standardized Observations						**Formulated Intensity ($I = t^{-1} \cdot a \cdot t^{b}$)**					
	2 years	**5 years**	**10 years**	**25 years**	**50 years**	**100 years**	**2 years**	**5 years**	**10 years**	**25 years**	**50 years**	**100 years**
5 min	109.12	143.10	164.13	189.38	207.32	224.58	132.26	172.96	197.01	224.76	243.82	261.66
10 min	82.43	105.18	116.85	128.68	135.88	141.99	86.25	113.25	129.55	148.71	162.10	174.82
15 min	67.96	87.70	99.98	114.80	125.41	135.66	67.15	88.38	101.35	116.76	127.64	138.05
30 min	48.83	63.32	71.70	81.20	87.60	93.49	43.78	57.85	66.63	77.24	84.84	92.21
1 h	32.48	43.66	51.03	60.31	67.23	74.14	28.55	37.87	43.80	51.09	56.39	61.59
2 h	20.80	28.84	34.33	41.44	46.86	52.39	18.61	24.79	28.80	33.79	37.48	41.14
3 h	15.27	21.39	25.79	31.78	36.56	41.59	14.49	19.35	22.53	26.54	29.51	32.49
4 h	12.41	17.16	20.55	25.12	28.73	32.51	12.13	16.23	18.93	22.35	24.91	27.48
5 h	10.84	14.85	17.60	21.16	23.88	26.67	10.57	14.16	16.54	19.57	21.84	24.13
6 h	9.63	12.97	15.23	18.12	20.32	22.55	9.45	12.66	14.81	17.55	19.62	21.70
8 h	7.81	10.29	11.89	13.87	15.32	16.75	7.91	10.62	12.45	14.79	16.56	18.35
12 h	5.96	7.78	8.94	10.37	11.41	12.44	6.16	8.29	9.74	11.61	13.04	14.49
18 h	4.37	5.61	6.37	7.29	7.94	8.56	4.80	6.47	7.62	9.12	10.27	11.45
24 h	3.62	4.89	5.79	6.99	7.94	8.92	4.02	5.43	6.40	7.68	8.67	9.68

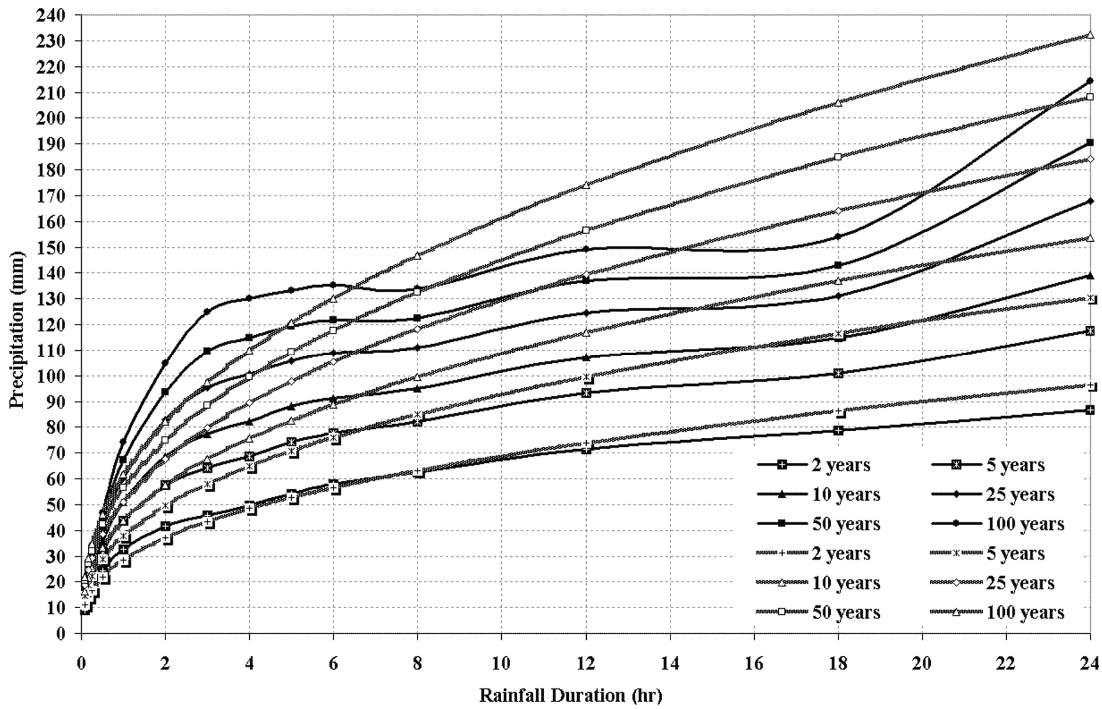


Figure 4.25 Log-Pearson III Distribution of Maximum Precipitation

4.4 Mapping

The sections under this topic deal with various map operations prior to initial GIS activities concerning quality improvements and preprocessing of data. These tasks are summarized in the following sections.

4.4.1 Base maps

The digital topographical base maps received from the TAFGCM by a special protocol. The gathering of resource inventory initiated with the topography of the watershed. This layer is important in determining the appropriate irrigation method and efficiency, run-off characteristics as well as erosion and flood risks. On the other hand, this layer is also important as it is the "base map" and all geographical coordinate references, therefore, should be associated with this layer. In addition, in order to better visualize the watershed within the digital environmental, digital elevation models are developed. This issue will be discussed under the topics related to GIS.

4.4.2 Soil maps

In 2001, GIS experts in TRGDRA-NIC, Ankara were asked for their assistance on the use of purchased soil maps. Some polygon errors that were encountered in the soils maps and erroneous entries in their attribute tables were fixed through a cooperative study with these experts in Ankara. Major soil groups and recent land use maps which were parts of these set of GIS layers, were then used to analyze together with the basin and catchment boundaries in order to judge whether or not a segmentation should be considered to reflect the hydrological characteristics of a particular basin. These issues are discussed in further detail in sections related with segmentation and modeling implementation. Brief information, however, is provided herein, about the 7 major soil groups in the watershed.

- Alluvial Soils: They exist on the northwestern and southeastern banks of the Köyceğiz Lake. These soils are formed by the accumulation of sediments conveyed by the streams. Thus, their mineral structure is heterogeneous and dependent on the dominant geological characteristics of the streams they are brought by and the structures they were in contact with throughout their transport. They are rich in lime and rather present a multi-layer texture. Alluvial soils show poor infiltration characteristics if they are finely grained and are subject to high water. They tend to have humid surface with rich organic content. On the other hand, if they are coarsely grained then they perform suitable drainage characteristics and thus dry rapidly on top layers. They are versatile to climatic conditions and hence, are a most appropriate soil group for any kind of fertile agricultural growth.
- Hydromorphic Alluvial Soils: This soil group is rather rare in the watershed and could be observe along the riparian of the lake and the lagoon system. These soils are formed under the dominance of water effects. Because of their plain topography, they are found together with high or above-surface waters. Thus, they always have high water content. They might be subject to oxidation and reduction reactions throughout the vertical groundwater movements. Natural expected land cover would comprise grass, meadows, various riparian vegetation and other hydrophilic crops. With improved drainage, the spectrum of available crops could be diversified.

- Alluvial Wetlands: These lands are situated along the shores of the lakes and the sea. Depending on the salinity characteristics of the waterbody they contact, they might have fresh, slightly saline, soda, slightly saline-soda or saline-soda structure. Thus, they lack agricultural significance.

- Co-alluvial Soils: The majority of these soils are located on areas towards northeast from the Lake. It is generally possible to encounter this soil type downhill to areas with high slope or at the entrance of valleys. Gravitation, landslide, runoff and tributary streams are the major elements, which cause the transportation of these materials to accumulate and form co-alluvial soil layers in time. Precipitation and runoff intensity dictates particle sizes and their layering. However, unlike to alluvial layers they are much more irregular. Those located at the edge of high slopes or valley entrances are poor of earth and generally contain coarse stones and rocks. The layer slopes are unique and increases towards downstream to the water resources they are formed by. They also show well drainage characteristics.

- Red-Brown Mediterranean Soils: This is a well-developed soil type with medium organic content, perfectly mixed with minerals. Color of this type could be red or brown and they would have a shape of prismatic blocks with straight edges. They are observed in arid, humid and semi-humid climatic conditions. Its material structure contains mainly hard calcite, granite on mountainous regions, clay stones, and various metamorphic crystal rocks.

- Brown Forest Soils without Lime: This soil type is dominant in the watershed. Its color ranges from brown to light brown. Due to surface washoff the upper zone is generally more acidic then the lower zone. Natural vegetation on this soil types are grass or shrubs. Climatic characteristics are semi-arid or semi-humid. This soil types are composed of mainly deposits with gravels, sand and clays.

- Other soil types: Bare rocks without any soil cover, dry stream beds, red-yellow paudsolic soil groups are insignificantly found in the watershed.

Soil maps gathered from the TRGDRA-NIC also show land capability classification, which is a method of land evaluation to indicate the specified potential use of a land. Such classification is usually presented as a thematic map with standard legends for land capability classes. There are eight standard major classes (I to VIII) universally accepted, ranking land-use potential on a “best” (I) to “worst” (VIII) basis for specified categories of agricultural uses. The land classification map for the watershed is shown in Figure 4.26. All the referred classes may be observed in the area (Tanık *et al.*, 2003). These classes could be described as follows (Frevert *et al.*, 1993):

- Class I indicates land suitable for regular cultivation where no special conservation measures are necessary.
- Class II refers to land suitable for regular cultivation requiring simple soil conservation measures.
- Class III states the land suitable for regular cultivation requiring intensive soil conservation measures.
- Class IV addresses land suitable for grazing and occasional cultivation requiring some erosion control measures.
- Class V points out land suitable for grazing and occasional cultivation requiring intensive soil conservation works.
- Class VI reflects land suitable for only grazing.
- Class VII presents land that is steep, infertile, or has shallow soils.
- Class VIII describes land, which should not be cultivated, and grazed.

Within each of these classes, sub-classes may also be used to indicate the nature of the land-use constraints. United States Department of Agriculture (USDA), uses the following sub-class categories; e: erosion hazard, w: excess water problems, s: soil root zone limitations (such as shallowness and stoniness), and c: climatic constraints. Figure 4.27 presents the international soil sub-groups classification standard used in this study.

Other soil characteristics that are gathered separately are demonstrated in Figure 4.28. The figure indicates the drainage characteristics and fertility capability of different soil types observed in the watershed.

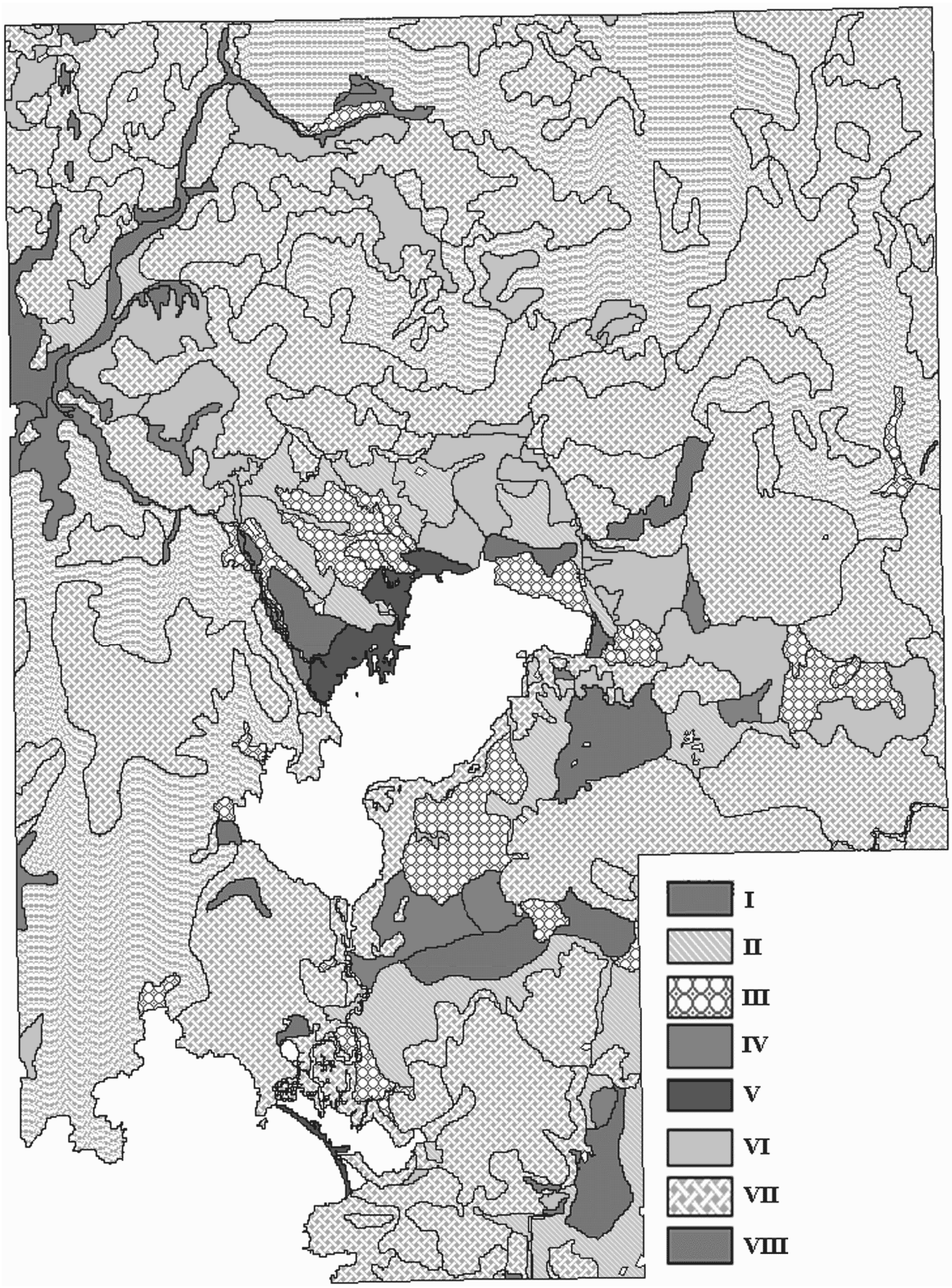


Figure 4.26 Soil classes

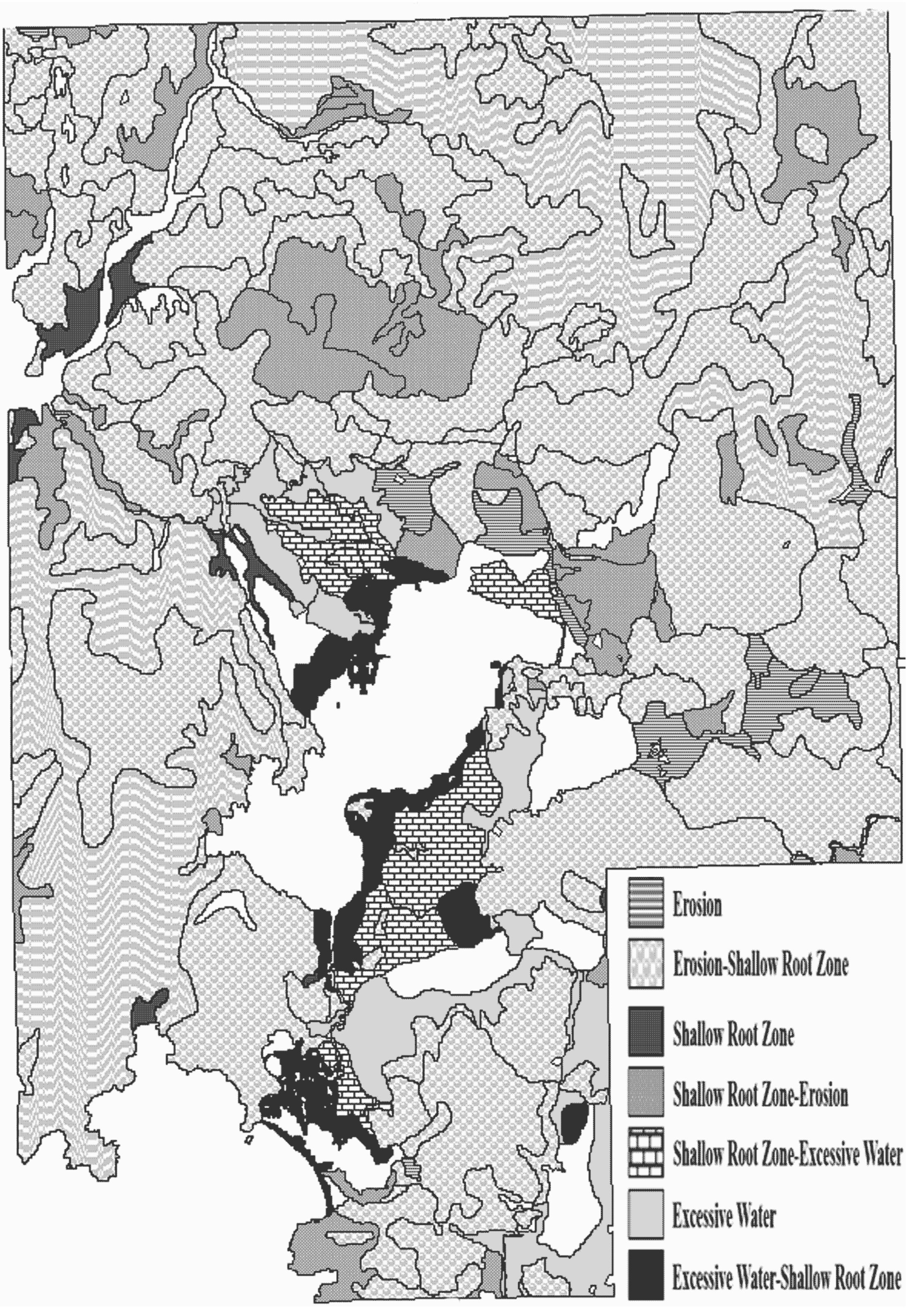


Figure 4.27 Soil sub-groups

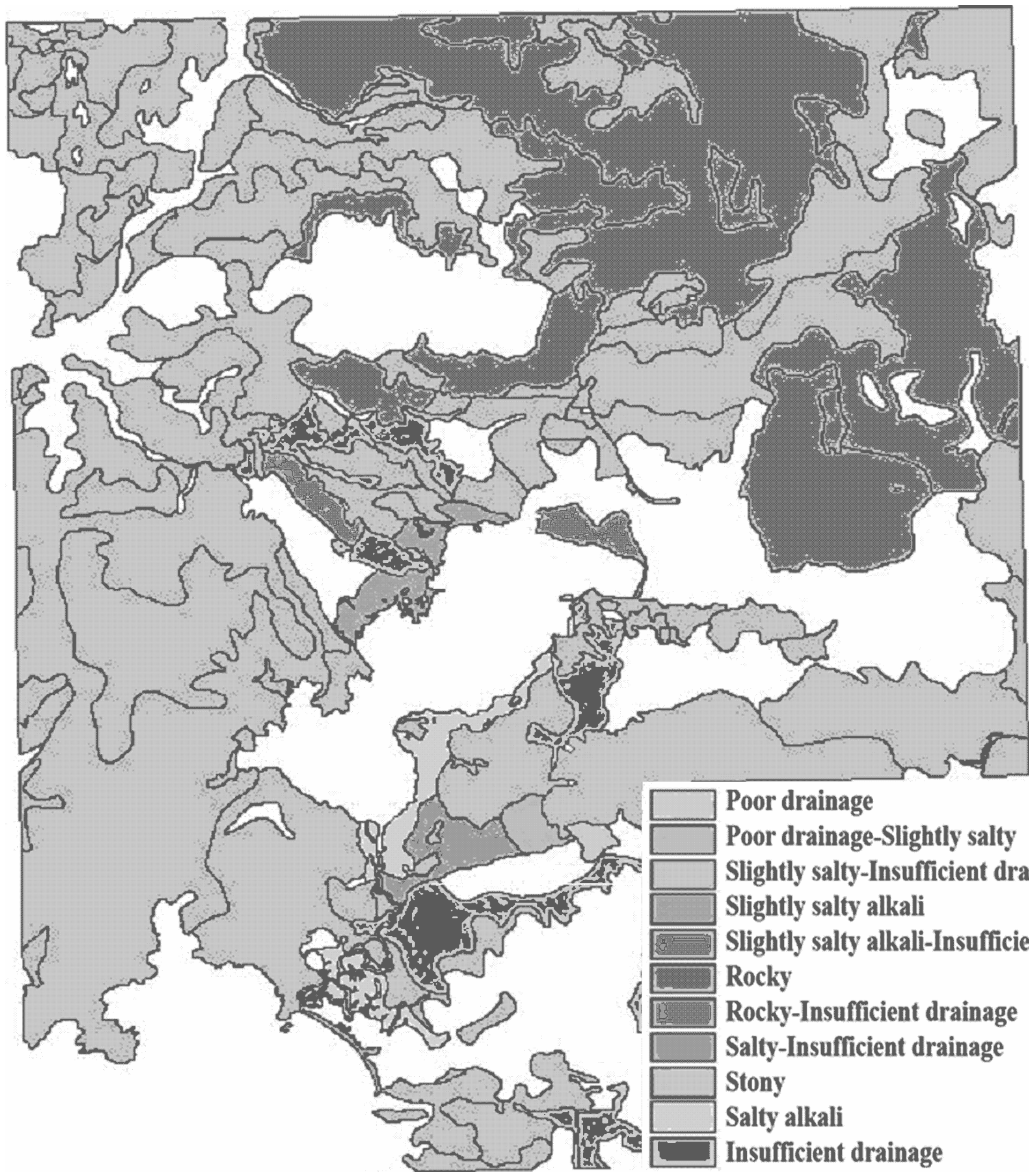


Figure 4.28 Other Soil Characteristics

4.4.3 Other maps

The socio-demographic data shows location of the settlements and the status of population distribution in the watershed. These are important factors in terms of evaluating the scale of imperviousness as well as the relationships between soil structure and land use. There exist no populated cities in the watershed, but two larger towns, Köyceğiz and Dalyan. Almost 75% of the population resides in the Köyceğiz Lake sub-watershed (northern to the lake-lagoon junction), whereas the rest lives in the Dalyan Lagoon sub-watershed (southern to the lake-lagoon junction until the Mediterranean coast). The coordinates of villages were obtained from the TAFGCM and then transformed to UTM Coordinate System to integrate this layer with the rest of thematic maps. Natural monuments and human-made infrastructure characteristics of the watershed must also be known to better understand the land and water properties. Such a survey will act as a guide during development of a management strategy. Other maps, which are directly used for GIS purposes, are provided in further sections.

