

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**ASSESSMENT OF WATER QUALITY BY
TOTAL MAXIMUM DAILY LOAD (TMDL)
ANALYSIS**

by
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April, 2007
İZMİR

ASSESSMENT OF WATER QUALITY BY TOTAL MAXIMUM DAILY LOAD (TMDL) ANALYSIS

**A Thesis Submitted to the
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in Environmental Engineering, Environmental Technology Program**

**by
Hülya BOYACIOĞLU**

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İZMİR

Ph.D. THESIS EXAMINATION RESULT FORM

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ASSESSMENT OF WATER QUALITY BY TOTAL MAXIMUM DAILY LOAD (TMDL) ANALYSIS

ABSTRACT

This study comprised of development of the new strategy to give better insight for the management of surface waters. This strategy is based on “Total Maximum Daily Load (TMDL)” analysis and aims sustainable basin management. Beneficial use designation is suggested being used as first step of the establishing strategy. The next step comprises interrogation of water quality to state whether or in which degree quality of water supports intended use. Water quality is defined by numerous variables (parameters). Selection of variables having significance for intended uses, determination of numerical limits for these variables are required and standards are suggested being used as a reference in this context. Existence of long list of variables defining overall water quality makes the procedure difficult and complicated. Application of environmetric analysis and water quality index methods is proposed to assist water experts in assessment process. Determination of indicator (key) variable(s) that are under pollution risk is another crucial component of the process. Indicator variable(s) will be the core for basin growth assumptions. Water quality modeling step intends to establish the cause-and-effect relationship between the key variable in waterbody and the pollutant sources. In this scope, pollutant loads from each source and total maximum daily load assimilated by the waterbody without exceeding standards are determined. In addition, alternative scenarios are developed to see effects of basin growth for various land uses on water quality. Each scenario ensures that water quality will attain and maintain water quality standards. Load contributions from pollution sources are investigated for each scenario to determine balance between pollutants originating from point and non-point sources. In the final stage, decision on basin growth and management plan is taken by policy makers.

The proposed approach was validated through a systematic application study in a field case in Turkey. Results revealed that decision process could assist policy makers

developing realistic strategies taking into account the basin specific conditions.

Keywords: Environmetric methods, Tahtali Basin, Total Maximum Daily Load (TMDL) analysis, water quality index, water quality management strategy.

SU KALİTESİNİN GÜNLÜK MAKSİMUM YÜK (GMY) ANALİZİ İLE DEĞERLENDİRİLMESİ

ÖZ

Sunulan çalışmada yüzeysel su kalitesi yönetimine daha etkin bakış açısı getirebilecek yeni bir strateji geliştirilmiştir. Bu strateji “Günlük Maksimum Yük (GMY)” analizine dayalı olup kaynağın sürdürülebilirliğini esas almaktadır. Bu süreçte su kaynağının kullanım amacının ortaya konması ilk adım olarak önerilmektedir. Daha sonra kalitenin planlanan kullanımı destekleyip desteklemeyeceğinin belirlenmesi (sorgulanması) gelmektedir. Kalite tanımlanmasında ise çok sayıda değişkenin (parametrenin) sorgulanması söz konusudur. Dolayısıyla ilk aşamada belirlenen amaç için önem teşkil eden parametrelerin seçilmesi, bunların sayısal hedeflerinin belirlenmesi önemlidir. Bu amaçla “su kalite standartları”nın referans olarak kullanılması önerilmektedir. Çok sayıda kalite değişkeni olması nedeniyle bunların sorgulanmasına yönelik süreçler oldukça karmaşık ve zordur. Sunulan tezde bu süreci kolaylaştıran ve anlamlı hale getirebilen “su kalitesi indeksi” ve “çok değişkenli istatistiksel yöntemler”in kullanımının yararlı olacağı düşünülmüştür. Kalite açısından risk altındaki değişken(ler)in belirlenmesi, sürecin en kritik ve önemli aşamasıdır. Risk altında olduğu belirlenen parametre(ler) havza gelişimine ve yönetimine dair kararların alınmasında esas teşkil edecektir. Bu değişken(ler) için havzadaki aktiviteler ile yüzeysel su kalitesinde yarattığı etkinin ilişkilendirilmesi amacıyla modelleme çalışması yapılmalıdır. Modelleme çalışması kapsamında noktasal ve yaygın kirlilik kaynaklarından gelecek yükler ve akarsuyun standartları aşmadan özümleyebileceği toplam yük değeri (Günlük Maksimum Yük) belirlenmelidir. Akarsu modelinin kurulup işlerliğinin ortaya konmasını takiben akarsu boyunca farklı arazi kullanım senaryoları oluşturularak bunların neden olacağı kalite değişimleri ortaya konmalıdır. Farklı senaryolar için yüklerin kaynaklara göre dağılımı (kirleticili paylarının ortaya konması) karar vericilerin arazi kullanımlarının kirlilikteki payını görmeleri açısından önemlidir. Son aşama ise değerlendirilen senaryolar ışığında havza gelişim ve yönetim politikasına karar verilmesidir.

Geliştirilen strateji Türkiye’de, İzmir Tahtalı Havzası’nda uygulanmıştır. Sonuçlar karar sürecinin havza koşullarını dikkate alarak etkin politika geliştirmede fayda sağlayacağını ortaya koymuştur.

Anahtar kelimeler: Günlük Maksimum Yük (GMY) analizi, çok değişkenli istatistiksel yöntemler, su kalite indeksi, su kalitesi yönetim stratejisi, Tahtalı Havzası.

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CHAPTER ONE

INTRODUCTION

In parallel to industrialization and population growth increased pollution loads have deteriorated the quality of surface water and groundwater sources around the world and pose serious threats to public health, agricultural- industrial production, ecological functions, and biodiversity etc. If pollution makes the water unfit for human use, degraded surface water, groundwater quality can even add to water shortages in water-scarce regions.

Water pollution, their impact on ecosystems and biodiversity are central issues for sustainable water resources development and management. Long-term development of global freshwater sources requires holistic management of resources and a recognition of the interconnectedness of the elements related to water quality. Few regions of the world are still exempt from problems of loss of potential sources of freshwater supply and pollution of surface and groundwater sources. Major problems affecting the water quality of rivers and lakes are inadequately treated domestic and industrial discharges, loss and destruction of catchments areas, deforestation, uncontrolled shifting cultivation and poor agricultural practices etc. Erosion, sedimentation, deforestation and desertification have also resulted in adverse effects on ecosystems. Many of these problems have arisen from a development model that is environmentally destructive and from a lack of public awareness and education about surface and groundwater resource protection (United Nations-UN, 1992).

Over the last three decades, water quality management in the world has been driven by the control of point pollution sources and the use of effluent-based water quality standards. Under this paradigm, the surface water has generally improved as wastewater treatment plants and point sources have responded to regulations. These regulations have required dischargers to comply with effluent-based standards set by local and national authorities. Although these efforts, most of the countries have not achieved the nations

water quality goals. Because discharges from other unregulated non-point pollution sources have not been successfully controlled. Today pollutants such as nutrients, which are often associated with non-point sources were not considered as criteria pollutants in the regulations. This array of challenges has shifted the focus of water quality management from effluent-based to ambient-based water quality management strategies based on holistic approach involving the drainage area for pollution control efforts. Total Maximum Daily Load (TMDL) analysis approach was derived from this fact and has been started to be applied in USA in last decade. It is based on the relationship between source of pollutants and in-stream water quality conditions. The TMDL establishes the allowable loadings for specific pollutants that a waterbody can receive without exceeding water quality standards thereby providing the basis to establish water quality based controls (United States Environmental Protection Agency-USEPA, 2001; National Research Council-NRC, 2001).

In contrast to this water quality management efforts performed mainly in developed countries there have been insufficient applications to protect and remediate water quality of the resources in developing/ under developed countries. One of the difficult tasks faced by environmental managers in these regions is how to control pollution after it has started limiting water uses for intended purposes. The main reason of the pollution problem is mis-planning and/or un-planning of basin growth. For example, in rural areas, water quality is mainly controlled by agricultural discharges and control of these sources is relatively difficult compared to point discharges. In spite of this fact generally spatial planning of the watersheds are made without considering the environmental effects of agricultural land uses. Therefore, there is a critical need to promote basin growth strategies that is based on the linkage between ambient water quality and drainage basin activities in these regions.

The thesis primarily focuses on the development and application of “TMDL based sustainable basin growth and management strategy” to give better insight for the management of surface waters that are used for various purposes such as drinking, irrigation water supply and other purposes. As has been discussed above controlling of

point discharges may not be sufficient to provide required ambient water quality. Thus, all the drainage area activities including point and non-point in a watershed should be related to the water quality to develop management strategy. In addition, assimilative capacity of the receiving bodies is suggested being used as a tool in guiding growth management. It is the capability of the waterbody resists the effects of pollutant sources without impairment of the water quality. Basin management approach combines these features investigates the watershed budget for pollutants (including point and non-point pollutants) that can be assimilated by a stream without causing impairment or water standards to be exceeded in the future in parallel to basin growth.

Procedural steps of the proposed approach are identified as the process for establishing “TMDL based sustainable basin growth and management strategy” comprises beneficial use designations and determination of targets, interrogation of the ambient water quality, selection of variable(s) for TMDL analysis, water quality modeling, basin growth scenarios development and decision on the basin growth plan.

The proposed approach is validated through a systematic application study in a field case in Turkey, known as Tahtali basin. Interpretation for the entire work, all the relevant aspects like advantages and difficulties in application are discussed in the final part of the thesis.

CHAPTER TWO

WATER QUALITY MANAGEMENT

2.1 Introduction

Integrated Water Resources Management (IWRM) includes social, economic and environmental factors in the planning, development, monitoring and protection of land and water resources. Hence, IWRM is not limited to addressing just physical relationships or water resource characteristics. It also includes water as an integral part of the ecosystem, a finite natural resource, and a social and economic good.

It is essential that water quality issues are addressed within an IWRM framework to properly handle. The often-conflicting demands on water resources has risen in many countries and this increased degradation of quality of ground waters, surface waters and also cost of treatment. Achieving the goal of water quality management, which is one of the most important components of IWRM, requires water quality issues should be handled properly (World Bank, 2003).

2.2 Historical Background of Water Quality Management

Before 1970's in USA water pollution control efforts were based on achievement of ambient water quality standards (Lung, 2001). This was economically efficient since each source would control its discharge only to the degree necessary to meet local water quality standards. However, the approach proved virtually impossible to administer, because of the difficulties in translating ambient standards into end-of-pipe effluent limits for individual discharges. The result was regulatory dissatisfaction and very little cleanup. One of the factors that contributed to the frustration was that the "translating" technology since water quality modeling was not fully developed (Lung, 2001).

In 1972 the Federal Water Pollution Control Act in the USA was amended to require a minimum level of control based on available treatment technology (Lung, 2001). Thus, the need to determine impact on the receiving water, which was the most difficult

determination to apply was largely eliminated. The result was substantial reduction in pollution even if this was achieved in areas in which cleanup was not needed to meet water quality goals. Over the following five years, secondary treatment was promulgated as the minimum level for all public treatment plants on the assumption that the expected water quality responses were worth the expenditure. Effluent limitation guidelines were established for industrial wastewaters. Wasteload allocation was used specifically for those instances in which there was some doubt that the water quality standards could be achieved by secondary treatment alone.

In 1977, the Clean Water Act was passed and water quality standards for toxic substances were prepared. It was clear by 1982 that the Environmental Protection Agency (EPA) strongly favored water quality based effluent limitations, rather than technology based limits, as basic water quality pollution control strategy, thereby reversing the regulatory trend. By that time, water quality modeling technology had advanced significantly and was ready to address a variety of water quality problems.

There is little doubt that the Clean Water Act of 1977 and its across-the-board abatement approach of secondary treatment required for municipal wastewaters has made substantial improvement in the water quality of many natural water systems. However, there remain a significant number of waterbodies that are water quality limited, thereby required additional work, leading to the development of so-called Total Maximum Daily Load (TMDL). Figure 2.1 shows the time lines for the water pollution control regulations and the evolution of water quality modeling technology (Lung, 2001).

Similar to the case in USA, EU member countries also handles the water resources in ecosystem approach. Since the year 2000, European Union Water Framework Directive also demands the management of the overall watershed (see Figure 2.2). Defining of boundaries of water basins, assessment of existing situation of basins with respect to pollutant sources and ambient water quality, monitoring and defining environmental

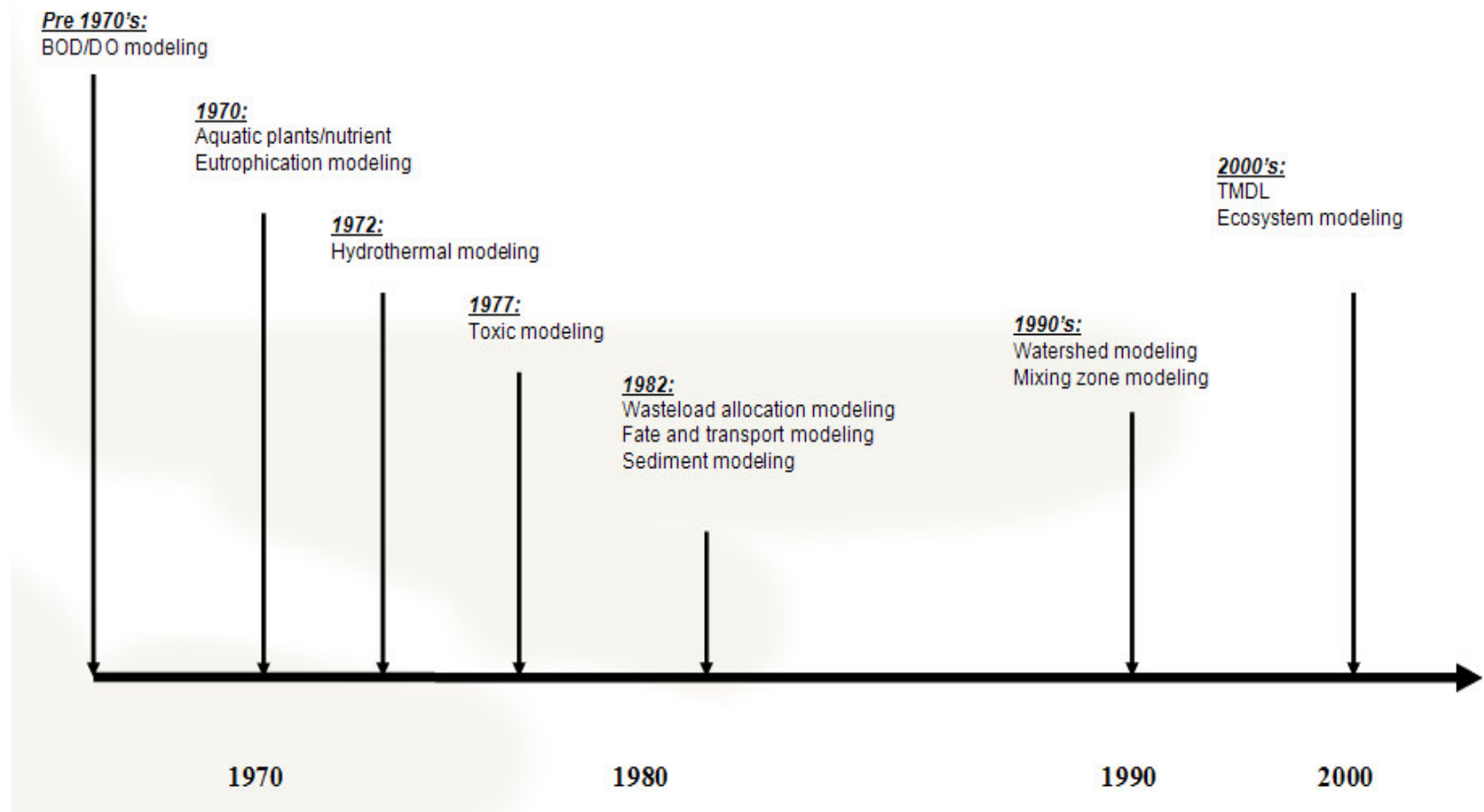


Figure 2.1 History of water pollution control and water quality modeling applications (Lung, 2001)

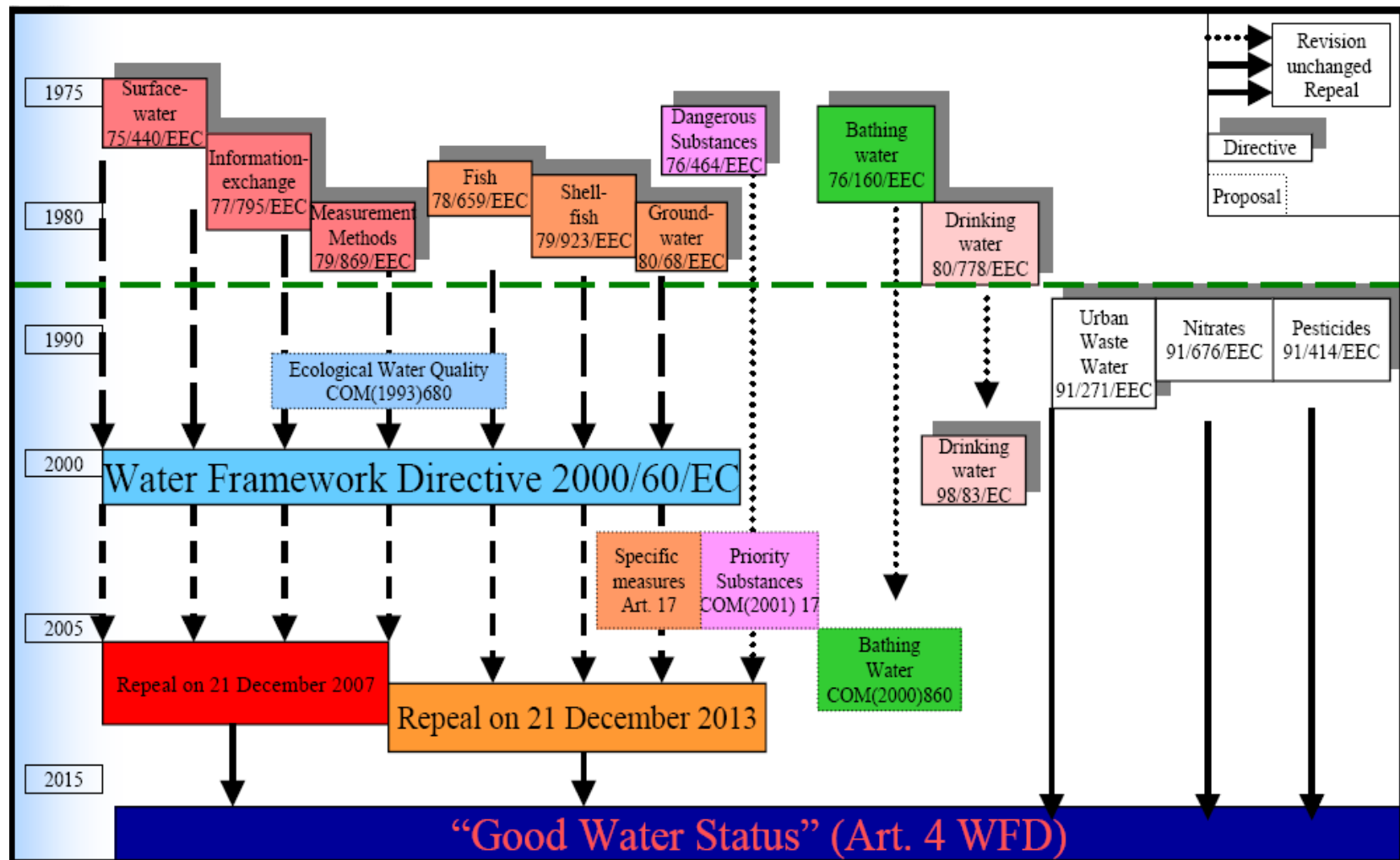


Figure 2.2 History of water management policies at EU (Boymanns, 2001)

goals, engaging the public should be implemented to achieve the goal by the end of 2015 in all the member states (Boymanns, 2001).

2.3 The Water Quality Based Approach to Pollution Control - Total Maximum Daily Load (TMDL) Analysis

Historically water pollution prevention efforts using end of pipe technologies have been developed for particular point sources discharging to a waterbody. This approach has produced significant improvements in water quality by establishing point source controls. In spite of these efforts, water quality degradation has limited using of surface waters for various purposes especially for drinking water supply. Some point sources need more controls and many non-point source impacts (from agriculture, forestry, urban run off etc.) cause or contribute to impairments in water quality. To address the combined cumulative impacts of both point and non point sources EPA has adopted a basin approach, of which TMDL's are a part. It enables a broad view of water resources that reflects the interrelationships of surface water, ground water, water pollutants, water quantity, and land management (United States Environmental Protection Agency-USEPA, 1999a).

2.3.1 What is a TMDL?

Total Maximum Daily Loads or TMDLs (also called Water Cleanup plans) are plans used to restore waterbodies (streams, rivers, lakes and estuaries) to good water quality. TMDL plan include:

- description of the type, amount, and sources of water pollution in a particular waterbody or segment
- analysis of how much the pollution needs to be reduced or eliminated to attain water quality
- strategy to control pollution and
- monitoring plan to assess effectiveness (Washington State Department of Ecology, 2002).

Community involvement is very important to the process of developing these plans and to putting the plans into action. The local community with ecology's support and assistance needs to be involved to help determine how pollution will be reduced to improve water quality. Strategies in the plans may include pollutant limits in wastewater discharge permits for municipalities and industries and recommending best management practices such as fencing, planting trees, and ensuring buffers next to streams etc. (Washington State Department of Ecology, 2002).

They are used to ensure that a waterbody will attain and maintain water quality standards including consideration of existing pollutant loads and reasonably foreseeable increases in pollutant loads. It is intended to provide an opportunity to compare relative contributions from all sources and consider technical and economic trade-offs between point and non-point sources.

The TMDL process is an essential element of the water quality-based approach to watershed management. Through the establishment and implementation of a TMDL; pollutant loadings from all sources are estimated; links are established between pollutants, sources, and impacts on water quality; maximum pollutant loads are allocated to each source; and appropriate control mechanisms are established or modified so that water quality standards can be achieved. Each TMDL is a carefully identified maximum allowable pollutant load or loads needed to meet water quality standards for defined critical conditions. This is the maximum amount of a pollutant that may be contributed to a waterbody so that it attains and maintains water quality standards. The TMDL may vary with time or the specific location and distribution of the pollutant sources. Therefore, it is necessary to determine the waterbody's critical conditions or periods for which the TMDL or TMDLs are developed (USEPA, 1999b).

Quantifying the Allowable Pollutant Load

A waterbody's allowable pollutant load contains wasteload allocations for point sources, load allocations for non-point sources, a margin of safety (MOS) sufficient to account for uncertainty and lack of knowledge, and an allowance for future growth. The

allowable pollutant load must ensure that the waterbody will attain and maintain water quality standards regardless of seasonal variations or design flow conditions and in consideration of reasonably foreseeable increases in pollutant loads. The illustration below shows how the allowable pollutant load is the total of these components.

Allowable Pollutant Load = Σ Wasteload Allocation + Σ Load Allocation + (MOS) + (Future Growth)
(USEPA, 1999b; Connecticut Department of Environmental Protection, 2005).

Wasteload Allocations

A wasteload allocation is defined as the portion of a TMDL's pollutant load allocated to a point source of a pollutant. Wasteload allocations for industrial and municipal point source facilities must be allocated to individual point sources of the pollutant that need to be controlled to attain and maintain water quality standards. Pollutant loads that do not need to be reduced to attain or maintain water quality standards can be considered as part of background loads (USEPA, 1999b).

Load Allocations

A load allocation is defined as the portion of a TMDL's pollutant load allocated to non-point sources of a pollutant. Non-point sources are generally land extensive activities that do not require discharge permits and include many agriculture and forestry activities, as well as small construction projects and unregulated storm water discharges etc. (USEPA, 1999b; 1999c).

Margin of Safety

The margin of safety (MOS) is a required component of a TMDL's maximum allowable pollutant load that accounts for uncertainty about pollutant loadings and waterbody response. The allowable pollutant load for each TMDL must include an MOS sufficient to account for uncertainties in establishing the TMDL and describe the manner in which an MOS is provided. The MOS may be established by leaving a portion of the assimilative capacity unallocated or by use of conservative analytical assumptions to

account for the uncertainties in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions). If a separate allocation of a capacity is set aside to provide an MOS, the amount of such allocation should be described. If protective assumptions are relied on to provide an MOS, the specific areas of the analysis that accommodate the MOS should be identified (USEPA, 1999a; 1999b).

2.3.2 Why EPA Developed Water Cleanup Plans “TMDL”?

Because it will result in cleaner lakes, streams, rivers and bays. Clean water is vital for quality of life - for both economic development and a healthy environment. But some water bodies are so badly polluted they need extra help.

Although municipal wastewater and industrial discharges require increasingly intense treatment under the Clean Water Act, many water bodies still fail to meet standards. Some receive so many point source discharges that even more stringent requirements must be used. Some waters are degraded by non-point pollution from runoff that carries bacteria, toxins, and excess nutrients from many sources. Water Cleanup Plans, also called Total Maximum Daily Loads or TMDLs, identify the pollution problems, allocate the maximum allowable pollution from various sources, and develop strategies to achieve those limits because federal law requires them. The Federal Clean Water Act of 1972 requires states to establish numeric standards for specific pollutants in water bodies. The Clean Water Act also requires states to prepare a list of water bodies that do not meet water quality standards every two years. A Water Cleanup Plan or TMDL must be developed for each of the polluted water bodies. The purpose of the plan is to determine the amount of pollution a water body can receive and still remain healthy for its intended uses, such as industrial, agricultural, drinking, recreation, and fish habitat. The plan must be approved by the US Environmental Protection Agency (Washington State Department of Ecology, 2002).

2.3.3 The Process of Establishing a TMDL

TMDL establishment is a process during which each of the discrete TMDL submittal elements will be developed. The following steps are identified as the process for establishing TMDLs:

- problem identification
- target analysis
- source identification and assessment
- linkage of the source and target
- allocating pollutant loads
- implementation and monitoring plan development
- assembling the TMDL (Devlin, 2000).

The sections below describe TMDL process briefly.

Problem Identification

The objective of this step is to identify the key factors and background information for a waterbody that describe the nature of the impairment and the context for the TMDL. Problem identification is a guiding factor in development of the remaining elements of the TMDL process (USEPA, 1999a; 1999c & 2001).

Target Analysis

This component intends to identify numeric or measurable indicators and target values that can be used to evaluate attainment of water quality standards in the waterbody. Often the TMDL target will be the numeric water quality standard for the pollutant of concern. In some cases, however, TMDLs must be developed for parameters that do not have numeric water quality standards. When numeric water quality standards do not exist, impairment is determined by narrative water quality standards or

identifiable impairment of designated uses (e.g., no fish). The narrative standard is then interpreted to develop a quantifiable target value to measure attainment or maintenance of the water quality standards (USEPA, 1999a; 1999c & 2001).

Source Assessment

During source assessment, the sources of pollutant loading to the waterbody are identified and characterized by type, magnitude, and location (USEPA, 1999a; 1999c & 2001).

Linkage of the Source and Target

To develop a TMDL, a linkage must be defined between the selected indicator(s) or target(s) and the identified sources. This linkage establishes the cause-and-effect relationship between the pollutant of concern and the pollutant sources. The relationship can vary seasonally, particularly for non-point sources, with factors such as precipitation. The linkage yields the estimate of total loading capacity (USEPA, 1999a; 1999c & 2001).

Allocations

Based on the established linkage, pollutant loadings that will not exceed the loading capacity and will lead to attainment of the water quality standard can be determined. These loadings are distributed or “allocated” among the significant sources of the pollutant of concern. The allocations are a component of the legally approved TMDL. Waste load allocations contain the allowable loadings from existing or future point sources, while load allocations establish the allowable loadings from natural background and from existing and future non-point sources. The margin of safety is usually identified during this step to account for uncertainty in the analysis, although it may also be identified in other TMDL components. The margin of safety may be applied implicitly by using conservative assumptions in the TMDL development process or

explicitly by setting aside a portion of the allowable loading (USEPA, 1999a, 1999c & 2001).

Follow-up Monitoring and Evaluation

TMDL submittals should include a monitoring plan to determine whether the TMDL has resulted in attaining water quality standards and to support any revisions to the TMDL that might be required. Follow-up monitoring is recommended for all TMDLs, given the uncertainties inherent in TMDL development. The rigor of the monitoring plan should be based on the confidence in the TMDL analysis: a more rigorous monitoring plan should be included for TMDLs with greater uncertainty and where the environmental and economic consequences of the decisions are greatest (USEPA, 1999a; 1999c & 2001).

Assembling the TMDL

In this component, those elements of a TMDL submittal required by statute or regulation are clearly identified and compiled and supplemental information is provided to facilitate TMDL review and approval.

In summary, the goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources. If the pollutant comes from a discrete (point) source such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse (non-point) sources such as general urban, residential, or farm runoff, the cumulative share is called a load allocation (Carroll, O'Neal & Golding, 2006).

CHAPTER THREE

WATER QUALITY ASSESSMENT

3.1 Introduction

The quality of water is defined in terms of its physical, chemical and biological parameters. Ascertaining its quality is very crucial before use for various purposes such as drinking, agricultural, recreational and industrial uses etc (Sargaonkar & Deshpande, 2003). Water quality assessment is the evaluation of the physical, chemical, and biological condition of water in relation to intended uses. It encompasses monitoring, data evaluation, reporting, and dissemination of the condition of the aquatic environment.

Major objectives of water quality assessment are:

- describe water quality at regional or national scales, including a determination of trends in time and space
- determine whether or not water quality meets previously defined objectives for designated uses, including public health
- determine investment options based on potential benefits from proposed or alternative remediation options
- provide a comprehensive assessment of river or lake basins and aquifers, especially to determine the relative importance of point- versus non-point-source pollution (World Bank, 2003).

Traditional approaches to assessing water quality are based on the comparison of experimentally determined parameter values with the existing guidelines. In many cases, the use of this methodology allows proper identification of contamination sources, and may be essential for checking legal compliance. However, it does not readily give a

global vision on the spatial and temporal trends in the overall water quality in a watershed (Debels, Figueroa, Urritia, Barra & Niell, 2005).

One of the difficult tasks facing environmental managers is how to convey their interpretation of complex environmental data into information that is understandable and useful to technical and policy individuals as well as the general public. Internationally, there have been number of attempts to produce method that meaningfully integrates the data sets (Nagels, Colley & Smith, 2001).

Great deal of consideration has been given to the development of “water quality index-WQI” since 1965 providing a tool for simplifying the reporting of water quality (Liou, Lien & Wang, 2004). WQI improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status. They are considered better for transmitting information to non-technical people. The concept of WQI is based on the comparison of the water quality parameters with respective regulatory standards. Previous developed indices mostly based on national standards expressing stream water quality for general recreational use including swimming and fishing etc.

Another difficult task facing environmental managers is assessment of environmental data characterized by high variability, because of a variety of natural and anthropogenic influences. Uncertainties from sampling, sample preparation, and measurement are also included in the data and affect their quality. The best approach to avoid misinterpretation of environmental monitoring data is the application of environmetric methods for environmental data classification and modeling. Environmetric data interpretation is used for better defining the sources and typology of the pollution (Reisenhofer, Adami & Favreto, 1996).

The following sections explain water quality index and environmetric methods including multidimensional scaling, cluster and trend analysis.

3.2 Water Quality Index

Since 1965, when Horton (1965) proposed the first water quality index (WQI), a great deal of consideration has been given to the development of “water quality index” methods with the intent of providing a tool for simplifying the reporting of water quality data (Liou et al., 2004).

WQI improves understanding of water quality issues by integrating complex data and generating a score that describes water quality status and evaluate water quality trends. These indices assess the appropriateness of water quality for a variety of uses (Cude, 2001). They are considered better for transmitting information to general audiences.

The concept of WQI is based on the comparison of the water quality parameter with respective regulatory standards (Khan, Husain & Lumb, 2003). Several authors have proposed the use of a WQI as a means to derive a numerical expression for the general quality of surface waters. A single WQI value makes information more easily and rapidly understood than a long list of numerical values for a large variety of parameters. In addition, because of the requirements from some international or regional directives most countries need to report the status of their water quality based on a classification scheme. Water quality index can also meet these expectations (Said, Stevens & Sehlke, 2004).

Objectives of the indices are summarized as:

- *Resource allocation:* WQI assist decision makers to determining priorities in water related decisions. It is used to test whether water quality support water bodies for designated uses or not.
- *Ranking of allocations:* It can be used for comparing water quality at different locations or geographical areas. Answers can be found to questions such as:

Which part of the basin has better water quality?

Which locations show similarities with respect to water quality?

- *Enforcement of standards:* They can also be applied to determine the extent to which legislative standards and existing criteria are being met or exceeded at specific locations.
- *Trend analysis:* It can be a way to assess effectiveness of existing environmental protection programs. Indices are used to determine the changes in the quality (degradation or improvement) in time at different locations.
- *Public information:* It can provide information to public on the status of the environment and progress towards its improvement.
- *Scientific research:* Water quality index, which translates a large quantity of data to a single score is immensely valuable in scientific research. For example in determining the effect of any pollution prevention activities, constructed treatment plants, different land uses etc (Abbasi, 2002; Harrison, Cooper & Ramm, 2000; Cude, 2001; Debels et al., 2005).

The process of development of a water quality index can be generalized in four steps:

- selecting the set of water quality variables of concern-*parameter selection*,
- transformation of the different units and dimensions of water quality variables to a common scale- *developing sub-indices*,
- weighting the water quality variables based on their relative importance to overall water quality-*assignment of weights*,
- formulation of overall water quality index- *aggregation of sub-indices to produce an overall index* (Harrison et al., 2000).

3.3 Universal Water Quality Index (UWQI)

In this section, as an example to WQI methods Universal Water Quality Index (UWQI) is explained. It provides to describe water quality of the source used for drinking water supply.

Meeting water quality expectations for streams, river, lakes etc. is required to protect water resources. Several regulatory agencies in the world issued very useful water quality criteria for this purposes. These have been studied to develop water quality indices to indicate water quality conditions. Previous developed indices mostly based on national standards and expressed stream water quality for general recreational use including swimming and fishing etc.

UWQI has advantages over preexisting indices with reflecting appropriateness of water for specific use-drinking water rather than general. In addition, it has been developed studying supranational standard-European Community standard (Boyacioglu, 2007).

The development of UWQI began with the selection of the most important variables that influence drinking water quality. Subsequently these variables needed to be grouped into vectors, namely observation and control vectors. The control vectors were based on European and Turkish standards. A comparison between the observation and control vectors identified classes for each variable, generally referred to a sub-index. It was then critical to select appropriate and non-biased weight factors for each of these variables depending on contextual conditions. The final calculations of UWQI were done using the sub-index values and weight factors for the vector that contains all variables (Boyacioglu, 2007).

UWQI was developed on the basis of following water quality standards:

- “the quality required of surface water intended for the abstraction of drinking water in the Member States” (see Appendix A-1). European Council Directive 75/440/EEC (European Council- EC, 1991).

- “the classification of inland waters according to quality” (See Appendix B-1). Turkish water pollution control regulation-WPCR (Official gazette, 2004).
- other reported scientific information (e.g. WHO reports).

According to EC legislation (75/440/EEC), water quality of surface waters intended for the abstraction of drinking water is classified into three groups. For each class treatment level required to transform surface water into drinking water are different and can be summarized as:

- *Category I-A1: Simple physical treatment and disinfection e.g. rapid filtration and disinfection.*
- *Category II-A2: Normal physical treatment, chemical treatment and disinfection e.g. pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination).*
- *Category III-A3: Intensive physical and chemical treatment, extended treatment and disinfection e.g. chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination) (EC, 1991).*

This classification is based on the assessment of about 45 water quality parameters (see Appendix A-1). Turkish WPCR has also quite similar categorization scheme. The main difference is that according to Turkish standard water quality parameters, which exceed the value set for Category III, defined the Category IV. Fourth class was excluded in UWQI development process considering appropriateness of water for drinking purpose (Boyacioglu, 2007).

UWQI parameters (water quality determinants) were selected among these 45 parameters. The concentration ranges of the determined variables for three categories were defined by referring to the 75/440/EEC and Turkish WPCR. In general, between both standards more restricted value for each class was accepted as reference value

(Boyacioglu, 2007). Summary of the proposed classification scheme is given in the Table 3.1.

Table 3.1 Classification of water quality for the development of UWQI (after Boyacioglu, 2007)

Parameter	Unit	Class I (excellent)	Class II (acceptable)	Class III (polluted)	Reference guideline	Remark
Total Coliform	CPU/100 ml	50	5000	50000	EC	It is used to indicate whether other potentially harmful bacteria may be present
Cadmium	mg/L	0.003	0.005	0.010	TR	Chemicals from industrial and domestic discharges
Cyanide	mg/L	0.010	0.050	0.100	TR	
Mercury	mg/L	0.0001	0.0005	0.002	TR	
Selenium	mg/L	0.010	0.010	0.020	TR, EC	Naturally occurring chemicals
Arsenic	mg/L	0.020	0.050	0.100	TR, EC	
Fluoride	mg/L	1	1.5	2	TR	
Nitrate-nitrogen	mg/L	5	10	20	TR	Chemical from agricultural activities
DO	mg/L	8	6	3	TR	Operational monitoring parameters
PH		6.5-8.5	5.5-6.4	<5.5	EC, TR	
			8.6-9	>9		
BOD	mg/L	<3	<5	<7	EC	Indicator of organic pollution
Total phosphorus-PO ₄ -P	mg/L	0.02	0.16	0.65	TR	It is included to satisfy the ecological requirements of certain types of environment

TR: Turkish Standard

EC: European Community Standard

Second step was the sub-indices development. Mathematical equations of corresponding value function curves that transform the actual concentration values into individual indices (sub-indices) were formulated. The assignment of weights to variables was followed by aggregation of sub-indices using weighted sum method to obtain overall index value (Boyacioglu, 2007).

It is useful to ascertain the suitability of water for drinking water supply at a particular location and to determine the level of acceptability for the individual

parameter by referring to the concentration ranges defined in the proposed classification scheme. Thus, the UWQI is definitely very useful to assess appropriateness of surface water quality status for drinking water supply. Following sections presents detailed information on procedural steps of UWQI development.

Water Quality Determinants Selected for UWQI

In drinking water quality monitoring, priority should be given to those substances which are known to be of importance to health and which are known to be present in significant concentrations in the water source (World Health Organization- WHO, 2006a). Qualitative prioritization scheme for setting drinking-water standards is depicted at Figure 3.1. Standards should be set at first for those contaminants that occur frequently and at significant concentrations in drinking-water and that have the greatest health impact. This figure can also assist determination of priorities in water quality monitoring.