4.5 Basins and Sub-catchments in the Watershed

The watershed boundaries were initially delineated on an analogue map. This analogue map was then digitized and furthermore, the produced digital map was eventually verified via Watershed Modeling System 6.1 (WMS) developed by US Army and Brigham Young University, UK (Akbulut, 2002). The final delineation of the basins is presented in Figure 4.29. The outcome of the basin maps was attained due to a long process of digital mapping operations by which the base maps shown in Figure 4.1 were merged and an elevation model is visualized.

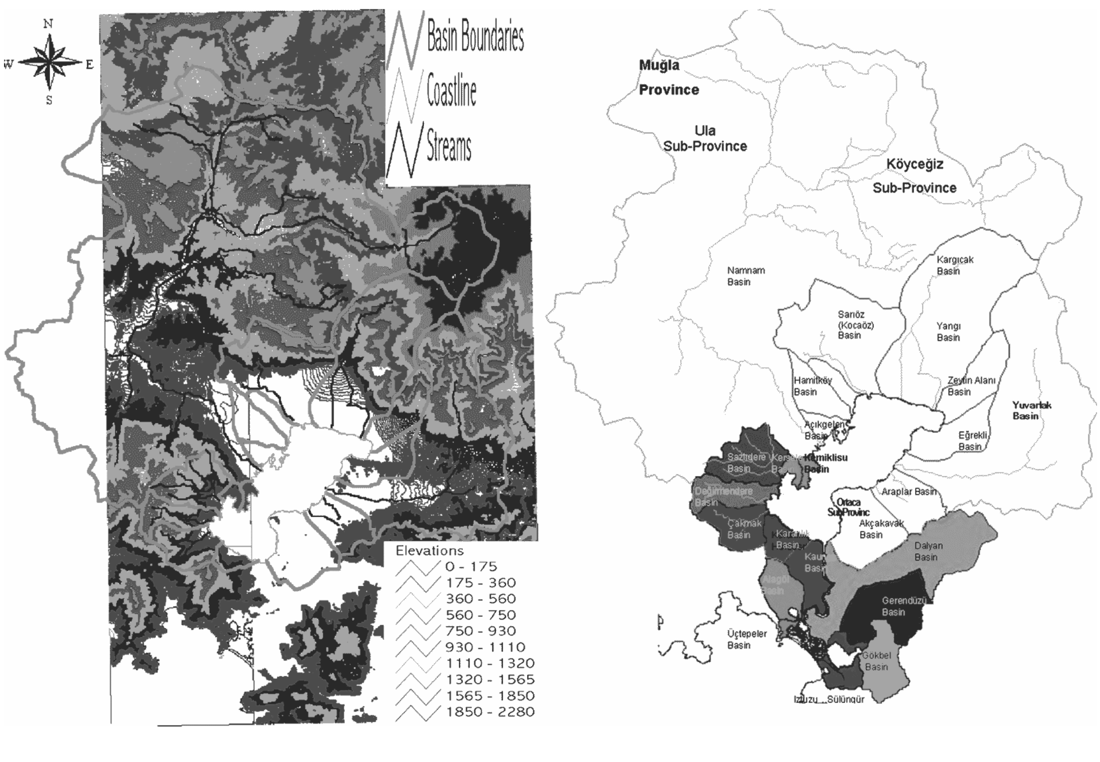


Figure 4.29 Basins

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. Clockwise from the İztuzu Beach at the junction of Mediterranean and the lagoon system; Üçtepeler, Sıratepeler, Mulazımoturağı, Gezbel, Sığırkuyruğu and Mezargedik hills form the southwest borderlines. Due to the large basin of Namnam Creek, which extends along north and northwest until it reaches the tops of Gölgeli Mountains at an elevation of +2 000m, 22 km away from the Lake Köyceğiz, the basin boundaries extend another 27 km of distance to north and follow the mountains. Following a series of mountains and hills on northeastern direction, the Namnam basin ends and after forming a short border to the Kargıcak basin, the second greatest basin Yuvarlak is reached to form eastern boundaries of the watershed. Starting from the latter, Kocabel, Bambal, Kuştüneği, Tüylü, Bayraklı, Oyuk, Kaldırayk, İncircik, Çobandağ, Arpatarlası ve Bozburun hills form the southeastern boundaries and connects to the south.

Two sub-watersheds could easily be perceived when the entire watershed is viewed:

- The Köyceğiz Lake Sub-watershed: The entire group of basins discharging into the Lake Köyceğiz comprising the major streams; Namnam, Kargıcak, and Yuvarlak, as well as many minor others.
- The Dalyan Lagoon Sub-Watershed: Starting from the lake-lagoon junction on north and extending until the Mediterranean shorelines, in which Lake Alagöl, Lake Sülüngür, and other minor lakes, together with the complex channel system and numerous minor streams connected to them.

As presented in Figure 4.29 these two sub-watersheds are split by many stream drainage basins. A list of these basins, together with the land use characteristics and their quantitative spatial distribution, is provided in Table 4.11.

4.6 Preliminary GIS Study

There existed an earlier progress on creating a GIS platform for the watershed, by which spatial data from the watershed could be assembled on a location-based framework. For this purpose, researches by Üstün (1998), Gürel (2000) and Temelatan (2001) brought a GIS platform into being designated for water quality data in the watershed. This study was then extended by

Gönenç *et al.* (2002a, 2002b), Büyükbay (2001), and Tanık *et al.* (2003) for GIS applications on land based sources.

Table 4.11 Basins and Land Use

Basins	Type*	Land Use (ha)						Area		
		Forest	Wetlands Reed Beds	Agriculture	Settlements	Rocks	Other	Total (ha)	Percentage in Watershed	Percentage in Sub-Watershed
Köyceğiz Lake Sub-Watershed		63 569	8 604	9 814	10 930	4 743		97 660	88.75%	100.00%
Namnam Basin	1	45 336	3 022	4 232	4 232	3 627		60 449	54.94%	61.90%
Other Basins		18 233	5 582	5 582	6 698	1 116		37 211	33.82%	38.10%
Karanlık Basin	1									
Çakmak Basin	1									
Değirmendere Basin	1									
Sazlıdere Basin	1									
Kersele Basin	1									
Kemiklisu Basin	1									
Açıkgelen Basin	1									
Hamitköy Basin	2									
Sarıöz (Kocaöz) Basin	1									
Kargıcak Basin	1									
Yangı Basin	1									
Zeytin Alanı Basin	1									
Eğrekli Basin	1									
Yuvarlak Basin	1									
Araplar Basin	1									
Akçakavak Basin	1									
Dalyan Lagoon Sub-Watershed		8 157	656	2 970	0	0	594	12 377	11.25%	100.00%
Üçtepeler Basin	3	127						127	0.12%	1.03%
Alagöl Basin	4	1 145						1 145	1.04%	9.25%
Kaunos Basin	3	870						870	0.79%	7.03%
Dalyan Basin	3	1 653		2 435			594	4 682	4.25%	37.83%
Gerendüzü Basin	3	2 289		286				2 575	2.34%	20.80%
Gökbel Basin	3	1 373		217				1 590	1.44%	12.85%
Sülüngür Lake Basin	4	445		32				477	0.43%	3.85%
İztuzu Basin	3	255						255	0.23%	2.06%
Wetlands	5		656					656	0.60%	5.30%
Entire Watershed		71 726	9 260	12 784	10 930	4 743		110 037		
(*) 1-Stream drainage, 2-Artificial channel drainage, 3-Lagoon drainage, 4-Lake/lagoon drainage, 5-Wetland										

The foremost prerequisite for developing a GIS framework is to set all thematic digital geographical maps in the same coordinate system and preferably in the same spatial resolution with the base maps. Examples to the thematic maps are; land use, soil information (structure, type and classes), geology, erosion, cultivability, crop types, streams and other surface waterbodies, administrative boundaries, settlements, natural reserves, roads, etc. All of these layered data assist the model implementation process by providing location-based data, for basin segmentation by agricultural applications, soil types and land use, pre-analysis and design of the fieldwork plan, basin geometry, etc. Hence, together with all other previously processed layers related to the entire aspects of integrated watershed a part of or other than NPS, an overall preliminary GIS platform was reformed in ArcView environment. Figure 4.30 represents on of the earlier studies on fine digitization of the lagoon system and forming point data layers for water quality monitoring stations, which gives interactive access to the users for the attributed monitoring results data tables (Gönenç *et al.*, 2002a).

Once all essential data was gathered and assembled under the land based GIS environment, integration of other spatial data resources was also initiated. Thus, The major earthquake history and the significant mining zones of the area were provided in province-based thematic maps. Both maps are gained from the General Directorate of Mineral Research and Exploration of the Turkish Republic (TRGDMRE). The hot springs, which are characteristic to the watershed, are introduced to the GIS database as point data. They are aligned alongside the Lagoon within a close distance to its banks. Seawater intrusion to the Lagoon occurs seasonally due to its hydrodynamic characteristics; therefore, the location of the springs has special scientific importance (Gürel, 2000; Ertürk, 2002).

Villages and other settlements in the region are widely scattered across available agricultural land covers and are provided in a separate layer. As forests and agricultural areas cover nearly 85% of the total area, NPS pollutant loads are very significant in the watershed. No detailed investigation on the forest areas has been conducted so far, however, fertilizers and pesticides applications are examined annually on monthly intervals for the year 1998 (Karak, 2000; Güvensoy, 2000). This information was gathered from each agricultural village authority in the watershed and numerically introduced into the GIS as point data attributed to each village. The nutrient loadings arising from agricultural areas are recorded in tabular format and presented in charts for each village. These attribute tables provide calculated figures for residual monthly loads after the reduction by crop uptake and other various reactions are also presented on village basis. The most significant 15 pesticides applied in the watershed are also listed in the GIS together with the basic physical, chemical and biological characteristics of each (Tanık *et al.*, 2002).

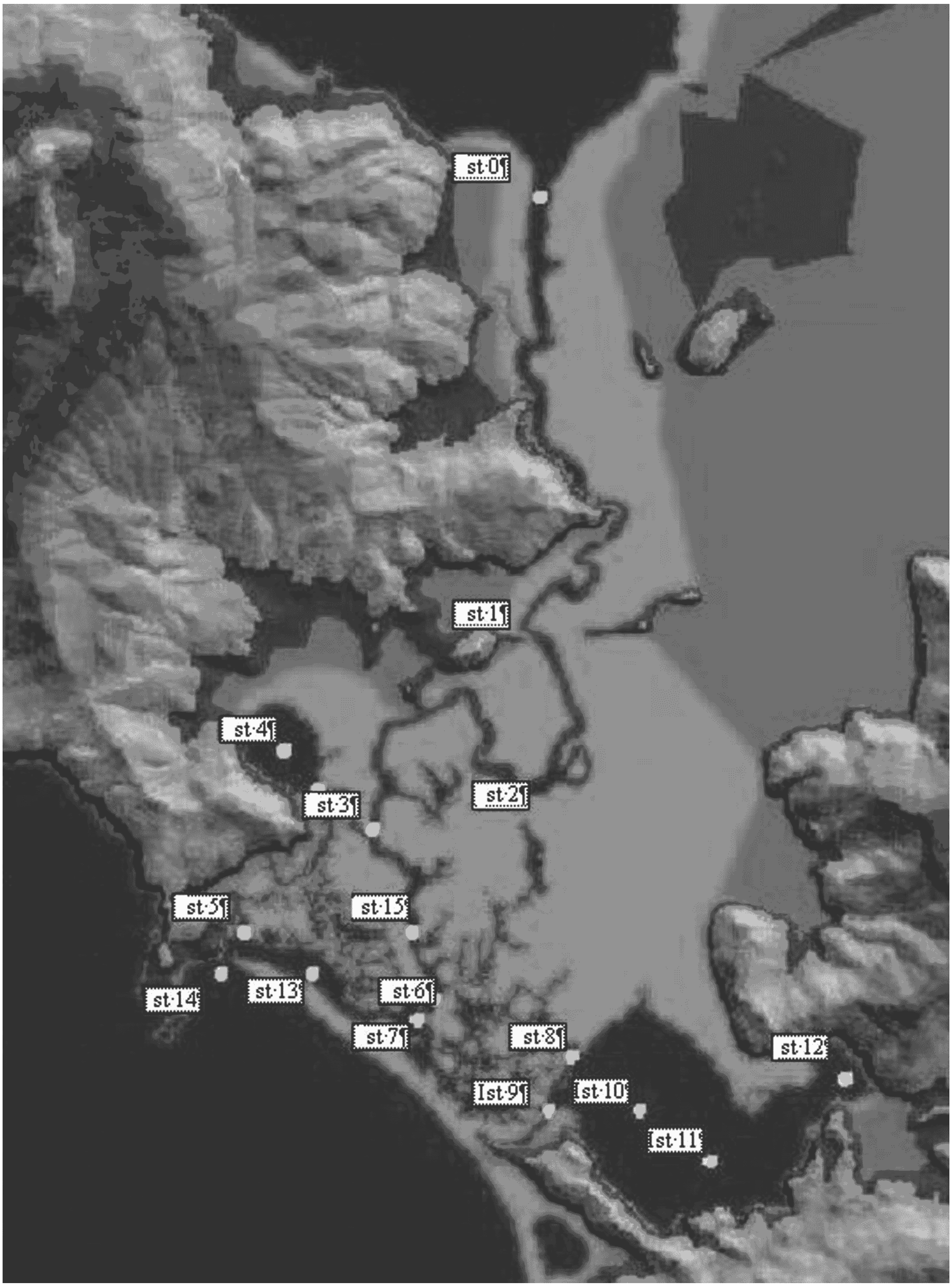


Figure 4.30 Water Quality GIS

The road map of Muğla is also added to the GIS database. Road maps are considerable due to their significance to human-driven functions. On the other hand, the fieldwork design would require access plans to the sampling stations or other on-site activities. Overlaying of related thematic maps for these activities with a road map layer would enable to select station serving better transportation alternatives or to analyze the field study schedule and routes accordingly.

Climatic and meteorological data layer is also significant, as these aspects drive irrigated agriculture. This layer also supplies information on soil-water balance, erosion risk and limiting conditions for plantation. The data sets for precipitation, evaporation, air and soil temperature, and humidity are required by almost every study related to watershed modeling, planning and management application. More specific data, such as; wind speed and direction, cloudiness, and solar radiation, would be necessary for their respective issues; discharge plume modeling, agricultural practices, and plankton growth.

4.7 Field Studies

The purpose of field studies could be summarized in two topics:

- To gather required missing data for modeling implementation process, by experimentation and measurements.
- To verify and validate the existing data and information remotely gathered so far, by site investigations and measurements.

In accordance with these principle purposes, in 2002, a decision was made to launch a series of soil analysis in the region to achieve the following objectives:

- To reach a quantified understanding of the
    - physical parameters,
    - infiltration, and
    - groundwater

  characteristics in a land segment, thereby to use data to construct the a justifiable hydrological model.

- To actualize a representative data set with chemical parameters measurements stating initial conditions or calibration values for NPS quality routing simulations
- To validate and –if needed– correct the existing gathered data for reliable use in modeling.
- To test and analyze results of earlier citations about the region, such as land use amendment recommendations or agricultural application alternatives, and to illuminate why and how, they were or they were not implemented.

4.7.1 Planning

Towards the objectives the following analysis were intended:

- Physical analysis of soil at every station: Field capacity, wilting point infiltration rate, soil humidity
- Soil efficiency analysis at every station: Total nitrogen standard soil efficiency analysis (texture, salinity, ph, lime, phosphorous, organic content)
- Groundwater analysis at sufficient number of stations: Table level, fluctuation and flows, ph, dissolved oxygen, bicarbonates, total nitrogen, soluble phosphorous, organic matter
- Pesticides: At every station, a single pesticide out of six critical pesticides should be analyzed in rotation or due to availability.

Within this framework, especially groundwater hydraulics and possible spatial and vertical distribution of parameters were the primary interest. Thus, using the Recent Land Use maps, 25 segments of land were determined representing 10 different land uses. There was, however, no estimation made on how many samples per segment would be necessary for representative fieldwork. Thus, due to this study, a meeting was held in 2002 with Ankara Soil and Fertilizer Research Center officials, in Ankara. The conclusions of the technical and administrative discussions were as follows:

1. Regarding the purpose of NPS pollution assessment, agricultural zones should be given the first priority in selection of representative segments to the watershed.

2. In order to evaluate the representative segments, land use and soil groups maps should be overlaid for determining unique pairs of soil structure and use. All of these pairs need to be addressed in terms of representation of the watershed.
3. Different plantation cover and soil characteristics should be taken into account by at least a single sampling station.
4. The sampling stations should be spread as much as possible for a better spatial representation, however the basins of major concern due to dense agricultural activity, should be prioritized.
5. Financial resources of the project are inevitably inadequate to cover;
    - a basin-based sampling system
    - grids or network of multiple sampling stations on each of the pairs of land use and soil types,
    - the vertical distribution of parameters on every one of sampling stations, and
    - all of the required parameters.
6. Thus, due to the financial constraints;
    - the total number of sampling stations should be limited to 20 for the entire watershed, thus;
        - basins with possible similar characteristics should be represented by a minimum number of stations, which is practically single,
    - the total number of sampling sets should be limited to 40 for the entire watershed and in order to achieve this;
        - number of parameters to be analyzed per station should be minimized
        - where theoretically or practically justified, the vertical change of parameters should be disregarded

- alluvial and co-alluvial soil types may present similar results relative to the needs of the study and thus they could be grouped as a single soil type.

7. For larger basins like Namnam, the elevation difference as well as the distance to the discharge, should be considered by installing several sampling stations at different elevations in the same basin. This would allow for an investigation on accumulation of quality constituents along the stream.
8. The fieldwork should be carried out with TRGDRA Menemen Soil and Fertilizer Research Center in Menemen, İzmir, as being the only regionally authorized institution to operate soil analysis in the case study area.
9. It is not possible to implement groundwater flow measurements without contribution by State Hydraulic Works regional office.
10. The pesticides analysis could have been practiced by Bornova Agricultural Conservation and Research Center, in Bornova, İzmir. However, the pesticides analyses were most expensive.

Consecutive to these conclusions, negotiations were initiated for establishing collaboration with TRGDRA Menemen Soil and Fertilizer Research Center. Meanwhile, a more definitive sampling plan was completed as presented in Figure 4.31 on the overlaid land use and soil types maps. This considered the following issues:

- Stations located on alluvial and co-alluvial soil types should be sampled with a single set. These land segments are numbered as 1, 6, 8, 10 to 16, and 18 to 19 in Figure 4.31.
- The rest of the land segments (2 to 5, 7, 9, 17, and 20, in Figure 4.31) should be investigated with vertically three sample sets.
- The remaining 4 sample sets should be reserved for contingency use.
- Thus, 40 samples will be gathered from the site for experimental analysis.

Eventually, the final financial considerations enforced the project to be economized. Thus, the measurements listed below had to be indefinitely postponed:

- Infiltration rate

- All groundwater measurements regarding dynamics and quality
- Pesticides analysis

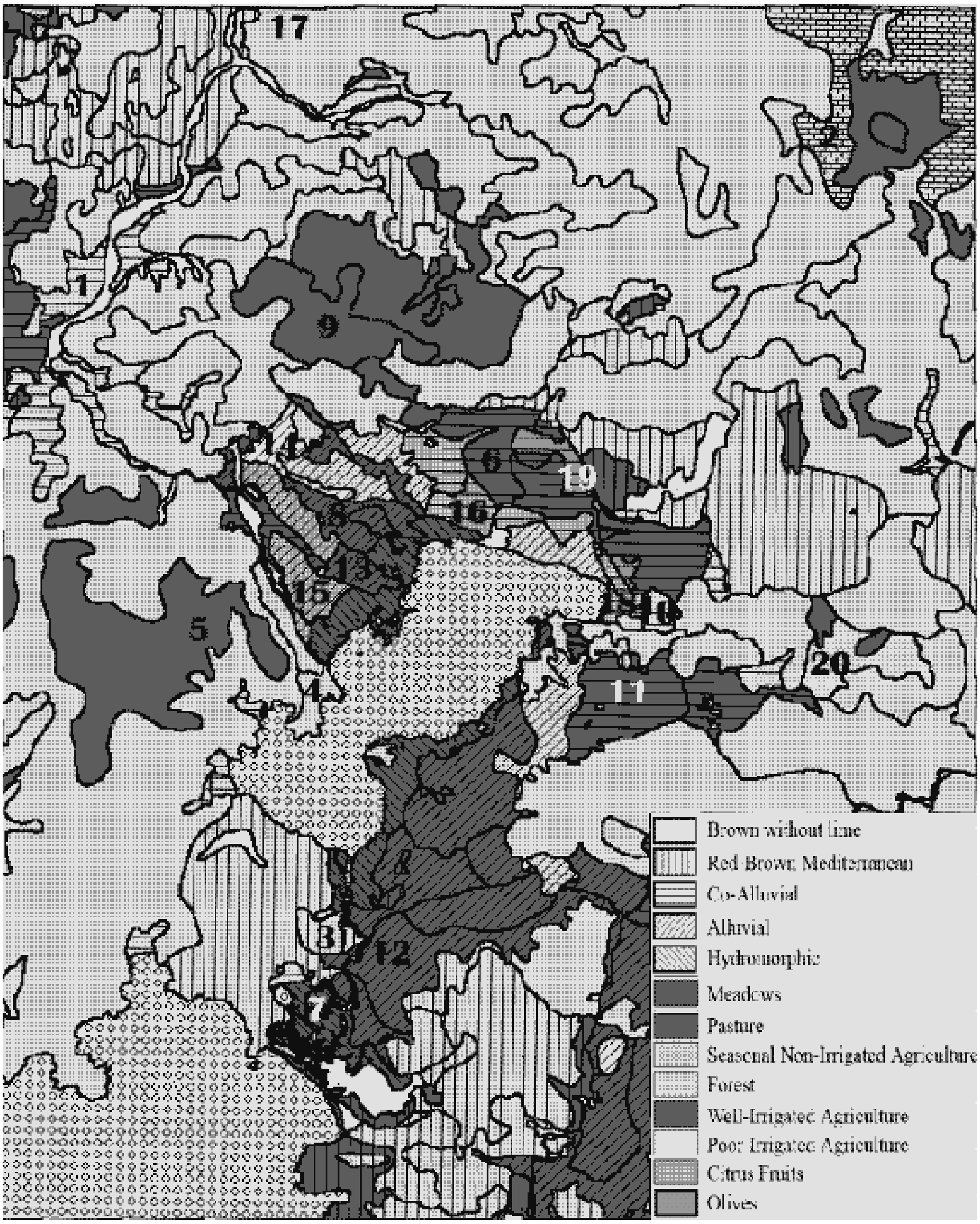


Figure 4.31 Initial Sampling Plan

As the first two sets of data were essential for the hydrological model, the model implementation process had to be based on literature data. Moreover, as there existed no significant data to compensate this gap, a further attempt had to be launched to gather more data on watershed hydrology.

On the other hand, it was anticipated that pesticide analysis could be undertaken by a possible collaboration with Bornova Agricultural Conservation and Research Center, but this would still require additional funding. Eventually, this funding requirement was not fulfilled and pesticides analysis could not be performed. However, the opportunity to make investigations on site was used to establish a knowledgebase for further studies, by surveying the usage of the predetermined critical pesticides at sampling station points with agricultural patterns.

Finally, due to funding inadequacies, the intended number of 40 samples had to be reduced to 26 and reconsideration of the final sampling plan is delayed until the actual situation on site is clarified.

4.7.2 Fieldwork

In order to finalize the field analysis plan based on actual conditions, a site expedition visit was made on 1st of November, 2002 with the participation of an expert from Menemen Soil and Fertilizer Research Center and their field team and the local chief of Köyceğiz Soil Studies Station. By this visit, the following missions achieved:

- More than 40% of the entire watershed area was personally observed.
- All data gathered so far, was validated in terms of hydrology, soil types and structure, infiltration patterns, agricultural applications and settlements
- Sampling stations was relocated with sufficient precision considering;
    - representation of segments of interest
    - ease of access to sampling stations
    - ease of sampling procedure and
    - optimization of overall sampling route, timing and efficiency.
- Sampling resolution arrangements are finalized for each station, based on the following conlusions:
    - For the hydromorphic, co-alluvial, and alluvial soil types, the vertical variation could be neglected due to the presumable homogenous drainage characteristics. However, this should be backed up by a

limited number of vertical sampling from (30 cm, 60 cm, and 90 cm) pre-located stations.

  - A vast majority of the basin arising from forested areas and mountains could be represented by surficial sampling (within top soil; 30 cm) since; the impervious main rock formations are as deep as 20-35 cm on average.

- A detailed report and datasheet was created for use of field sampling team in Köyceğiz as well as soil laboratory team in Menemen.
- Two of samples from the remote stations 1 and 17 was taken and brought to Menemen Research Center.

Hence, due to these outputs of the field visit, the stations were relocated as presented in Figure 4.32 and the final content of the field study was defined as follows:

- Sampling stations:

  1. Namnam I: Near Karabörtlen village on the slopes of forested area with brown soil. Thin soil cover. Single sample at 30 cm depth.
  2. Dalyan-Okçular I: Citrus gardens along the road between Dalyan and Okçular villages. Well-irrigated alluvial soils. Three samples at 30 cm, 60 cm and 90 cm depths. Survey with the landlord.
  3. Lagoon channels west coast III: Uncultivated wetlands along channel banks near Horozlar village. Irrigated alluvial soils. Three samples at 30 cm, 60 cm and 90 cm depths.
  4. Köyceğiz Lake central section II: On the west coast of Köyceğiz lake on the road from Sultaniye mud baths to north. Forested red-brown Mediterranean soils. Thin soil cover. Single sample at 30 cm depth.
  5. Yangı road: On the road from the Köyceğiz Soil Studies Station to Yangı village. Corn fields to represent well-irrigated agricultural zones with co-alluvial soils. Pesticide survey with the landlord. Three samples at 30 cm, 60 cm and 90 cm depths.

6. Köyceğiz Station I: Meadows on co-alluvial soil near the Köyceğiz Soil Studies Station. Single sample at 30 cm depth. Soil cover depth measurement.

7. Lagoon channels west coast I: Cotton fields to represent hydromorphic soils with seasonal agriculture. Single sample at 30 cm depth. Survey with the landlord.

8. Beyobası road: Citrus gardens on the road from Sancıbeli village to Kavakarası village. Well-irrigated agriculture on co-alluvial soil. Single sample at 30 cm depth.

9. Köyceğiz Station II: 1 km distance from the Köyceğiz Soil Studies Station to north. Forests red-brown Mediterranean. Single sample at 30 cm depth. Soil cover depth measurement.

10. Nasuhdede I: At the lake shoreline close to Nasuhdede village. Pastures on brown soils without lime. Single sample at the bottom of the soil cover.

11. Dalyan-Okçular II: Cotton fields along the road between Dalyan and Okçular villages. Well-irrigated alluvial soils. Single sample at 30 cm depth. Survey with the landlord.

12. Lagoon channels west coast II: Cotton fields along channel banks near Horozlar village. Well-irrigated alluvial soils. Single sample at 30 cm depth. Survey with the landlord.

13. Sultaniye: Uphill to Sultaniye mud baths. Forests on co-alluvial soils. Single sample at the bottom of the soil cover.

14. Döğüşbelen: In Döğüşbelen village. Citrus gardens on alluvial soils. Single sample at 30 cm depth.

15. Köyceğiz Lake central section I: On the west coast of Köyceğiz lake in the citrus gardens on alluvial soils within the delta of Namnam creek. Single sample at 30 cm depth.

16. Köyceğiz Station IV: Citrus gardens on co-alluvial soil. In the vicinity of the Köyceğiz Soil Studies Station. Single sample at 30 cm depth.

17. Namnam II: Near karaağaç village. Higher elevations of Namnam basin. Forests on brown soils without lime. Single sample at the bottom of the soil cover.
18. Nasuhdede II: Close to Nasuhdede village. Wheat, barley or corn fields to reflect seasonal non-irrigated agriculture on co-alluvial soils. Single sample at 30 cm depth.
19. Köyceğiz Station III: Olive gardens on co-alluvial soil. Neighboring Köyceğiz Soil Studies Station. Single sample at 30 cm depth.
20. Köyceğiz Station V: Barley and wheat fields on red-brown Mediterranean soil, close to Köyceğiz Soil Studies Station. Single sample at 30 cm depth.

- Cruise route:
    - First day: 6 **à** 16 **à** 14 **à** 15 **à** 4 **à** 13 **à** 7 **à** 12 **à** 3
    - Second day: 5 **à** 10 **à** 18 **à** 8 **à** 11 **à** 2 **à** 9 **à** 20 **à** 19
- Pesticide survey:
    - A small-scale pesticide survey was also conducted within the sampling cruise and landlords of the fields that measurements take place are questioned about the recent pesticide applications in their fields. The goal of this task is to locate 5 pesticides, which are shown to be most critical by earlier studies, namely, endosulfan, diazinon, methidathion, dichlorvos and deltamethrin.
    - If these pesticides were applied on sampled fields, a second cruise for pesticides would have been conducted for sampling. The initial anticipation was that because of the considerable financial burden, these analyses would not be exceeding two sampling points and six samples in total. However, later even these downscaled goals could not be achieved.
- Laboratory work:
    - The following analyses would be applied to each sample in Menemen Soil and Fertilizer Research Center Laboratory: Standard soil physical

analysis (texture, field capacity wilting point, bulk density), humidity, soil temperature (recorded on-site), total nitrogen, nitrates, standard soil efficiency analysis (texture, salinity, pH, lime phosphorous, organic matter)

The survey form used during the field study is presented in Figure 4.33.

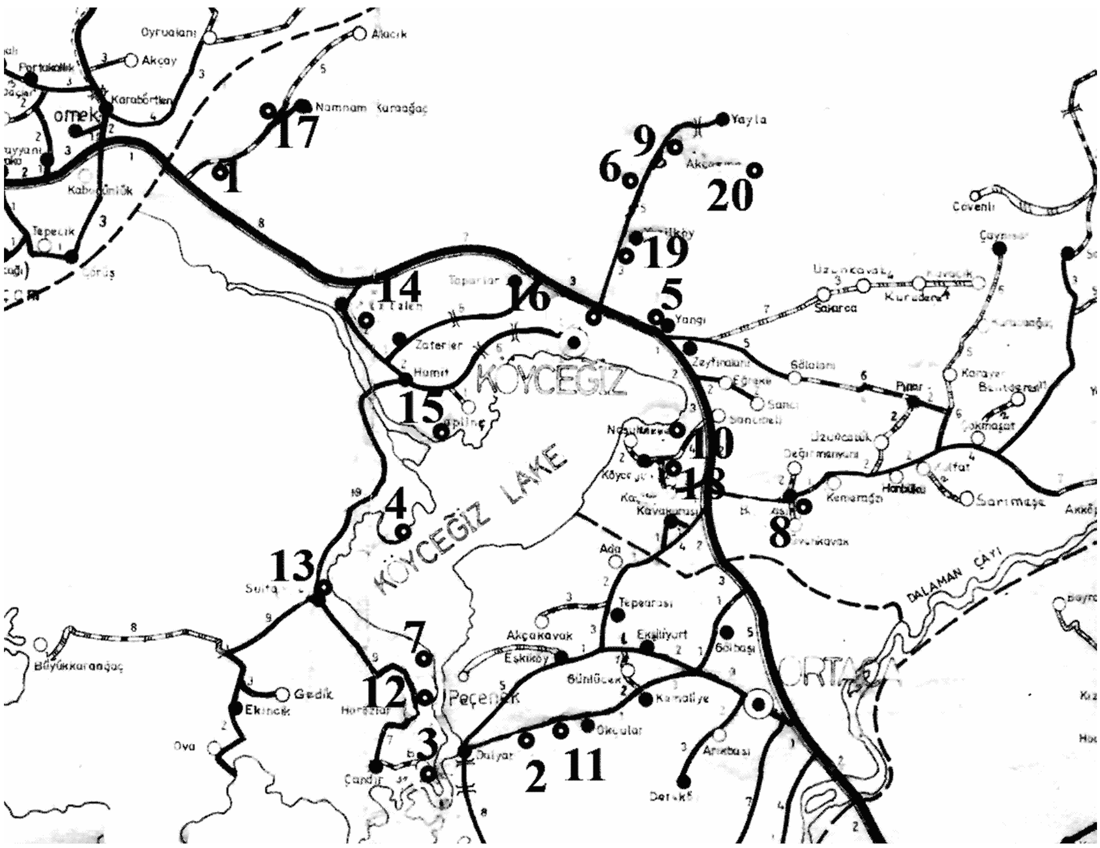


Figure 4.32 Finalized Sampling Station Locations

4.7.3 Analysis

The fieldwork was performed 13-14 November 2002. However, as the financial resources for the soil analysis depend on the funding from an extension to the TÜBİTAK project and the PhD Thesis Project from the İTU Research Fund, bureaucratic problems against utilization of these funds delayed the finalization of the soil analysis until March 2003. The results of the analysis are presented in Table 4.12a for samples 1-15.

İ.T.Ü. Environmental Engineering Department and Menemen Research Center
Köyceğiz-Dalyan Watershed Soil Characteristics Survey Study

No: *Check that apply*

1 2 3 4 5 6 7 8 9 10

11 12 13 14 15 16 17 18 19 20

Depth: *Check that apply*

☐ 30 cm
☐ 60 cm
☐ 90 cm
☐ At the top of main rock layer

Depth of rock layer: ____ cm

Record: *Fill in the blanks*

Date: ___ / ___ / ___
Time: ___ : ___
Name:
Surname:
Signature:

Location Description: *Fill in the blank*

Rain and Soil Conditions:

Date of last rainfall: ___ / ___ / ___ *Fill in the blanks*

Soil humidity condition: ☐ Dry ☐ Slightly Humid ☐ Humid ☐ Water Saturated ☐ Muddy *Check that apply*

Soil temperature at sampling depth: ___ °C *Fill in the blank*

Vegetation Cover: *Check that apply*

Is there cultivation? ☐ Yes ☐ No

Natural Vegetation Cover: *Do not fill if it is cultivated* *Check that apply*

☐ Meadows ☐ Pasture ☐ Wetland ☐ Forest

Agricultural Application: *Do not fill if there is no cultivation* *Check that apply*

Crop: ☐ Cotton ☐ Corn ☐ Sesame ☐ Olives ☐ Barley ☐ Wheat ☐ Citrus ☐ Greenhouse ☐ Other: ______ *Fill in the blank if it is another crop*

Crops on adjacent fields if available: *Check ALL that apply*
☐ Cotton ☐ Corn ☐ Sesame ☐ Olives ☐ Barley ☐ Wheat ☐ Citrus ☐ Greenhouse ☐ Other: ______ *Fill in the blank if it is another crop*

Crops cultivated in winter if available:
☐ Barley ☐ Wheat ☐ Melon ☐ Greenhouse *Check ALL that apply*
☐ Other: ______ *Fill in the blank if it is another crop*

Irrigation sources and description if available: *Fill in the blank*

Has one of these pesticides below been applied in the last 6 months? *Check ALL that apply*
☐ Endosulfane ☐ Diazinon ☐ Dichlorvos ☐ Deltamethrin ☐ Methidathion

Figure 4.33 Soil Survey Form

Table 4.12a Soil Analysis Results (1-15)

Parameter	Samples				
	1	2	3	4	5
Location:	1	2	2	3	3
Sample ID:	1324	1325	1326	1327	1328
Date Taken:	1/11/02	13/11/02	13/11/02	14/11/02	14/11/02
Time Taken:	15:30	15:30	15:30	09:50	09:50
Soil Depth (cm):	0-30	0-30	30-60	0-30	30-60
Water Saturation (%):	85	40	38	75	80
Salinity (1) (%):	0.085	0.049	(2)	0.226	0.690
pH (1):	7.01	7.3	7.36	7.55	7.67
$CaCO_3$ (%):	4.10	14.80	13.10	16.00	19.30
P_2O_5 (kg/da):	0.9	5.4	3.0	19.0	3.0
NO_3 (ppm):	22.9	10.4	7.3	64.9	26.1
Total N (%):	0.182	0.196	0.112	0.182	0.098
Total Organics (%):	2.6	2.2	1.0	2.2	1.3
Sand (%):	63.22	65.49	83.72	12.59	12.68
Clay (%):	18.13	18.00	5.87	56.62	58.59
Silt (%):	18.65	16.51	10.41	30.79	28.73
Soil Texture:	SL	SL	LS	C	C
Field Capacity (%):	47.0	17.5	9.7	37.0	37.8
Wilting Point (%):	36.4	11.5	6.3	25.6	24.9
Rock Layer Depth (3) (cm):	30	60			
Last rainfall:		11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:	Dry	Saturated	Saturated	Saturated	Saturated
Soil temperature (°C):		20.3	20.3	21.0	21.0
Crop Type:	Forest	Agricultural	Agricultural	Pastures	Pastures
Agricultural Crops:		Citrus	Citrus		
Adjacent Field Crops:		Citrus	Citrus		
Winter Crops Planted:					
Irrigation Resource:		Stream(pump)	Stream		
Pesticide Utilization:		Leaf fertilizer Forkan insecticide Mediterranean fly	Leaf fertilizer Forkan insecticide Mediterranean fly		
1- Under water saturated conditions. 2- Scarce 3- Too deep if not specified.					

Table 4.12a Soil Analysis Results (1-15; Continued)

Parameter	Samples				
	6	**7**	**8**	**9**	**10**
Location:	3	4	5	5	5
Sample ID:	1329	1330	1331	1332	1333
Date Taken:	14/11/02	14/11/02	13/11/02	13/11/02	13/11/02
Time Taken:	09:50	11:20	13:30	13:30	13:30
Soil Depth (cm):	60-90	0-30	0-30	30-60	60-90
Water Saturation (%):	85	88	44	46	44
Salinity (1) (%):	1.090	0.059	(2)	(2)	(2)
pH (1):	7.68	6.62	7.43	7.41	7.4
$CaCO_3$ (%):	21.70	0.40	0.40	2.11	1.20
P_2O_5 (kg/da):	1.1	4.1	1.7	1.0	0.8
NO_3 (ppm):	44.3	58.3	15.3	16.8	8.6
Total N (%):	0.098	0.406	0.168	0.126	0.112
Total Organics (%):	1.3	5.7	1.7	1.0	1.0
Sand (%):	12.77	39.44	49.19	53.21	47.23
Clay (%):	64.60	26.00	20.66	20.66	22.65
Silt (%):	22.63	34.56	30.15	26.13	30.12
Soil Texture:	C	L(CL)	L	SCL(SL)	L
Field Capacity (%):	40.0	36.7	20.2	20.7	18.6
Wilting Point (%):	28.8	24.3	9.2	10.0	10.0
Rock Layer Depth (3) (cm):		35			
Last rainfall:	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:	Saturated	Wet	Wet		
Soil temperature (°C):	21.0	20.0	17.8	17.8	17.8
Crop Type:	Pastures	Forest	Agricultural	Agricultural	Agricultural
Agricultural Crops:			Corn	Corn	Corn
Adjacent Field Crops:			Citrus	Citrus	Citrus
Winter Crops Planted:					
Irrigation Resource:			Aquifer	Aquifer	Aquifer
Pesticide Utilization:				None used.	None used.
1- Under water saturated conditions. 2- Scarce 3- Too deep if not specified.					

Table 4.12a Soil Analysis Results (1-15; Continued)

Parameter	Samples				
	11	**12**	**13**	**14**	**15**
Location:	6	7	8	9	10
Sample ID:	1334	1335	1336	1337	1338
Date Taken:	14/11/02	14/11/02	13/11/02	14/11/02	13/11/02
Time Taken:	16:40	10:10	15:00	16:00	14:35
Soil Depth (cm):	0-25	0-30	0-30	0-30	0-30
Water Saturation (%):	44	80	50	44	88
Salinity (1) (%):	(2)	0.520	0.050	(2)	0.136
pH (1):	6.43	7.77	7.61	6.77	6.89
$CaCO_3$ (%):	0.00	14.80	1.60	0.00	0.00
P_2O_5 (kg/da):	1.1	13.6	4.3	1.1	1.3
NO_3 (ppm):	27.0	23.5	16.2	13.1	62.7
Total N (%):	0.182	0.196	0.126	0.112	0.154
Total Organics (%):	2.1	2.2	1.9	1.5	3.1
Sand (%):	51.15	13.44	38.23	64.54	42.90
Clay (%):	22.70	53.71	21.09	12.98	33.08
Silt (%):	26.15	32.85	40.68	22.48	24.02
Soil Texture:	SCL(SL)	C	L	SL	CL
Field Capacity (%):	20.3	40.7	24.4	19.9	56.9
Wilting Point (%):	11.4	29.1	14.0	12.4	46.3
Rock Layer Depth (3) (cm):	25			40	70
Last rainfall:	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:	Wet	Saturated	Saturated		Wet
Soil temperature (°C):		18.6	20.9	15.6	20.3
Crop Type:	Meadows	Agricultural	Agricultural	Forest	Meadows
Agricultural Crops:		Cotton	Citrus		
Adjacent Field Crops:	Citrus	Cotton	Citrus		
Winter Crops Planted:					
Irrigation Resource:		Canal	Stream		
Pesticide Utilization:			Dusban 4 / KTS vitamins		
1- Under water saturated conditions. 2- Scarce 3- Too deep if not specified.					