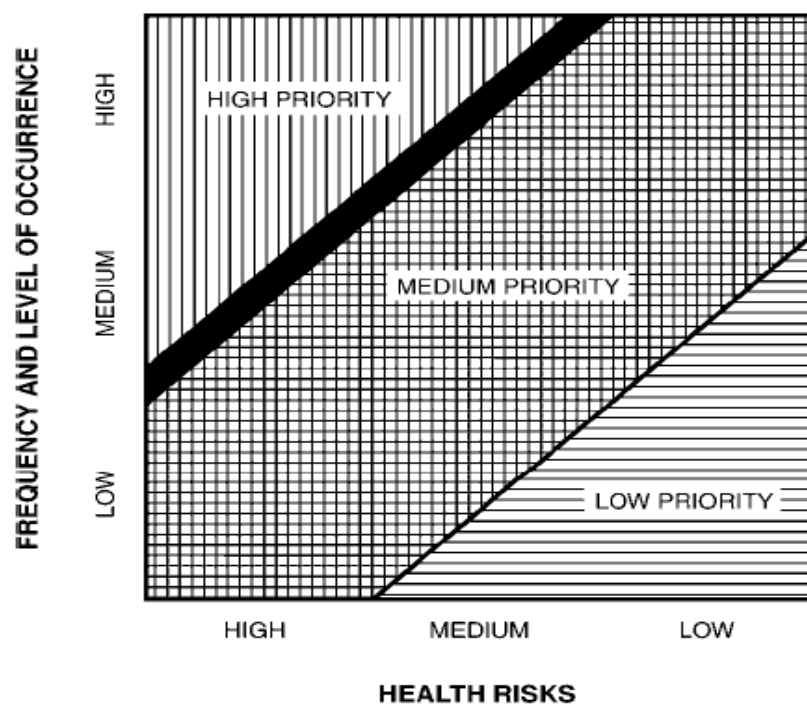


Figure 3.1 Priorities for setting standards (WHO 2006a)

Experience has shown that microbial hazards continue to be the primary concern in both developing and developed countries (WHO, 2004a). Based on the fact that microbiological contaminants belong to greatest health impact category have the highest priority in water quality monitoring. In addition, it is also important that monitoring of chemical water quality is linked to a process of hazard identification and risk assessment. There are a number of parameters that, when used in conjunction with a pollution source assessment, provide a good overall indication of chemical water quality. These parameters and others whose impact on human health or the environment are great should be included in initial testing. The presence at high levels of these parameters in the source water may indicate that other analyses are required. These variables include nitrate, pH, fluoride, dissolved oxygen (WHO 2006b). Furthermore, in assessment of the chemical quality it is also important to consider the arsenic and selenium. Extensive international experience has shown that arsenic, selenium, fluoride and nitrate cause widespread health effects in humans as a consequence of exposure through drinking water when they are present in excessive quantities (WHO, 2004b).

Arsenic, selenium and fluoride are present in water naturally. Nitrate may naturally occur but also it can be originated from agricultural source, sewage disposal and urban runoff. Agricultural sources may indicate that there will also be a problem with other agricultural pollutants such as pesticides (WHO, 2004b).

Toxic chemicals in drinking-water such as cadmium, cyanide and mercury etc. should also be included in initial testing. Because their existence in drinking water causes more serious health effects compared to the others.

Although some parameters such as pH, dissolved oxygen are not set at international drinking water standards and have direct health effects, they are important to assess the performance of control measures at appropriate time intervals.

All these facts were taken into account in selecting water quality determinants of the UWQI. Fecal coliform has been included as indicator parameter of microbial contamination for UWQI. To prevent long-term health effects from exposure to

contaminants, second priority was given to nitrate, arsenic, selenium, fluoride, cadmium cyanide and mercury. Operational monitoring parameters; dissolved oxygen and pH were also selected for UWQI index calculation. Finally, biochemical oxygen demand-BOD, which is indicator of organic pollution in water and phosphorus to satisfy the ecological requirements of certain types of environment, were considered as important determinants of water quality.

In summary based on extensive international experience as has been mentioned above twelve water quality parameters including cadmium, cyanide, mercury, selenium, arsenic, fluoride, nitrate-nitrogen, dissolved oxygen, biochemical oxygen demand, phosphorus, pH and total coliform were considered as the significant indicator parameters of UWQI to assess surface water sources (Boyacioglu, 2007).

Following sections briefly explains the potential sources and health effects of the selected parameters in drinking water. In addition limit values set in WHO guidelines for drinking water quality that is used by developing and developed countries worldwide as the basis for regulation and standard setting to ensure the safety of drinking-water is given to understand level of incidence that cause health risks.

Discussion of Selected Parameters

Selenium: Selenium is present in the Earth's crust, often in association with sulfur-containing minerals. Levels in drinking water vary greatly in different geographical areas but are usually much less than 0.01 mg/L (WHO, 2004a). In humans, the toxic effects of long-term selenium exposure are hair or nails loss, circulatory problems etc. (USEPA, 2003). The 1958 WHO international standards for drinking water recommended a maximum allowable concentration of 0.05 mg/L for selenium, based on health concerns. The 1993 guidelines proposed a health-based guideline value of **0.01 mg/L** on the basis of human studies (WHO, 2004a).

Arsenic: Arsenic is introduced into drinking-water sources primarily through the dissolution of naturally occurring minerals. In drinking water it causes significant health

effects and is considered to be a high-priority substance for screening in drinking-water sources. Levels in natural waters generally range between 1 and 2 mg/L, although concentrations may be elevated (up to 12 mg/L) in areas containing natural sources. It is an important drinking-water contaminant, because it is one of the few substances shown to cause cancer at particularly skin, bladder and lung through consumption of drinking water (WHO, 2004a; USEPA 2003). In several parts of the world, arsenic-induced disease, including cancer, is a significant public health problem. The 1958 WHO international standards for drinking water recommended a maximum allowable concentration of **0.2 mg/L** for arsenic, based on health concerns. Provisional guideline value for arsenic was set at the limit of **0.01 mg/L** in the 1993 guideline (WHO, 2004a).

Cadmium: Cadmium contamination in drinking water may be caused by erosion of natural deposits, discharge from metal refineries, run off from waste batteries and paints etc. Level in drinking water is usually less than 1 mg/L. Cadmium accumulates primarily in the kidneys and has a long biological half-life in humans of 10–35 years. There is evidence that cadmium is carcinogenic by the inhalation route. In the first edition of the WHO guidelines for drinking water quality, published in 1984, a guideline value of **0.005 mg/L** was recommended for cadmium in drinking water. This value was lowered to **0.003 mg/L** in the 1993 (USEPA, 2003; WHO, 2004a).

Cyanide: Cyanide is rarely found in drinking water, primarily as a consequence of industrial contamination (discharge from steel/metal, plastic and fertilizer factories). The acute toxicity of cyanides is high. As a consequence of the long-term consumption of high levels of cyanide effects on the thyroid and particularly the nervous system were observed in some populations. The 1958 WHO international standards for drinking water recommended a maximum allowable concentration for cyanide, based on health concerns. A health-based guideline value of **0.07 mg/L**, which was considered to be protective for both acute and long-term exposure, was derived in the 1993 guidelines (USEPA, 2003; WHO, 2004a).

Fluoride: The most important source of fluoride in drinking water is naturally occurring and can be released to the environment from the phosphate-containing rock used to produce phosphate fertilizers. These phosphate deposits contain about 4% fluorine. In addition, inorganic fluoride-containing minerals are used widely in industry for a wide range of purposes including aluminum production. In groundwater, concentrations vary with the type of rock the water flows through but do not usually exceed 10 mg/L and the highest natural level reported is 2800 mg/L (WHO, 2004a). Fluoride primarily produces effects on skeletal tissues (bones and teeth), children may get mottled teeth (USEPA, 2003). A guideline value for fluoride was set at the limit of **1.5 mg/L** by WHO in the 1993 guideline (WHO, 2004a).

Nitrate: Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Common source of nitrate and nitrite in water are runoff from fertilizer use, leaching from septic tanks, sewage and erosion of natural deposits etc. (USEPA, 2003).

Normally the nitrate concentration in groundwater and surface water is low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. Anaerobic conditions may result in the formation and persistence of nitrite. In most countries, nitrate levels in surface water do not exceed **10 mg/L**, although nitrate levels in well water often exceed 50 mg/L, nitrite levels are normally lower, less than a few milligrams per liter (WHO, 2004a).

Excessive levels of nitrate in drinking water cause serious illness and sometimes death. The problem in infants is due to conversion of nitrate to nitrite by the body, which can interfere with the oxygen-carrying capacity of the children blood. This can be an acute condition, in which health deteriorates rapidly over a period of days. Symptoms include shortness of breath and blueness of the skin “blue-baby syndrome” (USEPA, 2006).

Mercury: The important sources of mercury in drinking water are erosion of natural deposits, discharge from refineries and factories, runoff from landfills and croplands

(USEPA, 2003). Mercury is present in the inorganic form in surface water and groundwater at concentrations usually below 0.5 mg/L, although local mineral deposits may produce higher levels in groundwater. The toxic effects of inorganic mercury compounds are seen mainly in the kidney (USEPA, 2006; WHO, 2005). A guideline value for mercury was set at the limit of **0.001 mg/L** by WHO in the 1993 guideline (WHO, 2004a).

Dissolved oxygen: DO is considered by many water quality experts to be one of the most important measures of water quality (Kahler Royer, 1999). The DO content of water is influenced by the source, raw water temperature etc. Depletion of dissolved oxygen in water can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can also cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated. No health-based guideline value is recommended (WHO, 2004a).

Total coliform: Total coliforms are a group of closely related, mostly harmless bacteria that live in soil and water as well as the gut of animals. Presence of total coliforms can indicate the general quality of that water and the likelihood that the water is fecally contaminated. If total coliforms are found, then the public water system must further analyze that total coliform-positive sample to determine if specific types of coliforms (i.e., fecal coliforms or *E. coli*) are present. Fecal coliform are bacteria whose presence indicates that the water may have been contaminated with human or animal fecal material. Their presence in water is indicator of fecal pollution and potentially dangerous bacterial contamination by disease causing microorganisms. The site contaminated with these bacteria is not recommended for drinking and other contact recreation (Said et al., 2004; World Bank, 2003; USEPA, 1998a).

pH: It is one of the most important operational water quality parameter. No health-based guideline value was proposed for pH in the 1993 guidelines. In the first edition of the Guidelines for Drinking-water Quality, published in 1984, a guideline value for pH range was established as **6.5–8.5** based on aesthetic considerations (WHO, 2004a).

BOD: BOD is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. The greater the BOD is the greater the degree of pollution (World Bank, 2003). Organic matter can be measured as total organic carbon (TOC), BOD, or chemical oxygen demand (COD). BOD primarily used with wastewaters and polluted surface waters, and TOC is the only parameter applicable to drinking water (International Water Association- IWA, 2003).

Phosphorus: Phosphorus is the nutrient that is most often responsible for the impairment of surface water. It is primarily a surface water quality problem, rather than a groundwater problem. Excess phosphorus is a concern for aquatic ecosystems. Under most natural conditions, phosphorus is the limiting factor in the growth of aquatic plants. When large amounts of phosphorus enter lakes and streams, it enhances the growth of algae and other aquatic weeds, leading to excessive aquatic plant growth, often referred to as algae blooms. This unwanted burden of aquatic plant growth is termed “eutrophication.” This leads to a number of undesirable consequences. The water can become undesirable for recreational activities. In addition, when these aquatic plants die and decompose, they consume oxygen in the water and severe fish kills may occur. Decaying algae and plants may cause undesirable odor and taste in drinking water.

Phosphorus comes from both point and non-point sources. Point sources include municipal waste treatment plants, industrial operations, and large, confined livestock operations. Phosphorus also comes from non-point sources. Non-point sources of phosphorus include soil erosion and water runoff from cropland, lawns and gardens; private waste treatment systems; urban areas; small livestock confinement operations etc. (Devlin, Whitney & McWay, 2000).

Sub-Index Development

The proposed classification for UWQI along with ranges of concentrations of selected parameters based on standards is given in Table 3.1.

Considering required level of treatment, each class of water was assigned as:

- Class I: excellent
- Class II: acceptable
- Class III: polluted

Sub-indices are value functions (rating curves) to transform the different units and dimensions of water quality variables to a common scale. Development of rating curves is highly subjective and mostly based on the judgment of the author and a few of his associates. Opinions of the 14 water experts working at different institutions were asked about this process. They were agreed to assign fixed sub-index values for reference concentration values to formulate equations. Accordingly, if the content of detected parameter was lower than the value set for Class I the water quality sub-index was automatically registered “100”. Similarly, for the variable that exceeds the value set for Class III, the water quality sub-index was registered “0”. Fixed sub-index value, which corresponds to the values in the “acceptable class” category that are given at Table 3.1 was assigned as “50” (Boyacioglu, 2007).

Mathematical expressions were fitted for each parameter to obtain these fixed sub-index values (0, 50 and 100) against reference concentrations. Regression analysis was performed for this purpose using “*the Statistical Package for the Social Science Software-SPSS-10.0 for Windows*”. Mathematical equations are given in Table 3.2.

The value function curves (rating curves), wherein, the concentration of the parameter was taken on X-axis and index value on Y-axis were plotted for each parameter and are shown in Figure 3.2 through 3.12. These curves give the sub-index for individual parameters. For any particular concentration, the corresponding index can be read directly from these curves.

Table 3.2 Mathematical equations formulated for UWQI (Boyacioglu, 2007)

Variable	Range	Sub-index function
BOD	$X < 3$	$y = 100$
	$3 \leq X < 5$	$y = -25X + 175$
	$5 \leq X < 7$	$y = -22.5X + 162.5$
	$X \geq 7$	$y = 0$
Nitrate-nitrogen	$X \leq 5$	$y = 100$
	$5 < X \leq 10$	$y = -10X + 150$
	$10 < X \leq 20$	$y = -4.5X + 95$
	$X > 20$	$y = 0$
Arsenic	$X \leq 0.02$	$y = 100$
	$0.02 < X \leq 0.05$	$y = -1666.7 + 133.33$
	$0.05 < X \leq 0.1$	$y = -900X + 95$
	$X > 0.1$	$y = 0$
Dissolved oxygen	$X \geq 8$	$y = 100$
	$8 < X \leq 6$	$y = 25X - 100$
	$6 < X \leq 3$	$y = 15X - 40$
	$X < 3$	$y = 0$
Fluoride	$X \leq 1$	$y = 100$
	$1 < X \leq 2$	$y = -95X + 194.17$
	$X > 2$	$y = 0$
Total phosphorus	$X \leq 0.02$	$y = 100$
	$0.02 < X \leq 0.16$	$y = -357.14X + 107.14$
	$0.16 < X \leq 0.65$	$y = -91.837X + 64.694$
	$X > 0.65$	$y = 0$
Mercury	$X \leq 0.0001$	$y = 100$
	$0.0001 < X \leq 0.0005$	$y = -125000X + 112.5$
	$0.0005 < X \leq 0.002$	$y = -30000X + 65$
	$X > 0.002$	$y = 0$
Selenium	$X \leq 0.01$	$y = 100$
	$0.01 < X \leq 0.02$	$y = 4500X + 95$
	$X > 0.02$	$y = 0$
Cyanide	$X \leq 0.01$	$y = 100$
	$0.01 < X \leq 0.05$	$y = -1250X + 112.5$
	$0.05 < X \leq 0.1$	$y = -900x + 95$
	$X > 0.1$	$y = 0$
Cadmium	$X \leq 0.003$	$y = 100$
	$0.003 < X \leq 0.005$	$y = -25000X + 175$
	$0.005 < X \leq 0.010$	$y = -9000x + 95$
	$X > 0.010$	$y = 0$
Total Coliform	$X \leq 50$	$y = 100$
	$50 < X \leq 5000$	$y = -10.857 \ln X + 142.47$
	$5000 < X \leq 50000$	$y = -21,715 \ln X + 284.95$
	$X > 50000$	$y = 0$
pH	$6.5 \leq X \leq 8.5$	$y = 100$
	$5.5 \leq X \leq 6.4$ and	$y = 50$
	$8.6 \leq X \leq 9$	
	$X < 5.5$ and $X > 9$	$y = 0$

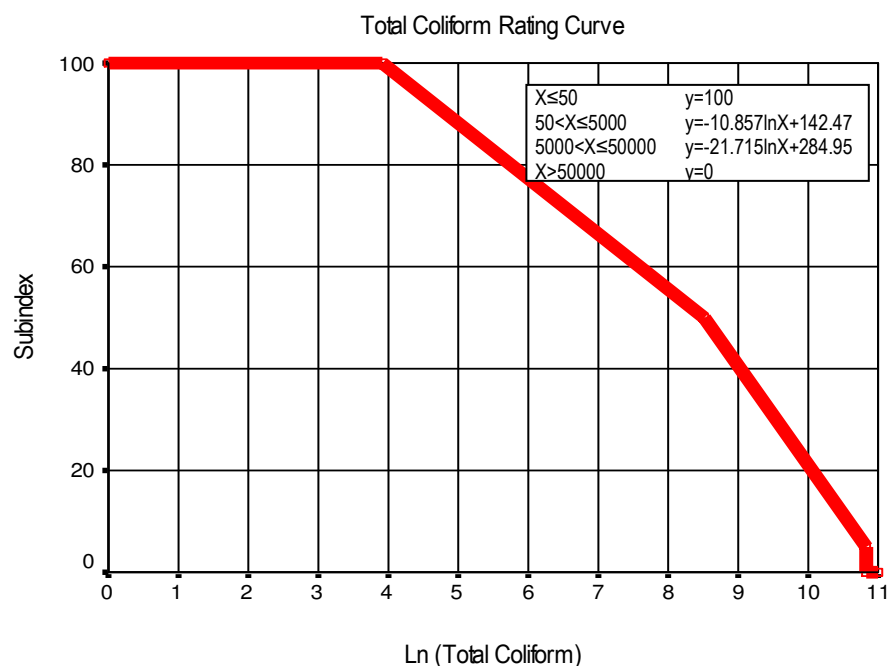


Figure 3.2 Total coliform rating curve

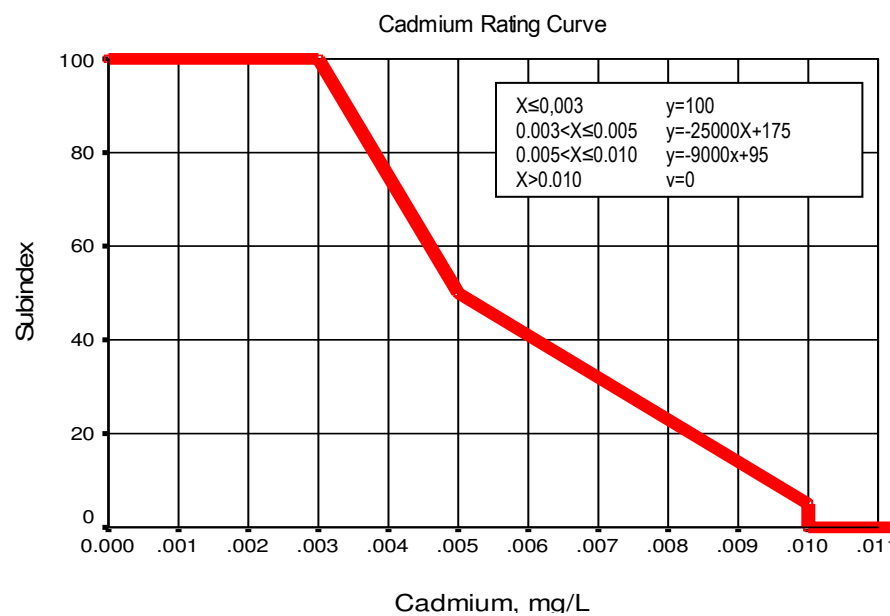


Figure 3.3 Cadmium rating curve

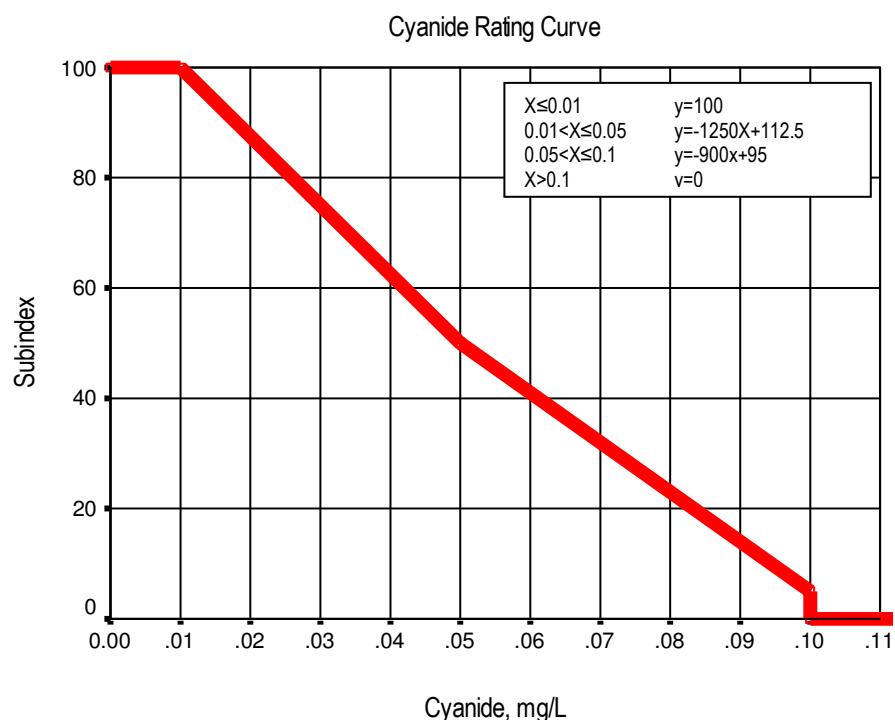


Figure 3.4 Cyanide rating curve

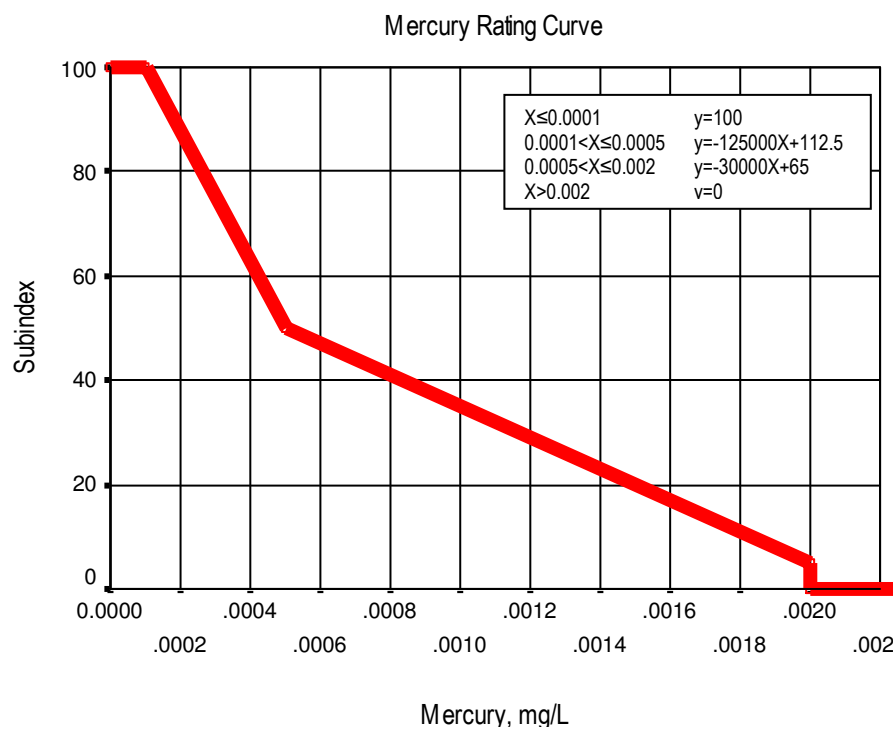


Figure 3.5 Mercury rating curve

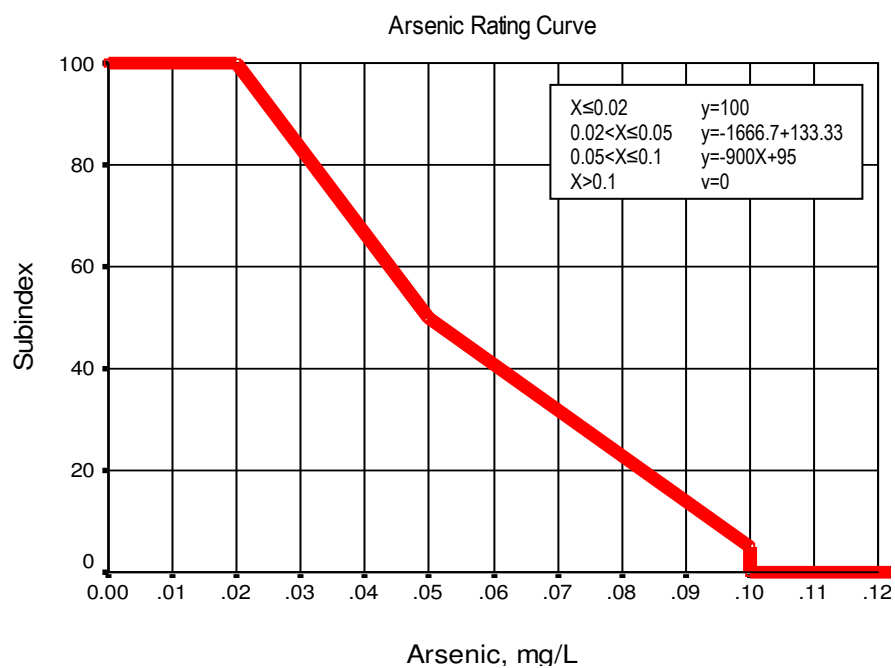


Figure 3.6 Arsenic rating curve

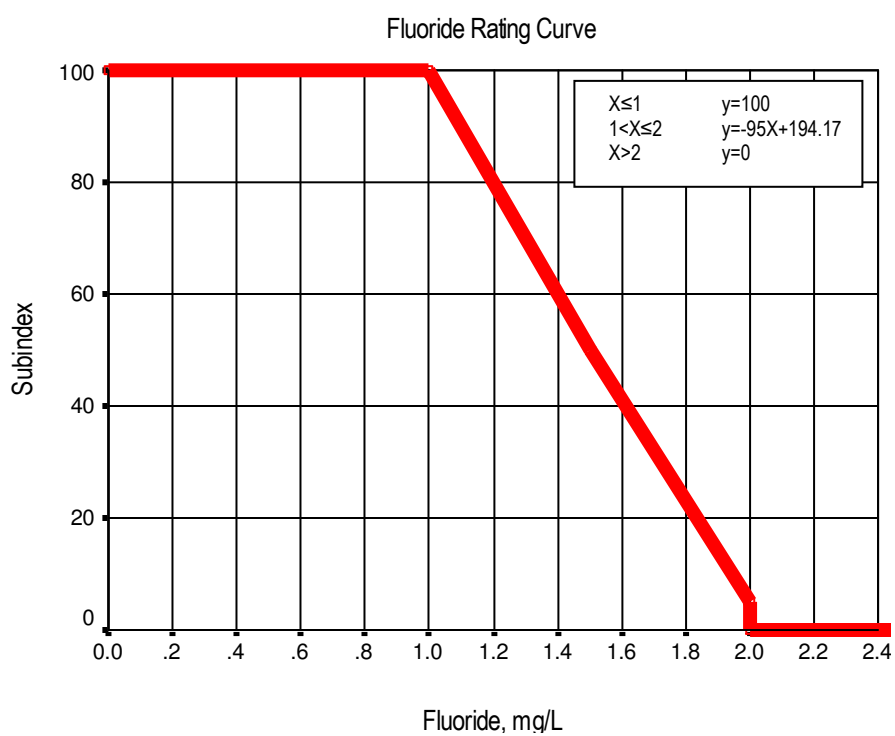


Figure 3.7 Fluoride rating curve

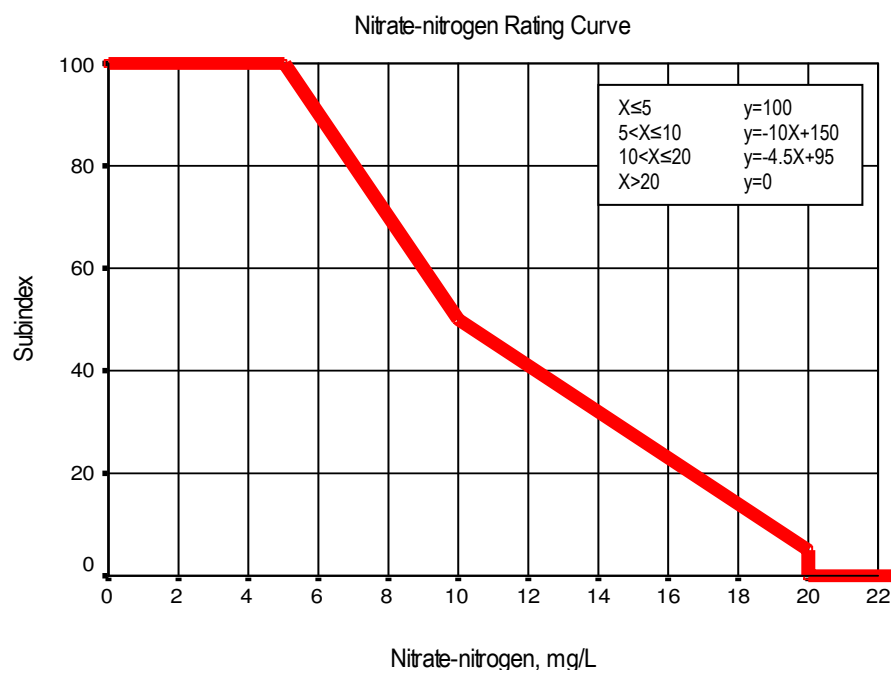
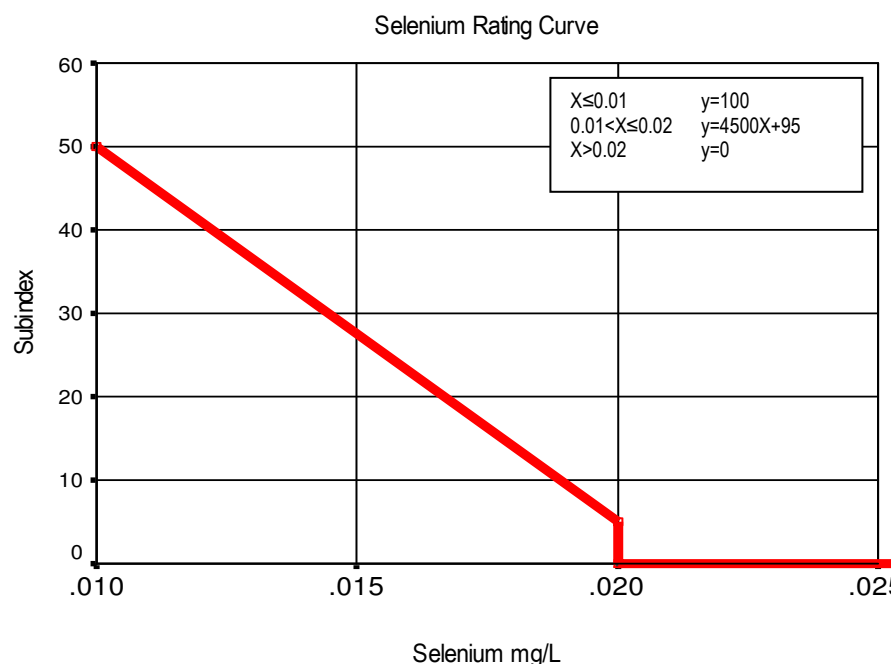


Figure 3.8 Nitrate-nitrogen rating curve



For $X \leq 0.010 \Rightarrow$ Subindex value $Y = 100$

Figure 3.9 Selenium rating curve

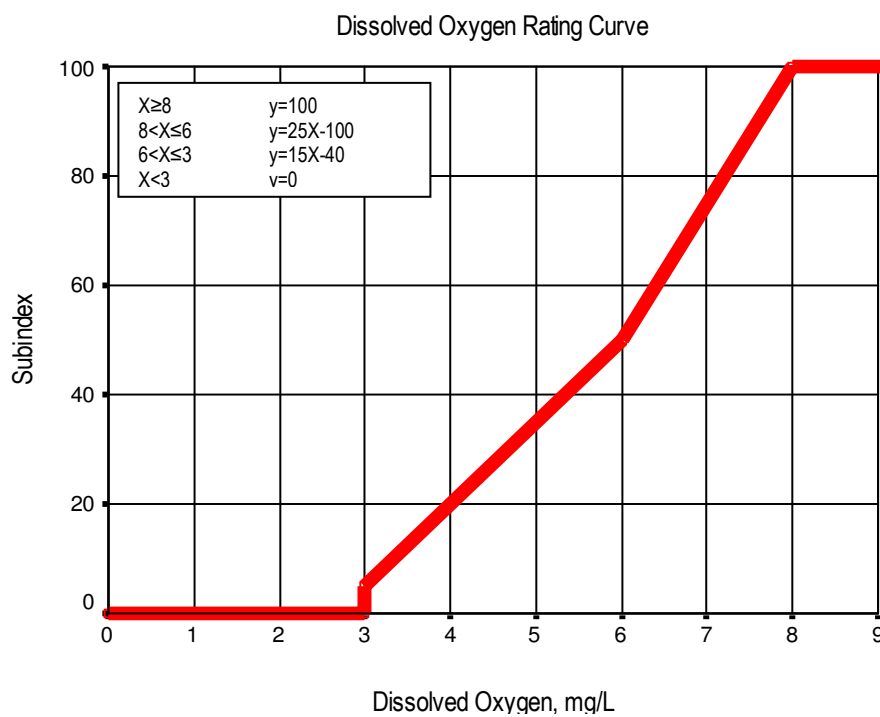


Figure 3.10 Dissolved oxygen rating curve

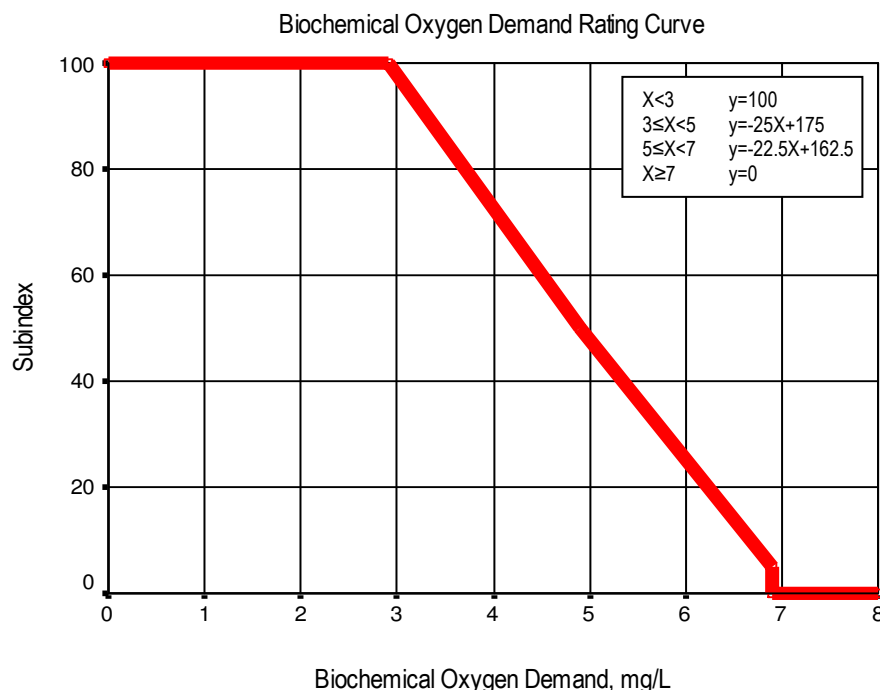


Figure 3.11 Biochemical oxygen demand rating curve

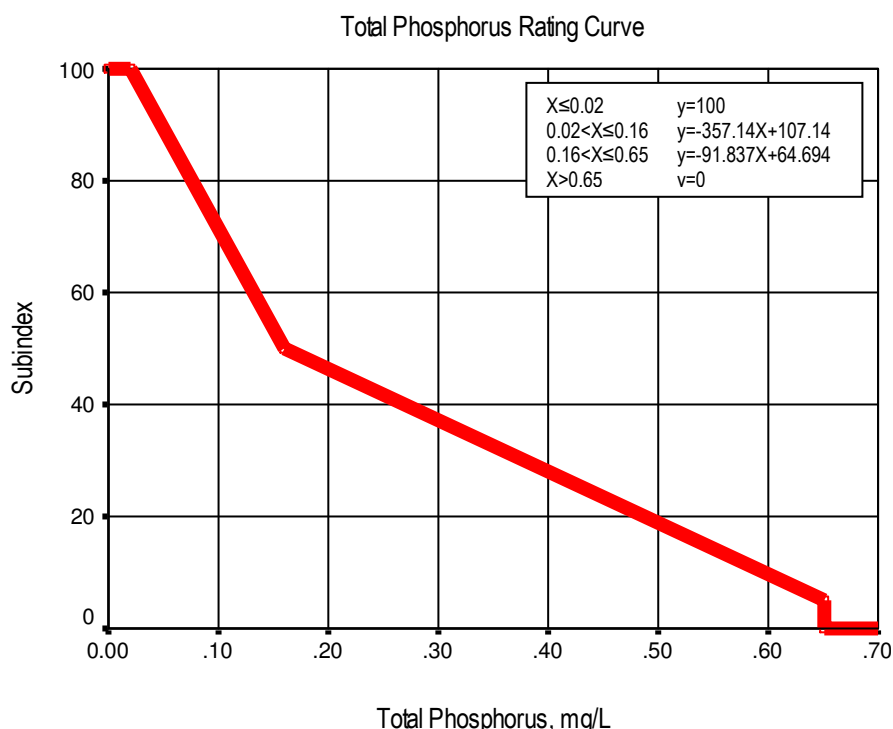


Figure 3.12 Total phosphorus rating curve

Overall Index Calculation-Aggregation of Sub-indices

Aggregation of sub-indices was done using weighted sum method. The assignment of weights to water quality variables was another important task. Factors taken into account for assigning weights to parameters are summarized as:

- chemical parameters had a lower weight than microbiological parameters, because microbiological contaminants belongs to greatest health impact category,
- high weight was given to those parameters of known health concern.

The temporary weights ranged from 1 to 4 on a basic scale of importance. On this scale 1, 2, 3 and 4 denote respectively little, average, great and very great importance. Each weight was then divided by the sum of all weights to arrive at the final weight factor (see Table 3.3).

Table 3.3 Temporary weights and weight factors assigned to variables of concern (Boyacioglu, 2007)

Category	Variable	Basis for Inclusion	Temporary weights (R _i)	Weight factor (W _i)=R _i / ΣR
Health hazard	Total Coliform	Indicator of fecal contamination	4	0,114
	Cadmium	Chemicals from industrial and domestic discharges	3	0,086
	Cyanide		3	0,086
	Mercury		3	0,086
	Selenium	Naturally occurring chemicals	3	0,086
	Arsenic		4	0,113
	Fluoride		3	0,086
Aesthetic	Nitrate-nitrogen	Chemical from agricultural activities	3	0,086
	DO	operational monitoring parameters	4	0,114
	PH		1	0,029
Oxygen depletion	BOD	Indicator of organic pollution	2	0,057
	Total phosphorus	It is included to satisfy the ecological requirements of certain types of environment	2	0,057
			ΣR=35	ΣW=1

The aggregation function was represented as:

$$UWQI = \sum_{i=1}^n W_i I_i \text{ where,} \quad (3.1)$$

W_i: weight for ith parameter

I_i: subindex for ith parameter (symbolizes with 'y' of table 3.2)

Considering treatment required to transform surface water into drinking water, which was stated at 75/440/EEC, the proposed UWQI index categorization schema is given in Table 3.4.