Out of the intended 26 samples, a total of 25 soil samples was taken from 20 different locations. This was because, the 26th sample was to be taken from Station 2 at 90 cm of depth, whereas the main rock layer was at 60 cm and thus, the sample was not taken. The following samples (16-25) are given in Table 4.12b. Graphical interpretation of these data are provided in Appendix A.

Every sample was identified with a ID number for the laboratory operations. The soil depth parameter shows the depth where the sample is taken from. 30 cm, 60 cm and 90 cm sampling layers were used in the fieldwork. For cases where the main rock layer intersected with these layers, then the samples were taken from the top of the rock layer. The topsoil is generally thin in the air, unless the soil types are alluvial or co-alluvial.

For pH and salinity tests, the soil sample should be saturated by water. This operation also gives a broad idea about the soil texture. However, this experiment was already performed in the study. The stations 3, 7, and 12 are much higher in salinity. Besides, at station 3 salinity rises with lower layers. This might be due to the bottom current in the channel. pH ranges between 6 °C and 8 °C in all samples with an average of 7.25.

According to the results of the analysis, lime is mostly observed on alluvial and hydromorphic soils. Stations located within Kaunos and Dalyan basins present higher lime results. Dalyan and Kaunos stations are also better in phosphorous conditions. Brown or red-brown soils or basins with these dominant soil types tend to show poorer phosphorous (P_2O_5) content.

Yuvarlak (8, 10, 18), Kersere (4), and Kaunos (3, 7, 12) basins are differentiated with higher NO_3 content. The rest of the basins are within 5-20 ppm concentrations. NO_3 concentration values above 20 ppm are evaluated to be good conditions for field vegetation. Otherwise would be poor.

Total Nitrogen values, however, are much more diversified and it is hard to formulate a distinct relationship between parameters such as, crop type, existence of cultivation, basins or soil type. Nonetheless, it is possible to assume lower values of Total Nitrogen in lower layers, due to plant uptake, which is also justifiable by the analysis results. Nitrogen is mostly in its organic form in soil and slightly in ammonia and nitrate forms. Total Nitrogen measurements were performed using the modified Kjeldahl method.

Table 4.12b Soil Analysis Results (16-25)

Parameter	**Samples**				
	16	**17**	**18**	**19**	**20**
Location:	11	12	13	14	15
Sample ID:	1339	1340	1341	1342	1343
Date Taken:	13/11/02	14/11/02	14/11/02	14/11/02	14/11/02
Time Taken:	16:00	09:30	10:45	12:15	12:45
Soil Depth (cm):	0-30	0-30	0-30	0-30	0-30
Water Saturation (%):	77	71	44	50	47
Salinity (1) (%):	0.093	0.590	(2)	0.044	0.040
pH (1):	7.97	7.41	6.23	7.92	7.83
$CaCO_3$ (%):	20.50	8.20	0.00	3.70	4.90
P_2O_5 (kg/da):	28.2	14.3	2.5	2.8	1.6
NO_3 (ppm):	17.5	83.5	22.4	21.5	3.8
Total N (%):	0.112	0.252	0.238	0.154	0.070
Total Organics (%):	1.6	3.4	3.3	1.8	1.6
Sand (%):	24.84	17.30	51.51	49.34	49.13
Clay (%):	53.24	46.84	16.66	18.73	12.64
Silt (%):	21.92	35.86	31.83	31.93	38.23
Soil Texture:	C	C	L	L	L
Field Capacity (%):	36.3	30.9	22.6	24.1	20.5
Wilting Point (%):	29.5	18.4	14.1	11.7	9.0
Rock Layer Depth (3) (cm):			40		
Last rainfall:	11/11/02	11/11/02	11/11/02	11/11/02	11/11/02
Soil humidity:	Saturated	Saturated	Wet	Saturated	Wet
Soil temperature (°C):	17.3	17.3	20.0	20.8	19.8
Crop Type:	Agricultural	Agricultural	Forest	Wetlands	Wetlands
Agricultural Crops:	Cotton	Cotton		Citrus	Citrus
Adjacent Field Crops:	Cotton	Cotton		Citrus	Citrus
Winter Crops Planted:					
Irrigation Resource:				Namnam	Wetland
Pesticide Utilization:				Leaf fertilizer/ (triona)	
1- Under water saturated conditions. 2- Scarce 3- Too deep if not specified.					

Table 4.12b Soil Analysis Results (16-25 Continued)

Parameter	Samples				
	21	**22**	**23**	**24**	**25**
Location:	16	17	18	19	20
Sample ID:	1344	1345	1346	1347	1348
Date Taken:	14/11/02	1/11/02	13/11/02	14/11/02	14/11/02
Time Taken:	13:15	16:00	14:00	13:35	13:55
Soil Depth (cm):	0-30	0-20	0-30	0-30	0-30
Water Saturation (%):	44	77	58	44	44
Salinity (1) (%):	0.032	0.043	0.051	(2)	(2)
pH (1):	7.7	6.63	6.62	7.22	6.88
$CaCO_3$ (%):	1.60	0.00	0.00	0.00	0.00
P_2O_5 (kg/da):	17.8	1.3	1.6	1.0	2.3
NO_3 (ppm):	5.8	25.3	41.9	10.9	20.2
Total N (%):	0.084	0.112	0.154	0.126	0.140
Total Organics (%):	1.4	2.1	2.2	1.5	1.6
Sand (%):	71.33	38.95	50.55	70.96	64.90
Clay (%):	8.59	24.76	22.81	4.58	12.62
Silt (%):	20.08	36.29	26.64	24.46	22.48
Soil Texture:	SL	L	SCL(SL)	SL	SL
Field Capacity (%):	17.2	37.0	34.6	14.6	18.4
Wilting Point (%):	8.1	20.3	21.0	7.0	9.8
Rock Layer Depth (3) (cm):		20			
Last rainfall:	11/11/02		11/11/02	11/11/02	11/11/02
Soil humidity:	Saturated	Dry	Wet	Wet	Wet
Soil temperature (^oC):	16.0		18.4	19.8	20.4
Crop Type:	Wetlands	Forest	Agricultural	Wetlands	Agricultural
Agricultural Crops:	Citrus		Wheat	Olive	Wheat
Adjacent Field Crops:	Citrus		Wheat	Citrus	Citrus
Winter Crops Planted:			Wheat		Wheat
Irrigation Resource:	Stream			Stream	
Pesticide Utilization:				None used.	None used.
1- Under water saturated conditions. 2- Scarce 3- Too deep if not specified.					

The organic content is not much deviated. Apart from the distinctly high values in Kersere basin (4), the results fluctuate around the average (1.5-3.0 Organics %).

Regarding the soil texture, Namnam (1, 14, 15, 17), Kargıcak (5, 6, 9, 16, 19, 20) and Yuvarlak (8, 10, 18) basins represent high sand percentage whereas Kaunos basins are significantly low. At stations 3 and 5 it is observed that the clay proportion in soil texture increases with depth. Kaunos basin is significantly rich with clay content. All basins represent a silt percentage below 40 %. Overall, L, SL and C textures are dominant in the watershed.

The field capacity parameter is higher than the average in Kaunos, Kersere, Namnam and Yuvarlak basins. The stations on which, cotton is cultivated tend to show higher field capacities compared to citrus and corn applications. The latter order is also valid for wilting point parameter. However, stations subject to natural land covers, olives and wheat applications are more diversified in terms of this parameter.

Alluvial soil types have thicker soil cover however; red-brown and brown soils are too shallow. Due to a recent rainfall before the fieldwork, the sampling stations were observed to be in humid or saturated conditions. The temperature of soil samples range between 15 °C to 20 °C. Vertical variations in soil temperature were not observed among the limited number of vertical measurements.

No trace of the selected pesticides could be found at the sampling points. Table 4.13 presents an overall qualitative evaluation of the analysis results.

4.8 GIS Overlay and Segmentation

GIS overlay is a very critical function of the GIS as a tool for MSS. The sections under this topic describe the significant GIS exercises involved in the project.

4.8.1 Data validation

Field analysis should also support mapping and visualization process by validation of the gathered data including the soil maps. During the optimization of sampling stations in terms of quantity and extent of experimental requirements, five attributes of the soil maps were referred. A land data evaluation table is then prepared by overlaying these five soil maps and further queries are performed based on these reference stations. Such an approach is also a process for assessing the relative suitability of indicated areas of land for actual land uses.

Table 4.13 Qualitative Evaluation of Soil Analysis Results

St	Land Cover	Layer (cm)	Salinity (%)	pH	$CaCO_3$ (%)	P_2O_5 (kg/da)	NO_3 (ppm)	Total N (%)	Organics (%)
Çakmak basin, co-alluvial soils									
13	Forest	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Rich	Fine
Dalyan basin, alluvial soils									
2	Citrus	0-30	None	Slightly alkaline	Medium	Low	Poor	Rich	Medium
2	Citrus	30-60	None	Slightly alkaline	Medium	Very low	Poor	Fine	Very low
11	Cotton	0-30	None	Strongly alkaline	Very	Very high	Poor	Fine	Low
Kargıcak basin, co-alluvial soils									
16	Citrus	0-30	None	Slightly alkaline	Slightly	Very high	Poor	Medium	Low
5	Corn	0-30	None	Slightly alkaline	Very slightly	Very low	Poor	Rich	Low
5	Corn	30-60	None	Slightly alkaline	Slightly	Very low	Poor	Fine	Very low
5	Corn	60-90	None	Slightly alkaline	Slightly	Very low	Poor	Fine	Very low
19	Olives	0-30	None	Slightly alkaline	Very slightly	Very low	Poor	Fine	Low
Kargıcak basin, red-brown soils									
6	Meadow	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Rich	Medium
9	Forest	0-30	None	Slightly acidic	Very slightly	Very low	Poor	Fine	Low
20	Wheat	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Fine	Low
Kaunos basin, alluvial soils									
12	Cotton	0-30	Medium	Slightly alkaline	Medium	Very high	Fine	Rich	Fine
3	Pasture	0-30	Slightly	Slightly alkaline	Very	Very high	Fine	Rich	Medium
3	Pasture	30-60	Extremely	Slightly alkaline	Very	Very low	Fine	Medium	Low
3	Pasture	60-90	Extremely	Slightly alkaline	Very	Very low	Fine	Medium	Low
Kaunos basin, hydromorphic soils									
7	Cotton	0-30	Medium	Slightly alkaline	Medium	Very high	Fine	Rich	Medium
Kersere basin, brown soils									
4	Forest	0-30	None	Slightly acidic	Very slightly	Low	Fine	Rich	High
Namnam basin, alluvial soils									
14	Citrus	0-30	None	Strongly alkaline	Slightly	Very low	Fine	Rich	Low
15	Citrus	0-30	None	Slightly alkaline	Slightly	Very low	Poor	Medium	Low
Namnam basin, brown soils									
1	Forest	0-30	None	Slightly alkaline	Slightly	Very low	Fine	Rich	Medium
17	Forest	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Fine	Medium
Yuvarlak basin, red-brown soils									
10	Pastures	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Rich	Fine
Yuvarlak basin, co-alluvial soils									
8	Citrus	0-30	None	Slightly alkaline	Slightly	Low	Poor	Fine	Low
18	Wheat	0-30	None	Slightly acidic	Very slightly	Very low	Fine	Rich	Medium

It should always be considered that, in order to achieve a proper land assessment it is utterly vital to maintain thematic maps that are up-to-date and authenticated by field investigations, as well as a representatively fine resolution soil monitoring system. However, due to the substantial reduction of data compared to what was intended at the planning phase of the study, the comparative analysis summarized in Table 4.14, should be interpreted as a guideline towards a complete land assessment procedure. On the other hand, the information provided in this table is still a good example for how the land-based information should be gathered to develop a strong basis for rational decision-making regarding the best land uses for the area under investigation.

As the case study watershed is one of the sensitive regions of the country and part of it is an officially declared Special Protection Area, discrepancies in the land data evaluation table do not appear to be significant. However, some of the land portions may have alternative uses, which could further be discussed subject to researches. Once the appropriate set of land characteristics are determined, the next step in the land suitability assessment process must be economic and social analysis. Such a process would be subject to a collaborative work among experts and professionals from various disciplines such as landholders, personnel from related agencies, consultants, etc. It is important to note that this process should be an iterative one, involving refinement and feedback. Close contact should be maintained between the resource survey and the land-use. At the end of this process, the land suitability classification can be finalized and be brought to the attention of decision-makers (Tanık ***et al.***, 2003).

4.8.2 Spatial analysis

Efforts that are more recent concentrated on establishing access to the results of the field analysis via GIS. Through handling such studies, spatial distribution maps for soil parameters could be derived. Although the information gathered in this study is quantitatively not sufficient for a justifiable output of spatial GIS analysis, as a remark on the methodology, some spatial distribution analysis was performed for various soil parameters. Two examples of these works are presented in Figures 4.34 and 4.35.

Table 4.14 Data Validation and Land Suitability by Soil Analysis Results

No	Soil Classes	Soil Types	Land Cover	Soil Sub-groups	Other Soil Characteristics	Data Validation Remarks
1	I	Brown	Forest			Data is validated on site.
2	II	Co-alluvial	Well-irrigated Agriculture	Wetness	Insufficient Drainage	Citrus fruits are dominant, but they are also applicable for this soil type.
3	VII	Alluvial	Pasture	Erosion-Shallow Root Region	Stony	Data is validated on site.
4	VII	Brown	Forest		Stony	Data is validated on site.
5	I	Co-alluvial	Well-irrigated Agriculture			The sample is taken from a cornfield surrounded by citrus fruits.
6	II	Mediterranean Red-Brown	Forest	Erosion-Shallow Root Region		The sampling is in a narrow meadow zone, downhill to huge woods.
7	VII	Hydromorphic	Pasture	Wetness-Shallow Root Region	Salty, Alkaline	The wetlands allow raising cotton, which necessitates well irrigation.
8	I	Co-alluvial	Well-irrigated Agriculture			The area hosts citrus fruits, which are also applicable for this soil type.
9	VI	Mediterranean Red-Brown	Forest	Shallow Root Region-Erosion	Stony	Data is validated on site.
10	VII	Mediterranean Red-Brown	Pasture	Erosion-Shallow Root Region	Stony	Meadows which are also expectable on this soil type, exist in the area.
11	II	Co-alluvial	Well-irrigated Agriculture	Wetness	Insufficient Drainage	Data is validated on site.
12	VII	Alluvial	Well-irrigated Agriculture	Wetness-Shallow Root Region	Salty, Alkaline	Data is validated on site.
13	VII	Mediterranean Red-Brown	Forest			Data is validated on site.
14	III	Alluvial	Citrus	Shallow Root Region		Data is validated on site.
15	V	Hydromorphic	Pasture	Wetness-Shallow Root Region	Slight Salty, Alkaline	There are also citrus fruit gardens in the area due to the nutrient-rich delta.
16	V	Co-alluvial	Citrus	Shallow Root Region-Erosion	Slight Salty, Alkaline	Data is validated on site.
17	II	Brown	Forest	Shallow Root Region	Stony	Data is validated on site.
18	VII	Co-alluvial	Forest	Erosion-Shallow Root Region	Stony	There exists a wheat plantation in the midst of forests.
19	VI	Alluvial	Olive	Shallow Root Region-Erosion	Stony	Data is validated on site.
20	VII	Brown	Forest	Erosion-Shallow Root Region	Stony	Rarely narrow wheat and dough fields exist in this sloping forested area.

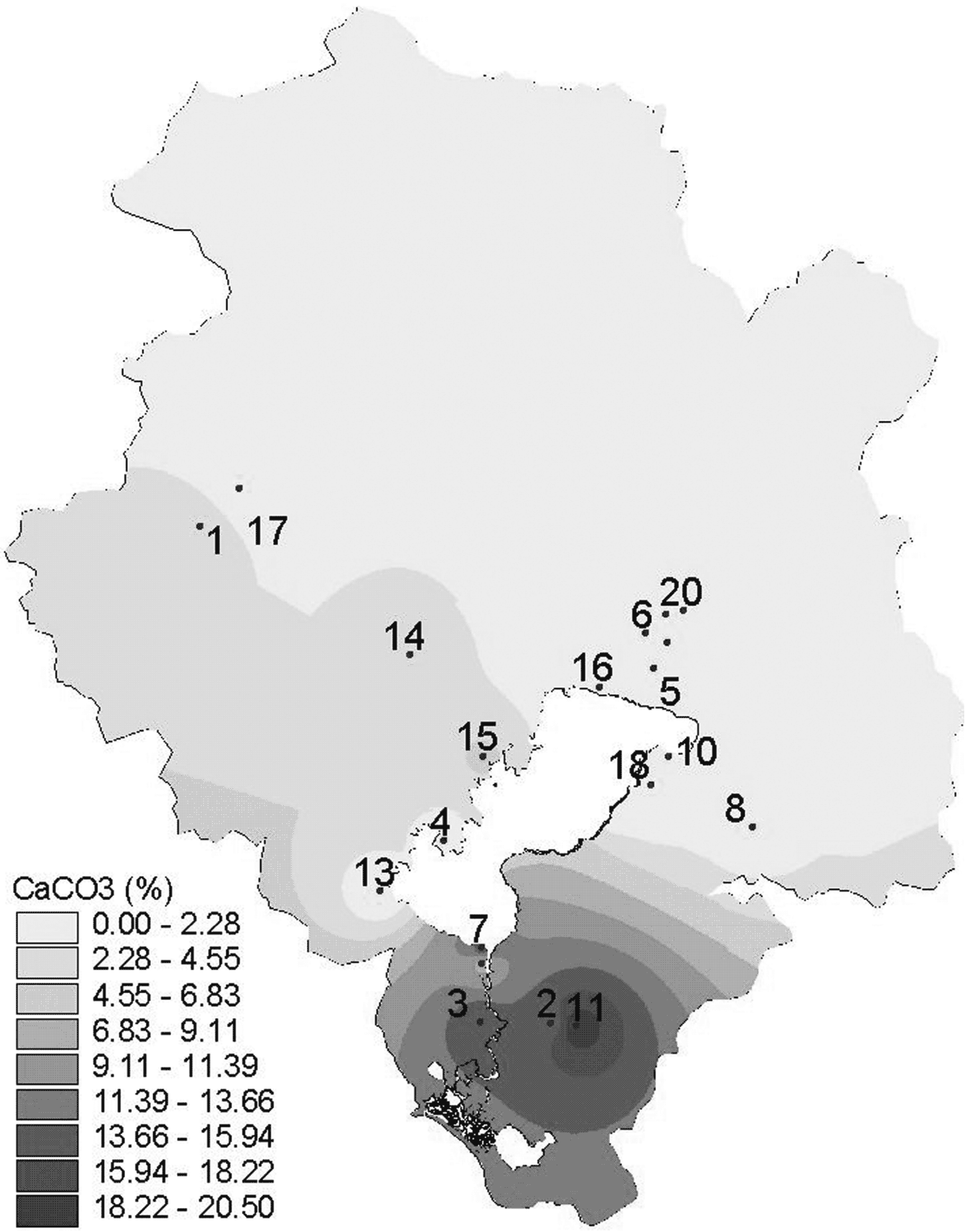


Figure 4.34 Spatial Distribution Model for Lime

Even though the datasets are of insufficient quantity, and furthermore, generalized interpretations might be misleading for many of coarse resolution data sets, the observably higher concentrations of lime within the lagoon sub-watershed and otherwise trend towards north might be reasonable. As, in previous geological ages the lagoon system was downstream to the Dalaman creek, an extraordinary lime accumulation in this area might be possible because of the remains of ancient flow.

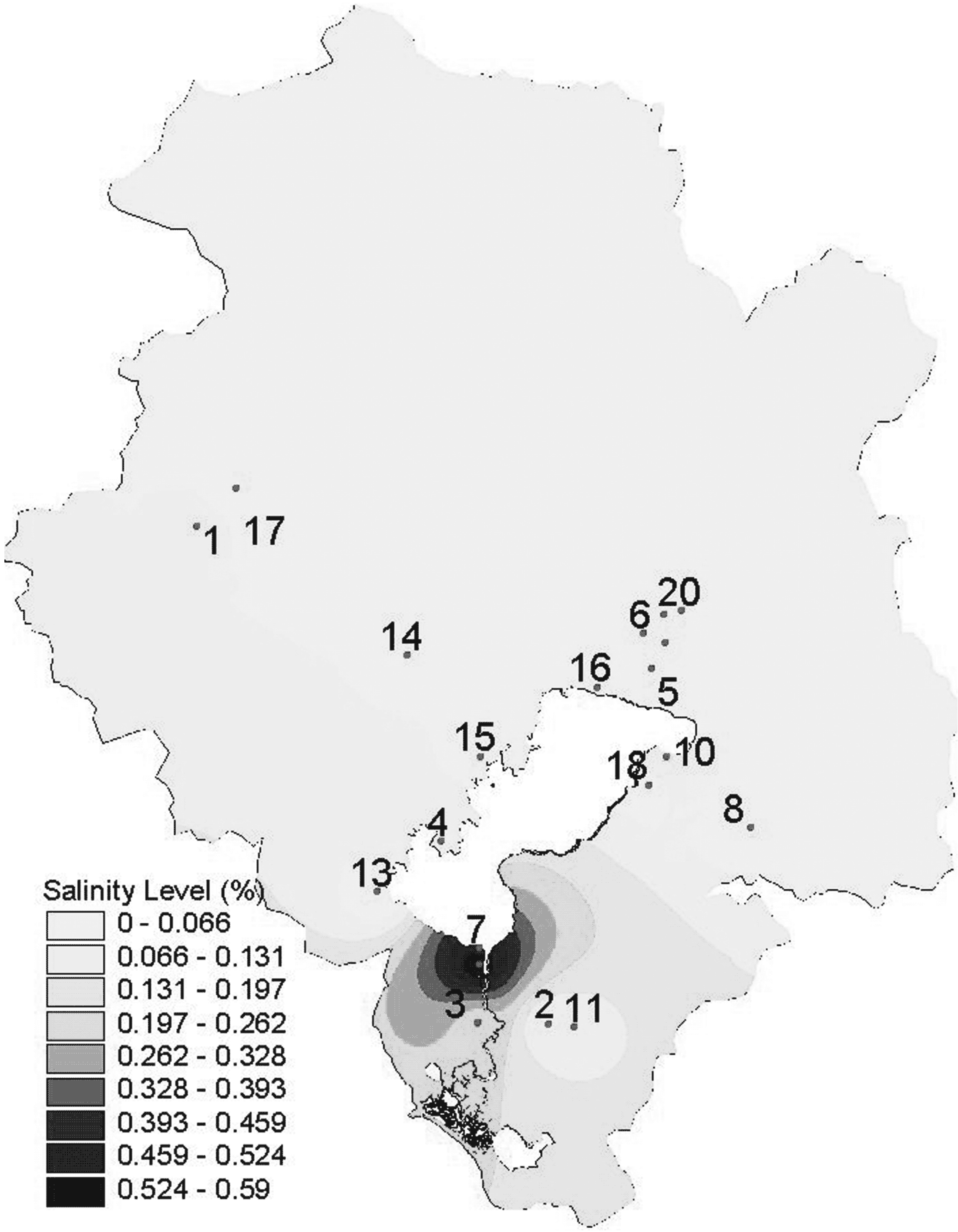


Figure 4.35 Spatial Distribution Model for Salinity

Previous studies indicate that there exists a reverse salinity-density flow along the bottom of the lagoon channel system (Gönenç *et al.*, 2002a, Ertürk, 2002). Given the high water under the wetland banks of the channel system, it would be reasonable to expect a soil salinity increase for all of the basins discharging into the channel system. Hence, the spatial analysis results reflect this situation by a gradient of high salinity values decreasing from south to north.

4.8.3 Segmentation

Segmentation is to determine the significantly different segments of land in a drainage basin or its catchment area regarding the following parameters in order:

1. Basin and/or catchment boundaries
2. Imperviousness
3. Soil type
4. Crop type or significant agricultural applications
5. Meteorological or climatic differences

All of these parameters were regarded in Köyceğiz-Dalyan watershed:

- Basin boundaries were digitized and associated with the GIS.
- The percentage of total impervious areas in the watershed area was very insignificant. Thus, there was no practical need to delineate and to model impervious land segments.
- Intense studies and field study backup were made ready to make soil type segmentation accessible for the model implementation process. Hence, basin boundaries were overlaid by soil type maps.
- The resultant map of soil types and basin boundaries were then overlaid by the land use maps to discover the soil-crop paired segments over all basins.
- Due to a very detailed meteorological analysis it was reliably decided to use a single meteorological station for weather data, therefore this layer was not superimposed.

The final segmented map for the watershed is presented in Figure 4.36.

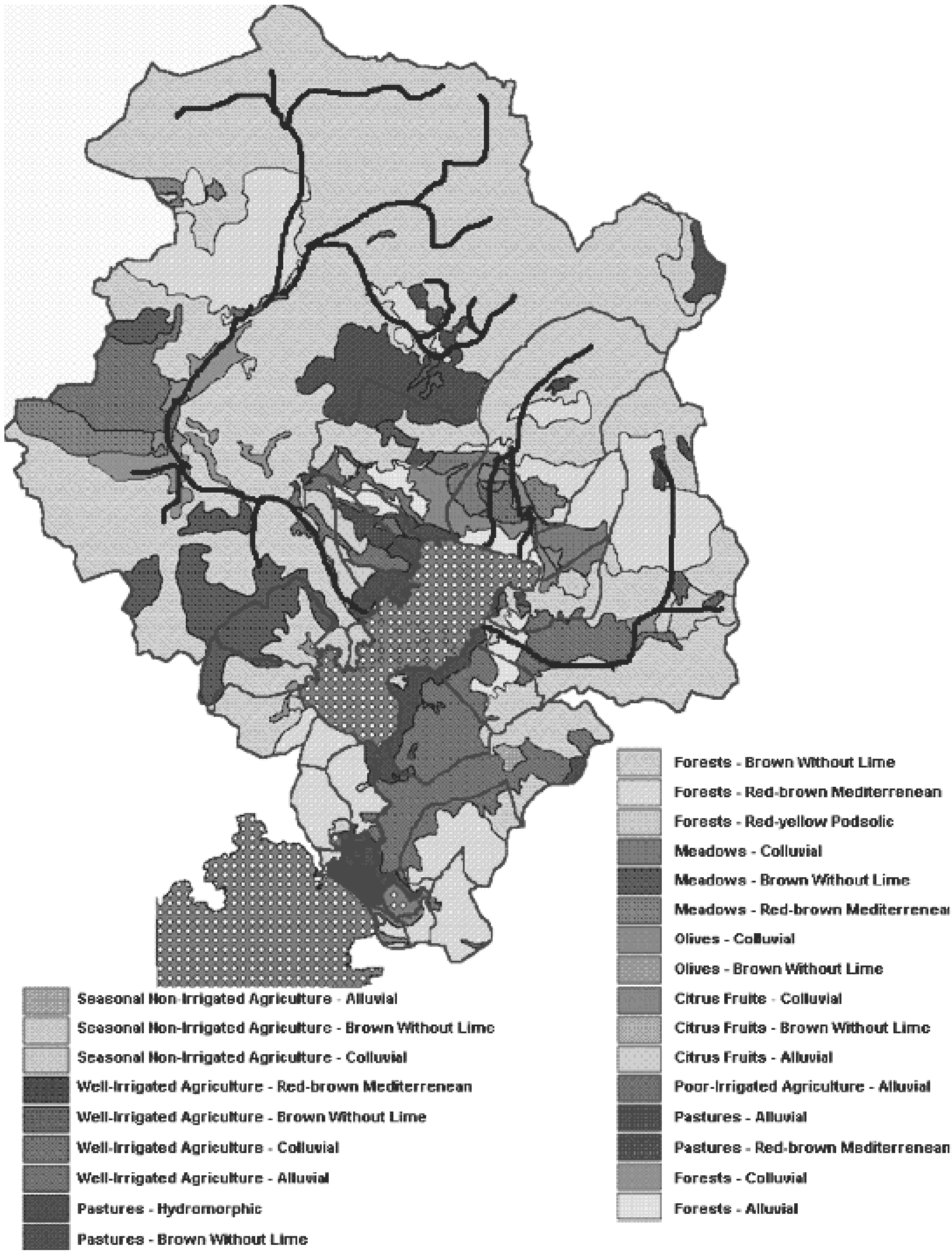


Figure 4.36 Watershed Segmentation for Modeling

5. MODELING PHASE

Within the modeling process described in this Section 5, all of the tools, data, information, and decisions provided by the MSS are finally used as inputs to define the modeling framework. Thus, the topics under this section describe how these inputs are used to develop an acceptable model framework.

The modeler should answer the following questions, prior to use of modeling input data.

- What are the spatial boundaries of the model? (modeling area)
- What are the temporal boundaries of the model? (simulation period)
- What are the parameters to be modeled? (quantity/quality parameters)
- How shall the simulation be calibrated? (calibration conditions)

These questions are answered within the following sections. However, it should be born in mind that this study focuses on formulating an approach for developing the MSS for NPS modeling, but not necessarily accomplishing a sound NPS quality modeling scheme. Thus, studies within this section are only extended to form a core hydrological model under a specific set of initial and boundary conditions and to attain a successful simulation run to demonstrate a hydrological calibration exercise. The results reached, however, will still be useful for further studies by modularly expanding this core model and extending to other basins in the watershed and/or time series.

Another crucial output of this Section is to provide valuable practical information on how to optimize/reduce modeling capabilities/target bound to availability of data. This expertise shall ease future efforts on defining the data deficiencies and to allow for cost and resource estimations to compensate them.

5.1 Model Boundaries

The first idea about the hydrological modeling plan, was to model all basins in the watershed throughout a common simulation period and gather the output by further calculations to reach a balanced water budget. However, due to the failure in gathering any of the stream and groundwater data, it was impossible to develop a justifiable hydrological model. Therefore, further data investigations were made and finally in May 2003, some flow rate data sets for Namnam and Yuvarlak streams were retrieved from TRSHW office in Ankara. These data sets comprised measurements from a single TRSHW station on Namnam stream from 1980 to 1986 and from 1990 to 1999 and another set of measurements from a station run by General Directorate of Electrical Works Administration (TRGDEWA) on Yuvarlak stream through 1960 until 1964 and from 1966 to 1968.

However, the suitability of these data sets needed to be analyzed. The following issues were effective on this analysis:

- The data sets for Yuvarlak stream were out-of-date. Besides, only precipitation data were available for the 1960-1968 period, whereas all other meteorological parameters were not.
- On-site observations, communication with experts and literature review (Gönenç *et al.*, 2002a) 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. This is due to the fact that, once a hydrological budget is not balanced, unknown groundwater flow data could always concern the modeler whether unbalancing difference might have arisen from this component or as a result of some other environmental/structural parameter.
- The data for Yuvarlak stream was also less preferable due to smaller quantity of measurements and their discontinuous pattern.
- Namnam stream is the largest stream, with its basin representing 55% of the entire Köyceğiz-Dalyan watershed and 62% of the Lake sub-watershed.

- Namnam data sets present a longer time series and are considerably up-to-date, which makes it available to use most of the meteorological data.
- Namnam is much preferable in terms of groundwater intrusion problem. The basin system is show 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 and an impervious rock formation underneath. Hence, even without the groundwater flow data, it would have been much more possible to calibrate a hydrological model on this basin.

As a result, of the arguments above, it was decided that the extent of the model application should be limited to the Namnam basin and its stream system. Hence, the model boundaries are downsized to Namnam drainage basin and its catchment zones.

The hydrological model and thus the annual water budget, is the core of the any level of rural NPS modeling application. Therefore, where there are significant uncertainties regarding the sources and sinks to the hydrological system, the spatial boundaries of the system might be reconsidered in order to minimize such intrusions. The selection approach between the two data available basins in this study could be generalized for modeling cases, where similar data unavailability or uncertainties might arise.

5.2 Simulation Period

In order to develop the most up-to-date results from the model, it was suggested that the simulation period should be as close as it could be to the actual time of modeling practice. The latest of the Namnam stream outflow data sets for a complete one calendar year term was available for 1998.

On the other hand, the earlier 1991, 1992 and 1998 meteorological data sets comprised minimum and maximum air temperature time series, which were needed for PET calculations. However, these parameters were not available in the long-term series, but instead 7:00h, 14:00h, and 21:00h measurements were.

As there were also earlier citations by Ün (2000), Güvensoy (2000) and Karak (2000) regarding computation of the agricultural NPS pollutant and pesticide loads for the year 1998, this period was chosen to be the target simulation period.

In accordance with the optimal requirements of the model for satisfactory annual simulation results, as well as the data availabilities, the time step for the annual simulation is preferred to be 1 day. Hence, preparation of daily time series input parameters for the year 1998 was ready to commence.

5.3 Model Framework

In order to prepare the input data, the modular and network structure of the model should be defined to find out the exact list of input parameters required. These issues are described in the following sections.

5.3.1 Modeling approach

Ideally, there should exist a separate calibration data set for each parameter to be simulated for each segment being modeled. However, this is neither the generally encountered situation nor it was for this particular study. The only possible calibration parameter for the hydrological model was the flow rate measurements at a single TRSHW station. Therefore, the model structure would have to be built to simulate the flow rate at this point.

The PERLND module computes the overland, interflow, percolation, and groundwater flows. These outflows from each catchment simultaneously are transferred as input data to RCHRES module to execute a hydraulic model for conveying the water to the successive reach in the network. Although there was no presupposed intention of running a stream model, it was inevitable to employ the PERLND and RCHRES modules of HSPF in tandem. This was because, it would then be able to simulate the local flow at the calibration point and thereby interpreting the relevance of the hydrological simulation results. Thus, the nodes should be located to make use of the TRSHW station, so that the flows would be simulated at the station could be compared with the measured actual data.

Once the flow at the station for the selected simulation period is calibrated, it would be more reliable to validate the calibrated environment variables for a different simulation period. This simulation period could be selected in a close but possibly a non-adjacent period, in order to assure and independent validation. If the model could still provide acceptable results, then the hydrological model could be considered validated.

The next task should be introducing the quality module PQUAL to the pervious hydrology model PERLND. By this way, studied periods could be modeled again for calibration of the quality model. Eventually, if the quality model is successfully calibrated by the loads of the quality constituents selected then some scenarios could be trailed for recent, prospective, or fictional conditions.

However, there are much more parameters involved in the calibration of quality models. Hence, it requires many trials and site measurements to attain a justifiable simulation run of the quality model. In case of an attempt to extend the core hydrological simulation of this study with the quality modules, the available data sets of soil quality analysis would be few. The calibration of the quality model is much difficult to overcome. Besides, as the data sets of the soil analysis reflect 2003 conditions, there could some errors due to the five years difference (1998-2003) between the simulation period and the calibration data.

5.3.2 Model network

Following the modeling approach described above, the Namnam basin is idealized by 4 catchments, 5 pervious land segments (PLS) and 4 channels (reaches). The representative schematization for the basin, its streams and the nodes defined in HSPF are presented in Figure 5.1 over the actual segmented map. This idealization is based on the following assumptions:

- The catchments could be idealized by fictional rectangular planes with an average slope SLSUR (m/m), a length LSUR(m), and the actual area (ha).
- P41 (forested northern catchment), P31 (forested western catchment), P21 (forested southern catchment), P12 (discharge catchment, forested PLS) and P11 (discharge catchment, citrus gardens PLS) are the segments defined to differentiate major land uses. P11, P21, P31 and P41 represent forest thin red/brown soil layers which saturate rapidly under storm, whereas P12 represents more pervious, thick layered citrus gardens with a slow interflow speed but with higher percolation and delayed water saturation.
- R4 (northern tributary streams collecting P41 NPS flows), R3 (western tributary streams collecting P31 NPS flows), R2 (southern tributary streams collecting P21 NPS flows), and R1 (discharge tributary streams collecting P11 and P12 NPS flows) are idealized channels with equivalent length of

total estimated overland flow traveling path length. As the major concern for using reaches is to calibrate the model by the stream flow rate measurements, but not to simulate the hydraulic behavior of the actual streams, this idealizations are quite coarse to be similar to the actual shapes of the streams. However, this is a common practice for these kind target specific purposes.

- The Namnam discharge into the lake is the outflow parameter of the reach R1.
- The calibration target TRSHW station is simulated by the outflow of R2. Although the station is located between the two ends of R2, this does not cause any difference in terms of calibration, because of the following reasons:
    - The time step of simulation is 1 day, therefore the difference in the travel time of the actual system would be much shorter to be observed on daily periods.
    - R2 is a comparatively short channel and hence the delay time elapsed between the location of the station and node point would again be less than the order of a day
    - The idealized reaches allow for rapid flow velocities, therefore the daily flow rate cannot be affected.
- None of the snow processes such as, snow pack or melt are not simulated due to the results of meteorological analysis

Table 5.1 presents the network geometry assumed in the simulation. The total area of the Namnam basin is supposed to be approximately 604.00 ha. ELDAT is the elevation difference between the average elevation of the PLS and the meteorological station. LSUR and SLSUR are fictional parameters to represent the PLS as a slanting plane with a characteristic length LSUR and a slope, SLSUR.

The catchments act as fictional planes but drain from the both sides of the reach. Thus, the characteristic length of the reach is used divided by 2. The reaches are represented by trapezoidal cross-sections, with the surface width expanding moving downstream.

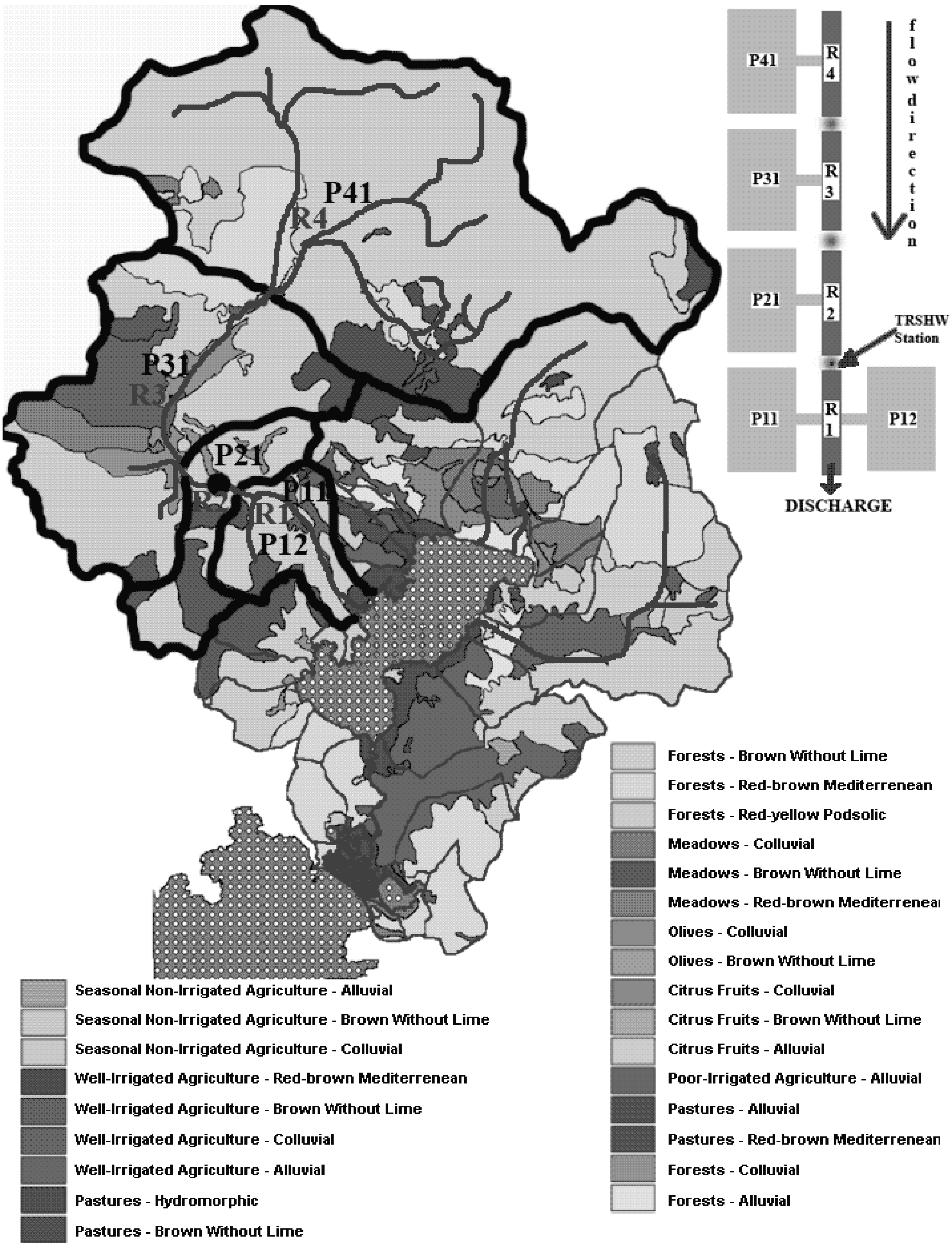


Figure 5.1 Model Network

Table 5.1 Model Network Parameters

PLS	**ELDAT (m)**	**LSUR(m)**	**SLSUR(m/m)**	**Area (ha)**
11	83.50	4379.56	0.0875	3184.25
12	371.00	4379.56	0.2746	4348.59
21	434.98	2468.11	0.313	4343.87
31	285.57	3767.89	0.3069	10399.38
41	922.24	2589.94	0.4618	38123.90
RCHRES	**LEN/2(m)**	**Bottom W (m)**	**H (m)**	**Surface W (m)**
1	430.00	10.00	2.71	75.00
2	440.00	10.00	2.50	70.00
3	690.00	10.00	2.29	65.00
4	3680.00	10.00	2.08	60.00

5.4 Preparation of WDM Datasets

Watershed Data Management (WDM) files are direct-access, binary files containing multiple time series data sets. These files are the primary storage files for HSPF time series data. WDM files are created and maintained by the WDMUtil and ANNIE programs and related-software (Bicknell *et al.*, 2001). All of the time series required by a module should be served to the model in this binary format. The time series required for PERLND and RCHRES are as follows:

- PREC : daily precipitation (mm) - Required by PERLND for hydrological computations.
- ATMP : daily air temperature (°C) - Required by PERLND for soil temperature computations.
- PETA : daily PET (mm) - Required by PERLND and RCHRES for considering PET loses.
- EVAP : daily pan evaporation (mm) - Required by RCHRES for direct evaporation from the stream surface.