Table 3.4 UWQI index categorization schema (Boyacioglu, 2007)

Rank	WQI value
Excellent	95-100
Good	75-94
Fair	50-74
Marginal	25-49
Poor	0-24

The index value between 0 to less than 25 represented poor quality, 25 to less than 50 marginal quality, 50 to 75 fair quality, 75 to less than 95 good quality and above excellent quality (see Figure 3.13).

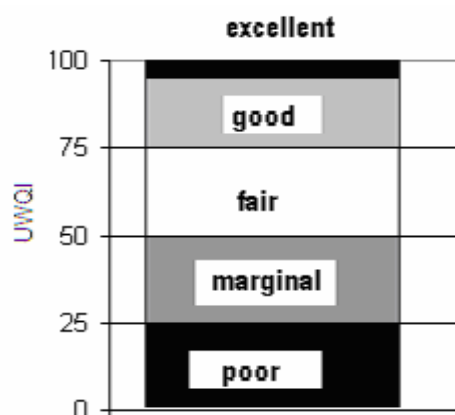


Figure 3.13 UWQI categorization scheme

3.4 Environmetric Methods in Water Quality Assessment

Environmental data are usually characterized by high variability, because of a variety of natural and anthropogenic influences. Uncertainties from sampling, sample preparation, and measurement are also included in the data and affect their quality.

The application of statistical approaches to the interpretation and modelling of environmental data (environmetrics) reveals a new type of information concerning time trends, seasonality and relationships between chemical components (Tsakovski et al., 2000). The best approach to avoid misinterpretation of environmental monitoring data is the application of environmetric methods (cluster, multidimensional scaling and trend analysis etc) for data classification and modeling. Environmetric data interpretation has also the advantage of visualization of the large amount of raw analytical measurements (Simeonov, Einax, Stanimirova & Kraft, 2002). They are used for better defining the sources and typology of the pollution (Reisenhofer et al., 1996).

Environmetric methods including multivariate statistical techniques, regression analysis, time series analysis etc cover the development and application of quantitative

methods in the environmental sciences and have been used successfully in ecological studies for many years. Surface water, groundwater water quality assessment and environmental research employing multi-component techniques are well described in the literature (Praus, 2005). They allow deriving information from the data set about the possible influences of the environment on water quality (Spanos, Simeonov, Stratis & Xristina, 2003).

Advantages of multivariate statistical techniques for ecological data can be summarised as:

- *reflect more accurately the true multidimensional, multivariate nature of natural ecological system*
- *provide a way to handle large data sets with large numbers of variables by summarizing the redundancy*
- *provide rules for combining variables in an “optimal way”*
- *provide a means of detecting and quantifying truly multivariate patterns that arise out of the correlation structure of the variable set (Mcgarial, Cushman & Stafford, 2000).*

The following section briefly explains environmetric methods including multidimensional scaling, cluster and trend analysis.

3.4.1 Multidimensional Scaling

Multidimensional Scaling (MDS) describes a family of techniques for the analysis of proximity data on a set of stimuli to reveal the hidden structure underlying the data. The proximity data can come from similarity judgments, identification confusion matrices, grouping data, same-different errors or any other measure of pairwise similarity. The main assumption in MDS is that stimuli can be described by values along a set of dimensions that places these stimuli as points in a multidimensional space and that the

similarity between stimuli is inversely related to the distances of the corresponding points in the multidimensional space (Steyvers, 2001; USEPA, 1998b).

3.4.2 Cluster Analysis

Cluster analysis (CA) is used to develop meaningful aggregations, or groups, of entities based on a large number of interdependent variables. Specifically the purpose is to classify a sample of entities into a smaller number of usually mutually exclusive groups based on the multivariate similarities among entities (Mcgarial et al., 2000). CA divides a large number of objects into smaller number of homogenous groups on the basis of their correlation structure. Within-group similarity is maximized and among-group similarity is minimized according to some objective criteria. An example of clustering is given in Figure 3.15. The input data is shown in Figure 3.14 (a), and the desired clusters in 3.14 (b).

Points belonging to the same cluster are given the same label. The objective is to identify the complex nature of multivariate relationships among the data (Zeng & Rasmussen, 2005; McGarial et al., 2000). Important characteristics of cluster analysis are:

- organizes observations into discrete classes or groups such that within group similarity is maximized and among-group similarity is minimized according to some objective criteria,
- assess relationships within a single set of variables; no attempt is made to define the relationship between a set of independent variables and one or more dependent variables,
- summarizes data redundancy by reducing the information on the whole set of N entities to information about G groups of nearly similar,
- identifies outliers by leaving them solitary or in small clusters that may then be omitted from further analysis (Mcgarial et al., 2000).

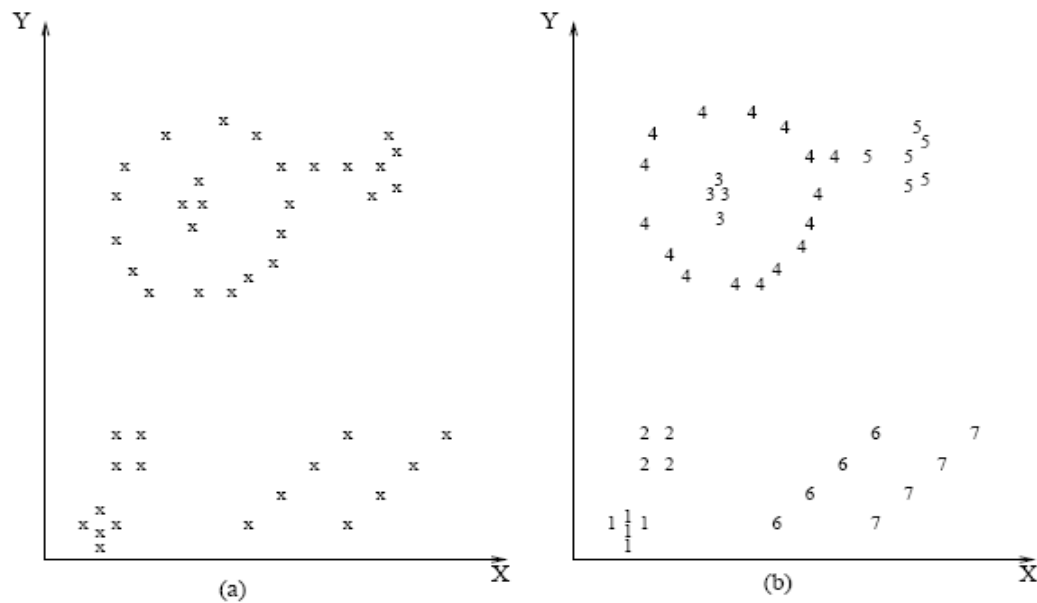


Figure 3.14 Data clustering (Jain, Murty & Flynn, 1999)

CA is the organization of a collection of patterns (usually represented as a vector of measurements, or observation) into clusters based on similarity. “Clustering” is used to describe methods for grouping of unlabeled data (Jain et al., 1999).

Typical clustering activity involves five steps including:

- *observation (pattern) representation*
- *definition of a pattern similarity*
- *clustering or grouping*
- *data abstraction*
- *assessment of output.*

3.4.3 Trend Analysis

A temporal trend is the general increase or decrease in observed values over time. Trend analysis is used to determine the significance of a trend in water quality and to estimate the magnitude of that trend. In this study Mann Kendall test and Sen's Slope estimator were used to evaluate trends for observed parameters. These two test statistics are described below.

Mann Kendall Trend Test: The Mann-Kendall trend test is a non-parametric signed rank test and assumes no particular distribution for the data. It is based on the statistic S . Each pair of observed values y_i, y_j ($i > j$) of the random variable is inspected to find out whether $y_i > y_j$ or $y_i < y_j$. Let the number of the former type of pairs be P , and the number of the latter type of pairs be M . Then S is defined as:

$$S = P - M$$

For $n > 10$, the sampling distribution of S is as follows. z follows the standard normal distribution where,

$$z = \begin{cases} (S - 1) / \sigma_s & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ (S + 1) / \sigma_s & \text{if } S < 0 \end{cases}$$

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5)}{18}} \quad (\text{Onoz \& Bayazit, 2003}). \quad (3.2)$$

There is a correction for ties when $y_i = y_j$. The null hypothesis that there is no trend is rejected when the computed z value is greater than z_α where α is level of statistical significance.

Sen's Nonparametric Estimator of Slope: Sen's Slope estimator is a nonparametric alternative for estimating a slope. This approach involves computing slopes for all the pairs of time points and then using the median of these slopes as an estimate of the

overall slope. As such, it is insensitive to outliers and can handle a moderate number of values below the detection limit and missing values. Assume that there are n time points, and let X_i denote the data value for the i^{th} time point. If there are no missing data, there will be $n(n-1)/2$ possible pairs of time points (i, j) in which $i < j$. The slope for such a pair is $b_{ij} = (X_j - X_i) / (j - i)$. Sen's slope estimator is then the median of the $n(n-1)/2$ pairwise slopes.

If there is no underlying trend, there would be an approximately equal number of positive and negative slopes, and thus the median would be near zero (Hirsch, Alexander & Smith, 1991).

CHAPTER FOUR

PROPOSED APPROACH

“TMDL BASED SUSTAINABLE BASIN GROWTH AND MANAGEMENT STRATEGY”

4.1 Concept Development

The initiative idea behind the proposed approach “TMDL based sustainable basin growth and management strategy” that is subjected to the thesis is the surface water pollution problems have been caused by mis-planning or non-planning of the watersheds in developing countries. Generally, spatial planning has been made without considering the environmental effects of various land uses on water quality in these regions. As has been discussed in Chapter 1 controlling of point discharges may not be sufficient to provide intended ambient water quality for some cases. Thus, drainage area activities including point and non-point sources should be evaluated together and related to the water quality for effective planning.

In this study TMDL analysis that takes into account assimilative capacity of the receiving bodies is suggested being used as a tool in guiding growth management. Assimilative capacity is defined as the capability of the watercourse and/or lake to resist the effects of discharges without impairment of the water quality (Baldwin, 2005). It defines total maximum loads assimilated by waterbody. According to proposed approach, the difference between the total maximum daily load that is calculated based on ambient water quality standard and the existing pollutant loads received by waterbody determines the pollutant load that can be reserved for basin growth comprising various land uses (see Figure 4.1). Thus in parallel to basin growth by urbanization, industrialization and agriculturization etc, waterbody will attain and maintain water quality standards. This approach is considered as a useful tool to develop sustainable basin management plans by linking pollutant sources, and impacts on water quality.

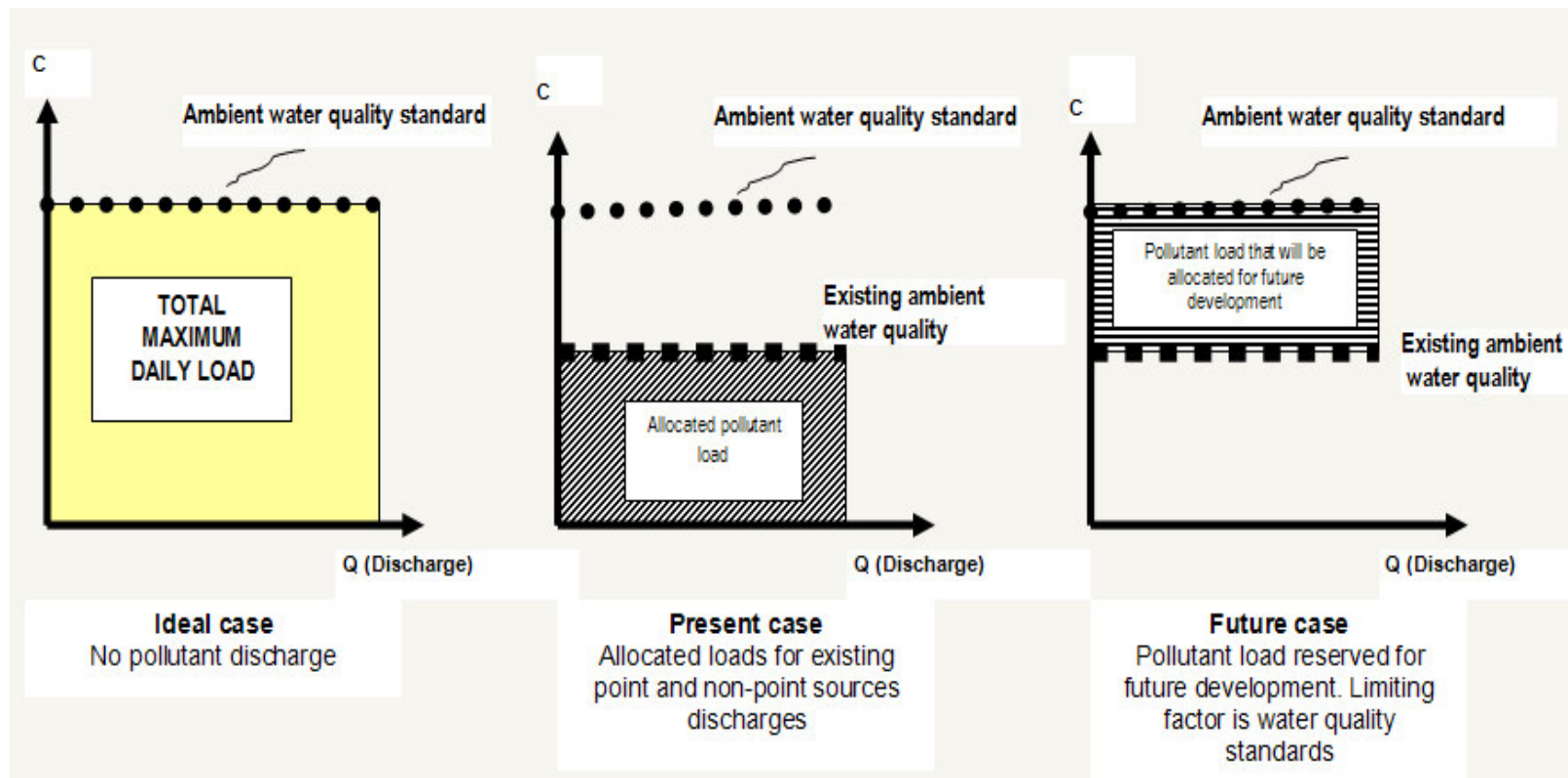


Figure 4.1 Proposed TMDL based approach for sustainable basin management

Development process of a basin management strategy should begin with the determination of beneficial uses (drinking and irrigation water supply, aquatic life support etc.) for the basins. There may be more than one use designation assigned to a waterbody. In addition, each use requires different water quality that is defined by numerous physical, chemical and biological parameters. If every variable is considered to describe water quality, the process becomes unwieldy. Water quality standards and guidelines can be used as a reference to filter parameters having significance for that specific use from the long list of variables. Therefore, this step can be considered as data reduction procedure of the parameters by determining water quality objectives. This is explained schematically in Figure 4.2.

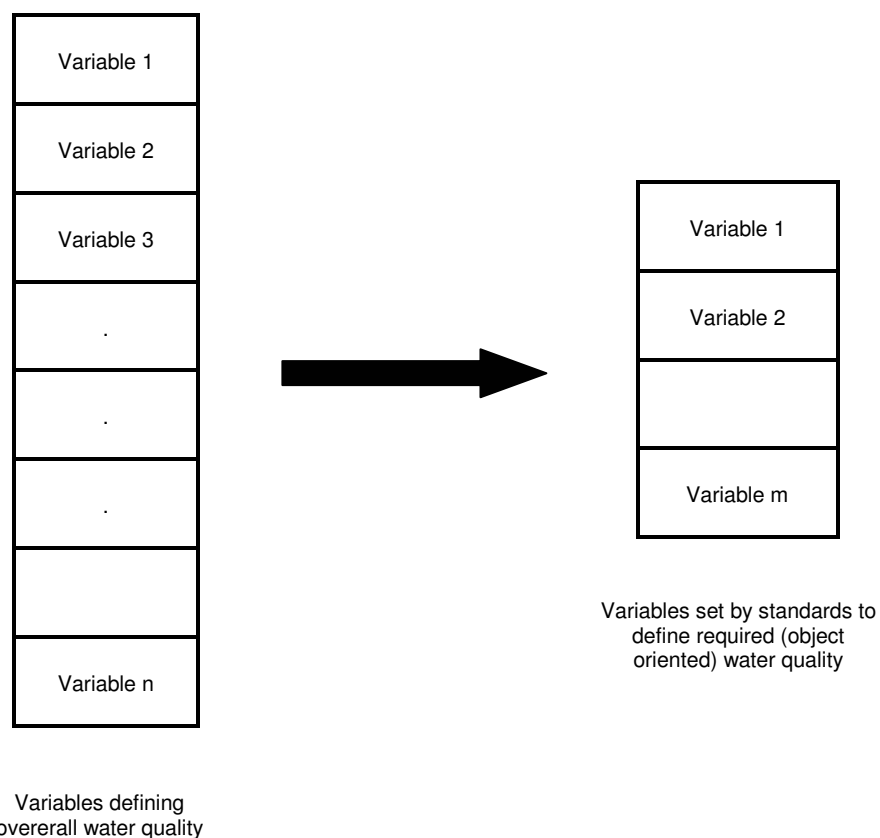


Figure 4.2 Reduction of number of parameters for assessing water quality based on water quality standards

Interrogation of water quality should also be taken a part in the planning procedure. It is targeted to state whether or in which degree quality of water supports intended use. Various methods including environmetric methods and water quality index calculations assist water experts in decision process. These methods have been discussed in Chapter 3. Water quality assessment could be followed by the determination of indicator (key) variable(s) that will be the core for basin growth assumptions. While some variables have risk to violate the limits set by standards others may not. On the other hand, some may have high significance for specific uses but others may not. Therefore key parameter(s) among numerous water quality variables should be determined by taking into considerations of various factors to get decisions for the future of the basins (see Figure 4.3).

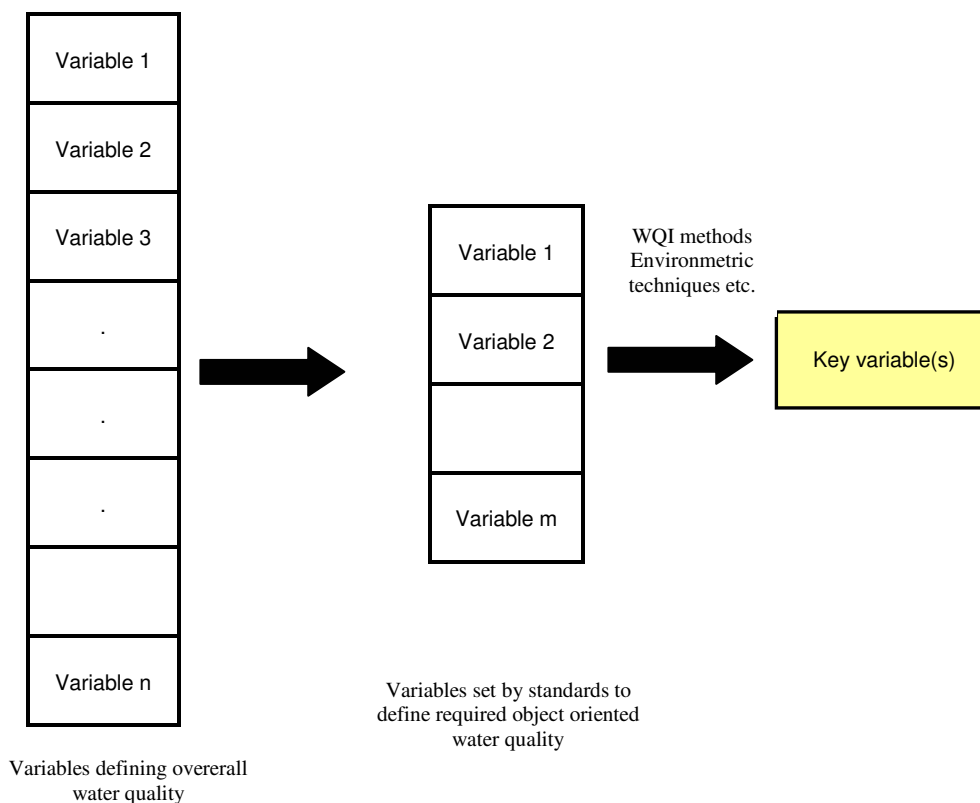


Figure 4.3 Determination of key variables from long list of water quality parameters

In the scope of the management strategy development process, water quality should be modeled to establish the cause-and-effect relationship between the pollutant of concern in waterbody and the pollutant sources. Moreover, pollutant loads from each source and total maximum daily load assimilated by the waterbody without exceeding standards should be determined. In addition, alternative scenarios should be developed to see effects of basin growth for various land uses on water quality. Each scenario ensures that water quality will attain and maintain water quality standards. Load contributions from pollution sources should also be investigated for each scenario to assist decision makers determining basin growth and management policy.

After basin growth plan is developed and approved by the related institutions follow-up monitoring is proposed being done to assess progress made during implementation of the strategy.

In summary, the procedural steps are identified as the process for establishing the new approach. “TMDL based sustainable basin growth and management strategy” are: (see Figure 4.4)

- beneficial use designations
- determination of water quality objectives and guidelines for intended uses
- interrogation of the ambient water quality
- selection of a water quality variable(s) for TMDL analysis
- water quality modeling
- various basin growth scenarios based on TMDL
- allocation of pollutant loads for each scenario
- proposed basin development strategy
- follow-up monitoring.

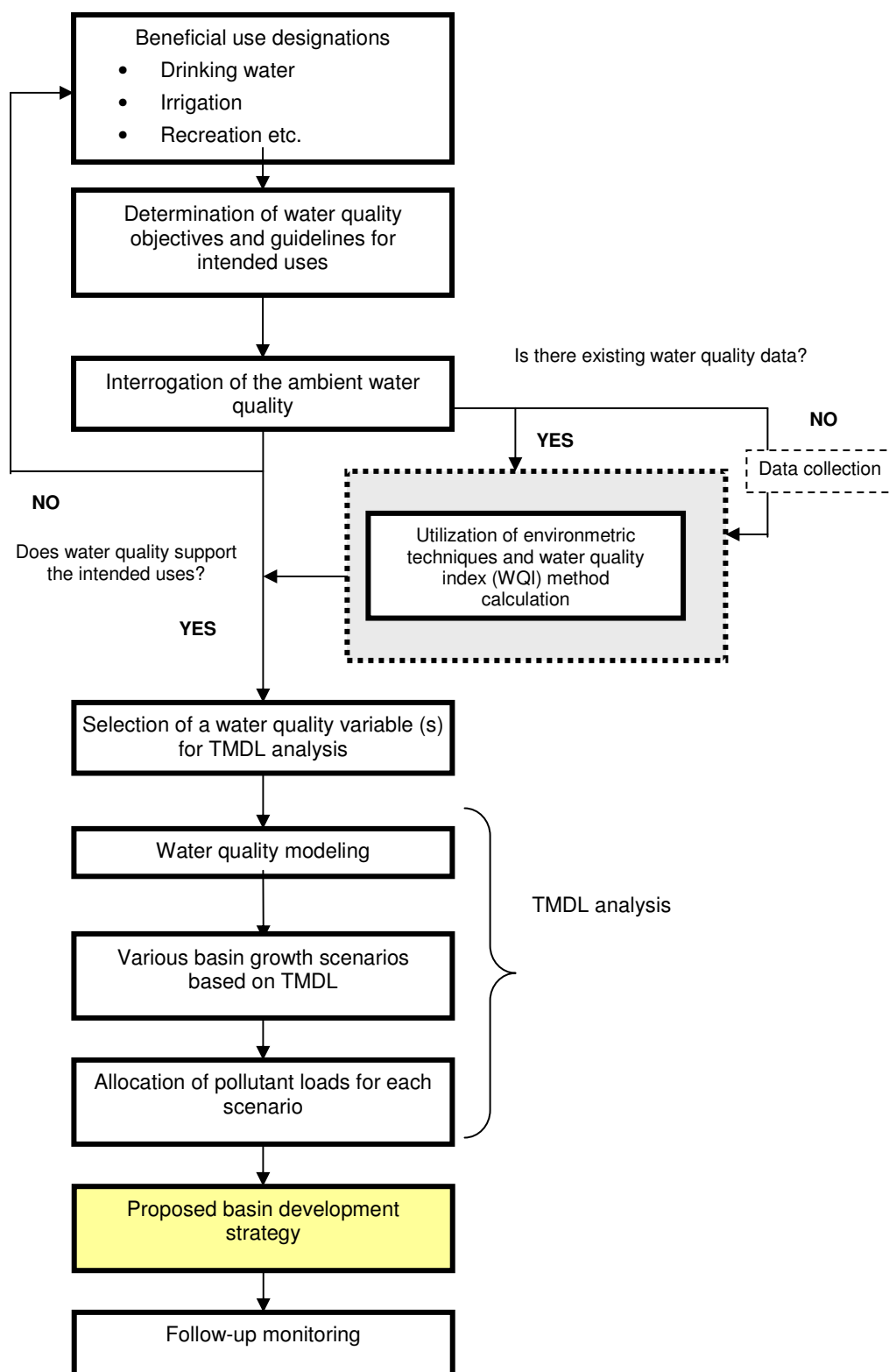


Figure 4.4 Proposed procedural steps of “TMDL based sustainable basin growth and management strategy”

4.2 Beneficial Use Designations

This step consist determination of beneficial use of waterbody. Beneficial use designations describe existing or potential uses of water sources.

Streams, lakes, rivers, and other water bodies, have uses to humans and other life. There are categories of beneficial uses, including but not limited

- *Drinking water supply*: The waterbody can supply safe drinking water with/without conventional treatment.
- *Agriculture*: The water quality is suitable for irrigating fields or watering livestock.
- *Industrial*: Water quality is sufficient to be used in industrial or manufacturing processes
- *Aesthetics/scenic*: The waterbody, when unimpaired, provides a unique aesthetic or scenic value.
- *Aquatic life support*: The waterbody provides suitable habitat for protection and propagation of desirable fish, shellfish, and other aquatic organisms.
- *Primary contact recreation (swimming)*: People can swim in the waterbody without risk of adverse human health effects.

In designating uses for a water body, the suitability of a water body for the uses based on the physical, chemical, and biological characteristics, its geographical setting and scenic qualities, and economic considerations should be examined. Each water body does not necessarily require a unique set of uses. Instead, the characteristics necessary to support a use can be identified so that water bodies having those characteristics can be grouped together as supporting particular uses (Scott, 2004).

4.3 Determination of Water Quality Objectives and Guidelines for Intended Use(s)

This step comprises determination of water quality standard(s) set for beneficial use(s). Each beneficial use has a set of water quality objectives to meet requirement of users. Thus, the designated use is a description of a desired endpoint for the waterbody.

Water quality objectives are tools for the effective management of water resources and based on water quality criteria, which are numerical concentrations for chemical, physical, biological characteristics of water to protect and enhance designated uses of water. They describe conditions that water managers have agreed should be met in order to protect the most sensitive designated uses of fresh, estuarine, and coastal marine waters. They are used in conjunction with other management tools such as effluent controls and pollution prevention planning to achieve high standards of water quality. Objectives are being prepared by related authorities of countries for specific bodies of surface waters, ground waters, estuarine, and coastal marine waters and water quality characteristics that may be affected by human activity now or in the future (Saskatchewan Environment and Resource Management- SERM, 1997).

As has been mentioned above different uses require different water quality (Explanatory notes regarding the some water quality variables, their sources potential and health effects are presented in Appendix A-2.). Therefore, each beneficial use has a set of water quality objectives to meet requirement of users.

Typical water quality concerns for various uses and supra-national standards set by international authorities are summarized in Table 4.1.

Following section comprises details on surface water quality objectives for specific uses.

Table 4.1 Main water characteristics for different water uses (After World Bank, 2003)

Use of water resources	Typical concerns	Typical water quality parameters	Examples of international standards/guidelines
Drinking water supply (domestic, industrial and other public uses)	Toxic pollution Bacteriological contamination	Turbidity Total dissolved solids Health related inorganic and organic compounds Microbial quality	WHO Guidelines US Safe drinking water act (SDWA) EU Directive 98/83/EC
Industrial water supply	Toxic pollution Bacteriological contamination	Largely industry-dependent	World Bank Pollution Prevention and Abatement Handbook (effluent/waste reduction)
Agricultural water supply	Salinization Toxic pollution Bacteriological contamination	Sodium content Total dissolved solids	FAO Guidelines on Water Quality for Agriculture (#29 rev.1)
Habitat maintenance	Oxygen depletion Toxic pollution Turbidity	Dissolved oxygen Chlorinated organic compounds	US Clean Water Act EU Directives 91/27/EEC & 98/15/EEC (wastewater treatment)
Aquaculture	Oxygen depletion Toxic pollution Temperature	Dissolved oxygen Heavy metals Algal toxins and pesticides	
Water contact and recreation (lakes, rivers, reservoirs, estuaries)	Bacteriological contamination Turbidity	Turbidity Toxic compounds Bacterial quality	US Clean Water Act EU Directives 76/160/EEC (bathing water) and 91/271/EEC & 98/15/EEC (wastewater treatment)

4.3.1 Specific Surface Water Quality Objectives

4.3.1.1 Potable Water Supply

The maintenance of good quality drinking water can be achieved both by protecting the water at source and by water treatment. It is possible to protect the water supply by means of pollution control measures that prevent undesirable constituents from entering the source by good watershed management practices. A wide range of treatment technologies is available to produce required drinking water quality.

Various water quality standards have been developed by different organizations (World Health Organization, European Union, US Environmental Protection Agency, related national water authorities) to assess the suitability of a water resource for drinking uses. Appendix A-3 summarizes selected supra-national water quality guidelines (World Health Organization-WHO Guidelines, European Union drinking water standards, US Environmental Protection Agency- EPA Safe Drinking Water Act). The WHO drinking water quality standards are a global reference, which are complemented in many countries (World Bank, 2003).

As has been discussed in Chapter 3, in EC legislation (75/440/EEC), water quality of surface waters intended for the abstraction of drinking water is classified into three groups. For each class treatment level required to transform surface water into drinking water are different. This classification is based on the assessment of about 45 water quality parameters (see Appendix A-1).

4.3.1.2 Aquatic Life

Objectives for protecting the aquatic life including fish, aquatic fauna and flora, are often more stringent than those applicable to other water uses. Because of the relatively stringent values for various constituents, these objectives will also likely afford protection to wildlife, which rely upon surface water for drinking water and for their source of food supply.

4.3.1.3 Livestock Watering

Livestock may be affected by poor quality caused by nitrates, sulfates, total dissolved solids (salinity), a number of metals and organic micro pollutants such as pesticides etc. In addition, blue-green algae and pathogens threats livestock. Some substances, or their degradation products, present in water used for livestock may occasionally be transmitted to humans. The purpose of quality criteria for livestock watering is, therefore, to protect both the livestock and human life (World Health Organization-WHO/ United Nations Environment Program- UNEP, 1997).

Criteria for livestock watering usually takes into account the type of livestock, the daily water requirements of each species, the chemicals added to the feed of the livestock to enhance the growth and to reduce the risk of disease, as well as information on the toxicity of specific substances to the different species. The objective stated by FAQ (Food and Agriculture Organization of the United Nations) is presented in Appendix A-4.

4.3.1.4 Irrigation

Water quality criteria for irrigation water generally take into account crop tolerance to salinity, sodium concentration etc. The effect of salinity on the osmotic pressure in the unsaturated soil zone is one of the most important water quality considerations due to influence on the availability of water for plant consumption. Sodium also adversely effect soil structure and reduce the rate at which water moves into and through soils. Trace elements such as boron, heavy metals and pesticides may inhibit the growth of plants. Contaminants in irrigation water may accumulate in the soil and, after a period of years, render the soil unfit for agriculture. Even when the presence of pesticides or pathogenic organisms in irrigation water does not directly affect plant growth, it may potentially affect the acceptability of the agricultural product for consumption. Criteria have been published by a number of countries as well as by the Food and Agriculture Organization of the United Nations (FAO). An example is given in Appendix A-5. Quality criteria may also differ considerably from one country to another, due to different annual application rates of irrigation water (WHO/UNEP, 1997).

4.3.1.5 Recreational Uses

Recreational water quality criteria are used to assess the safety of water to be used for swimming and other water-sport activities. The primary concern is to protect human health by preventing water pollution from fecal material or from contamination by micro-organisms that could cause health effects (gastro-intestinal illness, ear, eye or skin infections). Criteria are therefore usually set for indicators of fecal pollution, such as

fecal coliforms and pathogens. As a rule, recreational water quality criteria are established by government health agencies.

For example, The EU established quality criteria containing both guideline values and maximum allowable values for microbiological parameters (total coliforms, fecal coliforms, fecal, streptococci, salmonella, and entero viruses) together with some physico-chemical parameters such as pH, mineral oils and phenols (*Council Directive of 8 December 1975 Concerning the Quality of Bathing Water* -76/160/EEC). This Directive also states that member states should individually establish criteria for eutrophication-related parameters, toxic heavy metals and organic micropollutants.

Recreational use of water is often given inadequate consideration. Bacteriological contamination other types of pollution can cause to be water bodies unsuitable for recreational use. This is of particular concern as the recreational use of water is very popular in the touristic region and is also concentrated in water bodies closest to the large metropolitan areas (WHO/UNEP, 1997).

4.4 Interrogation of Ambient Water Quality

This step comprises to state whether or in which degree quality of water supports intended use. As was mentioned in Section 3 in detail water quality index method and environmetric techniques are proposed as useful tool for assessment of the water quality. When the data to assess existing water quality conditions are missing, then a data collection is suggested. Selection of sampling sites and water quality variables that should be monitored is also an important issue. Designated beneficial use and water quality objectives set for particular uses can be a guide for the monitoring process.

WQI can be used to report the state of the source by converting the complex water quality data into information that is understandable. Environmetric methods including multidimensional scaling and cluster analysis allow understanding of possible influences of the environment on water quality and also identifying natural groupings in the set of data. Trend analysis determines increase or decrease in observed values over time and is

generally used to assess effectiveness of water management programs. These methods were explained in detail in Sections 3.4.

4.5 Selection of Water Quality Variable(s) for TMDL Analysis

Along the procedure of the proposed approach, it is here that subjectivity creeps in. Different experts may have different perceptions of the selection of the water quality variable(s) for TMDL analysis. For example impairment categories including:

- health hazards (fecal coliform, heavy metals),
- oxygen depletion (DO, BOD, ammonia, nitrate nitrogen, total phosphorus),
- eutrophication or the potential for excess biologic growth,
- physical characteristics (temperature, total solids),
- dissolved substances (PH, dissolved solids) could be taken into account depending on the intended use and also importance of the parameter for that use.

It can also be an approach selection of the parameter, which has high risk to violate water quality standards. In other words based on the comparison of experimentally determined parameter values with the existing guidelines, the parameter(s) under pollution risk may be accepted as a reference for following steps of the analysis. On the other hand, water quality index method can be also used determining the key parameter(s). Results can be supported and verified by the environmetric methods. The variable(s) having lowest index score is the parameter(s) under pollution risk (see Figure 4.5). Thus parameter selection is laden with subjectivity and uncertainty that makes analysis useless, unless right decisions are taken. Therefore, to ensure the most representative parameter, enormous attention and care should be given to selection process. After a decision is taken about the variable, the modeling procedure begins.

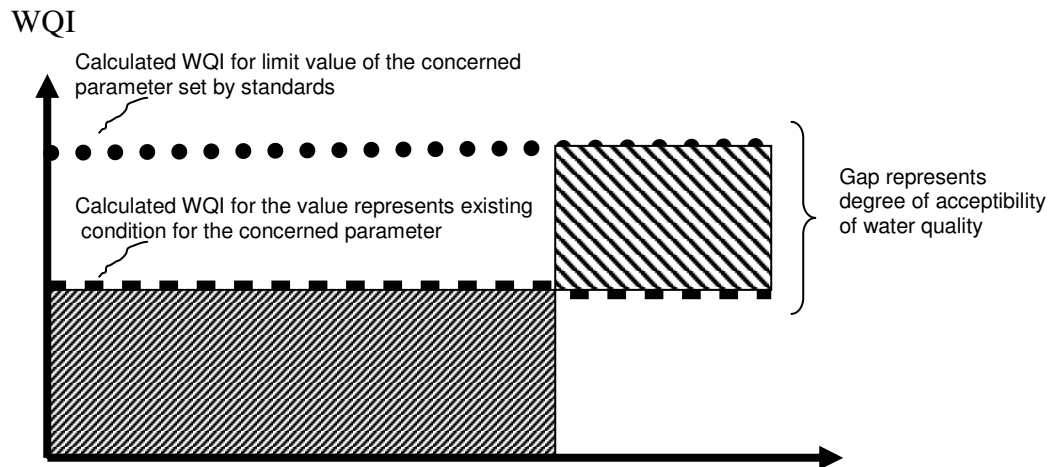


Figure 4.5 Application of WQI method for key variable determination

4.6 Water Quality Modeling

This step intends to establish the cause-and-effect relationship between the pollutant of concern in waterbody and the pollutant sources.

Simulation models are used extensively in water quality planning and pollution control. Models are applied to answer a variety of questions, support watershed planning and analysis, and develop TMDL's. Some models are highly specialized to simulate environmental phenomena and components of pollution problems; others incorporate more comprehensive assessment techniques. Historically, models have been used to support the analysis of wastewater discharges by modeling biochemical oxygen demand (BOD) and resulting in-stream dissolved oxygen (DO) concentrations. During the last two decades, numerous loading and receiving water quality models have been developed (USEPA, 1997).

Loadings models: These models involve techniques primarily design to predict pollutant movement from the land surface to waterbodies. Loading models can include simple loading rate assessments in which loads are a function of land use type and also be complex simulation techniques that more explicitly describe the process of rainfall, runoff, sediment detachment, and transport to receiving waters. Some loading models

operate on a watershed scale, integrating all loads within a watershed. Some watershed models allow for the subdivision of the watershed into contributing sub-basins. Field scale models are loading models that are designed to operate on a smaller, more localized scale. They have also been used to answer local management questions or to support the selection of the best management practices and have included models that specialize in agricultural systems (USEPA, 1997).

Receiving water models: Receiving water models emphasize the response of a waterbody to pollutant loadings, flows and ambient conditions. The range of complexity is encompassed from simple empirical formulations to deterministic models. Receiving water assessments can include examination of flow (hydrodynamics), as well as chemical and biological processes. The three general categories include hydrodynamic models, steady-state and dynamic water quality models.

Often watershed management planning requires that both the loading and receiving water response be addressed. In some cases models that internally link the loading and receiving water response have been developed. Ultimately, the loading and receiving water models can be used to determine the optimum combination of loads for the protection of water quality.

Integrated modeling system link the models, data and user interface within a single system. New developments in modeling systems have increasingly relied on geographic information systems (GIS) and database management systems to support modeling and analysis (USEPA, 1997). Following section comprises detailed information on “receiving water models”.

4.6.1 Receiving Water Models

The use of models to predict a receiving waterbody’s response to various pollutant loading scenarios is often an important aspect of watershed assessment. Receiving water

models are used to examine the interactions between loadings and response, evaluate loading capacities and test various loading scenarios.

A fundamental concept for the analysis of receiving waterbody response to point and non point source input is the principle of mass balance (or continuity). Receiving water models typically develop a mass balance for one or more interacting constituents taking into account three factors:

- transport through the system (describes the hydrologic and hydrodynamic regime of the water system),
- reactions within the system (determines the biological, chemical and physical reactions that affect constituents)
- inputs into the system (determines the inputs to or withdrawals from the system because of the anthropogenic activities and natural phenomena) (USEPA, 1997).

4.6.1.1 Hydrodynamic Models

Hydrodynamic models simulate the “dynamic” or time varying features water transport. Surface water flow is fundamental to the simulation of pollutant transport and transformation in waterbodies. Some of the key physical factors affecting the health of a waterbody include the quantity and velocity of flow.

Hydrodynamic models can potentially represent the features of water movement in rivers, streams, lakes, reservoirs etc. Depending on the type of system and the model capabilities, spatial dimensions of the simulation can include 1-D longitudinal, 2-D in the vertical, 2-D in the horizontal or fully 3-D formulations. Hydrodynamic models employ numerical solutions of the fundamental governing equations in order to predict water movement based on bottom topography and shoreline geometry (USEPA, 1997).

4.6.1.2 Water quality models (Steady State & Dynamic)

Water quality models simulate the chemical and biological processes that occur within a waterbody system, based on external and internal inputs and reactions. Eutrophication models include those, which simulate biological inputs, nutrients and algal growth in rivers, streams, lakes, reservoirs and estuaries. Other receiving water models specialize in the simulation of toxic constituents and their transformation and degradation in waterbodies.

Water quality models can also be grouped by how they address changes over time. Some models employ a steady-state formulation for simulation purposes. Typical steady-state applications include use of design flow, or pre-selected critical conditions, for the assessment of steady-state water quality impacts. Steady-state formulations are the most commonly used and the easiest to implement. However, steady-state applications are limited when addressing time-variable inputs such as non-point source loads or examining waterbodies that experience short-term violations of acute criteria (e.g. storm events).

Water quality models can be linked with hydrodynamic models for more detailed assessments of time-varying conditions in receiving waters. The use of dynamic water quality models allows for a more detailed evaluation of time-varying inputs, such as non-point sources and the examination of the short and longer term receiving water response. Fully dynamic applications require a significant level of effort in order to prepare data input files; set up, calibrate, and validate the model; and process output data. Dynamic models can also be applied to steady-state conditions (USEPA, 1997).

Selected example models that are used for TMDL application

QUAL2E. The Enhanced Stream Water Quality Model (QUAL2E), originally developed in the early 1970s, is a one-dimensional water quality model that assumes steady-state flow but allows simulation of diel variations in temperature or algal photosynthesis and respiration. QUAL2E represents the stream as a system of reaches of

variable length, each subdivided into computational elements of the same length in all reaches. The basic equation used in QUAL2E is the one-dimensional advection-dispersion mass transport equation. An advantage of QUAL2E is that it includes components that allow quick implementation of uncertainty analysis using sensitivity analysis, first-order error analysis, or Monte Carlo simulation. The model has been used widely for stream wasteload allocations and discharge permit determinations in the United States and other countries. QUAL2E has been applied where attached algae need to be simulated by applying a benthic sink rather than a source of ammonia nitrogen. EPA's Office of Science and Technology developed a Microsoft Windows-based interface for QUAL2E that facilitates data input and output evaluation, and QUAL2E is one of the models included in EPA's Better Assessment Science Integrating Point and Non-point Sources (BASINS) (USEPA, 1997).

WASP5. WASP5 is a general-purpose modeling system for assessing the fate and transport of conventional and toxic pollutants in surface waterbodies. Its EUTRO5 submodel is designed to address eutrophication processes and has been used in a wide range of regulatory and water quality management applications. The model may be applied to most waterbodies in one, two, or three dimensions and can be used to predict time-varying concentrations of water quality constituents. It might be somewhat limited for lake applications by a lack of internal temperature simulation. The model reports a set of parameters, including dissolved oxygen concentration, carbonaceous biochemical oxygen demand (CBOD), ultimate CBOD, phytoplankton, carbon, chlorophyll a, total nitrogen, total inorganic nitrogen, ammonia, nitrate, organic nitrogen, organic phosphorus, and inorganic phosphorus (USEPA, 1997).

EUTROMOD. EUTROMOD, a spreadsheet-based watershed and lake modeling procedure developed for eutrophication management, emphasizes uncertainty analysis. The model estimates nutrient loading, various trophic state parameters, and trihalomethane concentration using data on land use, pollutant concentrations, and lake characteristics. The model was developed using empirical data from EPA's national

eutrophication survey, with trophic state models used to relate phosphorus and nitrogen loading to in-lake nutrient concentrations. The phosphorus and nitrogen concentrations then are related to maximum chlorophyll level, Secchi depth, dominant algal species, hypolimnetic dissolved oxygen status, and trihalomethane concentration. EUTROMOD allows for uncertainty analysis by considering the error in regression equations using an annual mean precipitation and coefficient of variation to account for hydrologic variability. EUTROMOD is limited in its application because it is designed for watersheds in the southern United States and it provides predictions only of growing season averages predicted using empirical relationships derived from assessment of reservoir data.

QUAL 2K. QUAL2K (or Q2K) is a river and stream water quality model that is intended to represent a modernized version of the QUAL2E (or Q2E) model (Brown and Barnwell 1987). Q2K is similar to Q2E in the following respects:

- One dimensional. The channel is well-mixed vertically and laterally.
- Steady state hydraulics. Non-uniform, steady flow is simulated.
- Diurnal heat budget. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- Diurnal water-quality kinetics. All water quality variables are simulated on a diurnal time scale.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated (Chapra & Pelletier, 2003).

4.7 Various Basin Growth Scenarios Based on TMDL

The scenario approach used in this step emphasizes the importance of decision making by evaluating possible alternative policy sets rather than seeking a single preferred alternative. For development scenarios different land use alternatives including but not limited urbanization, industrialization and agriculturization etc. are considered. These alternatives not only consist of one land allocation alone (see Figure 4.6). Here, the restrictive factor is the water quality standards that determines maximum load

assimilated by the waterbody. Thus, each allocation strategy under consideration needs to be tested using the linkage analysis to evaluate the potential effect of the proposed alternative on water quality. Finally, all developed scenarios provide water quality that attain and maintain with the standards in parallel to basin growth.

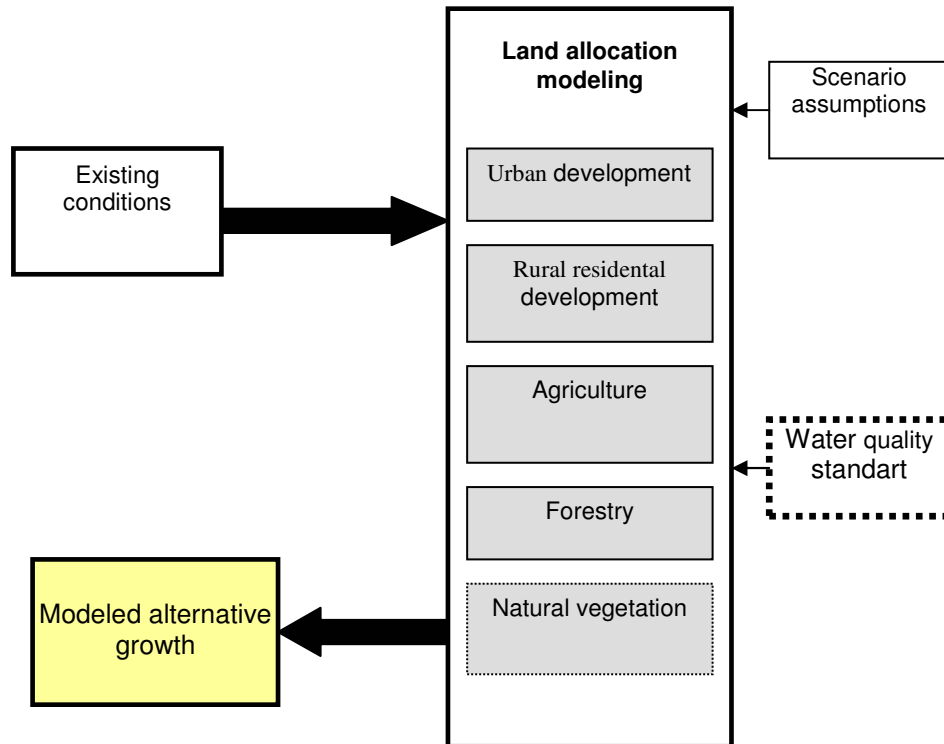


Figure 4.6 Alternative scenario development

4.8 Allocation of Pollutant Loads for Each Scenario

Proposed basin growth scenarios comprise various land uses and combination of point source and non-point source pollutant discharges are considered to meet the water quality goal. In this component, the available load is allocated among the various sources for each alternative scenario. The purpose is to determine the balance between pollutants originating from point and non-point sources. Because the manager needs to know how the loads causing the impairment are apportioned and results assist to select the scenario and develop management strategy.

4.9 Proposed Basin Development Strategy

After the modeling study and the development of scenarios, decision makers decide which development plan will be implemented. Factors such as social, economic, socioeconomic, climate, geology etc. are effective on selection procedure.

4.10 Follow-up Monitoring

In this step, follow-up monitoring is recommended to determine if established objectives are being met and also evaluate progress made during implementation of the strategy. In this context, collected data are assessed and findings are released.

CHAPTER FIVE

CASE STUDY: APPLICATION OF PROPOSED APPROACH TO TAHTALI RIVER BASIN, TURKEY

5.1 Basin Background

Tahtali basin is located in the southern part of the City of Izmir in Turkey and has about 550 km² drainage area with 162 million m³ annual average discharges. Location of the basin is shown in Figure 5.1. The climate of the region is typical Mediterranean: hot and dry in summers and temperate and rainy in winters.

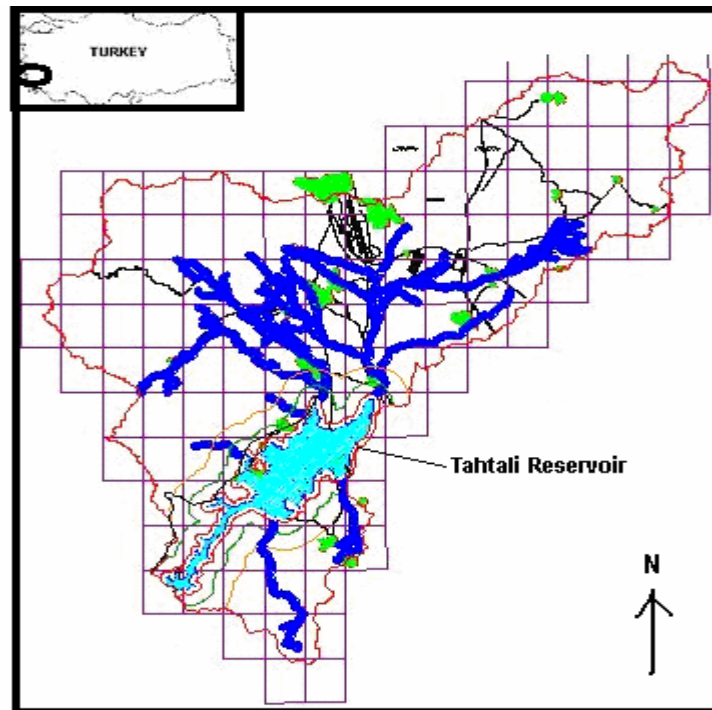


Figure 5.1 Location of Tahtali Basin

Construction of Tahtali Dam on Tahtali Creek was started in 1992 and completed in 1996. Storage capacity of the reservoir is 306 million m³. Reservoir water was designated mainly for the potable water supply. Existing situation at that region states that, this water is the main source for the Izmir City where approximately three million

inhabitants live in. This conclusion increases priority of the basin with respect to protection from pollution and over abstraction (Alpaslan, Boyacioglu & Dolgen, 2002).

5.1.1 Land Uses in the Basin

The land area of the Tahtali Basin is approximately 550 km², with forest and agriculture is the primary land uses. Percentages for land uses are depicted in Figure 5.2.

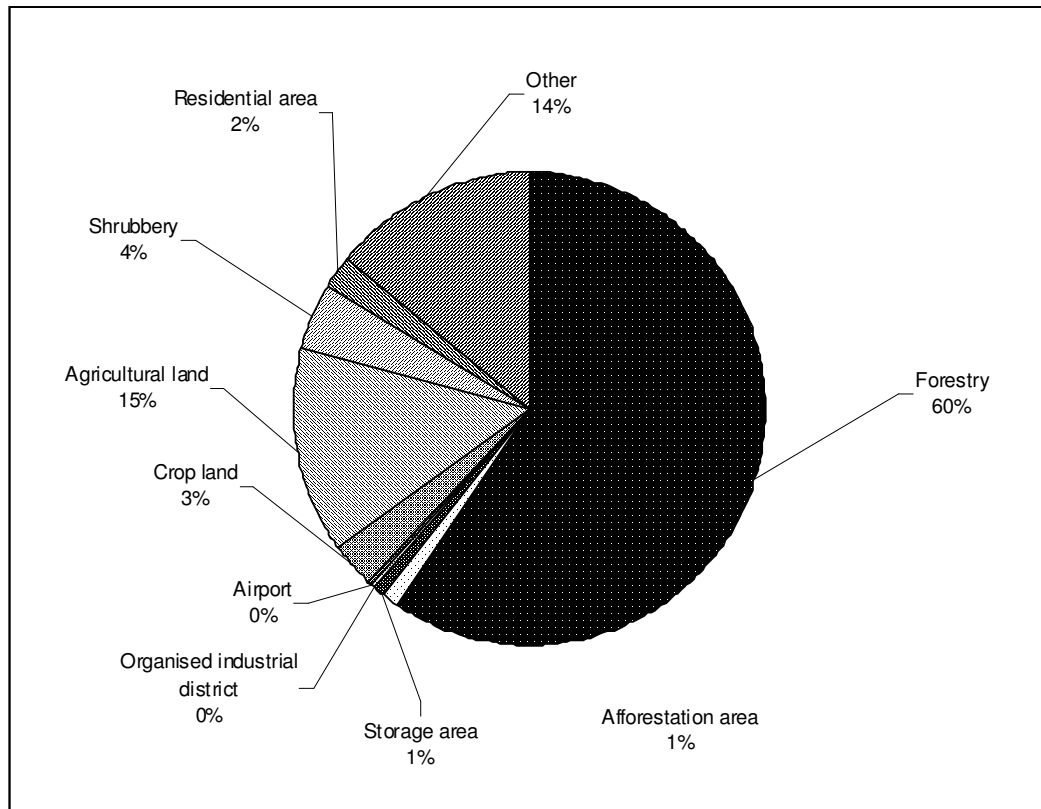


Figure 5.2 Land uses in the Tahtali Basin

The region has long been subjected to rapid increases in population since 1990's. There are about 30 settlements in the basin where about 60.000 people live in the catchment area as of 2000 (Alpaslan et al, 2002; Turkish Institute of Statistics- TUIK, 2002). Population of these settlements is presented in Table 5.1.

Table 5.1 Population of the settlements in the Tahtali Basin (Dokuz Eylul University- DEU, 2000)

Settlement	Population (2000)	Settlement	Population (2000)
Oglananası	2334	Gorece	7431
Yogurtcular	393	Menderes	16792
Demircikoy	725	Akcakoy	375
Karaagac	941	Develi	1919
Kısıık	554	Sarnic	17657
Belenbası	722	Kaynaklar	3771
Dogancılar	277	Golcukler	1621
Kırıklar	1041	Yeni mahalle	865

As is seen in Figure 5.3 settlements of which population is relatively high like Sarnic, Menderes located on the north part of the basin.

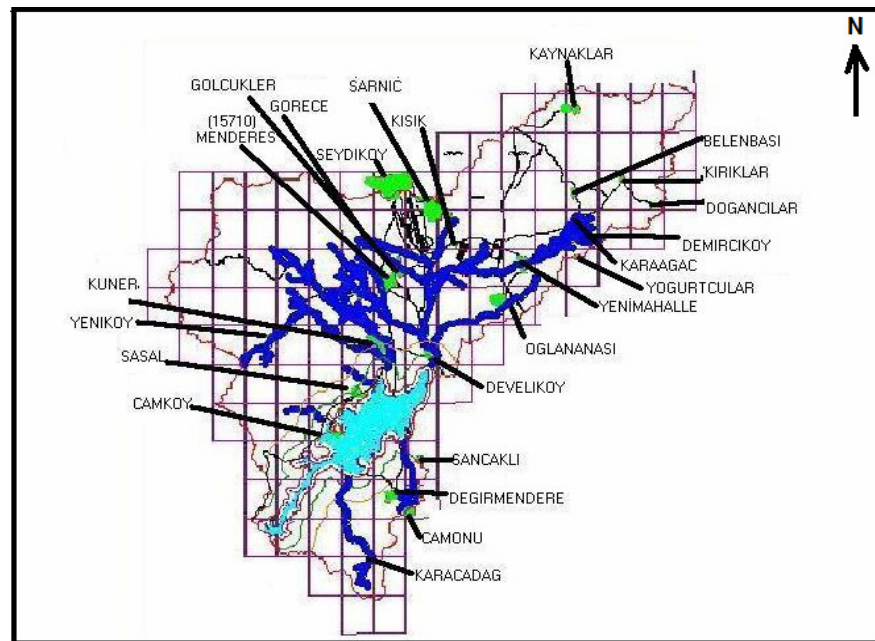


Figure 5.3 Settlements in the Tahtali Basin

5.1.2 Historical Water Quality Data

The ambient water quality of the Tahtali River has been monitored on an irregular basis by Water and Sewerage Authority of Izmir Municipality (IZSU). Since monitoring commenced in 1996, about 40 physical, chemical and biological water quality variables

have been recorded, some more regularly than others at 8 river monitoring stations, seven of which located on the creeks (see Figure 5.4) and one site on the reservoir (Station 1).

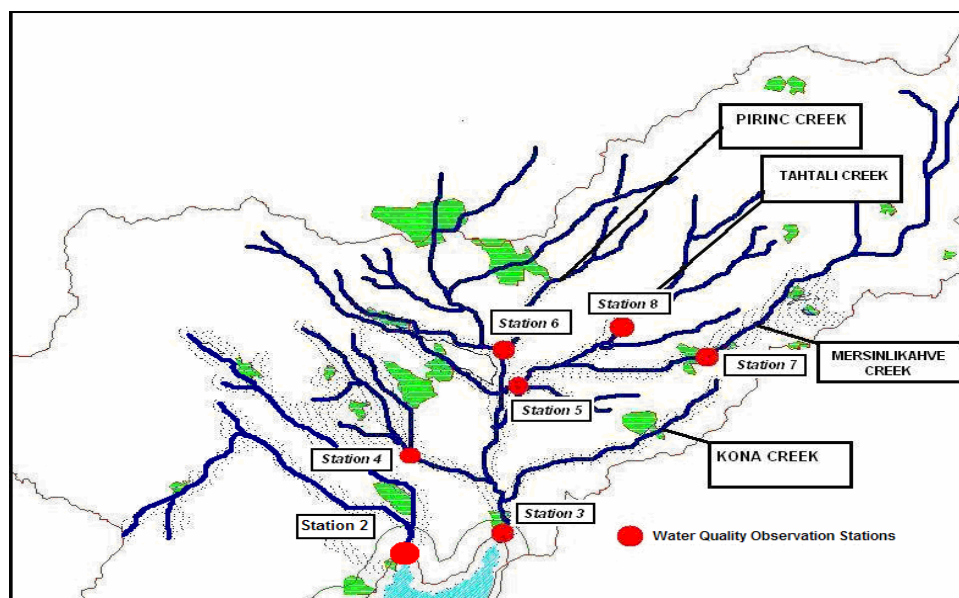


Figure 5.4 Tahtali Basin river water quality monitoring stations

List of the monitored water quality variables at these sites is presented in Table 5.2.

Table 5.2 Water quality parameters, monitored at the Tahtali Basin (DEU, 2000)

Variables		
Aluminum	Copper	Nitrite-Nitrogen
Arsenic	Dissolved Oxygen	PH
Barium	Emulsified Oil and Grease	Phenolic Substances
Bicarbonate	Fecal Coliform	Potassium
Biochemical Oxygen Demand	Fluorides	Sodium
Boron	Iron	Sulfate
Cadmium	Lead	Suspended Solids
Calcium	Magnesium	Temperature
Chemical Oxygen Demand	Manganese	Total Chromium
Chloride	Mercury	Total Dissolved Solids
Chromium	Methylene Blue Active Substances	Total Phosphorus
Color	Nickel	Total Coliform
Conductivity	Nitrate-Nitrogen	Zinc

Detailed information on location of the monitoring stations and also monitoring period of data set that is processed in the thesis is given in Table 5.3. Sampling frequency for each station is predominantly once or twice in a month.

Table 5.3 Ambient water quality monitoring stations in the Tahtalı Basin

Station #	Location	Monitoring period
1	Lake	05/1999-05/2000 09/2003-10/2004
2	Kocakavak Creek	12/1996-02/2000 11/2001-07/2004
3	Tahtalı Creek at Develikoy	01/2000-02/2000 11/2001-04/2005
4	Menderes	12/1996-02/2000 12/2001-04/2005
5	Tahtalı Creek at Golcukler just before conjunction of Pirinc Creek	12/1996-02/2000 11/2001-07/2004
6	Pirinc Creek at Golcukler	12/1996-02/2000 11/2001-07/2004
7	Mersinli Kahve Creek at Yeni Mahalle	12/1996-02/2000 12/2001-03/2005
8	Tahtalı Creek at upstream	12/1996-02/2000 12/2001-03/2005

5.2 Beneficial Use Designation for Tahtalı Basin

As has been mentioned in Section 5.1, Tahtalı Dam water was designated for the public drinking water use. Thus, beneficial use for the basin is potable water supply and the goal of the thesis is development of a management strategy for the basin not to limit water uses for intended purpose in parallel to basin growth in the future.

5.3 Applicable Water Quality Standards in Turkey

This section, second step of the proposed approach presents detailed information on applicable drinking water quality standards and legal aspects of protection of surface waters incase of the Tahtalı Basin, Turkey.

5.3.1 Water Quality Standards for Drinking Waters

The water quality standard for drinking waters, currently in effect in Turkey, was established by the Turkish Institute of Standards and is coded as TS266. The latest

version of this standard, developed in 1997, includes a description of drinking and spring waters; their properties and classification; sampling and analysis methods; and means of controlling the quality of waters conveyed for consumption. The standards classify drinking waters as:

Class 1: Spring waters;

Class 2: Potable waters (Turkish Institute of Standards, 1997).

TS 266 standard is presented in Appendix B-2.

5.3.2 Standards on the Quality of Inland Waters

The classification of inland waters with respect to their quality is given in the Water Pollution Control Regulation, which was drafted in accordance with the Environment Law No.2872 and published in the Official Gazette numbered 25687 and dated 31.12.2004 (Official Gazette, 2004). This classification defines four water quality classes as:

Class I : High quality waters

Class II : Moderate quality waters

Class III : Polluted waters

Class IV : Highly polluted waters

The limit values of the quality parameters that define each of the above classes are presented in Appendix B-1. The Regulation also describes the types of water uses for which each quality class supports.

Class I waters are appropriate for:

- domestic water supply after disinfection
- recreational water uses (including swimming)
- fishery (only trouts)
- water use for farming (including animal farming)
- other uses.

Class II waters are suitable for the following purposes:

- domestic water supply after appropriate or advanced treatment
- recreational purposes
- fishery (fish other than trouts)
- irrigational water use provided that irrigation water quality criteria defined in the Article on Technical Methods are satisfied
- all uses other than those defined in Class I.

The polluted waters described in Class III may be used for industrial water supply except for food and textile industries that require high-quality water. Class IV waters are highly polluted waters that cannot be used for particular purposes defined above for Classes I, II and III.

Class I waters are suitable for fishery production, such as that of trouts; thus, such waters are also assessed within the framework of the Law on Aquatic Products and its relevant regulations, issued by the Ministry of Agriculture and Rural Services. This law was first drafted in the Official Gazette dated 27.2.1973.

The Water Pollution Control Regulation defines also the limit values for control of eutrophication in lakes, swamps, marshes, and dam reservoirs. These values are presented in Appendix B-3 (International Water Management Institute- IWMI, 2000).

5.4 Interrogation of Surface Water Quality of Tahtali River Basin

As has been discussed in Section 4.4 water quality index methods and environmetric techniques can be used for assessment of the water quality to understand whether existing ambient water quality supports intended use, in other words experimentally determined parameters are in compliance with existing standards. In this thesis, UWQI and statistical methods including multidimensional scaling, cluster and trend analysis were performed for assessment of Tahtali Basin surface water quality.

5.4.1 Reservoir Water Quality Assessment

5.4.1.1 Application of UWQI to Tahtali Reservoir Water Quality Data

The UWQI was applied to assess the water quality status at Tahtali reservoir that is the main drinking water reservoir for the City of Izmir. The water quality data obtained from Station 1, a unique observation site of the reservoir, was used for calculation of UWQI.

The subset of the data included twelve parameters, which are water quality determinants of the UWQI. Descriptive statistics of these parameters are presented in Table 5.4. Statistical calculations were made using *Statistical Package for the Social Sciences Software-SPSS 10.0 for Windows*.

Table 5.4 Descriptive statistics of reservoir water quality data set

Variable	Unit	Number of data	Mean	Median	Mode	Minimum	Maximum
Cadmium	mg/L	31	0.003	0.003	0	0	0.004
Cyanide	mg/L	31	0.0009	0.001	0	0	0.0030
Mercury	mg/L	30	0.00004	0	0	0	0.0002
Selenium	mg/L	31	0.002	0.002	0	0	0.0080
Arsenic	mg/L	31	0.002	0.002	0.002	0	0.010
Fluorides	mg/L	31	0.4548	0.440	0.1	0.1	0.85
Nitrate-nitrogen	mg/L	31	3.9419	4.20	1.6	1.4	6.4
DO	mg/L	31	6.5365	7	8.7	0.9	13.2
BOD ₅	mg/L	31	2.4064	2	1	1	4.8
Total phosphorus	mg/L	31	0.0325	0.01	0	0	0.16
pH		31	7.88	7.9	7.9	7.5	8.2
Total Coliform	CPU/100 mL	31	104	90	170	10	185

In the second step, sub-index values were determined using mathematical expressions, which were given in Table 3.2 to assign each parameter a value between 0 and 100. To calculate the sub-indices, the characteristic value was accepted as median of data set for each parameter. Corresponding rating curves, which were given in Figure 3.2 through 3.12, could also be used to determine sub-indices. In the last step, weighted

sum method was employed to get overall index value using weights, which were presented in Table 3.3. Table 5.5 presents a sample calculation of UWQI.

$$UWQI = \sum_{i=1}^n W_i I_i \text{ where,}$$

W_i : weight for i^{th} parameter

I_i : sub-index for i^{th} parameter

Table 5.5 Universal Water Quality Index (UWQI) calculation for Tahtali Reservoir

Variable	Median (symbolic to X in Table 3.2)	Sub-index- I_i (symbolic Y to Table 3.2)	Weight factor- W_i (from Table 3.3)	Sub-total ($W_i * I_i$) (equation 3.1)
Cadmium	0.003	100	0.086	8.6
Cyanide	0.001	100	0.086	8.6
Mercury	0	100	0.086	8.6
Selenium	0.002	100	0.086	8.6
Arsenic	0.002	100	0.113	11.3
Fluoride	0.440	100	0.086	8.6
Nitrate-nitrogen	4.20	100	0.086	8.6
DO	7	100	0.114	11.4
BOD ₅	2	100	0.057	5.7
Total phosphorus	0.01	100	0.057	5.7
pH	7.9	100	0.029	2.9
Total Coliform	90	93.6	0.114	10.7
WQI				99.3

The index value was calculated as 99.3, which belonged to “excellent water” class (index value between 95 and 100, see Figure 5.5). On the other hand, sub-index value was the lowest for the parameter ‘total coliform’. Low value for the sub-index of this parameter could be explained as negative effects of the domestics discharges caused by urbanization. As has been mentioned in Section 5.1, the region has long been subjected to rapid increases in population since 1990’s and 60,000 people live in the catchment area as of 2000.

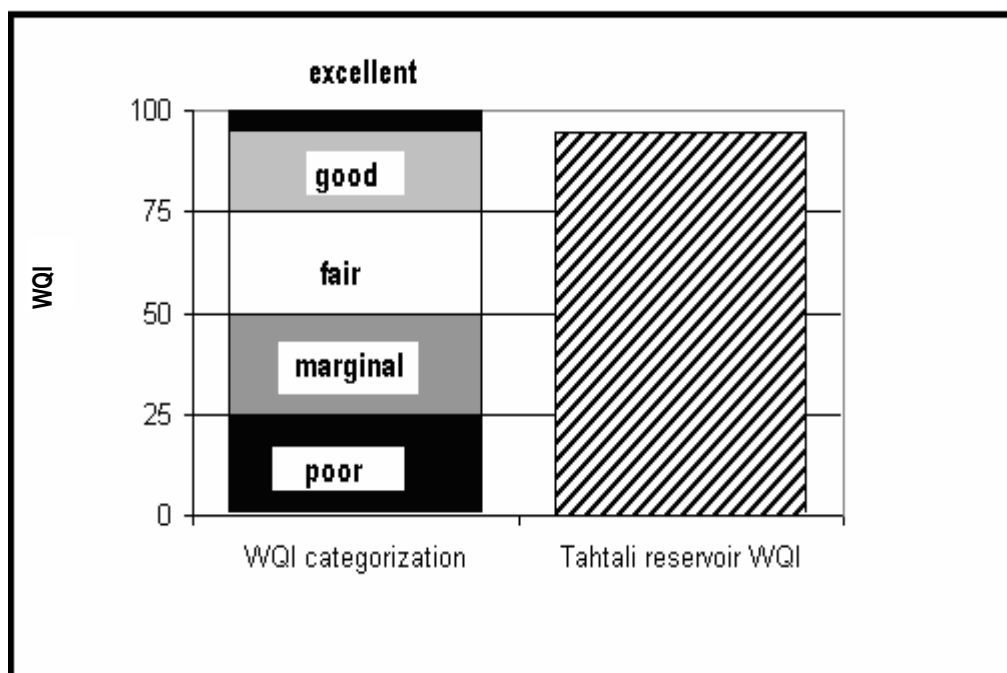


Figure 5.5 WQI categorization scheme and Tahtali Reservoir WQI

5.4.1.2 Reservoir Water Quality Trends

In this section, the question being asked was “if a significant increase or decrease trend in water quality parameters obtained from Tahtali reservoir used for UWQI calculation has occurred between 1999-2004 periods”. To answer this question, two statistical tests namely Mann-Kendall test and Sen’s Slope estimator (discussed in Section 3.4.3) were applied using “*Minitab 13 Statistical Software*”.

The first test -Mann-Kendall was used to evaluate whether a significant increase or decrease for each water quality parameter occurred. When a significant trend was found for a specific parameter, a second statistic- Sen’s Slope estimator was applied to estimate the slope (unit change per time period) or magnitude of the trend (King County, 2001).

Changes of concentrations in time for each parameter is also seen from the figures plotted concentrations versus time (from Figure 5.6 through 5.17). Each observation was

represented by a case number at these graphs. Case numbers assigned to observation dates are presented in Table 5.6.

Table 5.6 Case numbers assigned to observation date

	Month	Case number		Month	Case number
1999	January	1	2003	September	18
	February	2		October	19
	March	3		November	20
	April	4		December	21
	May	5	2004	January	22
	June	6		February	23
	July	7		March	24
	August	8		April	25
	September	9		May	26
	October	10		June	27
	November	11		July	28
	December	12		August	29
2000	January	13		September	30
	February	14		October	31
	March	15			
	April	16			
	May	17			

Mann Kendall trend test was applied to detect significant trend in each data set. Test statistics (z scores) were calculated using formula (3.2) and critical z value at 5 percent significance level was taken from the standard normal distribution table (see Appendix C).

Trend test results presented in Table 5.7 indicated that, there was significant trend for the parameters fluoride, DO, BOD₅ and phosphorus. Using Sen's Slope estimator, the magnitude of the trend was determined for these three parameters (see Table 5.8).