Figure 5.2 presents the four steps followed for forming the WDM files out of TRSMW data format. As discussed in previous sections, the first step is to use spreadsheet operations, preferably assisted by macro programming, to convert the text based TRSMW cross-table format into database format. Once the database is complete, the user may any time query the set of data required from the related database and export back it to spreadsheet environment. On the spreadsheet, the data to be used as a WDM data set should be listed as text with fixed width. The data should contain day, month, year, hour and seconds information together with the value of the record as separate columns. This sequence of text rows should then be saved as a separate text file for final conversion to WDM format by using the WDMUtil software. With WDMUtil software distributed for public use on the Internet by USEPA, WDM files could be managed via a graphical user interface. Once a blank WDM file is created, the user could select the “File-Import” menu to import data from text files into WDM binary format. Hence, as described, the data to be converted to WDM, should be preformatted as a text file. Final step is to assign the columns of the text file for their appropriate fields in the related window, accessed via the “import” menu item. Further instructions could be gained from the software documentation (Hummel *et al.*, 2001).

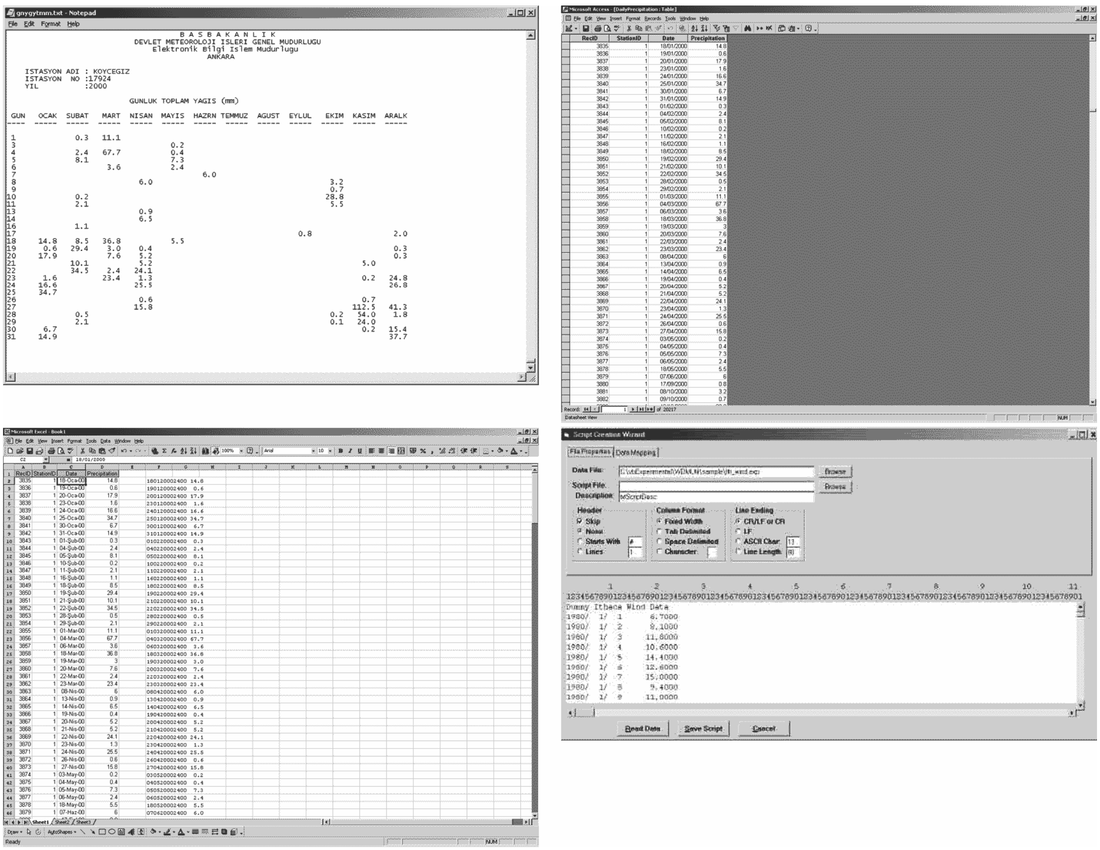


Figure 5.2 WDM Conversion Steps

Although this conversion method is applicable to almost all of the meteorological data sets, PET parameter needed to be separately computed due to its exceptions. As discussed in full detailed in sections regarding meteorological analysis, the evaporation data is not available during the winter season. Thus, the “0.7” factor, used to estimate PET from pan evaporation time series cannot be used for this period. Therefore, the Jensen PET computation function, which is available within WDMUTil, is used.

Jensen method requires the time series; minimum daily temperature, maximum daily temperature and solar radiation, as well as two coefficients and the detailed theoretical description on the computation could be gathered from Hummel *et al.* (2001). However, as the solar radiation parameter was not available by daily resolution, this data set had to be synthetically developed.

The monthly averages of solar radiation available in Langleys were then interpolated to estimate daily long-term average values. This synthetic data set of solar radiation was then introduced to the WDMUtil together with the minimum and maximum daily temperature data sets and the calculated coefficients. With all the required input data fulfilled, the compute function of WDMUtil shown in Figure 5.3 was executed.

The final procedure about producing PET data is, to combine computational Jensen PET values with the empirical values calculated simply by multiplying the pan evaporation time series by 0.7. The Jensen data set formed within the WDMUtil was first exported as a text file. This text file was then reopened as a spreadsheet together with the PET values based on the pan evaporation data. The missing data in the latter was then replaced with the Jensen data set to complete the time series. Using this method, optimal data reliability was attained. The resultant time series of PET and the interpolated daily solar radiation values are presented on Figures 5.4 and 5.5.

5.5 Custom Model Input Interface

HSPF uses a console application to interpret the user’s control input files (uci) and produces output files as a result. It is generally not quite practical to use the text editors and create the input files directly. WinHSPF, i.e., HSPF Version 12 solves this problem to some extent. However, especially use of site specific data needs customized spreadsheet solutions to manage input files creation process.

Within this study, a custom Microsoft Excel spreadsheet application was designed with VBA programming support to easily modify input files and execute them automatically. The application was designed with intelligent algorithms, which would generate HSPF input data files mostly without the notice of the user. Moreover, the latest version of the interface included a shell execution macro, by which the modified data could be written on the file system as an input file, and then be executed using WinHSPF. A preview of the application is presented in Figure 5.6.

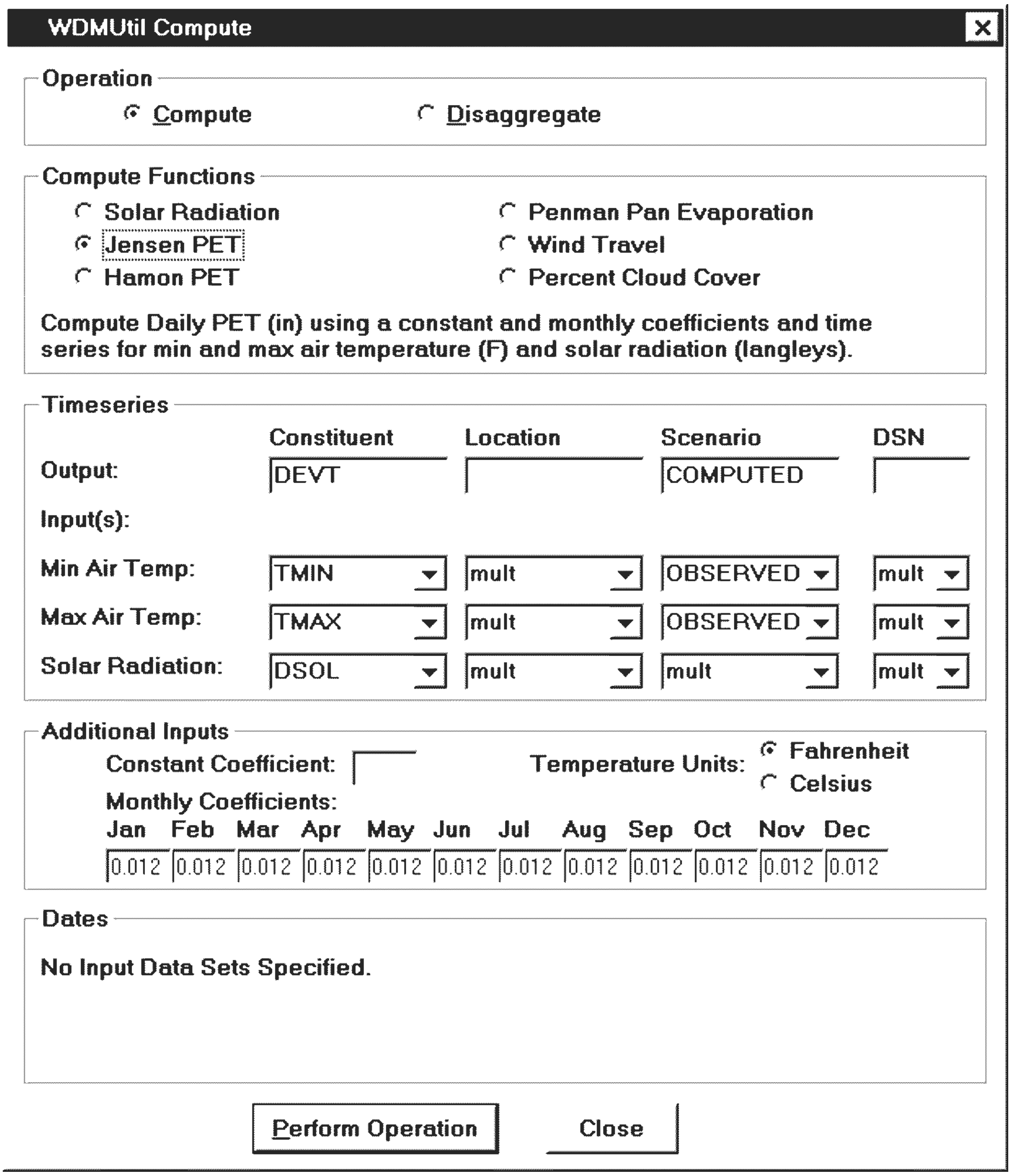


Figure 5.3 Computation of Jensen PET

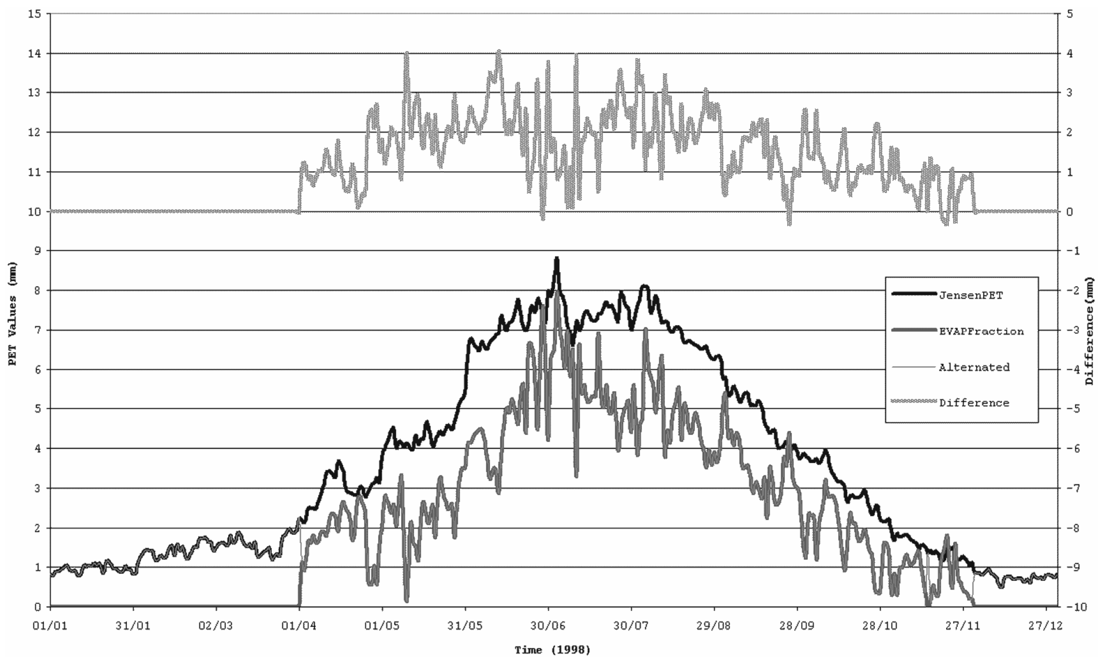


Figure 5.4 Final PET Time Series

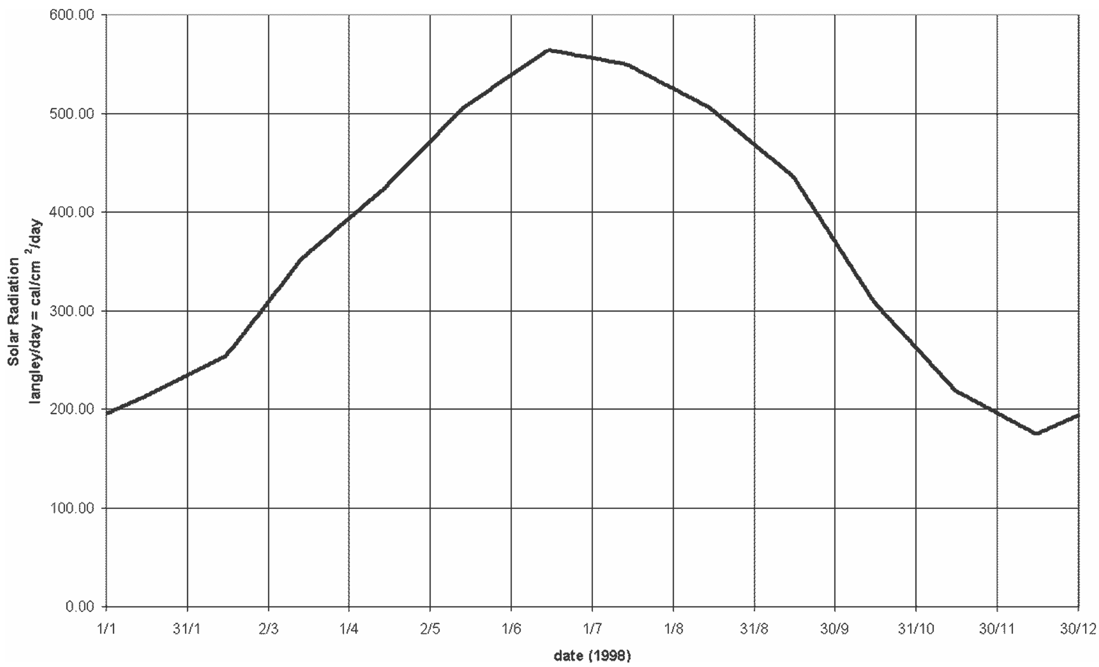


Figure 5.5 Synthetic Solar Radiation Time Series

5.6 Hydrological Model Execution

Using all the literature available and the data gathered, hydrological model execution was completed with overall satisfactory results. Figure 5.7 presents the results of the calibrated model for the outflow parameter at R2 reach, which is targeted to reflect the TRSHW flow measuring station recordings.

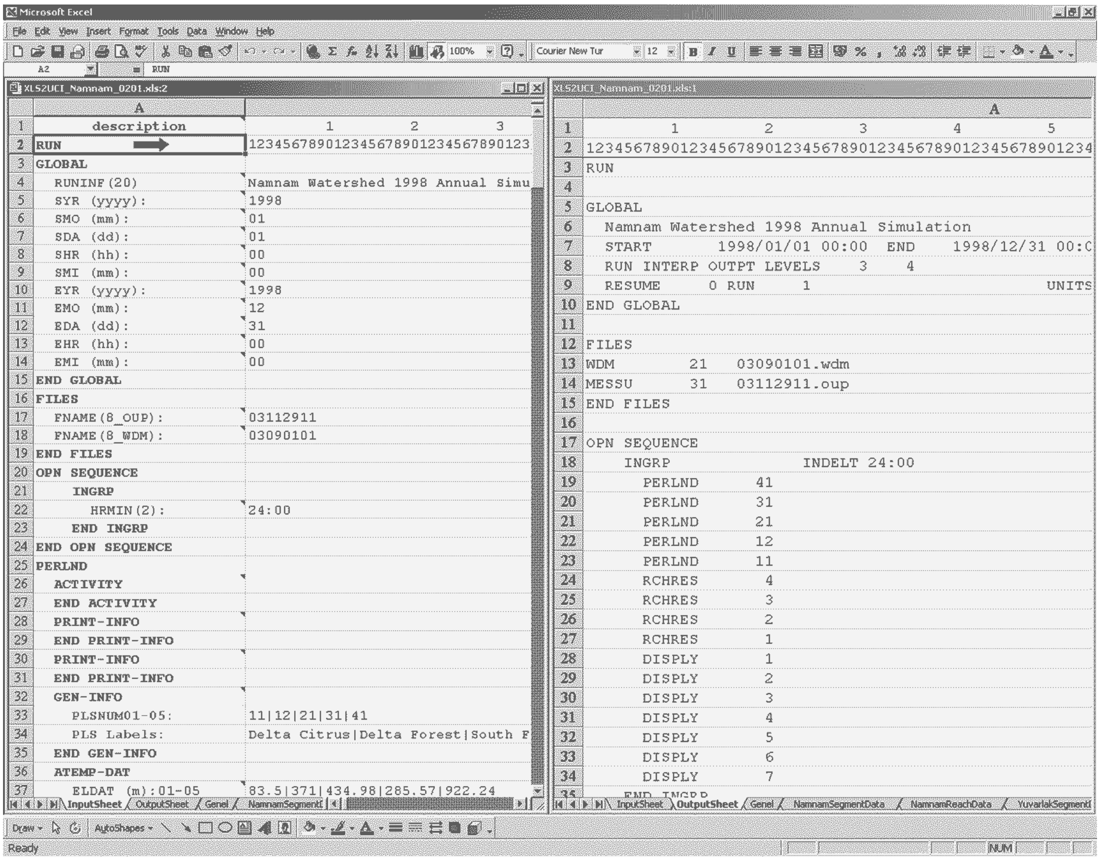


Figure 5.6 Custom Model Input Interface

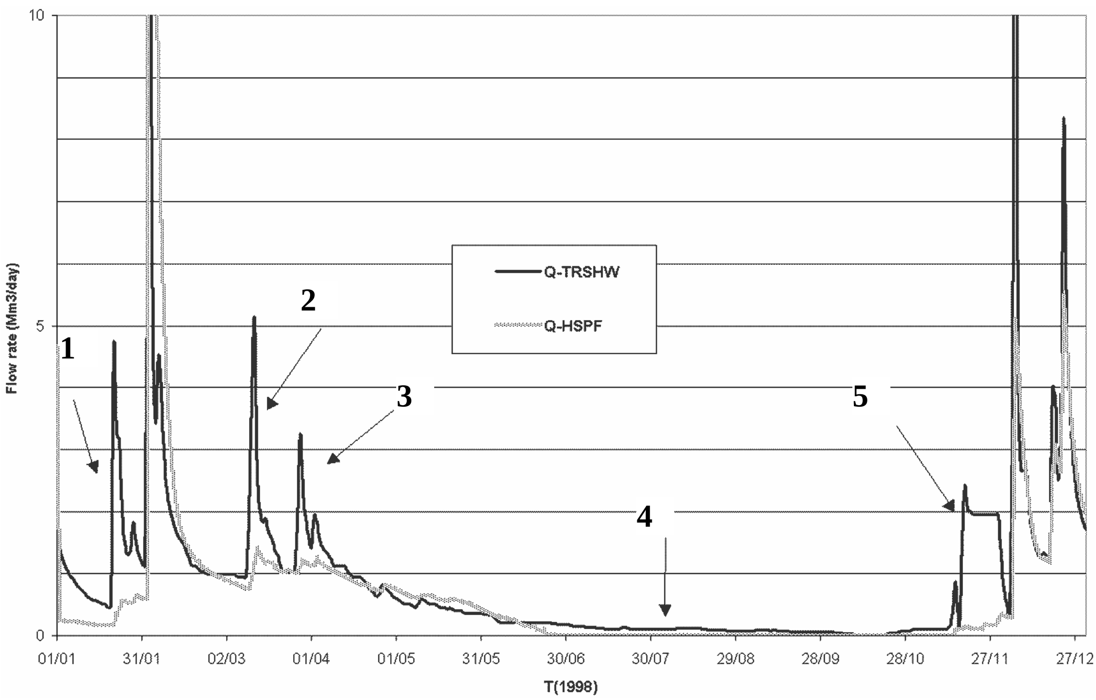


Figure 5.7 Model Calibration Results

Appendix B covers the input file used to generate the calibrated results. The interpretations of the results are as follows:

- The annual water flow derived by the simulation is 289 Mm^3/year and this value is 85% of the actual annual total measured at the station (338 Mm^3/year). This result is found satisfactory.
- The storm event dated 3rd of February 1998 caused a 24 hour precipitation of 239.2 mm/day. As it could be verified from Table 4.9, this value is even higher than the expected 100-year period storm of 214.19 mm/day. This kind of extraordinary occasions generally force the model to cause inconsistencies. Thus, despite this factor an 85% of overall convergence should be acceptable.
- In Figure 5.7, the arrows (1,2,3) that lasts by May 1 and the arrow 5 within November show several peaks, which the model failed to respond. These situations could have arisen due to differences in the actual precipitation patterns and the measurements in the station. Another reason could be a miscalculation at the percolation patterns of the model. The actual saturation periods of the land segments might be shorter than they are simulated, and hence the overland flow may decrease and show a slower response to the storm.
- Arrow 4 which points month August indicates another error of the simulation. During the dry weather period, the model returns zero flow. However, there should have been at least a base flow. For one reason, this might occur due to unsatisfactory representation of drainage patterns for the pervious land segments. As higher perviousness causes higher infiltration, the residual base flow may not be calculated. Another reason could be the groundwater intrusion, which compensates the system loss. However, as this parameter could not be represented, this base flow might not have been simulated as well.
- A snow melt input is not assumed. The simulation performance from March to mid June is quite positive. Therefore, it is unlikely to expect a melting impact on runoff.