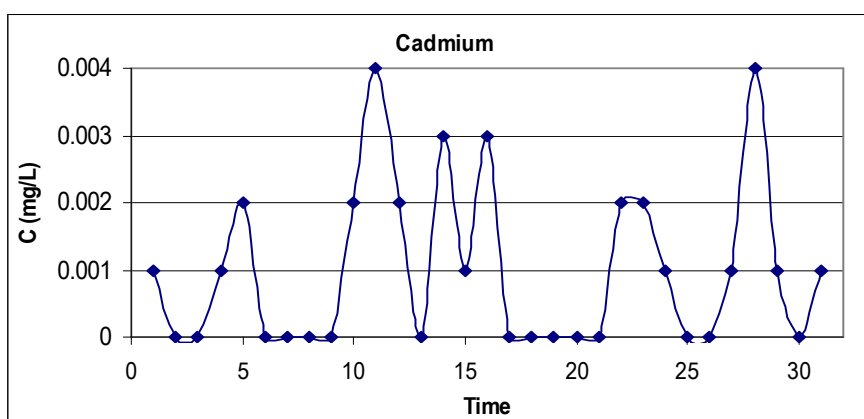


Figure 5.6 Cadmium concentrations versus time at Tahtali Reservoir

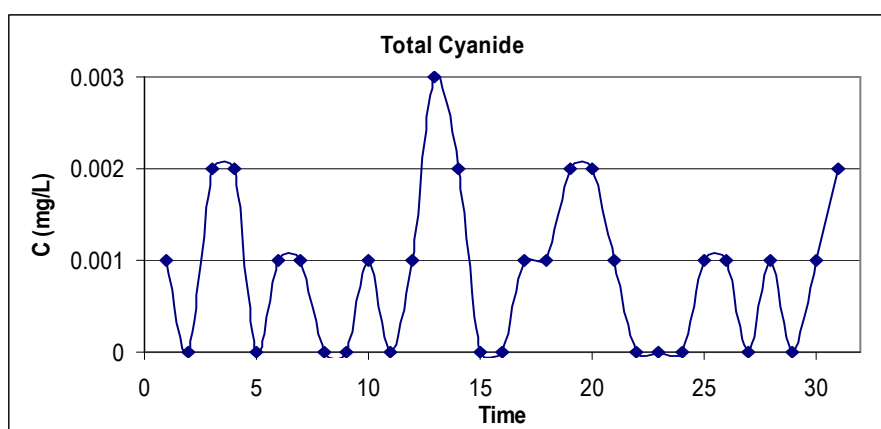


Figure 5.7 Total cyanide concentrations versus time at Tahtali Reservoir

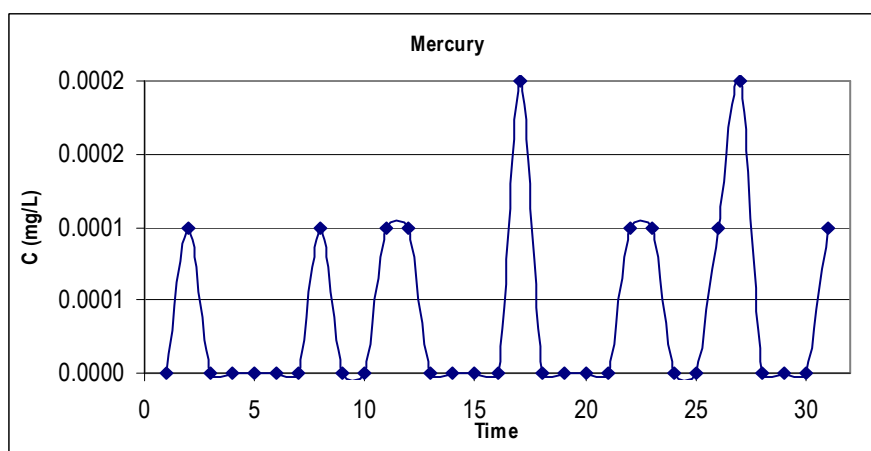


Figure 5.8 Mercury concentrations versus time at Tahtali Reservoir

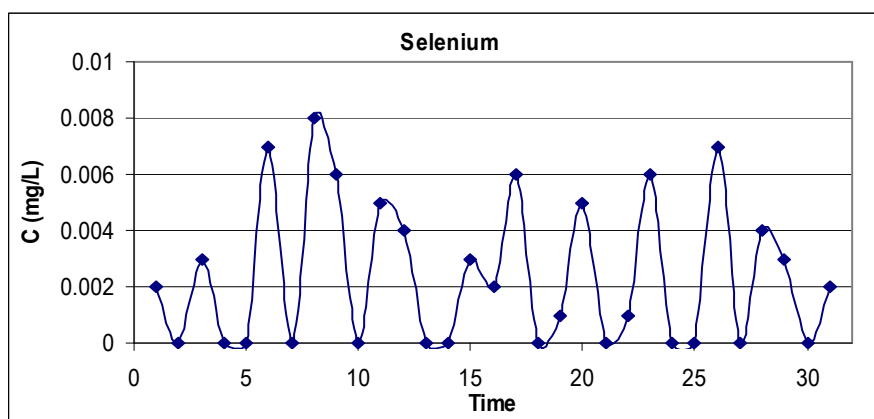


Figure 5.9 Selenium concentrations versus time at Tahtali Reservoir

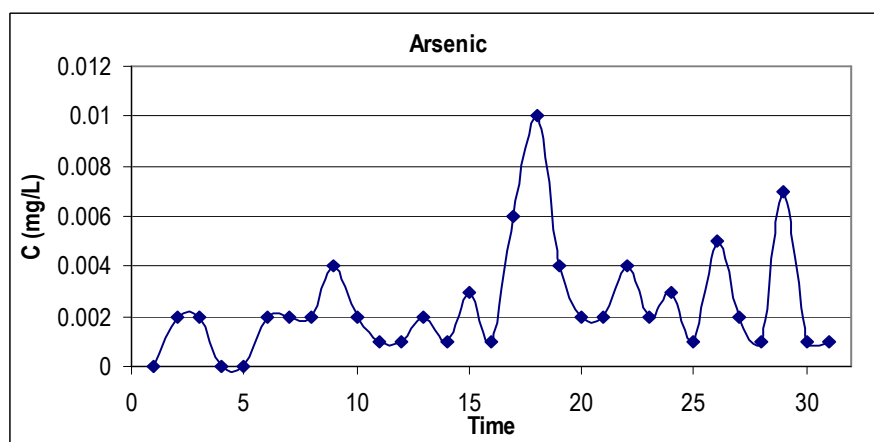


Figure 5.10 Arsenic concentrations versus time at Tahtali Reservoir

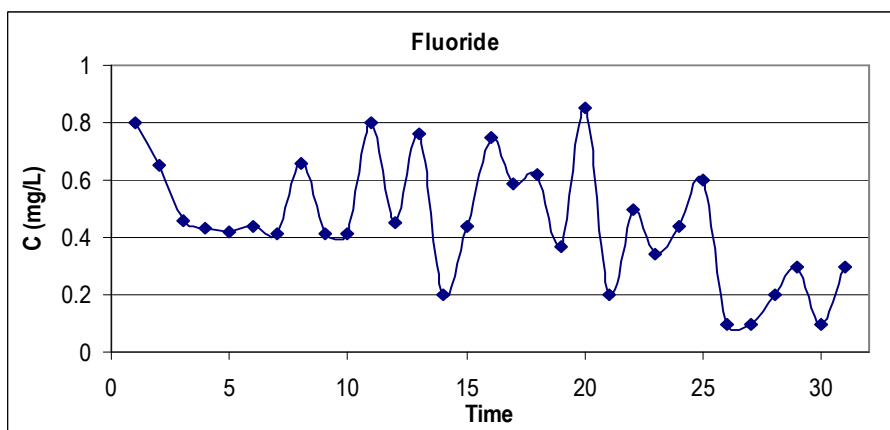


Figure 5.11 Fluoride concentrations versus time at Tahtali Reservoir

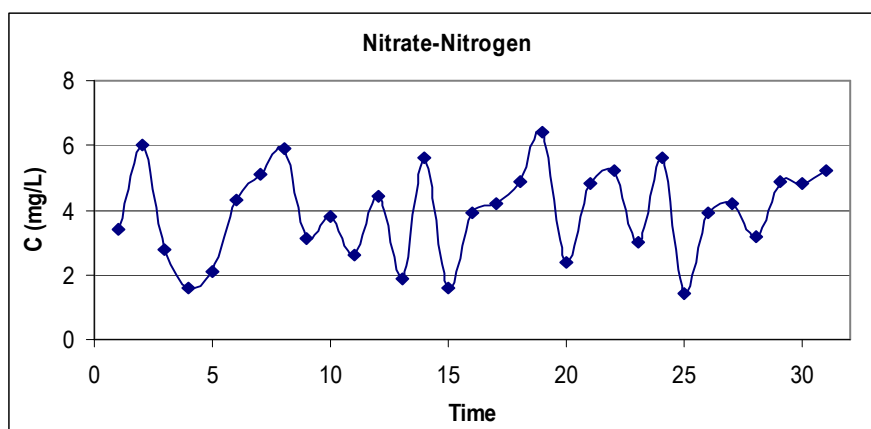


Figure 5.12 Nitrate-nitrogen concentrations versus time at Tahtali Reservoir

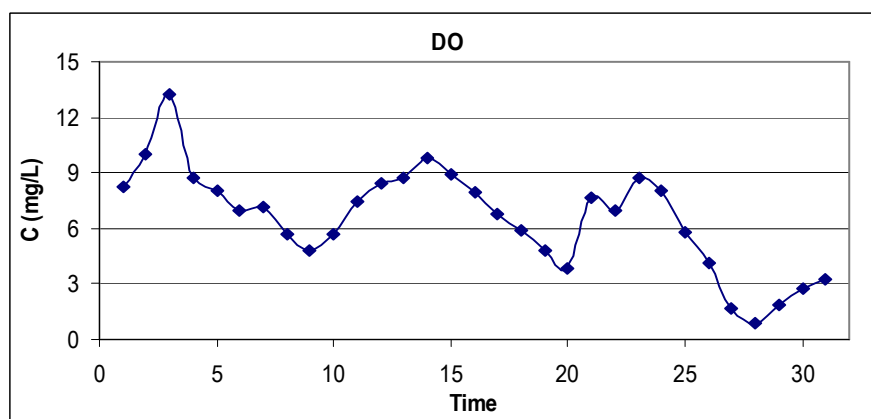


Figure 5.13 Dissolved oxygen concentrations versus time at Tahtali Reservoir

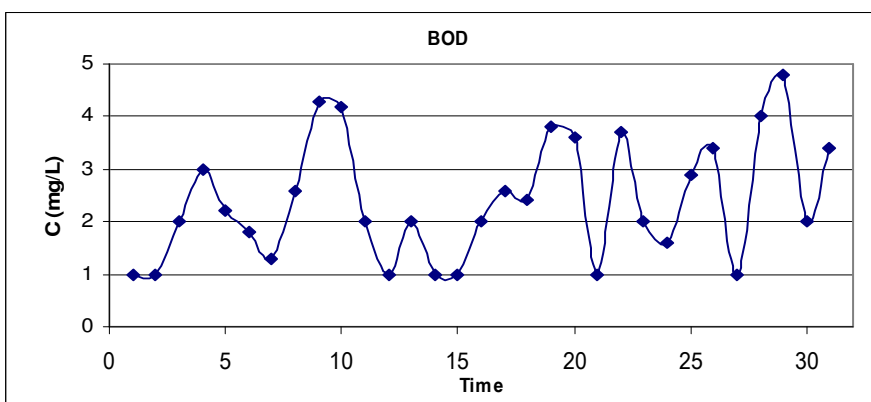


Figure 5.14 BOD concentrations versus time at Tahtali Reservoir

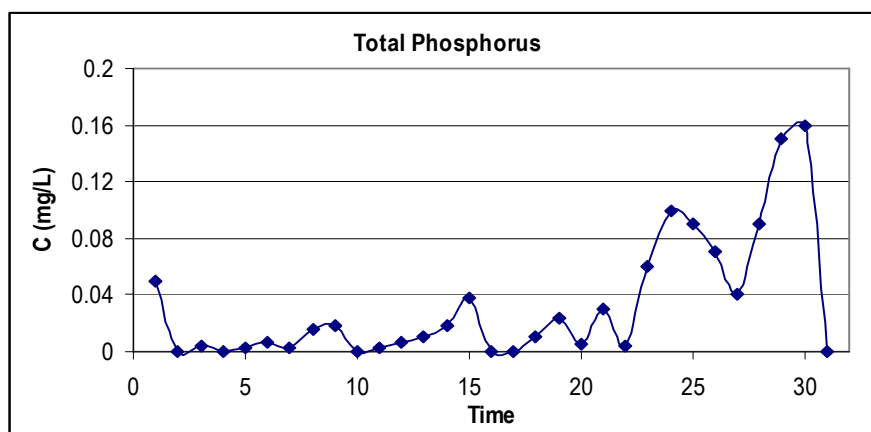


Figure 5.15 Total phosphorus concentrations versus time at Tahtali Reservoir

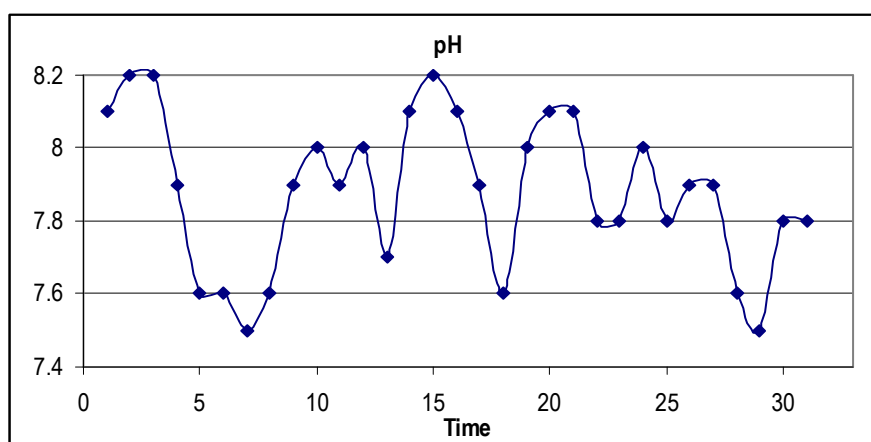


Figure 5.16 PH versus time at Tahtali Reservoir

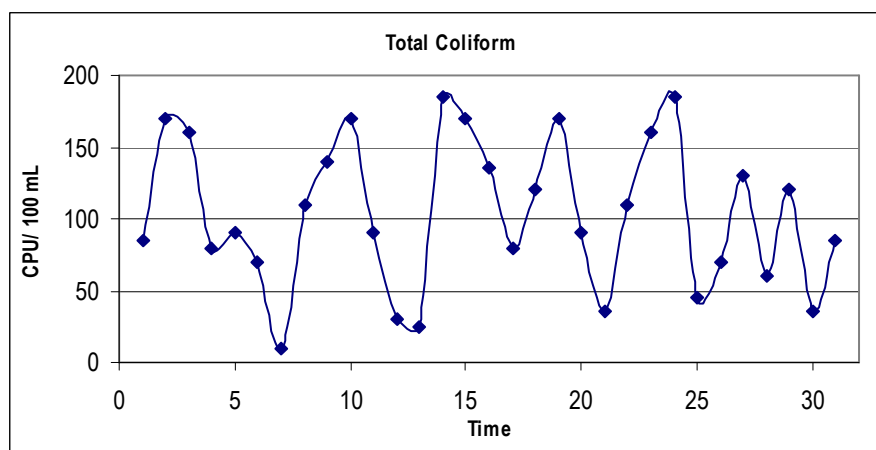


Figure 5.17 Total Coliform concentrations versus time at Tahtali Reservoir

Table 5.7 Results of Mann Kendall test for Tahtali reservoir water quality data

Variable	Calculated z score (equation 3.2)	$z_{0.95}$ (see Appendix C)	Significant trend
Cadmium	0.4023	1.645	
Cyanide	0.1276	1.645	
Mercury	0.3998	1.645	
Selenium	0.1242	1.645	
Arsenic	1.3035	1.645	
Fluoride	2.7601	1.645	Yes
Nitrate-nitrogen	0.9357	1.645	
DO	3.5727	1.645	Yes
BOD ₅	1.6495	1.645	Yes
Phosphorus	3.4333	1.645	Yes
pH	1.2920	1.645	
Total Coliform	0.4944	1.645	

Table 5.8 Sen's Slopes for Tahtali Reservoir water quality data

Variable	Trend direction	Sen's slope
Fluoride	down	-0.0100
DO	down	-0.2069
BOD ₅	up	0.0444
Total phosphorus	up	0.0022

Sen's Slopes presented in Table 5.8 shows that BOD₅ and phosphorus parameters increased over time (A trend with a negative slope indicates that the concentration is declining). However, presently this increase is not a serious threat limiting water use (since for both parameters sub-indices were '100' which represents *Class I* water).

5.4.2 River Monitoring Stations Water Quality Assessment

This section comprises the application of UWQI and environmetric methods including multidimensional scaling, cluster and trend analysis to investigate possible influences of the environment on water quality identify natural groupings in the set of data and also determine spatial and temporal changes at river monitoring stations.

WQI and environmetric methods were applied to data sets obtained from seven monitoring stations six of which located on Tahtali River and its tributaries.

Descriptive statistics of the data set including monitored parameters are given in Table 5.9. The reason not to include all the parameters in this table is that as was mentioned in Section 5.1.2 water quality observations showed sporadic character. While some parameters were observed frequently, some were not. In addition, concentration values for some water quality variables especially for heavy metals were under detection limits. Therefore, the parameters of which did not have reliable number of observations were excluded from the table.

Table 5.9 Descriptive statistics of water quality data obtained from river monitoring stations

Parameter (Unit)	Stations	N	Mean	Median	Mode	Minimum	Maximum
Aluminum (mg/L)	2	73	0.2	0.1	0.1	0.0	2.5
	3	62	0.2	0.1	0.1	0.0	0.9
	4	56	0.3	0.1	0.1	0.0	7.4
	5	82	0.3	0.1	0.1	0.0	11.0
	6	80	0.2	0.1	0.1	0.0	1.2
	7	54	0.2	0.1	0.1	0.0	4.3
	8	59	0.2	0.1	0.1	0.0	3.1
Arsenic (mg/L)	2	62	0.0008	0.0001	0.0000	0.0000	0.0100
	3	61	0.0007	0.0001	0.0000	0.0000	0.0000
	4	48	0.0006	0.0015	0.0000	0.0000	0.0000
	5	80	0.0027	0.0030	0.0000	0.0000	0.0300
	6	79	0.0032	0.0045	0.0000	0.0000	0.0200
	7	40	0.0005	0.0015	0.0000	0.0000	0.0000
	8	56	0.0012	0.0020	0.0000	0.0000	0.0100
Barium (mg/L)	2	76	0.04	0.03	0.03	0.01	0.31
	3	62	0.07	0.06	0.06	0.03	0.16
	4	58	0.05	0.04	0.04	0.01	0.47
	5	83	0.08	0.06	0.06	0.01	0.70
	6	81	0.07	0.06	0.06	0.02	0.15
	7	54	0.05	0.05	0.05	0.02	0.10
	8	60	0.09	0.08	0.09	0.02	0.73
BOD ₅ (mg/L)	2	108	3.0	1	1	0	14
	3	61	2.5	1	2	1	9
	4	83	2.9	1	1	0	12
	5	113	3.6	1.5	1	1	18
	6	111	3.2	2	1	1	17
	7	73	2.1	2.5	1	1	9
	8	77	2.2	1	1	1	12

Table 5.9 Descriptive statistics of water quality data obtained from river monitoring station (cont.)

Parameter (Unit)	Stations	N	Mean	Median	Mode	Minimum	Maximum
Boron (mg/L)	2	108	0.17	0.14	0.10	0.05	0.79
	3	62	0.21	0.20	0.20	0.10	0.90
	4	82	0.24	0.20	0.10	0.08	1.07
	5	116	0.41	0.33	0.20	0.10	1.73
	6	114	0.63	0.50	0.30	0.08	2.15
	7	73	0.21	0.18	0.10	0.00	1.02
	8	78	0.19	0.17	0.10	0.05	1.10
Zinc (mg/L)	2	71	0.17	0.17	0.20	0.01	0.57
	3	62	0.20	0.20	0.20	0.01	0.40
	4	57	0.19	0.17	0.17	0.01	0.58
	5	77	0.18	0.17	0.20	0.00	0.74
	6	75	0.18	0.16	0.16	0.00	0.70
	7	54	0.18	0.19	0.20	0.01	0.40
	8	60	0.20	0.20	0.20	0.00	0.40
DO (mg/L)	2	102	7.2	10.0	8.0	3.9	11.1
	3	62	7.4	9.0	6.7	4.4	11.5
	4	75	7.9	9.0	6.2	3.6	11.0
	5	109	7.6	9.2	6.0	4.1	10.9
	6	107	7.1	9.5	6.0	4.2	11.0
	7	65	7.6	9.0	6.0	5.0	9.8
	8	70	7.6	9.2	6.2	5.3	11.5
Iron (mg/L)	2	76	0.18	0.08	0.10	0.01	3.17
	3	58	0.09	0.0	0.03	0.01	0.40
	4	58	0.20	0.07	0.05	0.01	4.80
	5	83	0.28	0.08	0.11	0.00	12.00
	6	81	0.16	0.10	0.13	0.02	1.68
	7	55	0.17	0.04	0.04	0.00	4.60
	8	61	0.16	0.06	0.07	0.01	3.40
Fluoride (mg/L)	2	109	0.29	0.40	0.10	0.00	0.70
	3	62	0.23	0.40	0.20	0.10	0.50
	4	83	0.34	0.40	0.10	0.10	0.80
	5	116	0.40	0.44	0.40	0.10	0.80
	6	114	0.43	0.46	0.40	0.10	0.72
	7	73	0.29	0.42	0.10	0.00	0.74
	8	78	0.29	0.42	0.10	0.10	0.75
COD (mg/L)	2	112	8	8	4	1	31
	3	62	9	8	8	4	19
	4	86	10	8	4	2	43
	5	120	11	8	4	0	66
	6	118	10	8	8	0	38
	7	75	8	8	4	0	24
	8	80	8	8	4	0	27

Table 5.9 Descriptive statistics of water quality data obtained from river monitoring stations (cont)

Parameter (Unit)	Stations	N	Mean	Median	Mode	Minimum	Maximum
Manganese (mg/L)	2	76	0.03	0.02	0.01	0.00	0.26
	3	62	0.03	0.02	0.01	0.00	0.26
	4	58	0.03	0.02	0.01	0.00	0.24
	5	83	0.11	0.07	0.10	0.00	0.85
	6	81	0.12	0.10	0.10	0.01	0.50
	7	55	0.02	0.01	0.00	0.00	0.17
	8	60	0.01	0.01	0.01	0.00	0.13
Nitrate- nitrogen (mg/L)	2	110	1.2	4.3	0.0	0.0	7.0
	3	62	6.2	5.3	7.0	1.2	22.0
	4	84	3.9	5.0	4.0	0.0	15.6
	5	118	4.6	5.6	0.0	0.0	25.0
	6	116	4.9	5.6	3.0	0.0	24.0
	7	74	10.2	8.4	9.0	0.0	38.0
	8	79	4.9	5.0	3.0	0.0	23.0
Sodium (mg/L)	2	109	17.1	16.0	14.0	9.0	54.0
	3	61	23.5	22.0	23.0	10.0	56.0
	4	86	29.5	22.8	17.0	3.0	155.0
	5	116	42.1	39.5	21.0	11.0	114.0
	6	114	58.3	56.8	40.0	20.0	97.5
	7	73	16.6	16.0	15.0	0.0	68.0
	8	79	13.3	12.5	12.0	9.0	21.0
Sulfate (mg/L)	2	78	40	39	41	3	115
	3	42	46	46	46	21	74
	4	56	41	37	40	7	130
	5	88	44	44	35	0	112
	6	88	54	51	47	0	104
	7	49	30	29	18	8	86
	8	51	26	27	11	9	71
Total Dissolved Solids-TDS (mg/L)	2	102	297	297	303	111	622
	3	62	377	376	359	219	552
	4	75	393	361	330	165	923
	5	109	445	447	376	112	976
	6	107	484	493	467	218	685
	7	65	416	418	435	278	581
	8	70	340	337	290	214	473
Chloride (mg/L)	2	112	27	26	30	12	70
	3	62	43	41	50	20	80
	4	86	48	36	40	16	370
	5	120	63	61	30	6	182
	6	118	75	72	60	22	136
	7	75	36	36	34	22	56
	8	80	27	26	22	18	42

5.4.2.1 Application of UWQI

UWQI was calculated to assess water quality of the creeks in the Tahtali Basin and determine in which degree existing water quality comply with the standards. Median

value of each data set, which is presented in Table 5.10, was accepted as reference value for the calculations.

Sub-index values presented in Table 5.11 were determined using mathematical expressions given in Table 3.2. As has been discussed in section 3.3, sub-index value '100' correspond *Class I* water quality.

Table 5.10 River monitoring stations UWQI determinants median values

Variable	River monitoring stations						
	2	3	4	5	6	7	8
Cadmium	0	0	0.0015	0.002	0.001	0	0
Cyanide	0	0	0	0	0.001	0	0
Mercury	0	0	0.0001	0.0001	0.0001	0.0001	0
Selenium	0.002	0.005	0.0065	0.0050	0.0058	0.0038	0.0060
Arsenic	0.001	0.001	0.0015	0.003	0.0045	0.0015	0.002
Fluoride	0.4	0.4	0.4	0.44	0.46	0.42	0.42
Nitrate-nitrogen	4.27	5.32	5	5.61	5.6	8.4	4.96
DO	10	9	9	9.2	9.5	9	9.2
BOD ₅	1	1	1	1.5	2	2.5	1
Total phosphorus	0.02	0.02	0.01	0.03	0.02	0.04	0.01
pH	8.2	8.2	8	8.1	7.9	8.1	8.2
Total Coliform	160	170	180	160	180	195	160

Table 5.11 Sub-index-I_i (symbolic Y to Table 3.2) values

Variable	River monitoring stations						
	2	3	4	5	6	7	8
Cadmium	100	100	100	100	100	100	100
Cyanide	100	100	100	100	100	100	100
Mercury	100	100	100	100	100	100	100
Selenium	100	100	100	100	100	100	100
Arsenic	100	100	100	100	100	100	100
Fluoride	100	100	100	100	100	100	100
Nitrate-nitrogen	100	96.8	100	93.9	94	66	100
DO	100	100	100	100	100	100	100
BOD ₅	100	100	100	100	100	100	100
Total phosphorus	100	100	100	96.43	100	92.9	100
pH	100	100	100	100	100	100	100
Total Coliform	87.4	86.7	86.1	87.4	86.1	85.2	87.4

In the last step weighted sum method was employed to get overall index value using weights (from Table 3.3) and sub-indices (from Table 5.11). Table 5.12 presents UWQI results including sub-total values for each parameter and overall index value at each monitoring station.

Table 5.12 Universal Water Quality Index (UWQI) calculation for Tahtali Basin River monitoring stations

Variable	River monitoring stations						
	2	3	4	5	6	7	8
Cadmium	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Cyanide	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Mercury	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Selenium	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Arsenic	11.30	11.30	11.30	11.30	11.30	11.30	11.30
Fluoride	8.60	8.60	8.60	8.60	8.60	8.60	8.60
Nitrate-nitrogen	8.60	8.32	8.60	8.08	8.08	5.68	8.60
DO	11.40	11.40	11.40	11.40	11.40	11.40	11.40
BOD ₅	5.70	5.70	5.70	5.70	5.70	5.70	5.70
Total phosphorus	5.70	5.70	5.70	5.50	5.70	5.30	5.70
pH	2.90	2.90	2.90	2.90	2.90	2.90	2.90
Total Coliform	9.96	9.88	9.82	9.96	9.82	9.71	9.96
WQI	98.56	98.21	98.42	97.84	97.90	94.98	98.56

As is presented in Table 5.12 overall index values were mainly above 95 and water quality belonged to ‘excellent water’ class. However, sub-index values for nitrate nitrogen, total phosphorus and total coliform did not correspond Class I water quality. In other words sub-indices for these three parameters were lower than ‘100’ (see table 5.11). Low values for nitrate-nitrogen and total phosphorus can be explained by presence of agricultural activities in the basin where 18% of the total area is agricultural land. In addition, low total coliform sub-indices were due to domestic discharges.

Bar diagram plotted for nitrate-nitrogen sub-total index (calculated for median values) at each station is seen in Figure 5.18. Black filled bars were also given in this figure to show difference of observed values at these stations from limits set by the standards. At ‘y’ axis 8.6 corresponds Class I and 4.3 Class II water category sub-total indices.

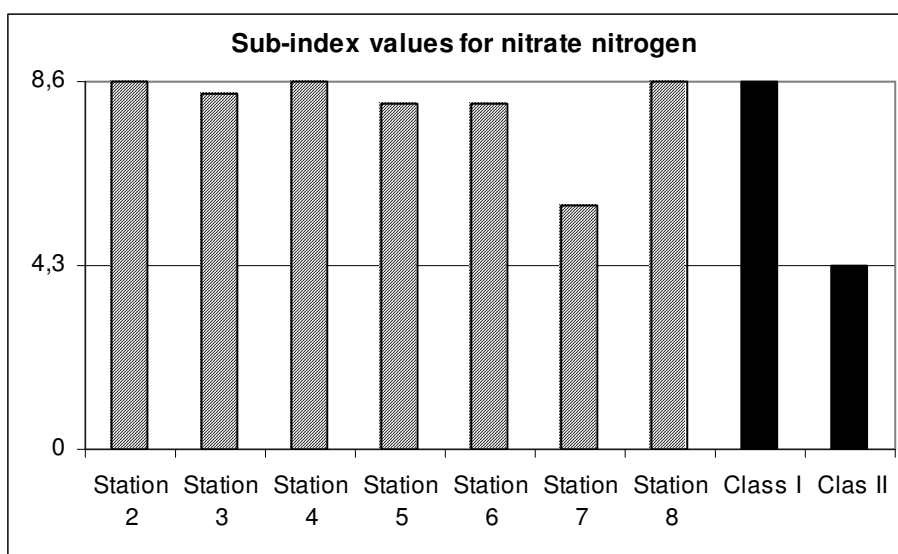


Figure 5.18 Nitrate- nitrogen parameter sub-total index values

UWQI results revealed that the highest nitrate nitrogen concentrations were observed at Station 7. In addition at Station 3, 5 and 6 concentrations were relatively high (see Figure 5.18).

Nutrients (nitrogen and phosphorus), salinity (sodium, calcium, magnesium and to a lesser extent potassium), major ions (e.g chloride, sulfate and nitrate) and pesticides etc. are mainly found in surface and subsurface drainage waters (Food and Agriculture Organization of the United Nations- FAO, 1997). Based on this statement and results of the index calculation it can be concluded that surface water quality at the Tahtali River and its tributaries was mainly affected from agricultural discharges with presence of high nitrate-nitrogen and total phosphorus concentrations. In addition, high total coliform values were also evidence of negative effects of domestic discharges in the region.

5.4.2.2 Application of Cluster Analysis

Cluster analysis organizes sampling entities (e.g. species, sites, observations) into discrete classes or groups such that within-group similarity is maximized and among-group similarity is minimized according to some objective criteria (McGarial et al.,

2000). In this study sampling site classification was performed by the use of cluster analysis (z-transformation of the input data, squared Euclidean distance as similarity measure and Ward's method of linkage) and dendrogram was generated.

A dendrogram that clearly differentiates groups of objects has small distances in the far branches of the tree and large differences in the near branches. The following example dendrogram ideally illustrates two clear groups (see Figure 5.19).

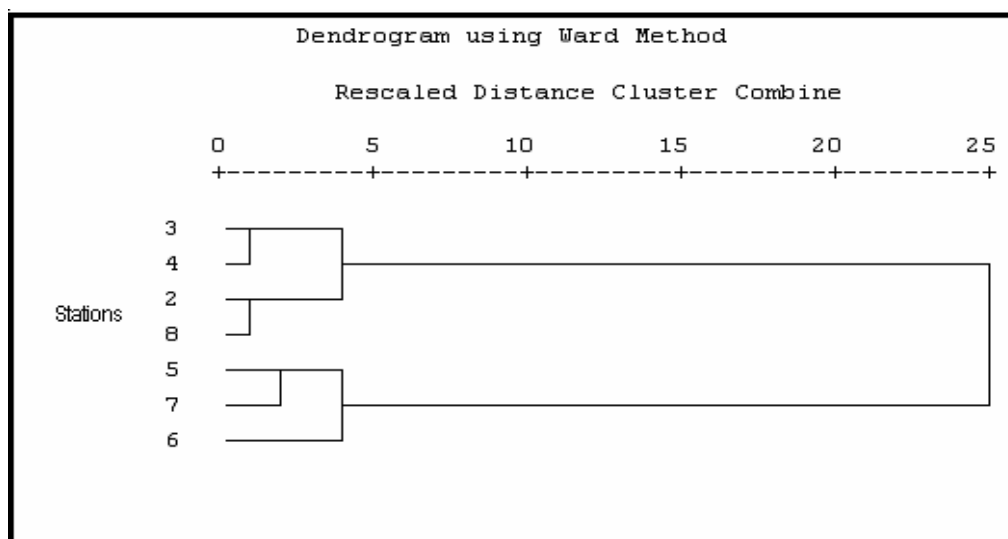


Figure 5.19 Ward's minimum variance dendrogram

Stations at each group are seen in Figure 5.20.

Based on the results of cluster analysis it is concluded that:

Cluster 1 (Stations 3-4-2-8): Sites from the downstream of the Akselvi Creek (Station 2). Tahtali Creek and its tributary (Stations 3 and 4) were grouped under this cluster. In addition Station 8 located at upstream of the Tahtali Creek showed similar water quality characteristics with these stations.

Cluster 2 (Stations 5-7-6): This cluster consisted sites that are located at the north and north-east part of the basin. At these stations water quality variables including TDS, nitrate nitrogen sodium, chloride and sulfate were relatively higher than the others (see

Figure 5.21). As was mentioned in Section 5.4.2.1 typical sources of these parameters are agricultural drainage waters. Therefore major water pollution threat at this part of the basin was agricultural land uses.

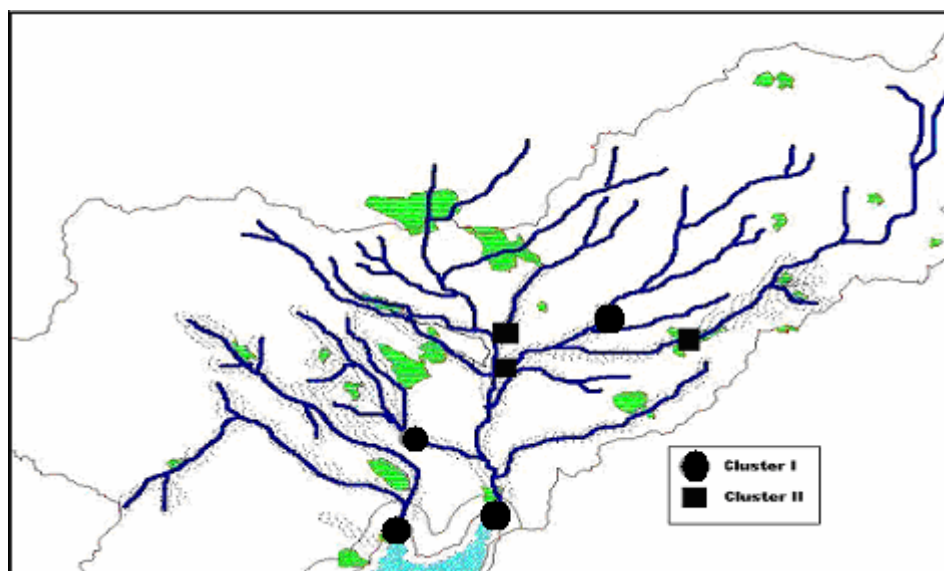


Figure 5.20 Grouped stations based on cluster analysis

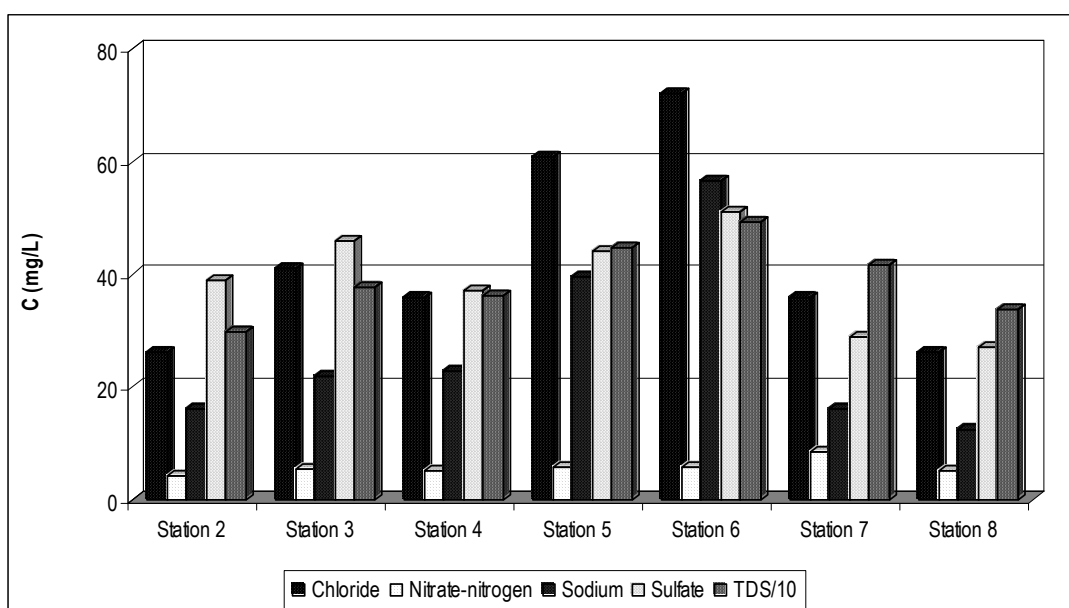


Figure 5.21 Chloride, nitrate-nitrogen, sodium, sulfate and TDS concentrations at river observation stations

5.4.2.3 Application of Trend Analysis

Agricultural land uses effect water quality predominantly at north and north-east part of the basin (from Section 5.4.2.2). In this section it is intended to determine if chloride, nitrate nitrogen, sodium, sulfate and TDS concentrations, indicators of agricultural discharges generally increase or decrease (getting "better" or "worse") over time at river stations (stations 2, 3, 4, 5, 6, 7 and 8). Mann Kendall test was applied determining significant trend and Sen's slope test for magnitude of trend. Results of the Mann Kendall test are presented in Table 5.13. Test statistics (z scores) were calculated using formula (3.2) and critical z value at 5 percent significance level was taken from the standard normal distribution table (see Appendix C).

Table 5.13 Results of Mann Kendall test for river monitoring stations surface water quality data

Variable	Station	Calculated z score (equation 3.2)	$z_{0.95}$ (see Appendix C)	Significant trend
Chloride	2	1.3064	1.645	Yes
	3	1.8122		
	4	0.5538		
	5	2.3214		Yes
	6	0.5992		
	7	1.0012		
	8	0.2846		
Nitrate-nitrogen	2	2.4528	1.645	Yes
	3	0.1886		
	4	0.8001		
	5	1.4799		Yes
	6	3.0545		
	7	1.4382		
	8	0.0127		
Sodium	2	0.6560	1.645	Yes
	3	1.6773		
	4	0.4367		
	5	2.4855		Yes
	6	3.5446		Yes
	7	1.7601		Yes
	8	1.5852		

Table 5.13 Results of Mann Kendall test for river monitoring stations surface water quality data

Variable	Station	Calculated z score (equation 3.2)	$z_{0.95}$ (see Appendix C)	Significant trend
Sulfate	2	0.6003	1.645	Yes
	3	0.6080		
	4	0.7923		
	5	1.4231		
	6	0.1981		
	7	1.5188		
	8	1.9445		
TDS	2	1.7698	1.645	Yes
	3	2.7704		Yes
	4	0.4164		Yes
	5	0.7516		
	6	2.2103		
	7	1.4213		
	8	1.3640		

Sen's slopes of the parameters showing significant trend are given in Table 5.14.

Table 5.14 Sen's Slopes for river monitoring stations surface water quality data

Variable	Station	Trend direction	Sen's slope
Chloride	3	down	-0.1290
	5	up	0.1667
Nitrate-nitrogen	2	up	0.0050
	6	down	-0.0190
Sodium	3	down	-0.0694
	5	up	0.1515
	6	down	-0.1962
	7	down	-0.0313
Sulfate	8	up	0.5157
TDS	2	down	-0.375
	3	down	-1.1364
	6	down	-0.8268

Trend analysis results revealed that water quality variables, which are indicators of agricultural pollution generally decreased over time or did not change at river

monitoring stations (see Table 5.15). This was expected consequences of pollution prevention efforts that have been performed by local authorities since 1996 in the basin.

Table 5.15 Water quality trends in Tahtali Basin

Variable	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8
NO ₃ -N	☹	-	-	-	☺	-	-
Na ⁺	-	☺	-	☹	☺	☺	-
SO ₄ ²⁻	-	-	-	-	-	-	☹
TDS	☺	☺	-	-	☺	-	-
Cl ⁻	-	☺	-	☹	-	-	-

☺: improving trend ☹: deteriorating trend -: no change

For the parameters showing trend concentration versus time graphs are presented in Figures from 5.22 to 5.33. At these graphs each observation was represented by a case number.