5.7 Keys for HSPF Calibration

In case of a further study to validate this simulation by another period of time, or re-run simulations using more accurate and complete data, the following remarks would be helpful to calibrate HSPF. Calibration performance of HSPF depends on the parameter simulated. It is possible to feel satisfied with the following ranges of calibration:

- Hydrology: 5-10%
- Erosion: 10-35%
- Sediment transport: 20-50%
- Pollutants: 10-20%

The following parameters of HSPF are critical for hydrologic calibration:

- High base flow and too little evapotranspiration
    - Deep percolation loss (DEEPFR) could be increased
    - Evapotranspiration (LZSN and LZETP) could be increased
    - Flow diversions which may not included in the model should be checked
- Fraction of groundwater inflow which is lost from the system through deep percolation (DEEPFR)
    - Increase in DEEPFR reduces flow
- Lower zone nominal storage (LZSN)
    - An increase in LZSN decreases flow by providing greater opportunity for ET
- Lower zone ET parameter (LZETP) - an index to deep-rooted vegetation
    - An increase in LZETP decreases surface runoff by increasing simulated ET
- Index to infiltration capacity of soil (INFILT)

    - Increase of INFILT results in a shift of drainage from surface runoff/interflow to base flow, i.e. peak reduces but base flow increases

- Interflow inflow parameter (INTFW)
    - Increase in INTFW decreases runoff runoff by shifting surface runoff to interfow
- Interflow recession parameter (IRC)
    - Increase in IRC generally flattens recession and decreases peak flow
- Basic groundwater recession rate (AGWRC)
    - An increase in AGWRC flattens the base recession
- Fraction of remaining potential ET which can be satisfied from baseflow (BASETP)
    - Increase in BASETP increases the difference between baseflows in different seasons (e.g. smaller baseflow in the summer)

6. RESULTS AND DISCUSSION

Section 6 provides an outline of the results of the study and includes brief discussion about these results.

6.1 Overview

The study documents a detailed background information on the improvements of rural NPS modeling and models used for this purpose. This information is extended with the concepts of MSS and Modeling Project Management Cycle, which defines a pathway on how the modeling efforts should be organized towards an integrated watershed management goal for sustainable use. The MSS term encompasses the entirety of the processes which precede the simulations. The study emphasizes that in the developing countries, establishing an MSS for rural NPS modeling is almost as challenging as developing a calibrated and validated model. Thus, the MSS approach is followed in the case study of Köyceğiz-Dalyan Watershed NPS modeling project to overcome these problems to a certain extent, at which all the necessary background data, information, survey, experimentation and analysis including preliminary HSPF hydrological modeling results, were provided. This set information is now advised for used of further researchers and/or decision makers, to replicate these studies on other sensitive watersheds of Turkey or to expand these efforts by filling necessary research/resource gaps highlighted by this study.

The study covers the issues below, all of which are briefly discussed within the following sections.

- Preliminary Phase
    - MSS and Modeling Project Management Cycle
    - Rural NPS Models and HSPF
- Data Processing Phase
    - Meteorological Analysis

  - Field Studies
  - Mapping, Segmentation, GIS and Spatial Analysis
- Modeling Phase
  - Pre-Modeling Activities
  - Simulation

6.2 Preliminary Phase

The preliminary covered the definitions of problems, project targets, as well as data and resource inventory, all of which had bidirectional impacts on model selection.

6.2.1 MSS and modeling project management cycle

The MSS provides the guidelines on how to achieve a sound watershed scale integrated modeling project by defining numerous data, information and analysis requirements. However, the case study shows that especially in developing countries like Turkey data gathering process could be very time and resource consuming. Therefore, the Modeling Project Management Cycle concept describes that under such circumstances, project and analysis management schemes should be flexible and that targets and methods could be altered, downscaled or omitted anytime due to untimely or imperfect resources. This was exercised multiple times on different occasions through the life time of the project, some of which are;

- Delayed gathering of topographical maps as a result of lack of funding
- Incomplete gathering of topographical maps due to Military secrecy
- Soil analysis requirement because of lost records of already made analysis
- Radical downscale of soil analysis by financial constraints
- Readjusting modeling boundaries and framework with regard to missing groundwater data and up-to-date stream data

However, these local bottlenecks summed up to a sound collection of potential threats, problems and their limited or practical workarounds. Thus, the results and experience documented in this study became a good starting point for further studies.

6.2.2 Rural NPS models and HSPF

Under the literary review of the study, regarding NPS models and HSPF, which is also an action to be taken during the preliminary phase of the MSS, a wide variety of alternative modeling tools and their backgrounds are presented. Different aspects of NPS models are reviewed for comparison. It is also emphasized under the Modeling Project Management Cycle that model selection is not only a function of pursued technical merits but also of data availability, financial resources and multidisciplinary expert contribution.

The comparative reviews reflected the clearly seen technical superiority of HSPF over other urban runoff quality models. However, as the overall complexity of the model is high, especially data requirement was noted as a critical issue to discuss prior to selecting this model. Even though, the need for collecting and assuming a vast amount of data is an important problem to overcome, since public domain data for worldwide applications of the model, EPA databases and numerous citations were available HSPF was found to be the technically most appropriate model software for the purposes of this study.

Given the complexity of the social and natural environment in Köyceğiz-Dalyan Watershed, such as agricultural zones, wetlands, high precipitation, groundwater resources, etc., even though there had been a certain level of failure to form the most complete and representative set of data to the model, the reasons to such inadequacy is dominantly due to very limited financial resources rather than technical sophistication to derive the input data as required. Besides, majority of the data processing analyses together with their tools and methods, are completed and made ready for further scientific researches.

6.3 Data Processing Phase

The data processing phase comprised data gathering and analysis activities on mainly three groups of information.

- Meteorological data : Requiring data gathering, statistical analysis and transformation

- Soils data : Requiring data gathering, multidisciplinary study, experimentation, field survey, and analysis
- Geographical data : Requiring data gathering, data refining, multidisciplinary study, and analysis

Anticipated data retrieval on groundwater resources and pesticide use failed due to lack of sufficient funding.

6.3.1 Meteorological analysis

Meteorological data sets were fully purchased from TRSMW. After a series of conversion operations, data were transferred into MS Access environment for database queries and analysis.

One of the first outputs of the study was to develop a comparative analysis method to test 5 alternative meteorological stations for their likeliness to represent rainfall regime of the watershed. The analysis were based on long term averages and trends of precipitation parameter, through which Köyceğiz Station was found to be the most reliable. Regarding the long term average rainfall statistics, during the winter season, an average storm event of 16 mm/day is normally expected within every 2 days. The probability, frequency and intensity remarks on the average precipitation regime of the watershed, are further analyzed in terms of probable maximum flows and their statistical patterns in the following section.

The long term maximum rainfall data were analyzed for compatibility with Normal, Log-Normal, Gamma-II, Gumbel, Pearson-III and Log-Pearson-III statistical distribution functions for 14 different durations. Hence, the most appropriate statistical distribution functions are determined by ranking their performance for each datasets of different durations. This ranking is decided upon a regression analysis for each of the durations between each distribution function results and targeted standardized observations for that duration. This original ranking method, are then used for an overall interpretation of the performance of these statistical functions. Thus, the results of the study show that the best compatible distribution function was Log-Pearson-III. Finally, these results were tested for a power function by which it would be possible to estimate the precipitation, dependent on the duration of the storm and the coefficients predetermined in accordance with the target recurrence period.

As a comparison of the average and maximum rainfall regimes it could be stated that a 5 minutes storm with a recurrence period of 100 years based on Log-Pearson III power function figures, could cause a rainfall intensity of 225 mm/hr which would correspond to the a scale 19 mm of rainfall which is 1 mm greater than the average rainiest December daily rainfall. On the other hand, a 24 hours storm with again a recurrence of 100 years could cause an 8 mm/hr rainfall intensity, which would almost equal the entire monthly rainfall in the rainiest December (215 mm). Hence, these conditions should be taken into consideration for prospective modeling efforts on risk assessment on agricultural runoff loads. For other analysis remarks Section 4 covers full detailed information.

6.3.2 Fieldwork

Field studies on soil analysis required collaboration from Menemen Research Center. Through these studies a general understanding of the watershed soil structure was attained. Design of the sampling system a long run of optimizations, through which at least a set of chemical and physical soil characteristics were analyzed by a minimal set of sampling locations and number of samples. This was due to the budget issues. However, the methodology implemented during these optimizations were a valuable output of the study. The number of sampling points were reduced from hundreds to 20 by superimposing different soil characteristics and types while bearing in mind which types of soils might show vertical distribution.

The spatial analysis employed on laboratory data showed that salinity stratification which was cited along the lagoon channel was also observed within the deeper layers of soil segments, adjacent to this stratified water media.

The produced results of the analysis could be used to expand the core hydrological model to a quality model.

6.3.3 Mapping, segmentation, GIS and spatial analysis

Many different geographical land based data were gathered, refined (corrected), input, superimposed and analyzed. All of the official authorities, where digital map layers for NPS modeling GIS support could be found, were identified, at least for the project area. Segmentation which is the basis of HSPF model network were handled by overlaying digital map layers, namely crop type, soil groups, basin boundaries, and streams. Spatial analysis tools of ArcView software was used by the collaboration established the İstanbul Technical University Geodesy and Photogrammetry Department.

6.4 Modeling Phase

Modeling phase activities can be categorized by two branches. First, is the pre-modeling activities which covers use of data gathered by MSS and transforming it to execute the simulation. And second is the simulation requiring tasks, i.e., trial executions for calibration.

6.4.1 Pre-modeling activities

Under this study an HSPF spreadsheet user interface is made available for ease of use during simulation trials. Another input is to provide detailed instructions on using the WDMUtil software which manages the binary WDM time series which is generally unfamiliar to Turkish or non-US researchers. The study also provides information on how to transform TRSMW data to WDM format, which is also crucial as time series input is the main data source that HSPF uses.

6.4.2 Simulation

Given the long lasting time period to gather all of the data that is needed for the execution of the model and yet critical incomplete data sets such as groundwater table, the modeling study itself, is still one of the very rare and early applications of HSPF model in Turkey. Thus, although it is “not” the primary mission of this study, to achieve a complete quality modeling project for the NPS, still the achievement under the limited circumstances is valuable. This is because, with this study there henceforth exists a methodology to implement HSPF modeling in Turkey, using Turkish data standards. Furthermore, it is also possible to develop a sound integrated watershed model in Köyceğiz-Dalyan lagoon, by necessary investment and making use of this study as a starting point. More solid comments are stated in Section 7.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following findings and information are produced as conclusion and outputs of this study.

1. The need for back up by Modeling Support Systems, which encompass all of the processes, operations and methods of modeling prior to simulation; is found obligatory for modeling applications in developing countries, where data resources are not developed enough for readily, public, detailed, standardized and comprehensive use, as they mostly are in developed countries.
2. As a result of the Modeling Support System study, the following questions are mostly answered regarding implementation of watershed scale quality models:
    a. Which governmental institutions and offices like State Meteorology Works, State Hydraulic Works, General Directorate of Rural Affairs and Turkish Armed Forces may provide data?
    b. What is the format of this data?
    c. What are the terms and conditions of delivery?
    d. Which data sets should go through what sort of analysis, quality control tests, and other operations, for proper use with modeling input systems?
3. Among various options of models the HSPF alternative was selected, and with the support from the related literature, the implementation of the activities in Item 2 was completed for Köyceğiz-Dalyan Watershed case study.
4. After an approximately 50 years analysis on rainfall records, the data sets from the SMW Köyceğiz Meteorology Station is determined to be the most representative for modeling the watershed NPS.
5. Within the maximum rainfall intensity analysis, a special ranking method is developed to test statistical distribution function for different rainfall event

durations. Log-Pearson III function is found to have higher correlation than the other five functions for the Köyceğiz Meteorology Station maximum rainfall data set.

6. As an output of the maximum flow analysis, an empirical formula is derived which makes it available to match any rainfall reading with its probable frequency. According to these results, in a 5 minutes lasting storm which has a recurring period of 100 years, it is probable to observe rainfall as high as the total daily average of the most rainy season. Again the 24 h lasting storm event which may be observed once in a century could cause the average total monthly rainfall of the most rainy season to precipitate within a day.

7. TRSMW text based data sets are successfully transferred to MS Access database format for analysis and US standard binary format WDM for use as time series by HSPF.

8. The following tasks are completed with regard to soil studies:

    a. The soil analyses required for watershed scale quality models are determined.

    b. The authorized institutions for such analysis in the case study area are investigated, found and organized for collaboration.

    c. Multidisciplinary studies were held to minimize monitoring costs and to optimize the data to be sampled and analyzed, in relevance.

    d. Field visits, site surveys, sampling location selection, monitoring program design, coordination of laboratory analysis are completed.

    e. Results of analysis from Menemen Research Center were spatially analyzed together with GIS experts.

9. Spatial analysis on results of soil measurements and experiments show that stations located in the vicinity of main lagoon canal the salinity parameter is significantly higher than any other sampling station in the entire basin and that this parameter higher in lower layers. This finding is parallel to the citations in the region suggesting a reverse bottom flow from the lagoon channels to the lake driven by density flows and intertidal activity.

10. Data gathered from GIS through digital maps on land use are validated by observations during sampling program field visits. These digital maps were

descendent of the analog maps developed during 1960s for the purpose of agricultural improvement. Hence, they are also justified with regard to the correctness of the land use policies at the time and abidance of the inhabitants. This reflects the importance incorporating the scientific methodology into the decision making process towards an integrated watershed management scheme, which may, as seen in this example, employ long lasting benefits both for the society and the environment.

11. MS Excel interface is developed for fast and practical input file editing. The application is also powered by VBA Macros.

12. A land based GIS platform is built, by overlaying soil types, land use, basin boundaries and stream layers, a segmentation study is carried out for the entire basin. The model boundaries were then downscaled to Namnam basin and its subcatchments.

13. A hydrological model was run for Namnam basin for the year 1998. According to the results the annual water budget is 85% of the total measured flow that year.

7.2 Recommendations

In order to attain a sustainable quality model for the integrated management of the watershed, the following actions are recommended for researchers and decision makers.

1. 1998 calibration attempt for Nannam creek should be repeated for a consequent or close annual period, in order to validate the model.

2. Flow and groundwater measurements should be conducted for every basin of the streams in the watershed.

3. On every basin in the watershed, soils and pesticide analyses, and on site infiltration tests should be completed. Total number of samples and sampling stations should be increased.

4. After the sufficient data gathered in items 1-3 are made available, land (PWATER), surface water (HRDR), soil sediments (SEDMNT), pesticide (PEST) and quality modules (PQUAL, NITR, PHOS) of HSPF should be run.

5. If the stream water quality module (RQUAL) is also integrated with rest of the above listed modules, the integrated watershed scale Non-Point Sources model shall be accomplished.

6. New trends in watershed modeling technology lead to full integration of GIS platform with the watershed models in a new framework. The calibrated HSPF Watershed Model should, thus, be integrated with GIS and the whole model should be reestablished under BASINS framework, which is fully referred in this study.

7. The following decision support scenarios should be analyzed under the BASINS framework:

    a. Total maximum daily load (TMDL) risks for acute sediment/toxic pollution should be assessed under 100 years period storm conditions, which are derived within this study.

    b. A control scenario should be developed, in which the entirety of the agricultural zones are replaced with natural grass cover. Hence, this scenario will show the added pollution load arising from mere agricultural use of the land.

    c. A forecast scenario should be developed to take the expansion of agricultural zone into account.

    d. The significance of NPS within the whole pollution profile should be identified. Thus, total estimated NPS loads and total estimated point source loads should be compared annually, so as to assess the engineering measures to control enhance either of the sources (Şahinoğlu *et al.*, 1998).

In addition to these conclusions, regarding the uncoordinated structure of data resources in Turkey and with the goal to compete with watershed management and related modeling practices in the developed countries; it is found to be most advisable, to establish a nation-wide data center, into which, compiled and/or generated data from independent researchers could be uploaded so as to accelerated collaboration of multidisciplinary scientific activities like rural area NPS modeling.