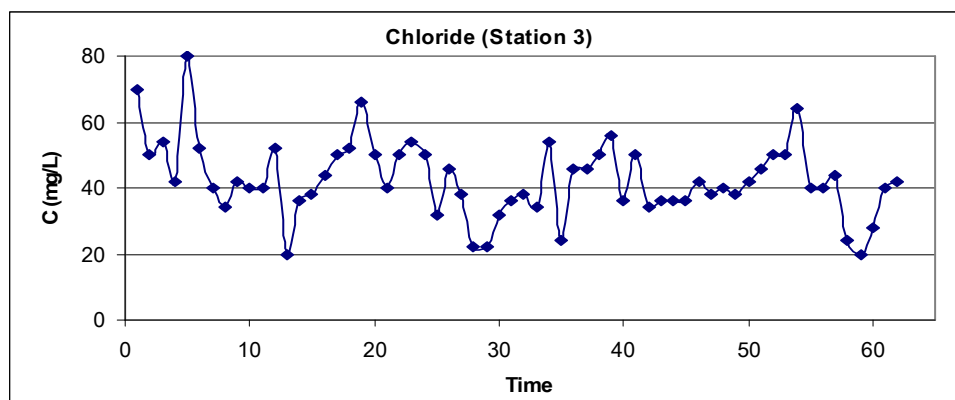


Figure 5.22 Chloride concentrations versus time at observation station 3

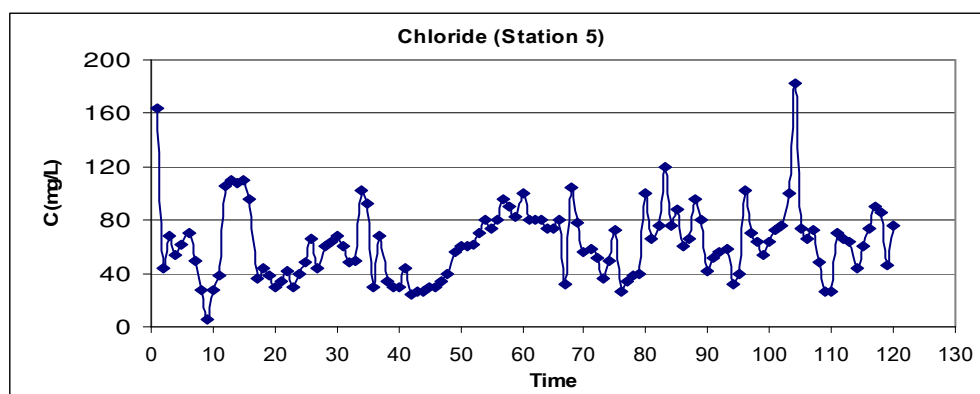


Figure 5.23 Chloride concentrations versus time at observation station 5

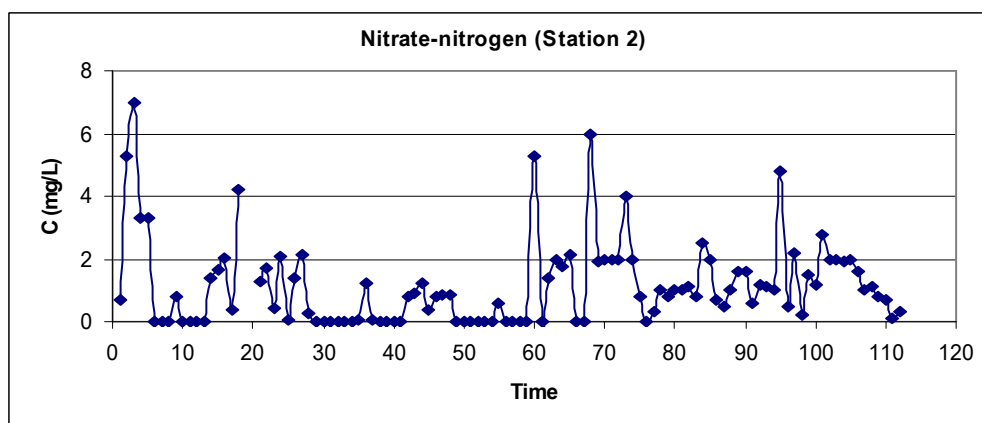


Figure 5.24 Nitrate-nitrogen concentrations versus time at observation station 2

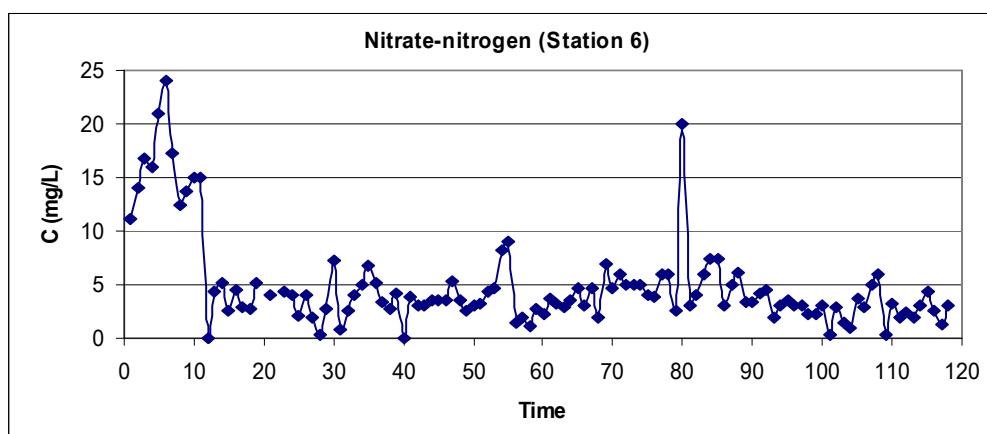


Figure 5.25 Nitrate-nitrogen concentrations versus time at observation station 6

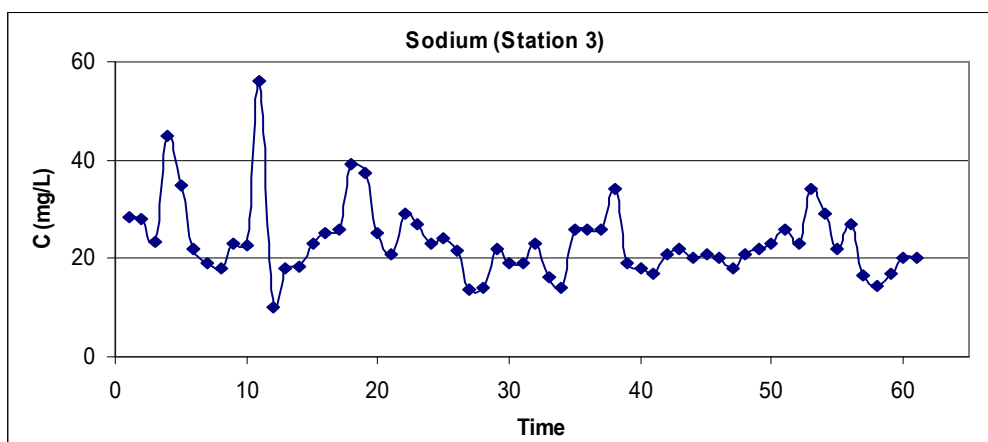


Figure 5.26 Sodium concentrations versus time at observation station 3

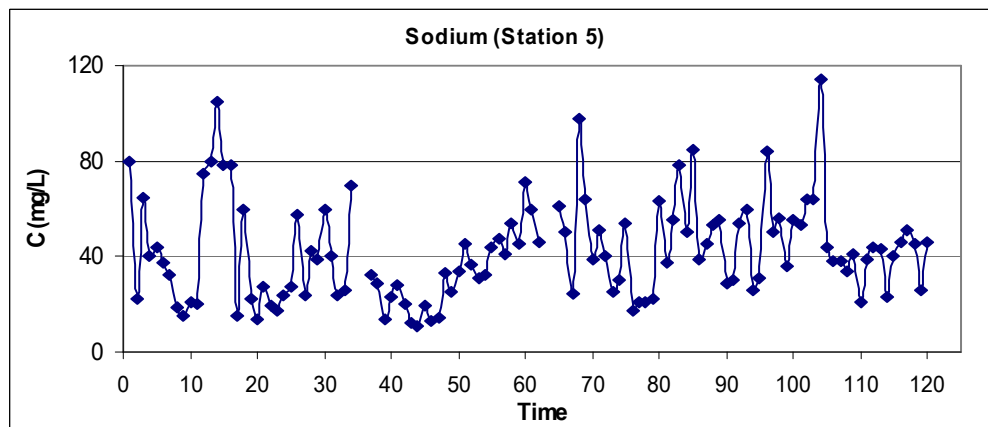


Figure 5.27 Sodium concentrations versus time at observation station 5

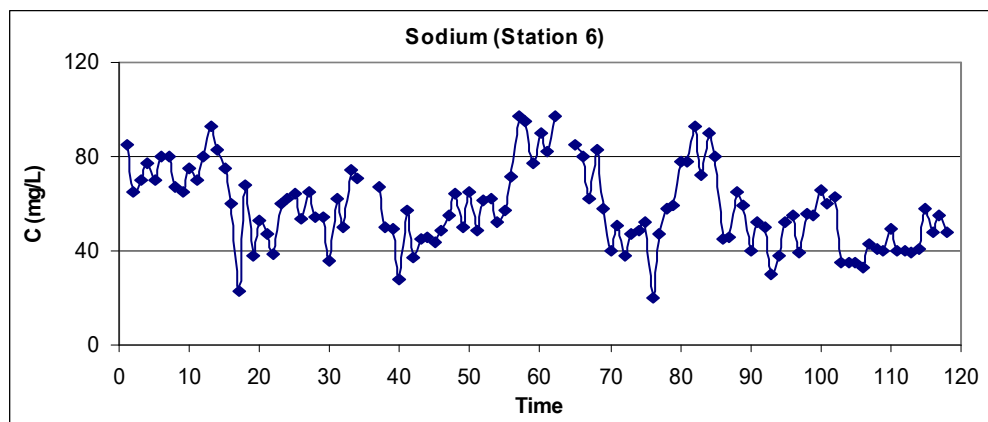


Figure 5.28 Sodium concentrations versus time at observation station 6

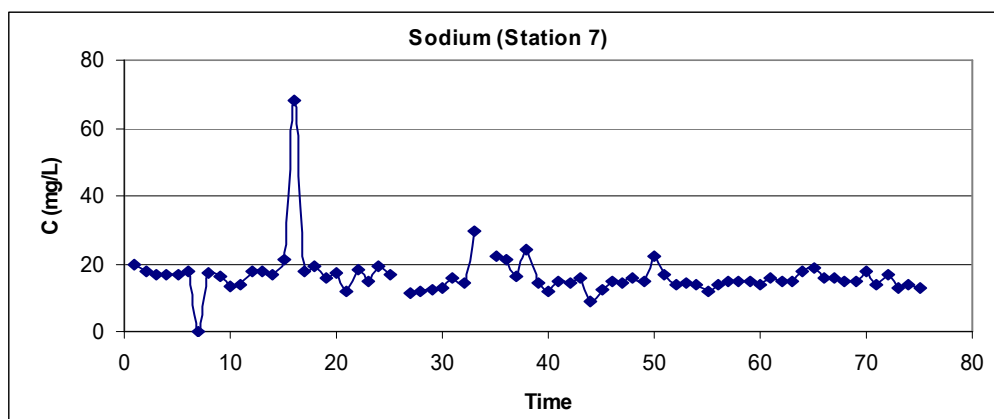


Figure 5.29 Sodium concentrations versus time at observation station 7

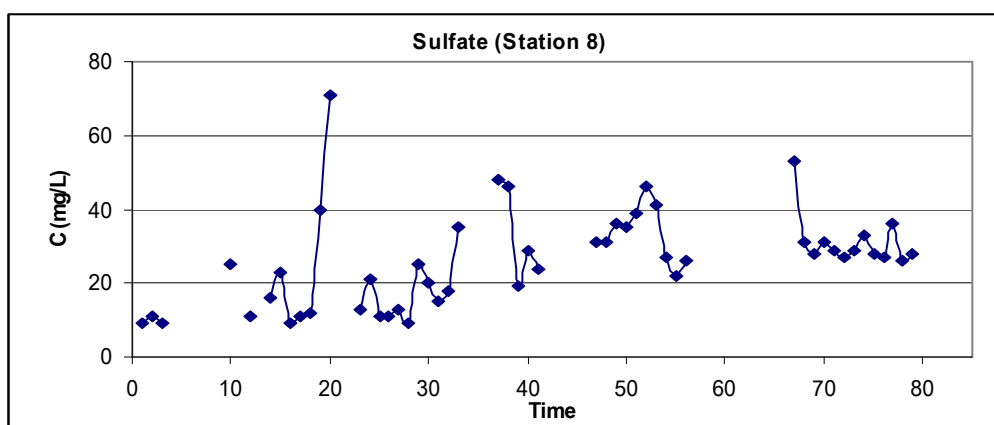


Figure 5.30 Sulfate concentrations versus time at observation station 8

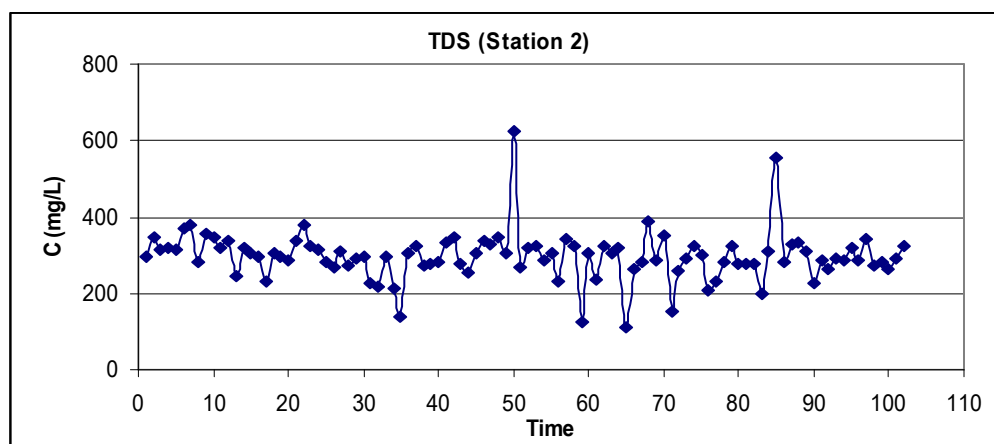


Figure 5.31 TDS concentrations versus time at observation station 2

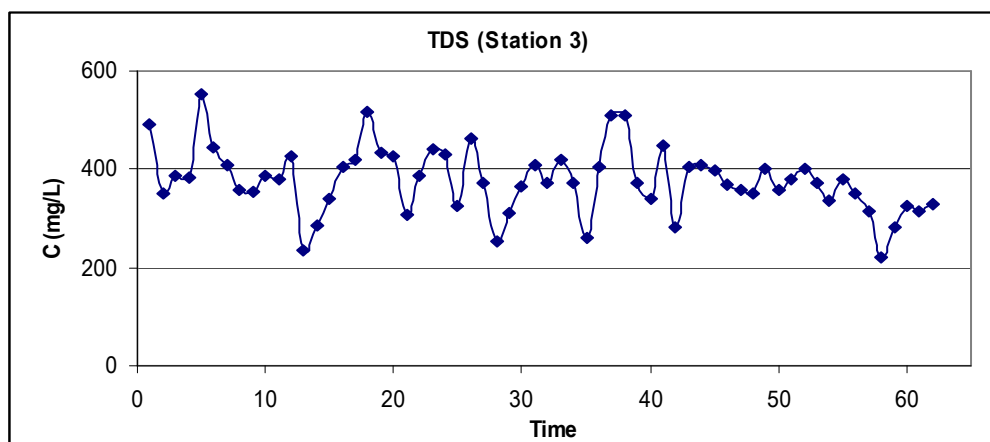


Figure 5.32 TDS concentrations versus time at observation station 3

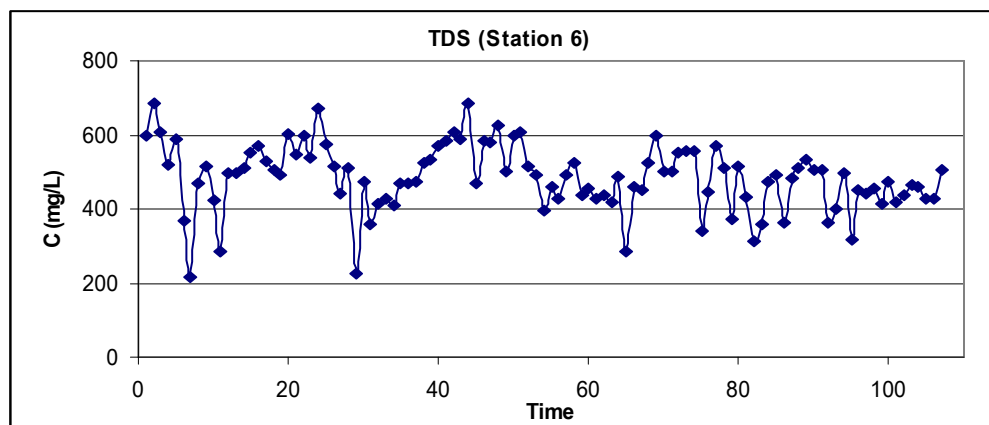


Figure 5.33 TDS concentrations versus time at observation station 6

5.4.2.4 Application of Multidimensional Scaling

In this thesis, multidimensional scaling was also performed to visualize similarities in data set including TDS, sodium, chloride, sulfate and nitrate-nitrogen parameters (Goodness of fit of the configuration to the dissimilarities was measured by Kruskal's stress coefficient). Based on the Euclidean distance model presented in Figure 5.34 it is concluded that observation stations for the parameters; total dissolved solids, sodium and chloride showed similar characteristics but nitrate and sulfate, which are mainly found in agricultural discharges, caused difference between these sites.

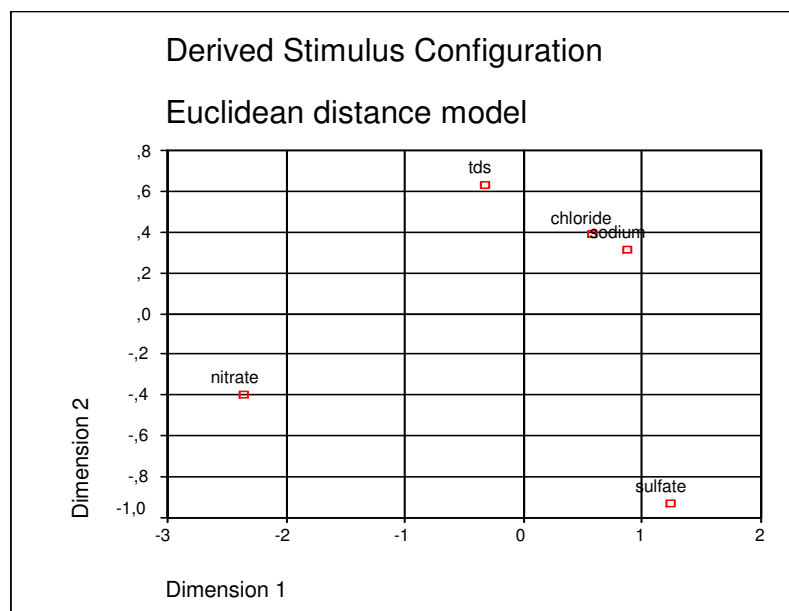


Figure 5.34 Euclidean distance model

5.5 Selection of a Water Quality Variable (s) for TMDL Analysis

As has been presented in Section 5.4 results of water quality index calculation revealed that Tahtali Basin surface water quality was mainly controlled by agricultural uses. Low sub-index values for nitrate and phosphorus could be explained by presence of agricultural activities in the region where 18% of the total area is agricultural land. In addition, low total coliform sub-indices were the consequences of negative effects of the un-controlled domestic discharges caused by rapid urbanization. Population growth since 1990's has created an additional stress on the environmental conditions in the region.

Two major groups of sampling stations were formed by treating all data by clustering. One cluster mainly consisted sites from the downstream of the creeks. On the other hand monitoring stations located at the north and north-east part of the basin were grouped under the same cluster. At these stations water quality variables including TDS, nitrate nitrogen, sodium, chloride and sulfate that are mainly found in agricultural drainage waters were relatively higher than the others. Thus, surface quality at this part was controlled by agricultural discharges. Results of multidimensional scaling method

(applied to data set including TDS, sodium, chloride, sulfate and nitrate-nitrogen parameters) revealed that nitrate and sulfate caused difference between these observation sites.

In summary major water pollution threats at the north and north-east part of the basin (covered by Mersinlikahve Creek Watershed) included agricultural land uses but their effects do not limit water use for drinking purpose presently. On the other hand infrastructure systems of the settlements in the region is either planning and /or construction phase. After all the projects are completed, treated domestic wastewaters would be transferred out of the Tahtali basin by transmission line. Thus, domestic discharges will not be serious threat for surface water quality in the near future.

Finally it is concluded that the most critical parameter among all the water quality determinants is “nitrate-nitrogen” and this pose a threat for surface water quality especially at north east part of the Tahtali Basin where is covered by sub-basin called Mersinlikahve Creek watershed. Although total phosphorus concentrations do not meet standards set for Class I waters, nitrogen has risk violating limit set for Class II waters in this region. As has been mentioned in Section 3.3 common sources of nitrate in water are runoff from fertilizer use, leaching from septic tanks, sewage etc. (USEPA, 2003). Phosphorus the variable under risk like nitrogen for the basin also comes from similar sources. Therefore, any efforts on controlling of agricultural nitrogen contributions in the region will have positive effects to decrease phosphorus concentrations.

All these facts were taken into account and nitrate nitrogen was selected as a key variable of TMDL analysis in the thesis. In this context following sections presents

- investigation of the current nitrogen loads from point sources, non-point sources,
- modeling of the impacts of these loads on the surface water quality and
- introduction of basin growth scenarios ensure that water quality will support intended use.

CHAPTER SIX

CASE STUDY: TMDL BASED DECISION PROCESS FOR THE MERSINLIKAHVE SUBWATERSHED PART A: WATER QUALITY MODELING

6.1 Introduction

As has been mentioned in Chapter 5 concerns for surface water quality in the Mersinlikahve Creek watershed include nutrient concentrations (nitrogen and phosphorus) and nitrate nitrogen has been selected as a key variable of the TMDL analysis. In this context basin growth plans including various land uses scenarios were done taking into consideration of this variable not to limit water uses for intended purpose (potable water supply) in the future. This chapter comprises presentation of background information on exiting pollutant sources and establishment of water quality model. Location of the study area is seen in Figure 6.1.

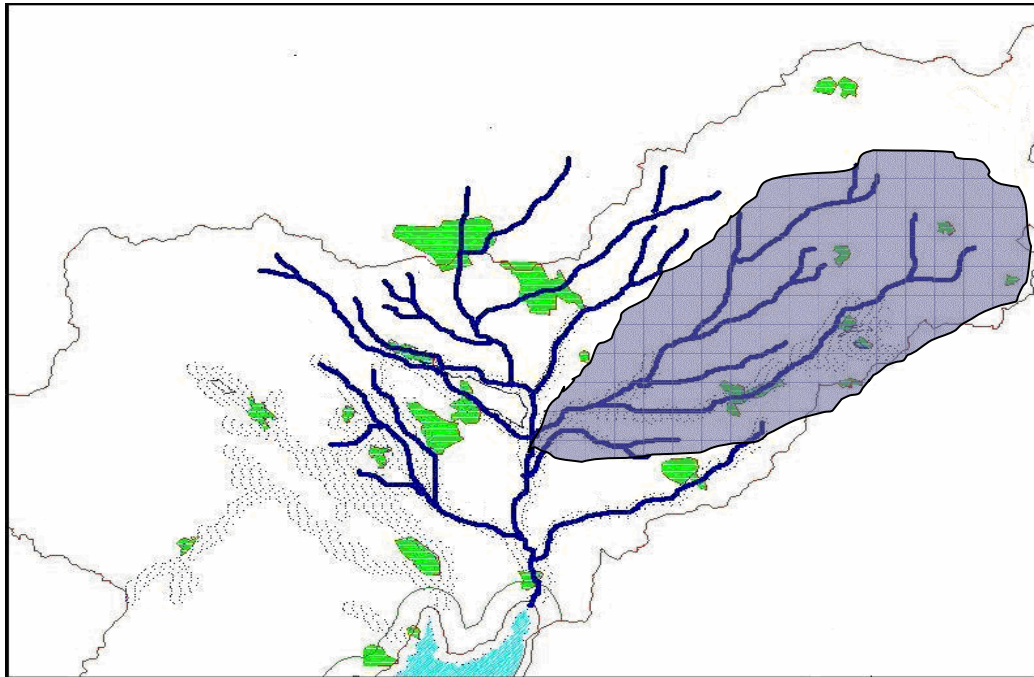


Figure 6.1 Projected area in Tahtali River Basin

Nitrogen

Excess nutrients in a waterbody can have many detrimental effects on designated and/or existing uses. Nitrogen reaches surface waters at an elevated rate as a result of human activities. The transport of nitrogen from their sources to the waterbody of concern is governed by several chemical, physical, and biological processes, which together compose the nitrogen cycle (USEPA, 1999).

Nitrogen Cycling

Nitrogen is plentiful in the environment. Almost 80 percent of the atmosphere by volume consists of nitrogen gas (N_2). Although largely available in the atmosphere, N_2 must be converted to other forms, such as nitrate (NO_3^-), before most plants and animals can use it. Conversion into usable forms, both in the terrestrial and aquatic environments, occurs through the four processes of the nitrogen cycle,

- nitrogen fixation,
- ammonification,
- nitrification—conversion of gaseous nitrogen into usable chemical forms,
- denitrification—conversion of fixed nitrogen back to the gaseous N_2 state (USEPA, 1999).

Nitrogen fixation: The conversion of gaseous nitrogen into ammonia ions (NH_3 and NH_4^+). Nitrogen-fixing organisms, such as blue-green algae and the bacteria, split molecular nitrogen (N_2) into two free nitrogen molecules. The nitrogen molecules combine with hydrogen molecules to yield ammonia ions (USEPA, 1999).

Ammonification: A one-way reaction in which decomposer organisms break down wastes and nonliving organic tissues to amino acids, which are then, oxidized to carbon

dioxide, water, and ammonia ions. Ammonia is then available for absorption by plant matter (USEPA, 1999).

Nitrification: A two-step process by which ammonia ions are oxidized to nitrite and nitrate, yielding energy for decomposer organisms. Two groups of microorganisms are involved in the nitrification process. First, *Nitrosomonas* oxidizes ammonia ions to nitrite and water. Second, *Nitrobacter* oxidizes the nitrite ions to nitrate, which is then available for absorption by plant matter (USEPA, 1999).

Denitrification: The process by which nitrates are reduced to gaseous nitrogen by facultative anaerobes. Facultative anaerobes, such as fungi, can flourish in anoxic conditions because they break down oxygen containing compounds (e.g., NO_3^-) to obtain oxygen. Once introduced into the aquatic environment, nitrogen can exist in several forms—dissolved nitrogen gas (N_2), ammonia (NH_4^+ and NH_3), nitrite (NO_2^-), nitrate (NO_3^-), and organic nitrogen as proteinaceous matter or in dissolved or particulate phases (Ecological Society of America- ESA, 1997; USEPA 1999).

The most important forms of nitrogen in terms of their immediate impact on water quality are the readily available ammonia ions, nitrites, and nitrates. Common source of nitrate and nitrite in water are runoff from fertilizer use, leaching from septic tanks, sewage and erosion of natural deposits etc. (USEPA, 2003). Table 6.1 presents nitrogen loadings of common non-point sources.

Table 6.1 Typical nitrogen loading ranges for various land uses (after USEPA, 1999).

Land use	Total nitrogen (kg/ha.yr)		
	Minimum	Maximum	Median
Roadway	1.3	3.5	2.4
Commercial	1.6	8.8	5.2
Single family, low density	3.3	4.7	4.0
Single family, high density	4.0	5.6	5.8
Multifamily residential	4.7	6.6	5.6
Forest	1.1	2.8	2.0
Grass	1.2	7.1	4.2
Pasture	1.2	7.1	4.2

As with all literature values, this table should be used discriminately and only in the absence of site-specific data (USEPA, 1999).

6.2 Median Water Quality Conditions in Mersinlikahve Creek Watershed

Median concentrations of monitoring data including BOD₅, NO₃-N, total-P and dissolved oxygen variables obtained from three monitoring stations located in the basin during the 1999-2000 period is given in Table 6.2. In this study, the target threshold was the limit value set for Class II water in Turkish Water Pollution Control Regulation for each parameter (see Appendix B1).

Table 6.2 Median concentrations of water quality parameters observed in Mersinlikahve Watershed

Monitoring Station	BOD ₅	NO ₃ -N	Total phosphorus	DO
5	1.50	3.40	0.02	9.2
7	2.50	4.30	0.04	9.0
8	1.00	2.80	0.01	9.2
Class II	8	10	0.16	6

During summer months (under low flow conditions) concentrations of water quality variables especially originating from agricultural land uses showed high fluctuations from the average concentrations and higher concentrations were observed during July-September period than other months of the year (see Table 6.3). Therefore, this time period is called as “critical period”. In the following sections of the thesis water quality modeling for nitrate nitrogen parameter was performed for various basin growth scenarios taking into account of **critical conditions** of 1999-2000 period as a basis.

Table 6.3 Median concentrations of water quality parameters observed at monitoring stations in critical period

Monitoring Station	BOD ₅	NO ₃ -N	Total phosphorus	DO
5	3.00	5.60	0.06	6.9
7	5.00	7.95	0.11	7.0
8	1.50	3.96	0.04	6.8
Class II	8	10	0.16	6

6.3 Objective and Scope of the TMDL Analysis for the Mersinlikahve Creek

The objective of the TMDL analysis for the Mersinlikahve Creek watershed is to establish the linkage between pollution sources and ambient water quality, determine total maximum daily load, generate basin growth scenarios and allocate pollutant loads. Under various scenarios water quality target will be met at all parts of the creek.

Basic steps of the analysis comprise:

- establishment of water quality model for Mersinlikahve Creek using U.S. EPA's Qual2K as a framework
- calibration Qual2K model to the average conditions of water quality and stream flow during the 1999-2000 period
- estimation of baseline nitrate loadings under the critical average conditions during the 1999-2000 period
- determination of total maximum daily load
- estimated load growths to the 1999-2000 baseline period under critical conditions. Allocation of nitrate loadings under the various TMDL scenarios.

6.4 Nutrient Sources in the Projected Area

Several nitrogen sources were identified throughout the data assessment and modeling efforts in the region. Sources can be divided into two categories as point sources and non-point sources.

6.4.1 Point Sources Assessment

Point source discharges include municipal and industrial discharges that are subject to the Turkish Water Pollution Control Regulation permits.

6.4.1.1 Domestic Discharges

There are 6 settlements in the basin and about 4600 people live in the catchment area as of 2000 (TIS, 2002). Population of the settlements subjected to analysis is presented in Table 6.4 and their location is seen in Figure 6.2.

Table 6.4 Population of the settlements located in the projected area (TIS, 2002)

Settlement	Population
Kiriklar	1041
Dogancilar	277
Belenbasi	722
Karaagac	941
Demircikoy	725
Yeni mahalle	865

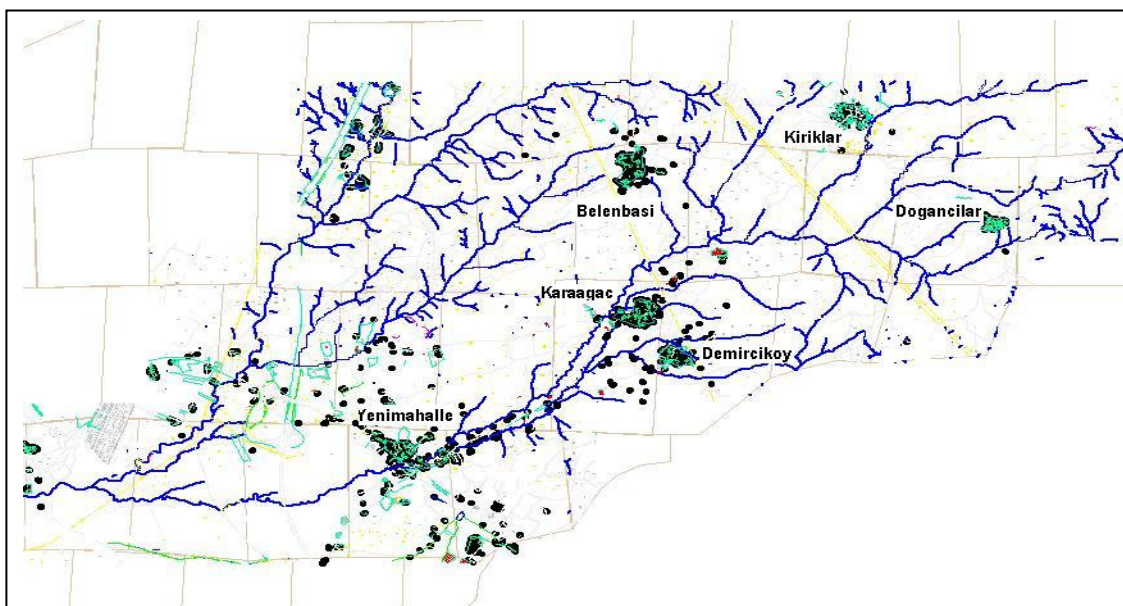


Figure 6.2 Location of the settlements in Mersinlikahve Creek Watershed

Kiriklar and Karaagac have completed sewage systems but collected wastewaters are discharged to the surface water without treatment. In this study, nutrient contributions to the stream from both domestic discharges were determined using typical values presented in Table 6.5.

On the other hand, infrastructure systems of all other settlements are either in the planning/project, or in construction phase. Collected wastewaters from septic tanks disposed by sewage tracks in charged of local authorities. Therefore, domestic wastewaters from un-sewered settlements were not considered as point pollutant sources in the scope of the thesis.

Table 6.5 Typical composition of untreated domestic wastewater (After Tchobanoglous & Burton, 1991)

Contaminants	Unit	Concentration
Total solids (TS)	mg/l	720
Suspended solids (SS)	mg/l	220
Settleable solids	mg/l	10
BOD ₅	mg/l	220
Total organic carbon (TOC)	mg/l	160
Chemical oxygen demand	mg/l	500
Nitrogen (total as N)	mg/l	40
Organic	mg/l	15
Free ammonia	mg/l	25
Nitrites	mg/l	0
Nitrates	mg/l	0
Phosphorus (total as P)	mg/l	8
Organic	mg/l	3
Inorganic	mg/l	5
Alkalinity (as CaCO ₃)	mg/l	100

6.4.1.2 Industrial discharges

There are more than twenty small and medium size enterprises (SMEs) active in the basin and only few of them have their own WWTPs. According to the records of authorities, no liquid waste is discharged from their activities. Similar to the domestic discharges produced industrial wastes are collected and disposed by sewage trucks. Therefore, their pollutant contribution to the creek was neglected in the thesis.

6.4.2 Non-point Source Assessment

Non-point sources of nutrients in the study area are originated from agricultural, residential, and atmospheric sources etc. Agricultural sources for nitrogen include animal waste, runoff from concentrated animal operations, and nitrogen based fertilizers.

Residential sources include water drainage from septic tanks and also urban areas. Atmospheric sources of nitrogen include both dry and wet deposition. In addition, there are natural sources of nitrogen compounds present in the environment that are the result of decomposing wildlife waste and decaying organic matter (Devlin et al., 2000).

6.4.2.1 Nutrient contribution from residential areas (Septic tanks + urban land uses)

Onsite septic tank treatment systems are source of nitrate-nitrogen to the groundwater and eventually surface water streams. No specific information regarding septic tank locations, septic tank densities, or effluent concentrations within the Mersinlikahve Creek watershed is available. However, almost the entire study area is un-sewered. According to the records of the responsible authority, wastewaters of septic tanks are collected and disposed by sewage trucks. Therefore, in this study pollutant contribution from septic tanks were neglected and drainage from urban land uses were considered as significant source. Loads were estimated based on the export rates that are presented in Table 6.6. and size of the urban lands.

Table 6.6 Nitrogen loadings of various land uses (after USEPA, 1999)

Land Use	Total nitrogen (kg/ha.yr)
Roadway	1.3
Commercial	1.6
Single family, low density	3.3
Single family, high density	4.0
Multifamily residential	4.7
Forest	1.1
Grass	1.2
Pasture	1.2

Urban land use areas and population densities are given in Table 6.7.

Table 6.7 Urban land uses in the Mersinlikahve Creek Watershed

Settlement	Urban land use (ha)	Population density (person/ha)
Kiriklar	15	70
Dogancilar	8	35
Belenbasi	15	48
Karaagac	16	59
Demircikoy	10	73
Yeni Mahalle	38	23

6.4.2.2 Agricultural Discharges

Land uses within the projected area are dominated by forests and agricultural uses. Table 6.8 presents the land use patterns.

Table 6.8 Agricultural land-uses in the projected area (ha) (DEU, 2000)

Settlement	Agricultural land		Orchard	Horticulture	Grain+tobacco+cotton	Forest	Pasture	Disused agricultural land
	irrigated	Non-irrigated						
Doancilar	120	200	256	-	50	1700	-	14
Belenbasi	4.2	163.2	200	10.1	155	1305	-	20
Karaagac	173.4	215	235.2	47.8	408.1	682	-	115.2
Kiriklar	-	195.3	272.6	34.4	93	13	-	57.6
Demircikoy	250	188.9	111.9	5	307	800	80	15
Yeni Mahalle	50	100	14	38.2	91.5	150	40	6.3

Potential land use nutrient export rates given in Table 6.9 were used to estimate the nutrient contributions from agricultural activities.

Table 6.9 Nitrogen export rates of agricultural land uses (after Feehan & Plunkett, 2003; after USEPA, 1999)

Agricultural land use	Total nitrogen (kg/ha.yr)
Crop	2.68
Vegetable	3.24
Orchard	1.80

6.5 Water Quality Modeling

QUAL2K was selected as the tool to develop the Mersinlikahve Creek water quality model and conduct the TMDL analysis. It is based on the assessment of water quality of critical environmental conditions that covers summer period (July – September).

Water quality data obtained from three river monitoring stations during the 1999-2000 period and also discharge data was used to calibrate the model. The model was downloaded from the US EPA website and operated in the Microsoft. Excel program as designed by the program authors. Data inputs in the Mersinlikahve Creek QUAL2K are discussed in the next sections of this chapter.

6.5.1 Input Data for Water Quality Modeling with QUAL2K

6.5.1.1 Stream Characteristics

The Mersinlikahve Creek QUAL2K model uses the Manning formula to describe stream hydraulic characteristics and assumes that stream has a rectangular channel cross-section. Estimates were made of the width, depth of flow and also slope of the channel in the river based on the document “*Izmir-Menderes Tahtali Dam Flood Studies*” prepared by State Hydraulics Works- DSI, (1992).

Stream channel geometry (reach lengths, width, depth and slope) of the creek and its tributaries are given in Table 6.10 and location of each reach is depicted in Figure 6.3.

Table 6.10 Stream channel geometry (DSI, 1992)

# of creek	Lenght (m)	Width (m)	Depth (m)	Slope
1	8600	3	2.0	0.01
2	1600	3.5	1	0.006
3	16500	2	2.5	0.01
3A	4600	4.5	1	0.01
4	16000	1.6	2.5	0.011

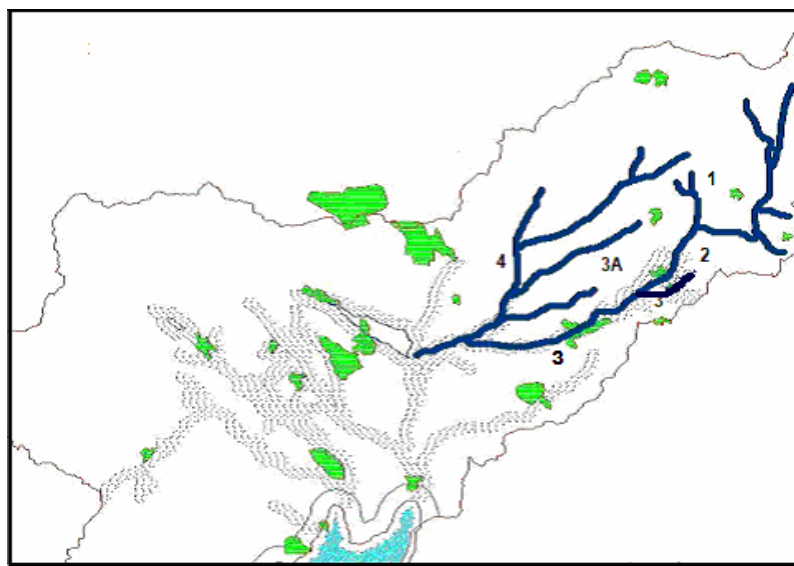


Figure 6.3 Location of reaches in the study area

6.5.1.2 Meteorological Data

Meteorological data obtained from the meteorology station located in the Adnan Menderes Airport were used to model water quality. Data set including the minimum, average, and maximum temperatures and average rainfall etc. is presented in Table 6.11.

Table 6.11 Adnan Menderes Airport station meteorological data 1990-1999 (DEU, 2001)

	January	February	March	April	May	June	July	August	September	October	November	December
Temp. (°C)												
min	4.3	4.5	5.7	8.9	13.3	17.7	20.7	20.9	16.6	13.2	8.8	6.4
average	8.0	8.4	10.1	14.0	18.9	24.3	26.6	26.5	22.2	18.1	12.9	9.7
max	12.3	12.9	15.1	19.1	24.3	29.8	32.5	32.7	28.5	24.1	17.9	13.6
Humidity (%)	72.5	71.5	70.8	71.5	67.5	60.2	59.2	61.6	64.9	70.9	72.4	74.9
Cloud cover	4.2	4.7	4.0	3.9	2.7	1.0	0.5	0.5	1.2	2.9	4.4	5.5
Average wind speed	2.7	3.1	2.9	2.3	2.4	3	3.8	3.6	2.8	2.3	2.5	2.8
Sun intensity (Cal/m ²)	166.2	227.0	335.0	422.8	505.0	566.0	558.2	501.4	417.8	277.1	178.5	135.1
Average rainfall (mm)	77.8	81.3	85.9	56	40.7	1.4	-	1.7	20.4	33.2	106.9	163.2

6.5.1.3 Stream Flow

There are no active gauging stations in the region. A gauge station which was in operation from 1968 through 1988 was situated at south of the Tahtali watershed. However although no gauge was in place on Mersinlikahve Creek during the water quality monitoring period (1999-2000), discharge data for that period of time must be estimated.

The unique gauge data from the station mentioned above was considered reasonable for estimating flow for Mersinlikahve Creek since it has similar geology, topography, land use. The drainage area to this station was 512 km² and the minimum and average discharges for the critical period of 1968-1988 are given in Table 6.12.

Change of discharges over time is seen in Figure 6.4. Each monthly discharge value is represented by a case number in this graph. Case numbers assigned to months are also seen in Table 6.12.

Table 6.12 Average and minimum discharges of Tahtali Creek (DSI from 1968 through 1989)

Water Year	Month	$Q_{\min}$ (m ³ /s)	Q_{average} (m ³ /s)	Case number
1968	July	0.155	0.251	1
	August	0.065	0.097	2
	September	0.036	0.042	3
1970	July	0.140	0.211	4
	August	0.100	0.123	5
	September	0.083	0.100	6
1971	July	0.200	0.258	7
	August	0.145	0.169	8
	September	0.145	0.151	9
1972	July	0.115	0.167	10
	August	0.100	0.126	11
	September	0.115	0.121	12
1974	July	0.050	0.136	13
	August	0.080	0.097	14
	September	0.060	0.086	15
1975	July	0.165	0.335	16
	August	0.100	0.141	17
	September	0.080	0.101	18
1976	July	0.100	0.131	19
	August	0.100	0.112	20
1986	July	0.180	0.287	21
	August	0.050	0.106	22
	September	0.050	0.050	23
1987	July	0.200	0.320	24
	August	0.080	0.138	25
	September	0.050	0.066	26
1988	July	0.155	0.251	27
	August	0.065	0.097	28
	September	0.036	0.042	29
1989	July	0	0.016	30
Median		0.100	0.125	

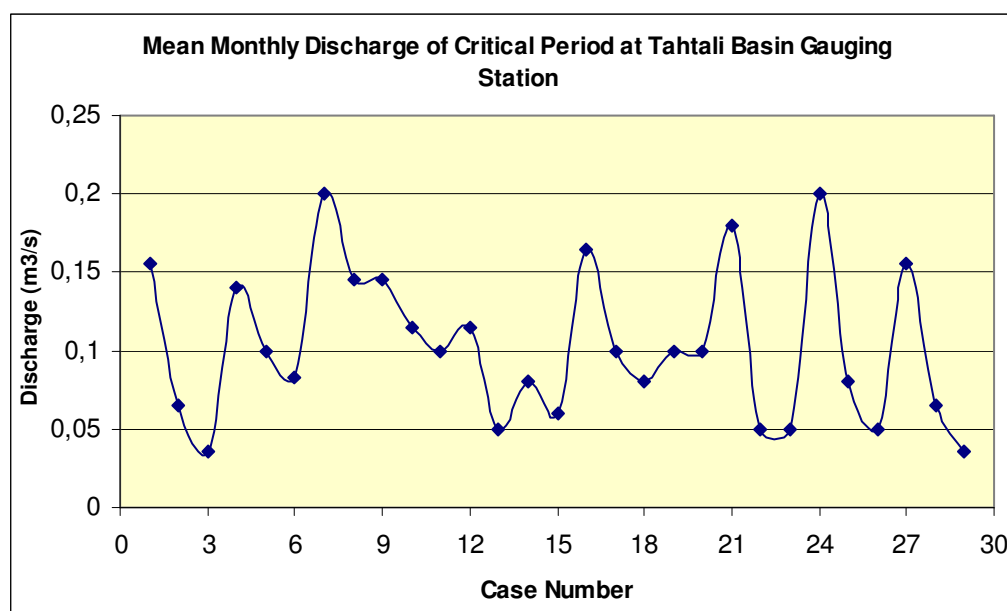


Figure 6.4 Mean monthly discharges of critical at Tahtali Basin gauging station

The discharges of the creeks in the study area were estimated based on their drainage areas and median value ($0.125 \text{ m}^3/\text{s}$) of monthly average discharges observed at unique gauging station in critical months along around 10 years (see Table 6.13).