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APPENDIX A

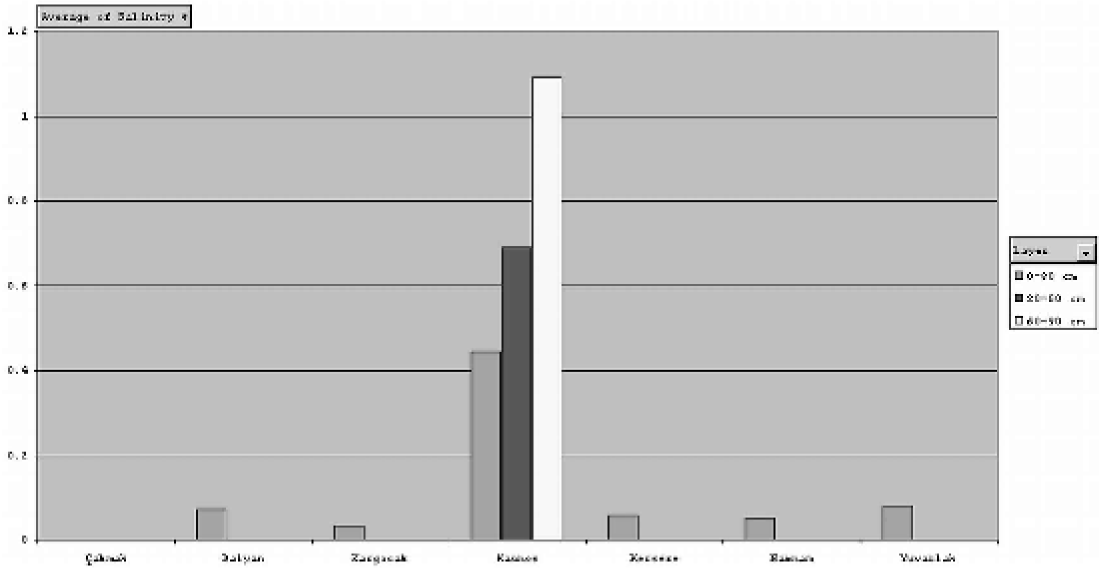

Figure A.1 Salinity

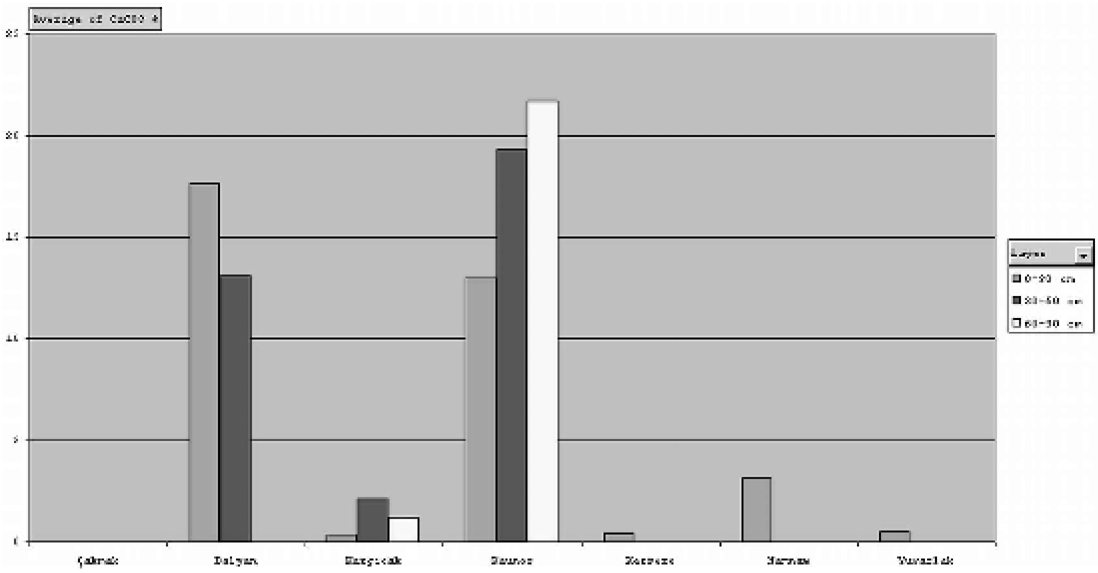

Figure A.2 $CaCO_3$

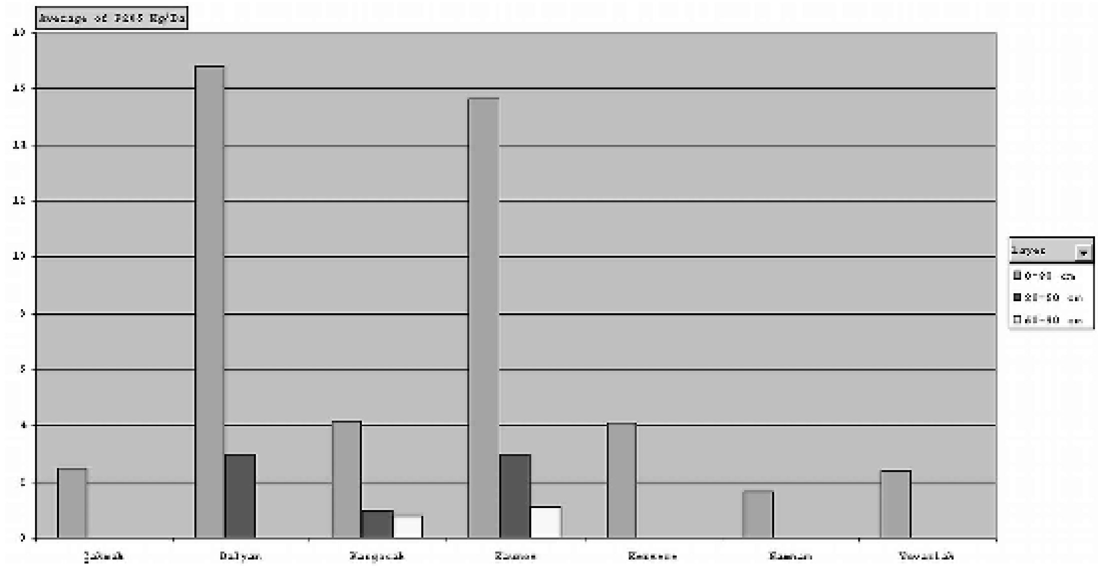

Figure A.3 P_2O_5

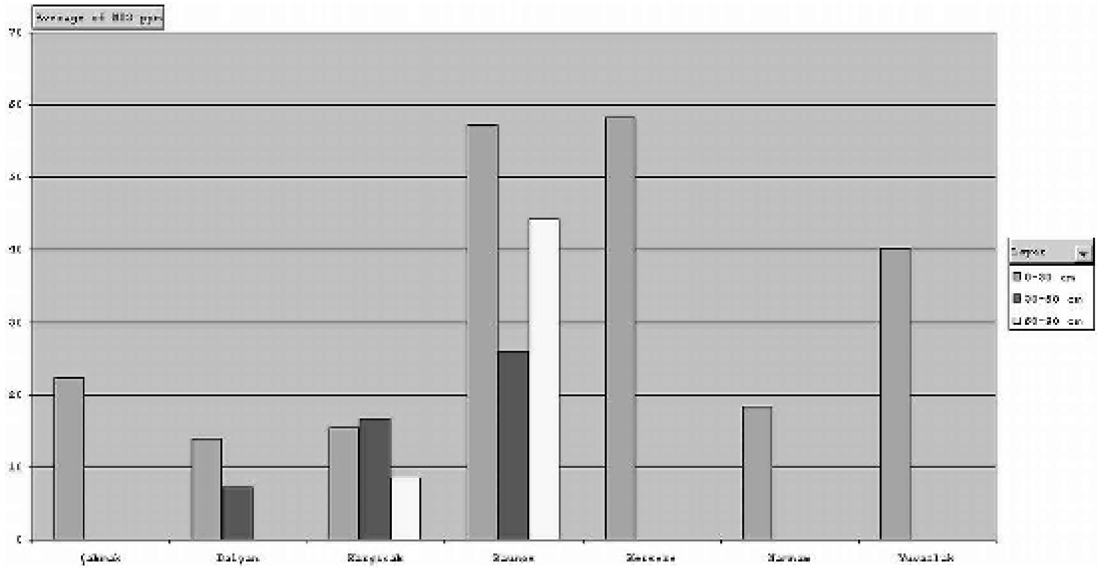

Figure A.4 NO_3

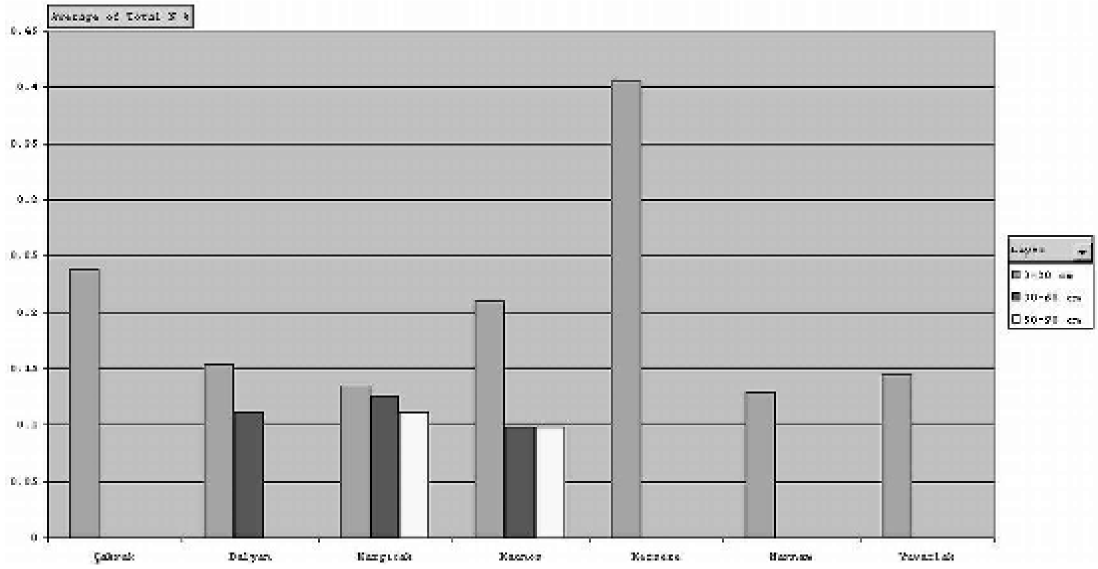

Figure A.5 Total N

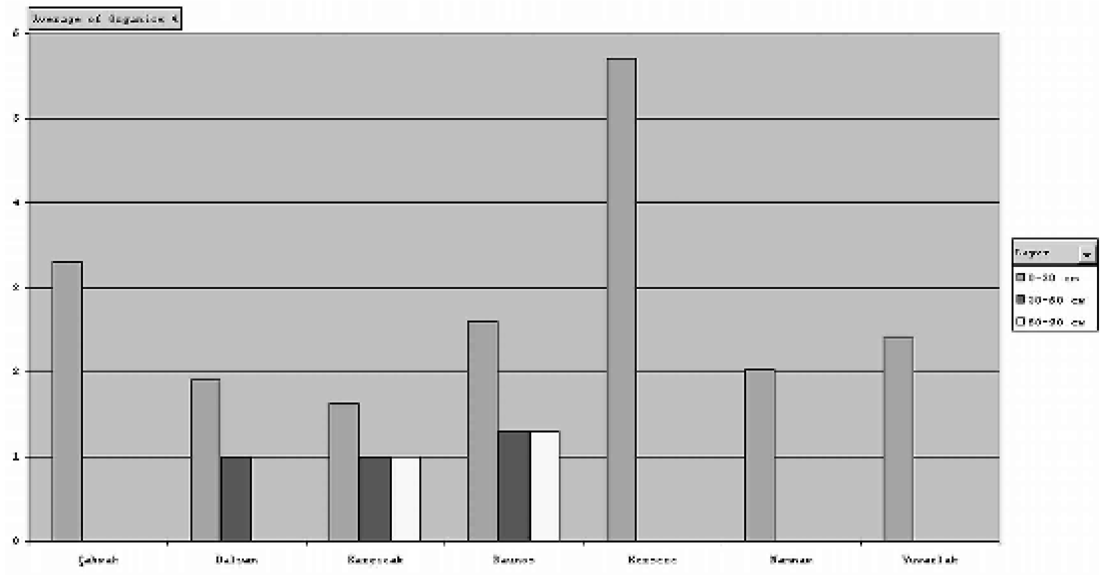

Figure A.6 Organics

APPENDIX B

Table B.1 Calibrated Model Input File

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
RUN

GLOBAL
  Namnam Watershed 1998 Annual Simulation
  START       1998/01/01 00:00  END    1998/12/31 00:00
  RUN INTERP OUTPT LEVELS    3    4
  RESUME     0 RUN     1                         UNITS     2
END GLOBAL

FILES
WDM        21   03090101.wdm
MESSU      31   03112911.oup
END FILES

OPN SEQUENCE
    INGRP              INDELT 24:00
      PERLND      41
      PERLND      31
      PERLND      21
      PERLND      12
      PERLND      11
      RCHRES       4
      RCHRES       3
      RCHRES       2
      RCHRES       1
      DISPLY       1
      DISPLY       2
      DISPLY       3
      DISPLY       4
      DISPLY       5
      DISPLY       6
      DISPLY       7
    END INGRP
```

```
END OPN SEQUENCE

PERLND
  ACTIVITY
*** # -  # ATMP SNOW PWAT _SED _PST _PWG PQAL MSTL PEST NITR PHOS TRAC
   11   41    1    0    1    0    1    0    0    0    0    0    0    0
  END ACTIVITY
  PRINT-INFO
*** # -  # ATMP SNOW PWAT _SED _PST _PWG PQAL MSTL PEST NITR PHOS TRAC PIVL _PYR
   11   41    4         4         4                                          12
  END PRINT-INFO
  GEN-INFO
*** # -  #                               _tin tout Engl Metr
   11   11 Delta Citrus                     2    2    0   31
   12   12 Delta Forest                     2    2    0   31
   21   21 South Forest                     2    2    0   31
   31   31 West Forest                      2    2    0   31
   41   41 North Forest                     2    2    0   31
  END GEN-INFO
  ATEMP-DAT
    # -  #   El-diff    Airtmp ***
   11   11     83.50      6.90
   12   12    371.00      5.90
   21   21    434.98      5.70
   31   31    285.57      6.50
   41   41    922.24      4.60
  END ATEMP-DAT
  PWAT-PARM1
    # -  # CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC ***
   11   41    0    0    0    1    1    1    1    1    1    2
  END PWAT-PARM1
  PWAT-PARM2
    # -  # ***FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
   11   11     0.000    293.39      1.27   4379.56    0.0875     0.000     0.970
   12   12     0.000    293.39      2.54   4379.56    0.2746     0.000     0.980
   21   21     0.000    293.39      2.54   2468.11    0.3130     0.000     0.980
   31   31     0.000    293.39      2.54   3767.89    0.3069     0.000     0.980
   41   41     0.000    293.39      2.54   2589.94    0.4618     0.000     0.980
  END PWAT-PARM2
  PWAT-PARM3
    # -  # ***PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
   11   11      4.44      1.67       2.0       2.0      0.00      0.03      0.20
   12   12      4.44      1.67       2.0       2.0      0.00      0.03      0.20
   21   21      4.44      1.67       2.0       2.0      0.00      0.03      0.20
```

```
 31   31       4.44       1.67        2.0        2.0       0.00       0.03       0.20
 41   41       4.44       1.67        2.0        2.0       0.00       0.03       0.20
END PWAT-PARM3
MON-INTERCEP
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11    11 0.61 1.63 3.18 1.77 2.06 0.00 0.00 0.00 2.43 0.82 1.54 2.25
 12    12 0.61 1.63 3.18 1.77 2.06 0.00 0.00 0.00 2.43 0.82 1.54 2.25
 21    21 0.61 1.63 3.18 1.77 2.06 0.00 0.00 0.00 2.43 0.82 1.54 2.25
 31    31 0.61 1.63 3.18 1.77 2.06 0.00 0.00 0.00 2.43 0.82 1.54 2.25
 41    41 0.61 1.63 3.18 1.77 2.06 0.00 0.00 0.00 2.43 0.82 1.54 2.25
END MON-INTERCEP
MON-UZSN
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11    11 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5
 12    12 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5
 21    21 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5
 31    31 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5
 41    41 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5 23.5
END MON-UZSN
MON-MANNING
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11    11 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
 12    12 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
 21    21 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
 31    31 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
 41    41 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
END MON-MANNING
MON-INTERFLW
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11    11 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00
 12    12 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00
 21    21 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00
 31    31 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00
 41    41 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00
END MON-INTERFLW
MON-IRC
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11    11 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70
 12    12 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70
 21    21 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70
 31    31 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70
 41    41 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70 0.70
END MON-IRC
MON-LZETPARM
```

```
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC ***
 11   11 0.40 0.40 0.40 0.50 0.50 0.50 0.50 0.50 0.50 0.40 0.40 0.40
 12   12 0.40 0.40 0.40 0.50 0.50 0.50 0.50 0.50 0.50 0.40 0.40 0.40
 21   21 0.40 0.40 0.40 0.50 0.50 0.50 0.50 0.50 0.50 0.40 0.40 0.40
 31   31 0.40 0.40 0.40 0.50 0.50 0.50 0.50 0.50 0.50 0.40 0.40 0.40
 41   41 0.40 0.40 0.40 0.50 0.50 0.50 0.50 0.50 0.50 0.40 0.40 0.40
END MON-LZETPARM
PWAT-STATE1
  # -  # ***  CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
 11   11         0         0     23.47         0    293.39      25.4         0
 12   12         0         0     23.47         0    293.39      25.4         0
 21   21         0         0     23.47         0    293.39      25.4         0
 31   31         0         0     23.47         0    293.39      25.4         0
 41   41         0         0     23.47         0    293.39      25.4         0
END PWAT-STATE1
PSTEMP-PARM1
  <PLS >  Flags for section PSTEMP***
  # -  # SLTV ULTV LGTV TSOP***
 11   41    1    1    1    2
END PSTEMP-PARM1
MON-ASLT
  <PLS >  Value of ASLT at start of each month (deg C)***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
 11   41-3.04-3.04-3.04-3.04-3.04-3.04-3.04-3.04-3.04-3.04-3.04-3.04
END MON-ASLT
MON-BSLT
  <PLS >  Value of BSLT at start of each month (deg C/C)***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
 11   41 1.37 1.37 1.37 1.37 1.37 1.37 1.37 1.37 1.37 1.37 1.37 1.37
END MON-BSLT
MON-ULTP1
  <PLS >  Value of ULTP1 at start of each month (TSOPFG=2)         ***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
 11   41    1    1    1    1    1    1    1    1    1    1    1    1
END MON-ULTP1
MON-ULTP2
  <PLS >  Value of ULTP2 at start of each month (TSOPFG=2)         ***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
 11   41  1.6  1.3  1.7    2  2.4    3  4.5  5.8  6.4  5.9  3.8  2.2
END MON-ULTP2
MON-LGTP1
  <PLS >  Value of LGTP1 at start of each month (TSOPFG=2)         ***
  # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
 11   41 1.15 1.01 0.98 0.92 0.89 0.89  0.9 0.93 0.97 1.04 1.13 1.19
```

```
  END MON-LGTP1
  MON-LGTP2
    <PLS >  Value for LGTP2 at start of each month (F deg) (TSOPFG=0) ***
    # -  #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
   11   41    0    0    0    0    0    0    0    0    0    0    0    0
  END MON-LGTP2
  PSTEMP-TEMPS
    <PLS >  Initial temperatures***
    # -  #     AIRTC     SLTMP     ULTMP     LGTMP***
   11   11       6.9      7.59      8.73     10.04
   12   12       6.9      7.59      8.73     10.04
   21   21       6.9      7.59      8.73     10.04
   31   31       6.9      7.59      8.73     10.04
   41   41       6.9      7.59      8.73     10.04
  END PSTEMP-TEMPS
END PERLND

RCHRES
  ACTIVITY
    RCHRES Active sections***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
    1    4    1    0    0    0    0    0    0    0    0    0
  END ACTIVITY
  PRINT-INFO
    RCHRES Printout level flags***
    # -  # HYDR ADCA CONS HEAT SED GQL OXRX NUTR PLNK PHCB PIVL PYR***
    1    4    4                                              12
  END PRINT-INFO
  GEN-INFO
    # -  # Name               NExit      _tin tout Engl Metr LKFG ***
    1    1 Delta Zone            1         2    2    0   31    0
    2    2 South Zone            1         2    2    0   31    0
    3    3 West Zone             1         2    2    0   31    0
    4    4 North Zone            1         2    2    0   31    0
  END GEN-INFO
  HYDR-PARM1
    RCHRES Flags for HYDR section***
    # -  #  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
            FG FG FG FG  possible   exit *** possible   exit     possible   exit
    1    4   0  1  1  1    4
  END HYDR-PARM1
  HYDR-PARM2
    # -  #      FTBN       LEN     DELTH     STCOR        KS ***  DB50
    1    1         1       430       0.0       0.0         0      0.25
```

```
    2    2         2       440       0.0       0.0         0      0.25
    3    3         3       690       0.0       0.0         0      0.25
    4    4         4      3680       0.0       0.0         0      0.25
  END HYDR-PARM2
  HYDR-INIT
    RCHRES       VOL  Cat  Initial value of COLIND ***   Initial value of OUTDGT
    # -  #      Mmt3        for each possible exit ***    for each possible exit
          <-------->   <><---><---><---><---><---> *** <---><---><---><---><--->
    1    1      1.91         5
    2    2      1.67         5
    3    3      1.53         5
    4    4      1.20         5
  END HYDR-INIT
END RCHRES

DISPLY
  DISPLY-INFO1
*** # -  #<----------Title----------->***TRAN PIVL DIG1 FIL1  PYR DIG2 FIL2 YRND
    1     PLS41-Overland Flow (Mm3day)   SUM     0    2   31    1    2   31   12
    2     PLS41-Interflow (Mm3day)       SUM     0    2   31    1    2   31   12
    3     PLS41-Groundwater (Mm3day)     SUM     0    2   31    1    2   31   12
    4     PLS41-Total Outflow (Mm3day)   SUM     0    2   31    1    2   31   12
    5     PLS41-Deep GW Loss (Mm3day)    SUM     0    2   31    1    2   31   12
    6     PLS41-Infiltration (Mm3day)    SUM     0    2   31    1    2   31   12
    7     RCH2-Total Outflow (Mm3day)    SUM     0    2   31    1    2   31   12
  END DISPLY-INFO1
END DISPLY

FTABLES
  FTABLE      1
 rows cols ***
    2    5
     depth  *** area    volume  outflow1  outflow2  outflow3  outflow4  outflow5
      (mt)  *** (ha)    (Mmt3)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)
       0.0     430.0         0     10000     10000
       2.7    3225.0     49.50     10000     10000
  END FTABLE  1
  FTABLE      2
 rows cols ***
    2    5
     depth  *** area    volume  outflow1  outflow2  outflow3  outflow4  outflow5
      (mt)  *** (ha)    (Mmt3)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)
       0.0     440.0         0     10000     10000
       2.5    3080.0     44.01     10000     10000
```

```
  END FTABLE  2
  FTABLE      3
 rows cols ***
    2    5
     depth  *** area    volume  outflow1  outflow2  outflow3  outflow4  outflow5
      (mt)  *** (ha)    (Mmt3)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)
       0.0     690.0         0     10000     10000
       2.3    4485.0     59.31     10000     10000
  END FTABLE  3
  FTABLE      4
 rows cols ***
    2    5
     depth  *** area    volume  outflow1  outflow2  outflow3  outflow4  outflow5
      (mt)  *** (ha)    (Mmt3)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)  ( mt3/s)
       0.0    3680.0         0     10000     10000
       2.1   22080.0    268.37     10000     10000
  END FTABLE  4
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
WDM      1 PREC     METR              SAME PERLND  11  41 EXTNL  PREC
WDM      2 ATMP     METR              SAME PERLND  11  41 EXTNL  GATMP
WDM     13 PETA     METR              SAME PERLND  11  41 EXTNL  PETINP
WDM      1 PREC     METR              SAME RCHRES   1   4 EXTNL  PREC
WDM      3 EVAP     METR              SAME RCHRES   1   4 EXTNL  POTEV
END EXT SOURCES

SCHEMATIC
<-Source->                  <--Area-->     <Trgt><-->  <ML->  ***     <m#>
<Name>   #                  <-factor->     <Name>   #      #  ***      # #
PERLND  41                     38123.9     RCHRES   4      1
PERLND  31                     10399.4     RCHRES   3      1
PERLND  21                      4343.9     RCHRES   2      1
PERLND  12                      4348.6     RCHRES   1      1
PERLND  11                      3184.3     RCHRES   1      1
RCHRES   4                                 RCHRES   3      2
RCHRES   3                                 RCHRES   2      2
RCHRES   2                                 RCHRES   1      2
END SCHEMATIC

MASS-LINK
  MASS-LINK        1
```

```
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
                            10m3/ha*ha>>Mm3***
PERLND     PWATER PERO          0.00001     RCHRES         INFLOW IVOL
  END MASS-LINK    1
  MASS-LINK        2
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     ROFLOW ROVOL                    RCHRES         INFLOW IVOL
  END MASS-LINK    2
END MASS-LINK

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
PERLND  41 PWATER SURO         0.38124     DISPLY   1      INPUT  TIMSER 1
PERLND  41 PWATER IFWO         0.38124     DISPLY   2      INPUT  TIMSER 1
PERLND  41 PWATER AGWO         0.38124     DISPLY   3      INPUT  TIMSER 1
PERLND  41 PWATER PERO         0.38124     DISPLY   4      INPUT  TIMSER 1
PERLND  41 PWATER IGWI         0.38124     DISPLY   5      INPUT  TIMSER 1
PERLND  41 PWATER INFIL        0.38124     DISPLY   6      INPUT  TIMSER 1
RCHRES   2 HYDR   ROVOL                    DISPLY   7      INPUT  TIMSER 1
END NETWORK

END RUN
```

CIRRUCULUM VITÆ

Kızıltan Yüceil, MSc

Yüceil was born in 1974 in İstanbul. He was a graduate of Moda Private College when he attended İstanbul Technical University, Environmental Engineering Department, in 1991. After his graduation as an engineer in 1995, he continued his academic studies in the same department and completed his MSc studies in 1997, and attended the PhD program in 1998. He worked as a planning engineer in 1995, from 1998 to 2000. Since 2002 he is working as a business development manager in information technology sector. He is single and living in İstanbul.