Table 6.13 Drainage areas and discharges of Mersinlikahve Creek and its tributaries

# of creek	Drainage area (km^2)	Discharge (l/s)
1	19	4.639
2	0.75	0.183
3	52.1	12.720
3A	3.73	0.911
4	74.75	18.250

6.5.1.4 Model Segmentation

The Mersinlikahve Creek Qual2K Model consisted of model reaches starting from its headwater to the confluence with the Tahtali Creek. The model covered approximately 16.5 km of stream length. Figure 6.5 displays the reaches on the watershed map. Due to the structure of Qual2K the stream was further divided into a number of computational elements. A length of 2.0 km was assigned to all computational elements within the

Mersinlikahve Creek Qual2K Model. Schematic representation of Mersinlikahve Creek is shown in Figure 6.6. To establish water quality model tributaries of the creek were processed as point discharges to the main stream.

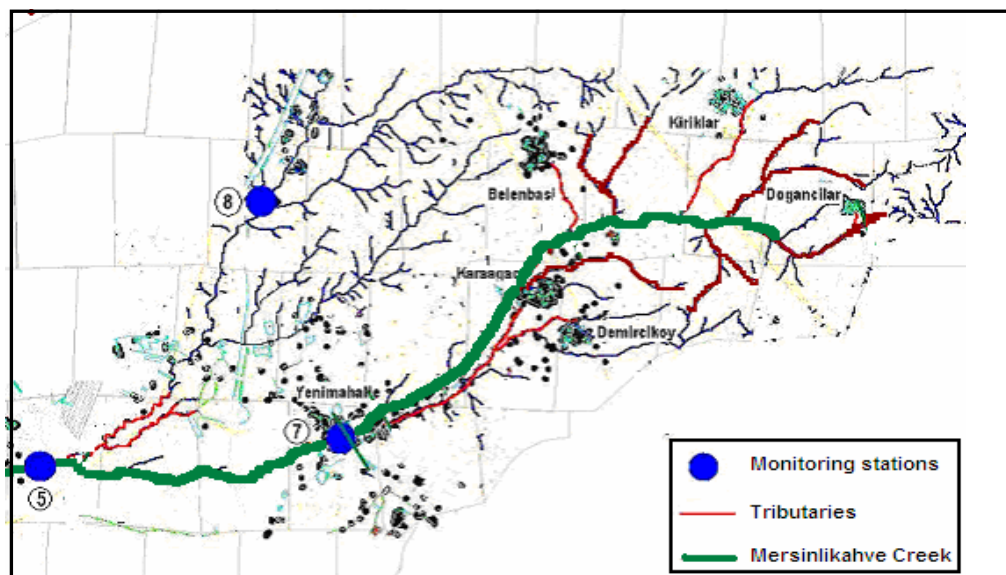


Figure 6.5 Modeled reaches of Mersinlikahve Creek

6.5.1.5 System Parameters

The physical, chemical, and biological processes simulated by QUAL2K are represented by a set of equations that contain many parameters. Some are global constants, some are spatial variables, and some are temperature dependent variables. Detailed descriptions of these parameters and associated processes are available in the QUAL2K user's manual (State of Delaware, 2005; Chapra & Pelletier, 2003). Climatic rate input parameters of Tahtali Basin are presented in Table 6.14.

Table 6.14 Mersinlikahve Creek QUAL2K model climatic rate input parameters

Parameter	Value	Unit
Air temperature	22.2	Degrees C
Dew point temperature	19	Degrees C
Wind speed	3.4	m/s
Cloud cover	50	%
Shade	15-75	%

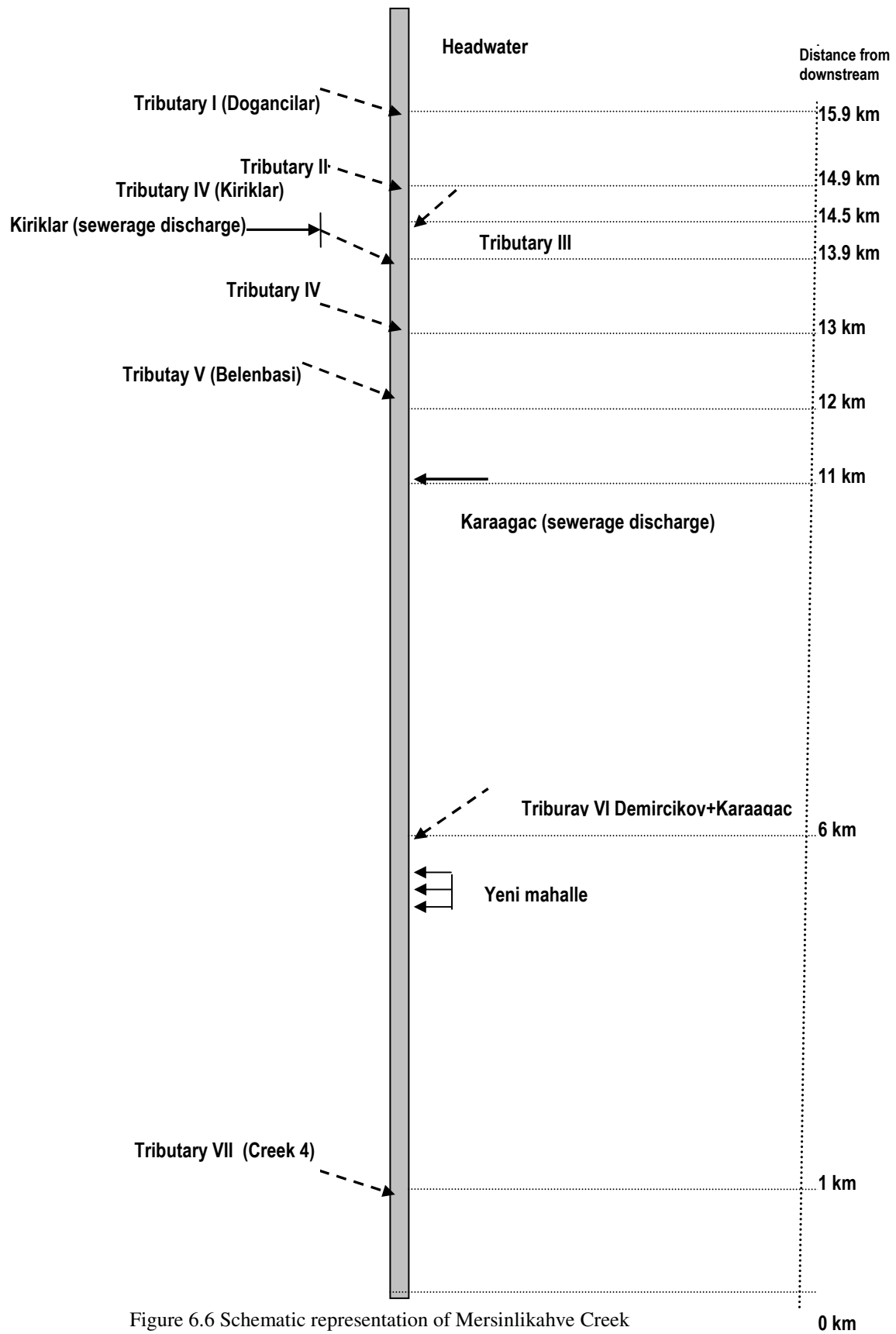


Figure 6.6 Schematic representation of Mersinlikahve Creek

6.5.1.6 Boundary Condition

Qual2K uses different data groups to define model boundary conditions. It requires the headwater data group to define the most upstream boundary conditions of a model domain. Downstream boundary condition can be defined by the user, or computed internally (State of Delaware, 2006).

The headwater conditions of the Mersinlikahve Creek Qual2K Model were defined by monitoring data collected at Station 8. To calibrate the model for critical conditions, median concentrations of the summer months (July – September) were used with the average flow presented in Table 6.15.

Table 6.15 Some parameters under annual average critical condition

Parameter	Value	Unit
Temperature	21	Degrees C
Conductivity	470	μmhos
Dissolved Oxygen	9.00	mgO ₂ /l
NH ₄ -Nitrogen	0.0	ugN/l
NO ₃ -Nitrogen	3000	ugN/l

6.5.1.7 Point Discharges

Two point sources in the study are domestic discharges from Kiriklar and Karaagac. Point source load contributions were estimated based on literature values (see Table 6.16). Water discharges was accepted as 100 l/ca.d for the calculations.

Table 6.16 Nitrogen contributions from domestic discharges

Settlement	Discharge (m ³ /d)	Organic nitrogen (kg/d)	Free ammonia (kg/d)
Kiriklar	104.1	1.6	2.6
Karaagac	94.1	1.4	2.4

Kiriklar sewerage is discharged to Tributary IV and Karaagac sewerage to the main stream.

6.5.1.8 Non-point Discharges

In this section, nutrient loadings originating from diffuse sources were evaluated for each settlement. The sources include,

- agricultural lands
- various land uses including, residential areas, forests, pasture, grass.

Contribution from wet deposition, grazing etc. was not considered individually. Instead, 5 percent of the total nitrogen contributions were allocated for these sources in the modeling study.

The following section summarizes load contributions from pollutant sources.

Nitrogen Contributions from Agricultural Lands

Nutrient export rates and size of agricultural lands were used to estimate nitrogen load contribution in the study area (see Table 6.17).

Table 6.17 Daily estimated total nitrogen loads from agricultural lands (kg/day)

Settlement	Agricultural land use daily total nitrogen contributions (kg/day)				Total
	Irrigated	Orchard	Horticulture	Grain+tobacco +cotton	
Dogancilar	1.07	1.26	0.00	0.37	2.69
Belenbasi	0.04	0.99	0.09	1.14	2.25
Karaagac	1.54	1.16	0.42	3.00	6.12
Kiriklar	0.00	1.34	0.31	0.68	2.33
Demircikoy	2.22	0.55	0.04	2.25	5.07
Yeni mahalle	0.44	0.07	0.34	0.67	1.52

Nitrogen Contributions from Various Land Uses

For each settlement total nutrient loads originating from various land use including forests, pasture, grass, residential areas were calculated by summing the individual loads as described in section 6.4.2 and are presented in Table 6.18.

Table 6.18 Daily nitrogen contributions from various land uses in projected area (kg/day)

Settlement	Nitrogen contribution (kg/day)				Total
	Forest	Pasture	Grass	Residential area	
Dogancilar	5.12		0.05	0.19	5.36
Belenbasi	3.93		0.07	0.10	4.10
Karaagac	2.06		0.38	0.19	2.63
Kiriklar	0.04		0.19	0.21	0.43
Demircikoy	2.41	0.26	0.05	0.13	2.85
Yeni mahalle	0.45	0.13	0.02	0.49	1.09

6.5.2 Model Calibrations

The Mersinlikahve Creek Qual2K Model was calibrated based on median water quality conditions observed during 1999-2000 using 1968-1989 median flows.

Analysis of flow data for the Tahtali Basin Gaging Station showed that median flows occurred most often in the month of March. QUAL2K requires a date be set in the model, so, March 15, 2000 was chosen as a representative date to be the date of interest in the medians model. Inputs for the headwaters and tributaries were based on available data. Reach specific decay rates and constants were set at levels consistent with other models, literature values and best professional judgment. The total nitrogen loads, which were summarised in Section 6.5.1, translated into contributions to the stream.

Figure 6.7 displays the model calibration results for nitrate nitrogen under average conditions of 1999-2000. The simulated mean concentrations are presented as a solid line. Stream water quality for nitrate nitrogen at all modeled reaches was below the value of 5 mg/l, which is the limit for the Class I water set by Turkish Water Pollution Control Regulation.

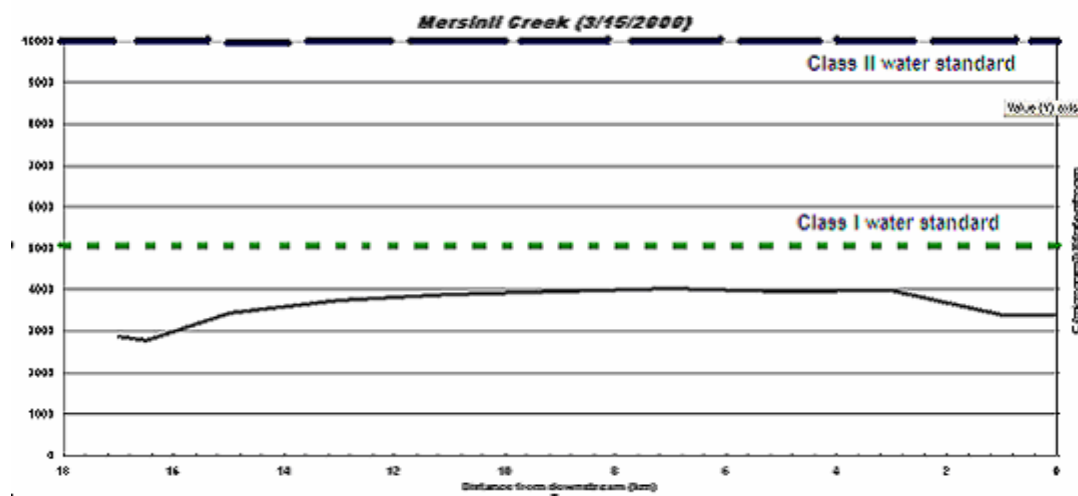


Figure 6.7 Calibrated model nitrate-nitrogen levels for the Mersinlikahve Creek

Critical Condition Analysis

Calibrated model rates were used with summer (July- September) median water quality data to simulate water quality conditions of the Mersinlikahve Creek during the critical summer- period. The results of this analysis are presented in Figure 6.8. Nitrate nitrogen concentrations at all modeled segments were below the target value of 10 mg/l nitrate nitrogen.

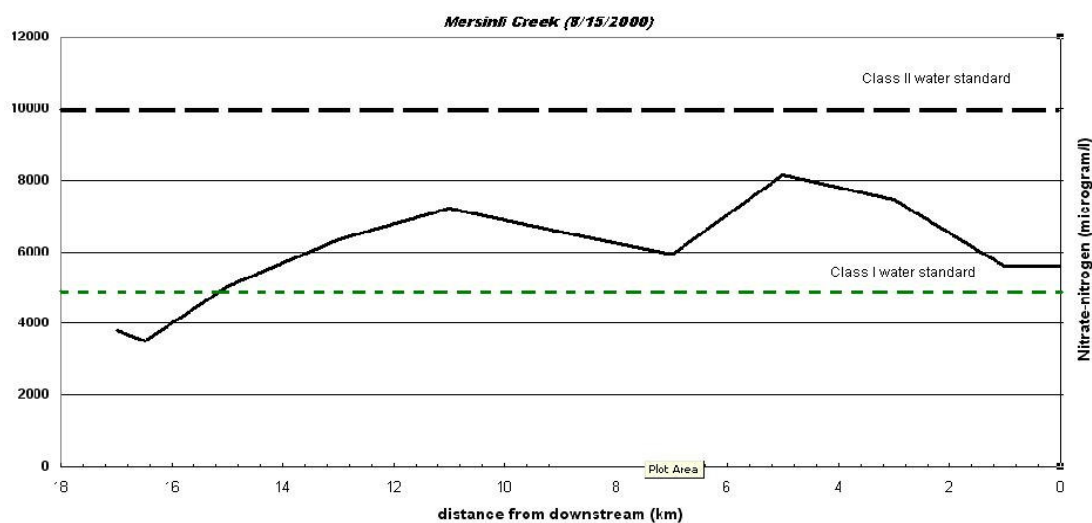


Figure 6.8 Critical condition model nitrate-nitrogen levels for the Mersinlikahve Creek

6.6 Nitrate Contributions to the Stream under Median Conditions

Based on median conditions among non-point sources forest lands contributed around 40% of the total nitrogen reaching Mersinlikahve Creek (see Figure 6.9). As has been discussed in previous chapter nitrogen contribution per unit area is lower for forest than any other uses. The total forest load is only significant due to large area of forest in the watershed. In addition, domestic point discharges allocated only 18% of the total nitrogen loads contributing to the Mersinlikahve Creek and its tributaries (see Figure 6.10).

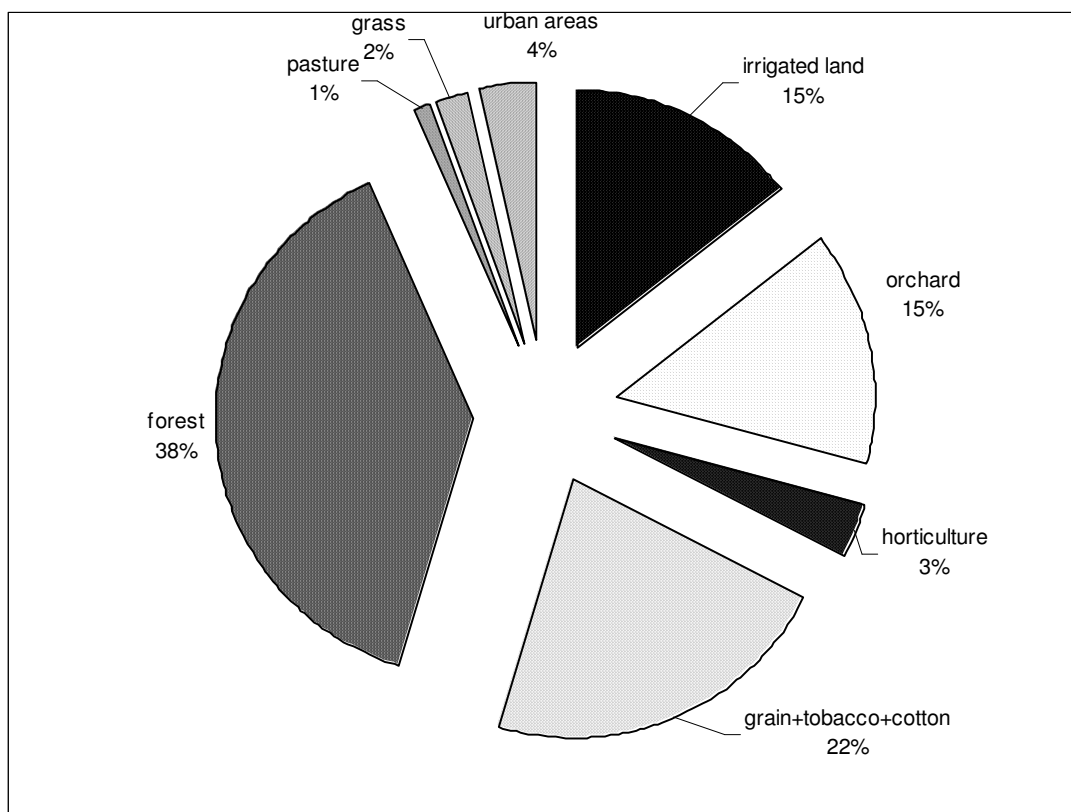


Figure 6.9 Distribution of non-point sources nitrogen load contributions

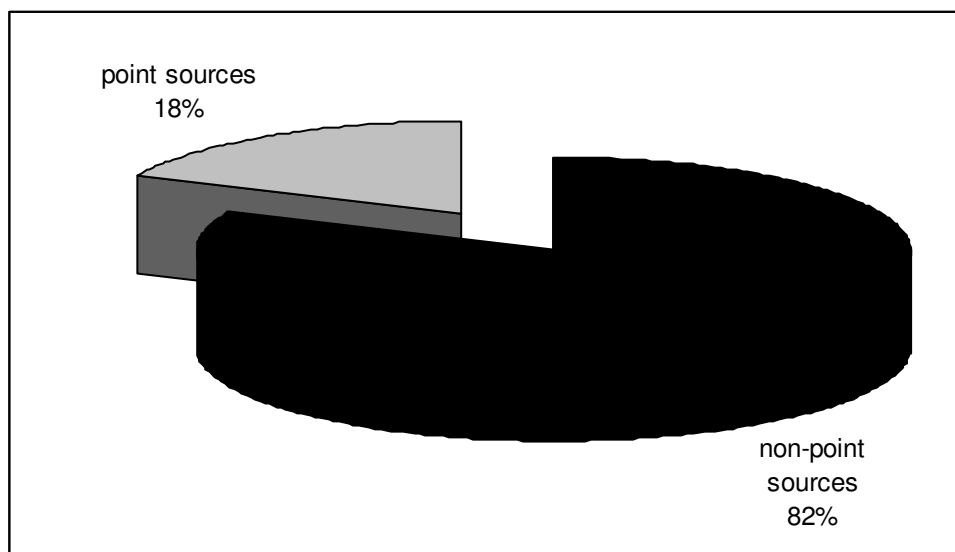


Figure 6.10 Distribution of point and non-point sources nitrogen load contributions

6.7 Nitrate Contributions to the Stream under Critical Conditions

The total nitrogen reported in Table 6.17 and 6.18 were distributed unequally over the year. In this study considering seasonal variations only nitrogen loads originating from irrigated agricultural lands were taken into account to model water quality under critical conditions. Distribution of nitrogen contributions from diffuse sources in this period is depicted in Figure 6.11.

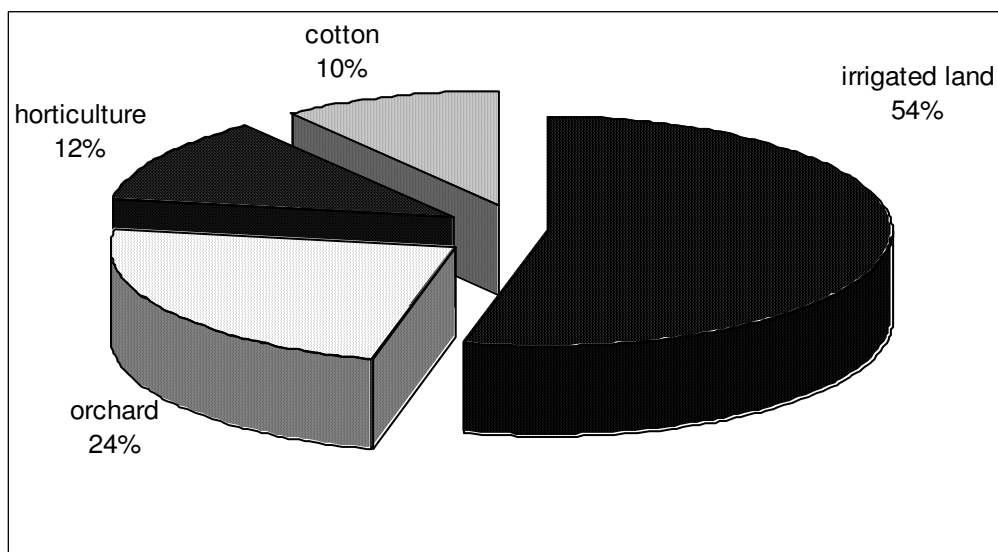


Figure 6.11 Distribution of non-point sources nitrogen load contributions under critical conditions

Distribution of non-point source nitrogen load contribution for each settlement is seen in Figure 6.12.

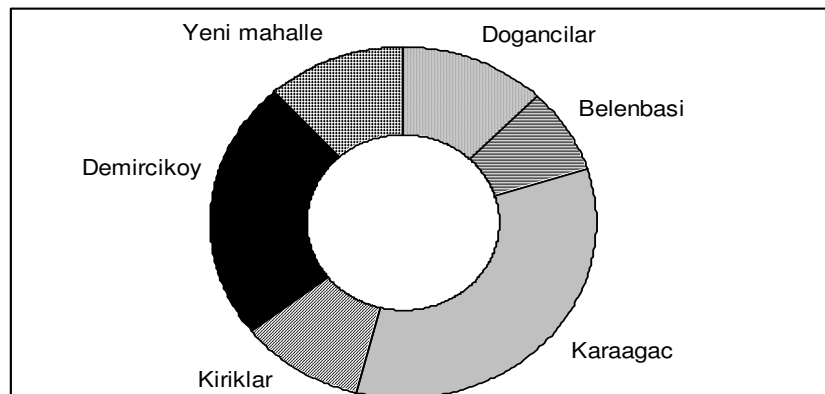


Figure 6.12 Distribution of non-point source nitrogen load contribution for each settlement under critical conditions.

6.8 Total Maximum Daily Load for Mersinlikahve Creek Under Critical Conditions

As is seen in Figure 6.7 there is a gap between the line representing existing water quality concentrations and the target value correspond Class II water quality. This gap allows additional nitrogen loads contributed the waterbody and boundary condition is not to violate the standards for the peak concentrations. In the next chapter, allocation scenarios were proposed but here to give an idea about the dimensions of the additional pollutant loads, existing loads (including non-point discharges and domestic discharges from Karaagac and Kiriklar) were increased by 25%. Response of ambient water quality is depicted in Figure 6.13. Daily nitrogen loads contributed to the stream from point and non-point sources in summer period is presented in Table 6.19.

Table 6.19 Daily nitrogen loads contributed to the stream from point and non-point sources in summer period

Settlement	Nitrogen load kg/day	25% additional load
Dogancilar	1.19	0.30
Belenbasi	0.78	0.20
Karaagac	7.12	1.78
Kiriklar	5.26	1.32
Demircikoy	2.33	0.58
Yeni mahalle	1,16	0.29

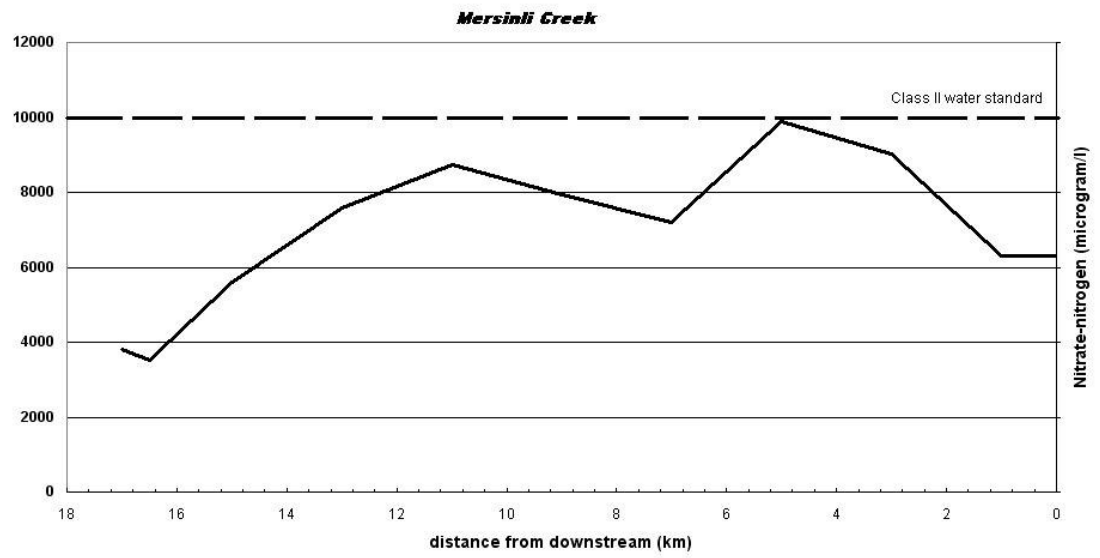


Figure 6.13 Nitrate-nitrogen levels for the Mersinlikahve Creek in the case of 25% increase in existing pollutant loads

CHAPTER SEVEN

CASE STUDY: TMDL BASED DECISION PROCESS FOR THE MERSINLIKAHVE SUBWATERSHED PART B: LOAD ALLOCATION SCENARIOS

7.1 Introduction

In this section, loading scenarios were developed by controlling point discharges and/or shifting land uses. Nitrate TMDL allocation scenarios were designed to reliably meet the Class II water standards-10 mg/l NO₃-N with no violations. An explicit 5 percent margin of safety was incorporated into the TMDL. Therefore, the modeled concentrations were targeted for a maximum amount of **9.5 mg/l** within all the sections.

In Chapter 6 it was mentioned that infrastructure system of the settlements consisting sewerage and treatment plant are either in project and/or construction phase. After completion of all the projects, point discharges would be transferred out of the catchment area in near future. Therefore, point discharges were not taken into consideration in the developed load scenarios in this study.

Following sections presents a variety of load growths to the 1999-2000 baseline period under critical conditions. Under the TMDL scenarios nitrate loadings were also calculated for each land use.

7.2 Scenario Development

Allocation scenarios were evaluated using the QUAL2K model and existing loads to the non-point sources in the Mersinlikahve Watershed were increased until the water quality goal of 9.5 mg/l nitrate-nitrogen was met along the creek.

The allocation scenarios described below were taken into account seasonal variation of nitrogen contributions.

7.2.1 Scenario A

Under this scenario, possible impacts of complete removal of the point discharges on water quality were determined. No other load reductions were presumed. In other words 100% of the nitrogen load was assumed being allocated for diffuse pollution sources. Nitrate-nitrogen levels for the Mersinlikahve Creek under scenario A is seen in Figure 7.1.

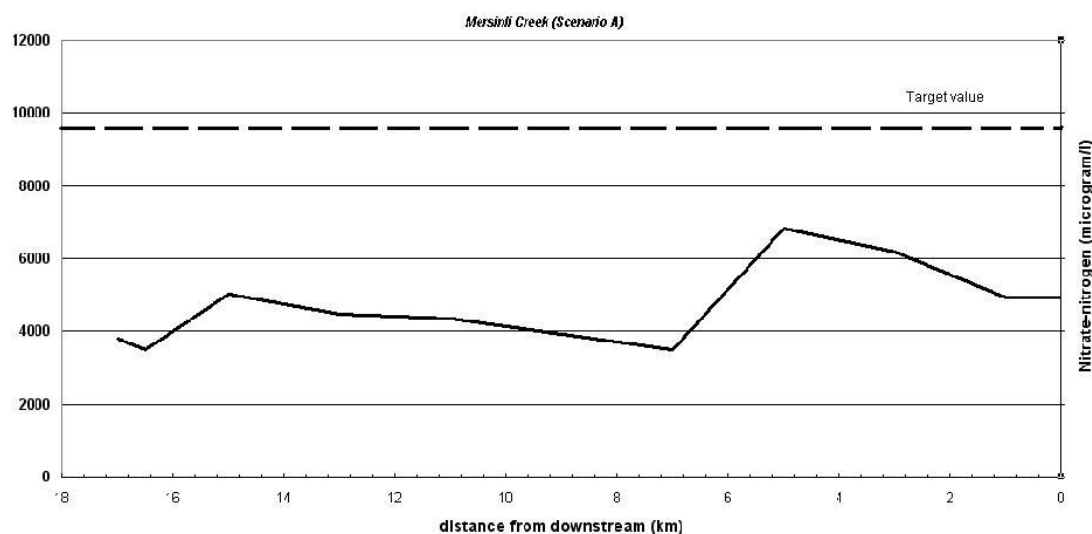


Figure 7.1 Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario A

Table 7.1 presents daily total nitrogen load contribution for each land use in the study area for Scenario A. Load distribution is also seen in Figure 7.2.

Table 7.1 Daily total nitrogen load contribution under Scenario A

Land use	Nitrogen load (kg/day)
Irrigated land	5.30
Orchard	2.34
Horticultural land	1.20
Cotton field	1.00
Total load	9.84

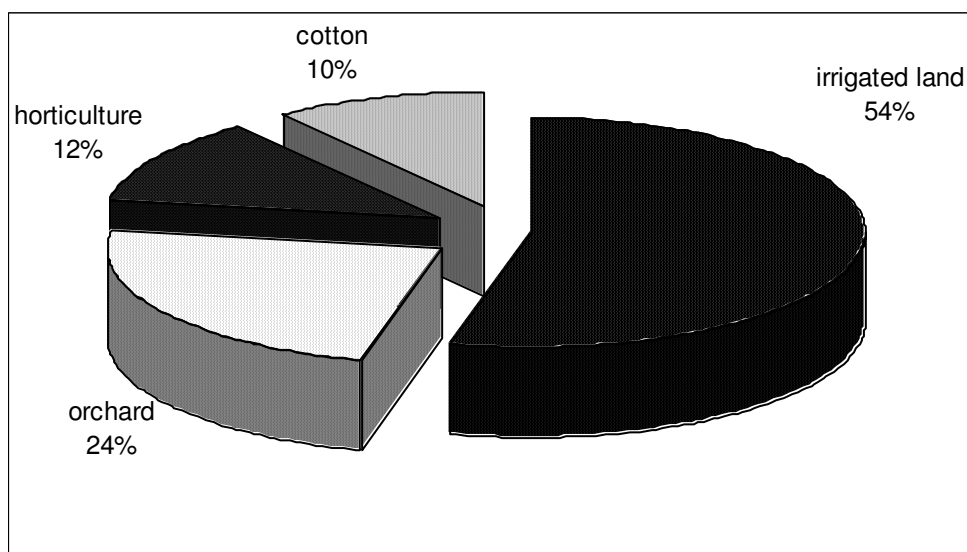


Figure 7.2 Nitrogen load distribution under Scenario A

7.2.2 Scenario B

As has been mentioned at Chapter 6 each settlement has disused agricultural land which could be served to various type of crop production. Size of the land for each settlement is presented in Table 7.2. Scenario B postulated that disused fields would be allocated for cotton production.

Table 7.2 Disused agricultural fields in the study area

Settlement	Disused agricultural land (ha)
Doancilar	14
Belenbasi	20
Karaagac	115.2
Kiriklar	57.6
Demircikoy	15
Yeni Mahalle	6.3

The estimated nitrate-nitrogen concentrations in the modeled segments of the stream for scenario B is seen in Figure 7.3 and daily load contributions for each type of land use is presented in Table 7.3. Distribution of these loads is depicted in Figure 7.4.

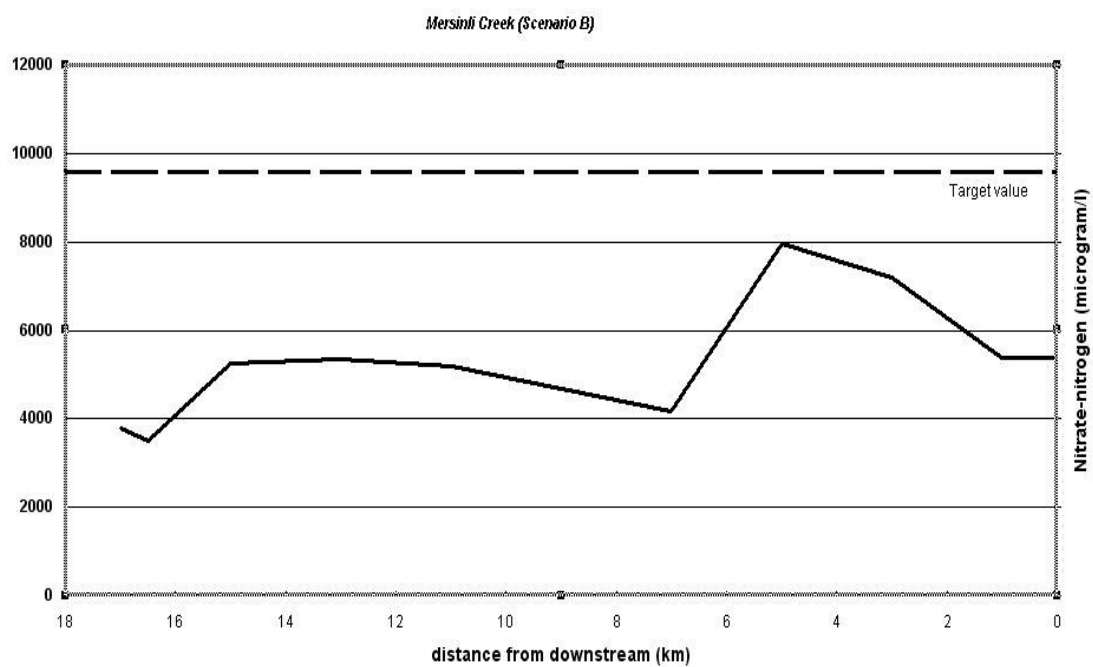


Figure 7.3 Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario B

Table 7.3 Daily total nitrogen load contribution under Scenario B

Land use	Nitrogen load (kg)
Irrigated land	5.30
Orchard	2.34
Horticulture	1.20
Cotton field	2.68
Total load	11.52

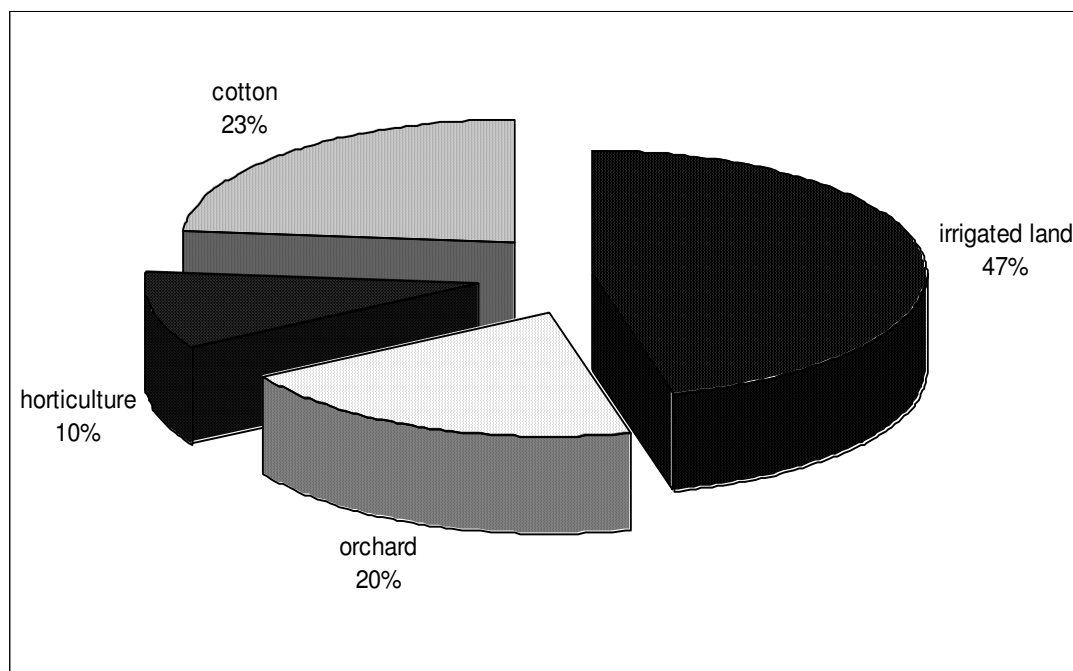


Figure 7.4 Nitrogen load distribution under Scenario B

7.2.3 Scenario C

This scenario postulated that disused fields would be allocated for horticultural land uses. Daily load contributions under Scenario C is presented in Table 7.4. Figure 7.5 shows distribution of these loads.

Table 7.4 Daily total nitrogen load contribution under Scenario C

Land use	Nitrogen load (kg/day)
Irrigated land	5.30
Orchard	2.34
Horticulture	3.23
Cotton field	1.00
Total load	11.87

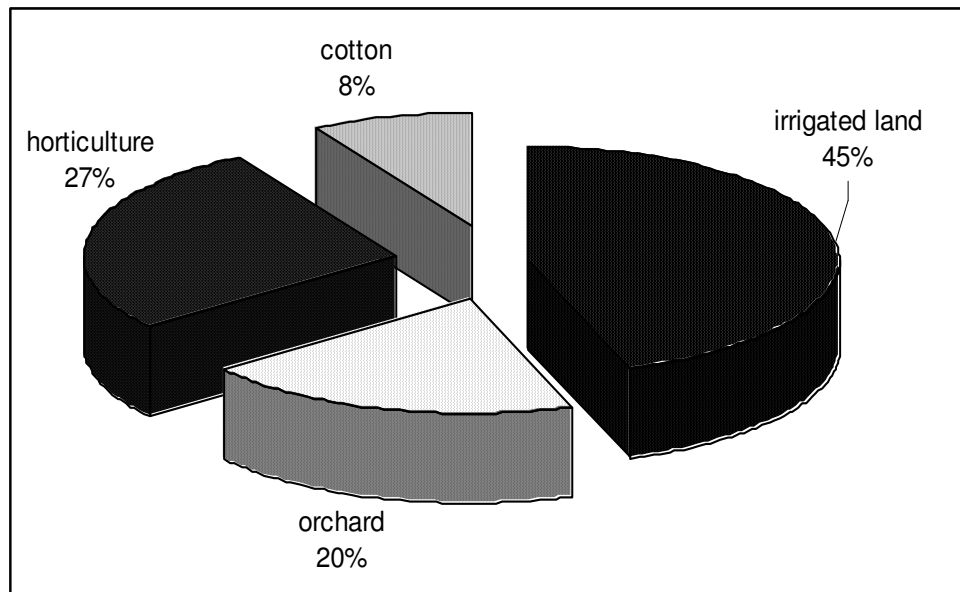


Figure 7.5 Nitrogen load distribution under Scenario C

The estimated nitrate-nitrogen concentrations in the modeled segments of the stream for Scenario C is seen in Figure 7.6.

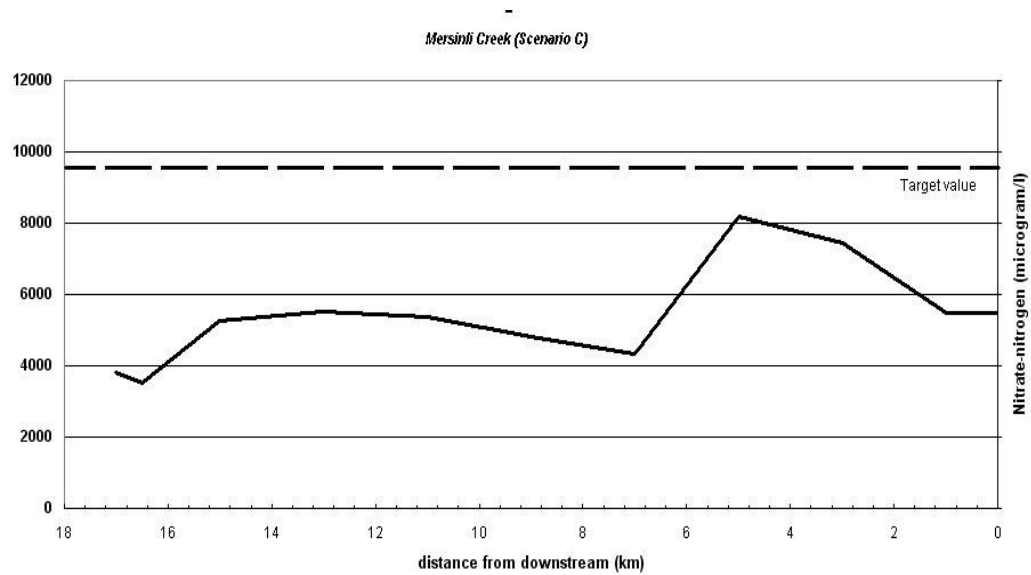


Figure 7.6 Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario C

7.2.4 Scenario D

Scenario D examined effects of shifting cultivation practices on surface water quality. Under this scenario, it was presumed that cotton fields would be shifted to horticultural production areas and disused lands would be cultivated for the same purpose. Nitrogen contribution for each land uses is given in Table 7.5 and Figure 7.7 shows distribution of these loads.

Table 7.5 Daily total nitrogen load contribution under Scenario D

Land use	Nitrogen load (kg/day)
Irrigated land	5.30
Orchard	2.34
Horticulture	4.43
Total load	12.07

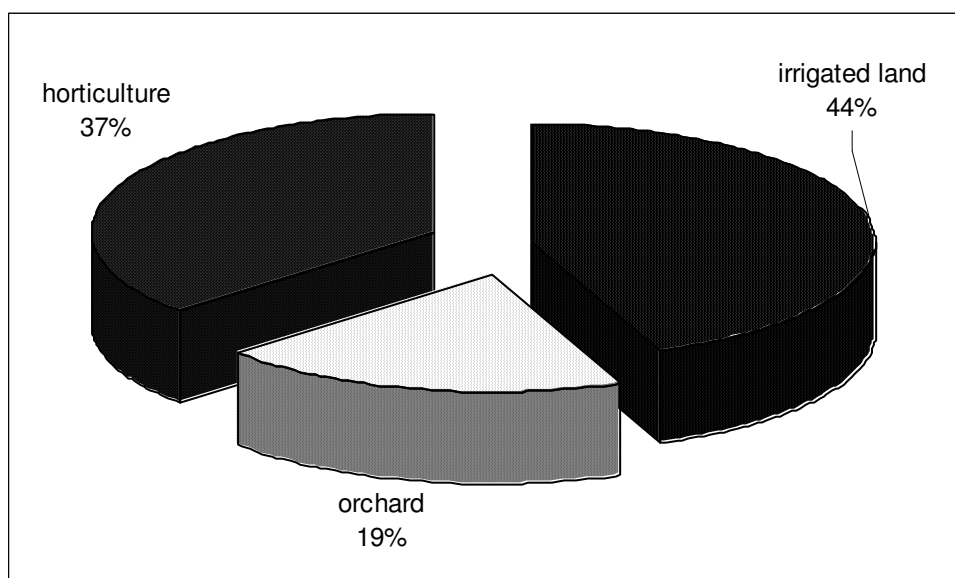


Figure 7.7 Nitrogen load distribution under Scenario D

Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario D is seen in Figure 7.8.

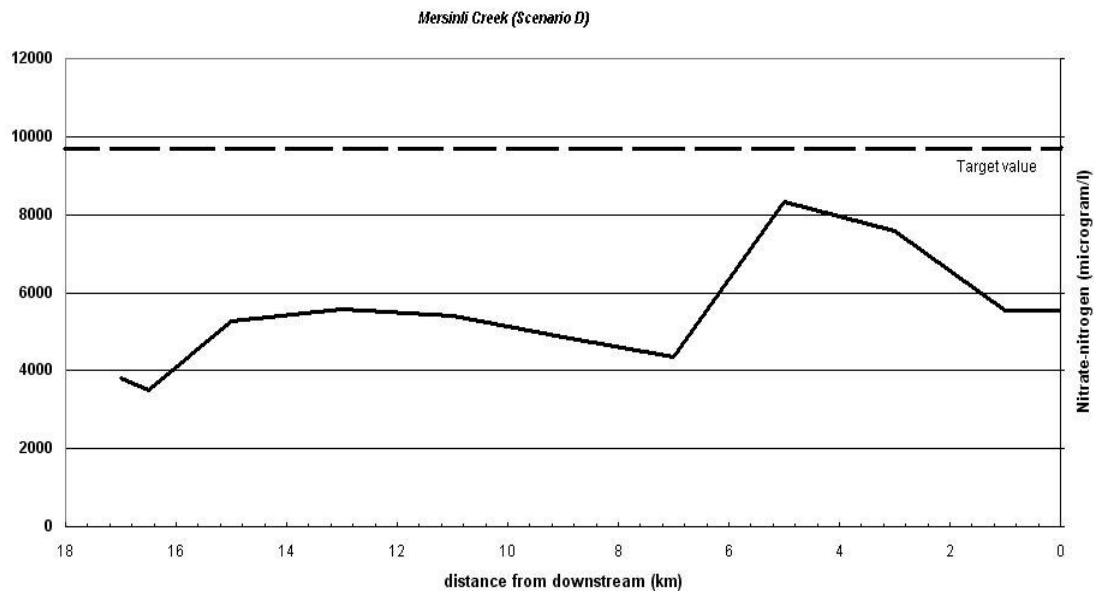


Figure 7.8 Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario D

7.2.5 Scenario E

As is seen in Figure 6.10 more than half of the total nitrogen load is contributed to the Mersinlikahve Creek by two settlements called Karaagac and Demircikoy. Therefore, effect of any prevention measures at these locations should be examined to get decisions by water experts. Scenario E assumed that 50% of the irrigated lands would be allocated for grain cultivation. Annual nitrogen load contribution allocated for each land use is given in Table 7.6 and percentages are given in Figure 7.9.

Table 7.6 Daily nitrogen load contribution under Scenario E

Land use	Nitrogen load (kg/day)
Irrigated land	3.43
Orchard	2.34
Horticulture	1.20
Cotton field	1.00
Total load	7.97

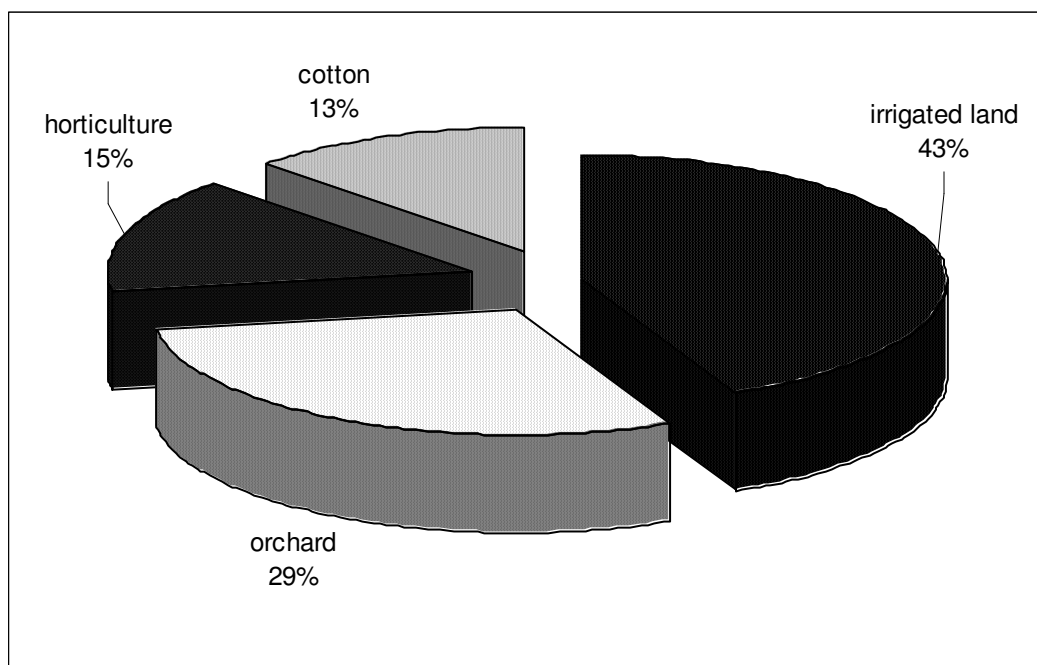


Figure 7.9 Nitrogen load distribution under Scenario E

Distribution of nitrogen load contribution for each settlement and their effect on water quality is depicted in Figure 7.10 and 7.11.

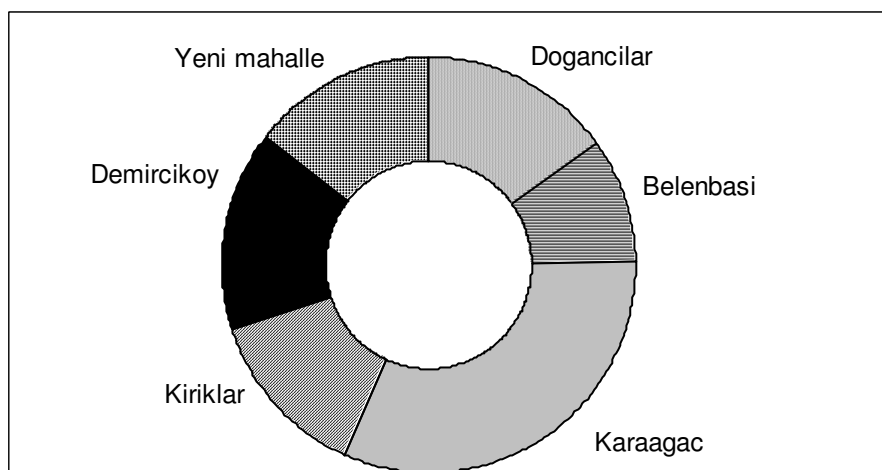


Figure 7.10 Distribution of nitrogen load contribution for each settlement under Scenario E

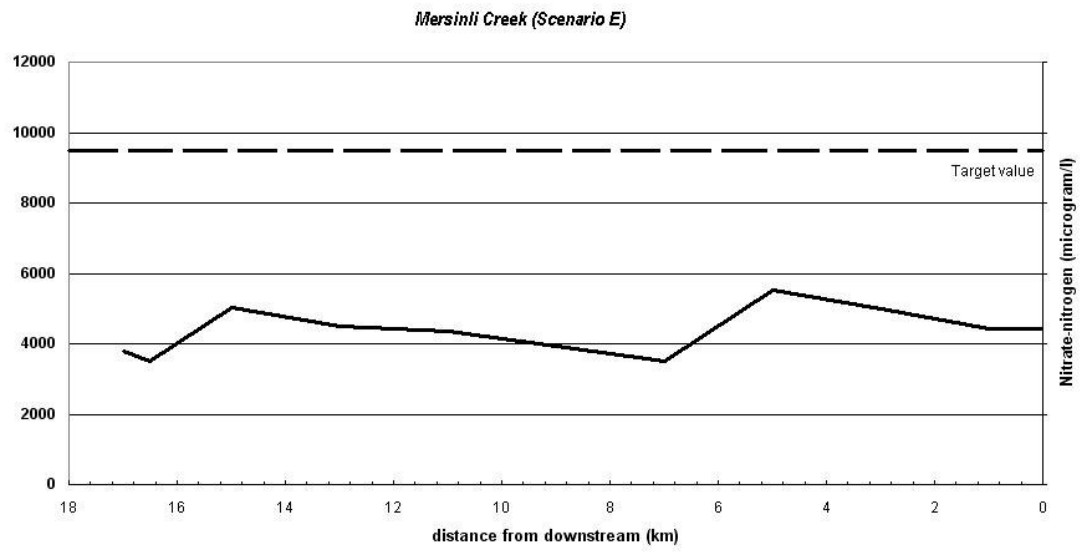


Figure 7.11 Nitrate-nitrogen levels for the Mersinlikahve Creek under Scenario E

CHAPTER EIGHT

SUMMARY AND DISCUSSION

This thesis focused on the development and application of “TMDL based sustainable basin growth and management strategy” to give better insight for the management of surface waters designated for various purposes.

The ultimate goal of the thesis was to validate this approach through a systematic application study in a field case in Turkey, known as Tahtali Basin that is the main drinking water source for the city of Izmir with 3 million inhabitants.

Tahtalı Dam constructed on Tahtali Creek was designated for the public drinking water use. Thus, beneficial use for the basin was potable water supply. National (“*the classification of inland waters according to quality*” -Turkish Water Pollution Control Regulation) and supra-national (“*the quality required of surface water intended for the abstraction of drinking water in the Member States*” -European Council Directive) standards were selected as a reference in this study.

Interrogation of water quality of the reservoir and creeks was performed separately. Firstly, water quality data of unique observation site in the Tahtali reservoir was assessed using Universal Water Quality Index-UWQI method. The index value was calculated as 99.5 (from section 5.4.1, Table 5.5), which belonged to “excellent water” class. On the other hand, sub-index was the lowest for the parameter total coliform. Low sub-index values for this parameter could be explained as the consequences of uncontrolled discharges caused by rapid urbanization. Population growth since 1990’s has created an additional stress on the environmental conditions in the region. The next step was to find an answer to the question being asked was “if a significant increase or decrease trend in water quality determinants of UWQI has occurred for the Tahtali reservoir between 1999-2004. Trend analysis including two tests namely Mann-Kendall test and Sen’s slope estimator was performed. Results of the Mann Kendall trend test indicated that there was significant trend for the parameters fluoride, DO, BOD₅ and

total phosphorus (see Table 5.7). Sen's slope test showed that BOD₅ and total phosphorus parameter concentrations increased over time (see Table 5.8). But this increase was not a threat for the water quality presently. Both parameters belonged to excellent water class with having sub-index value-100 (see Table 5.5).

Application of UWQI method and environmetric techniques to Tahtali Basin surface water quality data obtained from seven river monitoring stations was the second part of the water quality interrogation component. Results of index calculation revealed that overall index values were mainly above 95 and water quality belonged to 'excellent water' class at each observation site. However, sub-index values for nitrate nitrogen, total phosphorus and total coliform did not correspond Class I water quality. In other words sub-indices for these three parameters were lower than '100' (see table 5.11). In addition the highest nitrate nitrogen concentrations were observed at Station 7 located at north east part of the basin. Based on results of the index calculation and hydrochemical aspects of water it can be concluded that surface water quality at the Tahtali River and its tributaries was mainly affected from agricultural discharges with presence of high nitrate-nitrogen and total phosphorus concentrations. Total coliform values were also high at the observation stations and this could be explained by uncontrolled domestic discharges in the region.

Sampling site classification was performed by the use of cluster analysis at section 5.4.2.2. The aim of the procedure was detecting similarities and dissimilarities among the sampling sites and explaining the observed clustering in terms of affected conditions. Two major groups were formed by treating all data by clustering. Results revealed that *Cluster 1 mainly consisted sites from the downstream of creeks (the Akselvi Creek, Tahtali Creek and its tributary). Cluster 2 involved sites that are at the north and north-east part of the basin.* At these stations water quality variables including TDS, sodium, chloride and sulfate were relatively higher than the others. As has been mentioned at section 5.4.2.1 typical sources of these parameters are agricultural drainage waters. Thus surface quality at this part was mainly controlled by agricultural land uses. Results of multidimensional scaling method (applied to data set including TDS, sodium, chloride,

sulfate and nitrate-nitrogen parameters) revealed that nitrate and sulfate caused difference between these observation sites. Additionally to determine temporal changes in water quality at river monitoring stations, trend analysis was applied. Results indicated that water quality variables, which are indicator of agricultural pollution generally, decreased over time. Thus, pollution prevention efforts performed by local authorities since 1996 in the basin were successful.

Based on results of the methods applied to assess water quality and other criterias including infrastructure of the settlements, land uses etc, it was concluded that the most critical parameter among all the water quality determinants was “nitrate-nitrogen”. This posed a threat for surface water quality especially at north east part of the Tahtali Basin, where is consisted by sub-basin called Mersinlikahve Creek watershed. Therefore, nitrate nitrogen was selected as a key variable of TMDL analysis in the thesis and Mersinlikahve watershed was determined as study area.

As a scope of the TMDL analysis, water quality model for Mersinlikahve Creek using U.S. EPA’s Qual2K as a framework was established. During summer months (under low flow conditions) concentrations of nitrate showed high fluctuations from the average concentrations and higher concentrations were observed during July-September period than other months of the year (see Table 6.3). Therefore, this time period was called as “critical period” and water quality modeling was performed for various basin growth scenarios taking into account of this period as basis. Seasonal variations were also considered to estimate nitrogen contributions from agricultural land uses. Water quality modeling study results revealed that 54% of the total nitrogen was originated from irrigated lands and 46% from cotton fields, horticultural lands and orchards in summer period. Nitrate-nitrogen concentrations at all modeled segments mainly fluctuated between 6mg/l and 8 mg/l (above the value of 5 mg/l-the limit value set for Class I waters in Turkish Water Pollution Control Regulation). Highest concentrations were observed between the ‘10th- 12th’ km and ‘4th-6th’ km from downstream of the Mersinlikahve Creek. The main reason of having high concentrations at these parts of the stream was domestic discharges from the settlements- Karaagac, Kiriklar and

confluence of Tributary VI (which flow through the agricultural fields of Demircikoy and Karaagac) with the main stream. Distribution of nitrogen load contribution for each settlement showed that Karaagac and Demircikoy allocated more than 50% of the total nitrogen load. Furthermore, two domestic point discharges contributed %45 of the total nitrogen loads to the surface water in the region under critical conditions. Daily nitrogen loads contributed to the stream from point and non-point sources in summer period was about 18 kg/day. When the loads from each settlement was increased by 25% peak concentrations along the river also rised up to 10 mg/l. It can be concluded that about 75% of the total load that could be assimilated by the waterbody without violating the limit value set for Class II waters was allocated by existing discharges.

Loading scenarios were developed by shifting land uses. Infrastructure system of the settlements (consisting sewerage and treatment plant) were either in project and/or construction phase. After completion of all the projects, point discharges would be transferred out of the catchment area in near future. Therefore, point discharges were not taken into consideration in the developed load scenarios in this study. Scenario A determined possible impacts of complete removal of the point discharges on water quality. Nitrate-nitrogen levels along the Creek under this scenario were mainly below the 6 mg/l. Elimination of domestic discharges provided decrease of peak concentration from 8.1 mg/l to 6.8 mg/l. Alternative two scenarios interrogated allocation of disused agricultural lands of the basin for cotton and horticultural production. Size of the disused lands varied settlement to settlement (see Table 7.2). Modeling study results for both scenarios revealed that there would not be significant difference with respect to water quality between two cases. About 50% of the total loads were contributed from irrigated land and 50% from cotton fields, orchards and horticultural lands. Under these assumptions similar to the present case nitrate nitrogen concentrations drastically increased after the confluence of Tributary VI flowing through the Demircikoy and Karaagac with the Mersinlikahve Creek. Therefore, two settlements having largest area of agricultural land were responsible of the high fluctuations from average concentrations. Another scenario examined effects of shifting cultivation practices on

surface water quality. It was presumed that cotton fields would be shifted to horticultural production areas and disused lands would also be cultivated for the same purpose. Modeling results under this scenario did not show significant changes from previous two alternatives. Last assumption was the allocation of 50% of the irrigated lands in Demircikoy and Karaagac for grain cultivation. This provided considerably reduction in total nitrogen loads contributing to the surface water. On the other hand, nitrate nitrogen concentrations along the stream were fluctuated between 3.9 mg/l and 5.6 mg/l. Class I limit was not violated at most of the segments of the creek.

In summary, major water pollution threat in the Tahtali Basin was agricultural discharges but their effects do not limit water use for potable water supply presently. Northern and north-eastern basin comprised the most affected locations by agricultural land uses. Results of the study conducted for Mersinlikahve watershed based on the proposed approach revealed that Demircikoy and Karaagac had the highest proportion of the total nitrogen load contributed to the surface water in the region. Especially in summer months under existing point and non-point discharges nitrate nitrogen concentrations along the Creek raised up to 8.2 mg/l. Various pollutant load scenarios showed that elimination of all the point discharges would not be sufficient providing Class I water quality along the Mersinlikahve Creek. On the other hand shifting cultivation practices comprising allocation of 50% of the irrigated lands for grain production in Demircikoy and Karaagac resulted in considerable decreases in extreme concentrations. Therefore, priorities should be given to these locations and shifting cultivation practices should be taken into consideration to control agricultural pollution in the future. In this context, crop type that requires less fertilizer should be preferred in the basin. For example, greenhouse cucumber production, which was increased by 64% between 1996 and 2000 (from the reference DEU, 2000), is suggested being limited.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

In the thesis, new approach “TMDL based sustainable basin growth and management strategy” was introduced to develop basin specific management programmes. Surface water pollution problems caused by mis-planning or non-planning of the watersheds were the initiative idea behind the proposed approach. Drainage area activities including point and non-point sources were suggested being evaluated together and related to the water quality for effective planning. In this context TMDL analysis that takes into account assimilative capacity of the receiving bodies was used as supporting tool guiding growth management. The ultimate goal is providing intended ambient water quality (generally defined by the standards set by national-international authorities) in parallel to basin growth by urbanization, industrialization and agriculturization etc. in the future.

The establishment of the decision process comprised beneficial use designations and targets, interrogation of the ambient water quality, selection of variable(s) for TMDL analysis, water quality modeling, basin growth scenarios development and decision on the basin growth plan.

The application of the developed approach in the case of Mersinlikahve Creek Watershed, Turkey revealed that decision process can assist policy makers to determine realistic strategies that take into account the basin specific conditions. On the other hand, subjectivity creeps in to almost every components of the process. Procedural steps difficulties and advantages of the proposed methods to carry out the requirements of the each step are briefly explained below.

Designation of the beneficial uses and determination of water quality targets are believed being crucial components, which provide meeting the expectation of the beneficiaries, and also frame the strategy. Each water use requires different water quality that is defined by numerous physical, chemical and biological parameters and this cause

differences in pollution prevention measures that should be taken to control water quality of the sources. Management strategy development process becomes unwidely without describing the borders by putting the targets. Therefore, these steps should not be ignored in the decision process.

Traditional approaches to assessing water quality are based on the comparison of experimentally determined parameter values with the existing guidelines but in many cases it does not readily give information on status of the source. Therefore, in the proposed strategy water quality index (WQI) method and environmetric techniques were suggested as effective tools to interrogate ambient water quality. They could be used to test whether existing water quality supports designated uses or not for the waterbody. Index method provides determining the level of acceptability for the individual parameter by referring to the concentration ranges defined in the classification scheme. On the other hand, environmetric methods could successfully be used to derive information from the data set about the possible influences of the environment on water quality and also identify natural groupings in the set of data. These methods are important to avoid misinterpretation of environmental monitoring data due to uncertainties caused by sporadic character of the data set.

Selection of water quality variable(s) for TMDL analysis is laden with subjectivity and uncertainty that makes analysis useless, unless right decisions are taken. Therefore, to ensure the most representative parameter, enormous attention and care should be given to selection process. Water quality index may assist selecting the key parameter(s). Results could be supported and verified by the environmetric methods. Furthermore, it may also be an approach selection of the parameter having high significance for the specific use and also risk violating water quality standards etc.

Water quality modeling intends to establish the cause-and-effect relationship between the key variable in waterbody and the pollutant sources. One of the most important concern must be addressed here is data availability and also reliability of the data which influence the reliability in output and cause unrealistic decisions for the basin. Therefore

input data requirement of the water quality model and available data characteristics should be taken into consideration in water quality modeling applications.

Basin growth scenarios provide water experts to see effects of any changes in the element of the basin activities (including point and non-point sources) on ambient water quality. They evaluate possible alternative policy sets rather than seeking a single preferred alternative. The limiting factor of growth estimations is ambient water quality standards, which were set by the authorities to describe desired end points of the water sources. In addition, the available load is allocated among the various sources for each alternative scenario. The purpose is to determine the balance between pollutants originating from point and non-point sources. Because the managers may need to know how the loads causing the impairment are apportioned and results assist to select the scenario and develop management strategy.

In conclusion, proposed approach “TMDL based sustainable basin growth and management strategy” can assist policy makers to determine realistic strategies that take into account the basin specific conditions.

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Appendix A-1
Characteristics of surface water intended for the abstraction of drinking water

	Parameters		A1 G	A1 I	A2 G	A2 I	A3 G	A3 I
1	pH		6.5 to 8.5		5.5 to 9		5.5 to 9	
2	Coloration (after simple filtration)	mg/l Pt scale	10	20 (O)	50	100 (O)	50	200 (O)
3	Total suspended solids	mg/l SS	25					
4	Temperature	°C	22	25 (O)	22	25 (O)	22	25 (O)
5	Conductivity	µs/cm ⁻¹ at 20 °C	1 000		1 000		1 000	
6	Odour	(dilution factor at 25 °C)	3		10		20	
7*	Nitrates	mg/l NO ₃	25	50 (O)		50 (O)		50 (O)
8 ⁽¹⁾	Fluorides	mg/l F	0.7 to 1	1.5	0.7 to 1.7		0.7 to 1.7	
9	Total extractable organic chlorine	mg/l Cl						
10*	Dissolved iron	mg/l Fe	0.1	0.3	1	2	1	
11*	Manganese	mg/l Mn	0.05		0.1		1	
12	Copper	mg/l Cu	0.02	0.05 (O)	0.05		1	
13	Zinc	mg/l Zn	0.5	3	1	5	1	5
14	Boron	mg/l B	1		1		1	
15	Beryllium	mg/l Be						
16	Cobalt	mg/l Co						
17	Nickel	mg/l Ni						
18	Vanadium	mg/l V						
19	Arsenic	mg/l As	0.01	0.05		0.05	0.05	0.1
20	Cadmium	mg/l Cd	0.001	0.005	0.001	0.005	0.001	0.005
21	Total chromium	mg/l Cr		0.05		0.05		0.05
22	Lead	mg/l Pb		0.05		0.05		0.05
23	Selenium	mg/l Se		0.01		0.01		0.01
24	Mercury	mg/l Hg	0.0005	0.001	0.0005	0.001	0.0005	0.001
25	Barium	mg/l Ba		0.1		1		1
26	Cyanide	mg/l Cn		0.05		0.05		0.05
27	Sulphates	mg/l SO ₄	150	250	150	250 (O)	150	250 (O)
28	Chlorides	mg/l Cl	200		200		200	

Appendix A-1 (continued)
Characteristic of surface water intended for the abstraction of drinking water

	Parameters	A1 G	A1 I	A2 G	A2 I	A3 G	A3 I
29	Surfactants (reacting with methyl blue) mg/l (laurylsulphate)	0.2		0.2		0.5	
30* (2)	Phosphates mg/l P ₂ O ₅	0.4		0.7		0.7	
31	Phenols (phenol index) paranitraniline 4 aminocantipyrine mg/l C ₆ H ₅ OH		0.001	0.001	0.005	0.01	0.1
32	Dissolved or emulsified hydrocarbons (after extraction by petroleum ether) mg/l		0.05		0.2	0.5	1
33	Polycyclic aromatic hydrocarbons mg/l		0.0002		0.0002		0.001
34	Total pesticides (parathion, BHC, diel- drin) mg/l		0.001		0.0025		0.005
35*	Chemical oxygen demand (COD) mg/l O ₂					30	
36*	Dissolved oxygen saturation rate % O ₂	> 70		> 50		> 30	
37*	Biochemical oxygen demand (BOD ₅) (at 20 °C without nitrification) mg/l O ₂	< 3		< 5		< 7	
38	Nitrogen by Kjeldahl method (except NO ₃) mg/l N	1		2		3	
39	Ammonia mg/l NH ₄	0.05		1	1.5	2	4 (O)
40	Substances extractable with chloroform mg/l SEC	0.1		0.2		0.5	
41	Total organic carbon mg/l C						
42	Residual organic carbon after floccula- tion and membrane filtration (5 µ) TOC mg/l C						
43	Total coliforms 37 °C /100 ml	50		5 000		50 000	
44	Faecal coliforms /100 ml	20		2 000		20 000	
45	Faecal streptococci /100 ml	20		1 000		10 000	
46	Salmonella	Not pre- sent in 5 000 ml		Not pre- sent in 1 000 ml			

I = mandatory.

G = guide.

O = exceptional climatic or geographical conditions.

* = see Article 8 (d).

(1) The values given are upper limits set in relation to the mean annual temperature (high and low).

(2) This parameter has been included to satisfy the ecological requirements of certain types of environment.

Appendix A-2

Water quality variables, their potential pollution sources and health effects (EPA, 2003)

Contaminant	Potential health effects from exposure above the limits	Common sources of contaminant in drinking water
Antimony	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes
Asbestos (fibers >10 micrometers)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chlorine (as Cl ₂)	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chromium (total)	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands

Appendix A-2

Water quality variables, their potential pollution sources and health effects (EPA, 2003) (cont.)

Contaminant	Potential health effects from exposure above the limits	Common sources of contaminant in drinking water
Nitrate (measured as Nitrogen)	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Polychlorinated biphenyls (PCBs)	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Selenium	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Total Coliforms (including fecal coliform and E. coli)	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present ⁵	Coliforms are naturally present in the environment as well as feces; fecal coliforms and E. coli only come from human and animal fecal waste.
Turbidity	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing micro-organisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Uranium	Increased risk of cancer, kidney toxicity	Erosion of natural deposits

Appendix A-3

Selected drinking water quality guidelines (World Bank 2003)

WHO categories	Parameter	Units	WHO, 1993	EU, 1998	US-EPA
Bacteriological quality	Total coliforms	Counts/100ml	0	0 (i)	
	Total coliforms	Number of samples/month			5%
Inorganic Chemicals (of health significance)	Arsenic	mg/l	0.01 (p)	0.01 (c)	0.05
	Barium	mg/l	0.7		2
	Boron	mg/l	0.5 (p)	1 (c)	
	Cadmium	mg/l	0.003	0.005 (c)	0.005
	Chromium	mg/l	0.05 (p)	0.05 (c)	0.1
	Copper	mg/l	2 (p)	2 (c)	1.3 (r: 1.0)
	Cyanide	mg/l	0.07	0.05 (c)	0.2
	Fluoride	mg/l	1.5	1.5 (c)	4.0 (r: 2.0)
	Lead	mg/l	0.01	0.01 (c)	0.015
	Nickel	mg/l	0.02	0.02 (c)	
	Nitrate - NO ₃	mg/l	50	50 (c)	10
	Nitrite - NO ₂	mg/l	3	0.5 (c)	1
	Manganese	mg/l	0.5 (p)	0.05 (i)	0.05 (r)
	Mercury	mg/l	0.001	0.001 (c)	0.002
	Selenium	mg/l	0.01	0.01 (c)	0.05
Pesticides	Dieldrin	µg/l	0.03	0.03 (c)	
	Atrazine	µg/l	2	0.03 (c)	3
	DDT	µg/l	2	0.1 (c)	
	Gamma-HCH (Lindane)	µg/l	2	0.1 (c)	0.2
	Permethrin	µg/l	20	0.1 (c)	
	Pesticides total	µg/l		0.5 (c)	
Disinfectants and disinfectant by-products	Chlorine	mg/l	5		
Radioactive constituents	Gross Alpha activity	Bq/litre	0.1		
	Gross Beta activity	Bq/litre	1		
Aesthetic guidelines	Turbidity	NTU	5 (a)		
	Aluminum	mg/l	0.2 (a)	0.2 (i)	0.05 - 0.2 (r)
	Ammonia - N	mg/l	1.5 (a)	0.5 (i)	
	Chloride	mg/l	250 (a)	250 (i)	250 (r)
	Copper	mg/l	1		
	Hydrogen sulfide - H ₂ S	mg/l	0.05 (a)		
	Iron	mg/l	0.3 (a)	0.2 (i)	0.3 (r)
	Manganese	mg/l	0.1	0.05 (i)	0.05 (r)
	Dissolved Oxygen	mg/l		> 5 (i)	
	pH		< 8 (a)	6.5 - 9.5 (i)	6.5 - 8.5 (r)
	Sodium	mg/l	200 (a)	200 (i)	
	Sulfate	mg/l	250 (a)	250 (i)	250 (r)
	Sulfides	mg/l		0.05 (i)	
	Total dissolved solids	mg/l	1000		500 (r)
	Electrical conductivity	µS/cm		2500 (i)	
	Zinc	mg/l	3 (a)		
	Residual chlorine	mg/l	0.6 - 1		

Sources: EU, 1998. Drinking water standards (EU Directive 98/83/EC). (i) Indicator parameter; (c) chemical parameter

US-EPA, 1974. Safe Drinking Water Act (SDWA), plus subsequent amendments. Maximum Contaminant Level (MCL) values (health, enforceable);

(r) Secondary Drinking Water Regulations (aesthetically recommended, but nonenforceable)

WHO, 1993. Guidelines for Drinking Water Quality. 2nd edition. (p) Provisional guideline value; (a) aesthetic guideline.

Appendix A-4

Selected water quality guidelines for livestock (WHO, 2003)

Parameter	Units	Value	Ratings/Indicator
Salinity (Electrical Conductivity)	$\mu\text{S/cm}$	< 1500 1500 - 5000 5000 - 8000 8000 - 11000 11000 - 16000 > 16000	Excellent Very satisfactory Satisfactory for livestock; unfit for poultry Limited use for livestock, unfit for poultry Very limited use Not recommended
Magnesium (maximum values)	mg/l	< 250 < 400 < 500	Poultry, Swine, Horses, cows (lactating), Ewes with lambs Beef cattle Adult sheep

Sources: FAO, 1986 - water for animals. Report # AGL/MISC/4/85. FAO, 1985 - Water Quality for Agriculture (#29 rev. 1). Values are the limits between None Slight/moderate - Severe.

Appendix A-5

Selected irrigation water quality guidelines (WHO, 2003)

Potential irrigation problem	Parameter	Unit	No restriction on use	Slight to moderate restriction on use	Severe restriction on use	Remarks
Salinity (affects crop water availability)	EC _w TDS	μS/cm mg/l	< 700 < 450	700 – 3000 450 – 2000	> 3000 > 2000	
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC _w and SAR together)	EC _w	μS/cm	> 700 > 1200 > 1900 > 2900 > 5000	700 – 200 1200 – 300 1900 – 500 2900 – 1300 5000 – 2900	< 200 < 300 < 500 < 1300 < 2900	SAR: 0 - 3 SAR: 3 - 6 SAR: 6 - 12 SAR: 12 - 20 SAR: 20 - 40
Specific Ion Toxicity (affects sensitive crops)	Sodium (Na)	SAR	< 3	3 – 9	> 9	Surface irrigation Sprinkler irrigation Surface irrigation Sprinkler irrigation
	Chloride (Cl)	me/l	< 3	> 3		
	Chloride (Cl)	me/l	< 4	4 – 10	> 10	
	Chloride (Cl)	me/l	< 3	> 3		
Miscellaneous effects (affects susceptible crops)	Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0	
	Nitrogen (NO ₃ -N)	mg/l	< 5	5 – 30	> 30	
	Bicarbonate (HCO ₃)	me/l	< 1.5	1.5 – 8.5	> 8.5	
	pH			Normal range 6.5 - 8.4		

Source: FAO, 1985 - Water Quality for Agriculture (#29 rev.1).

Appendix B-1

The classification of inland waters according to quality (Official Gazette, 2004)

Water quality parameters	Water Quality Classes			
	I	II	III	IV
A) Physical and inorganic-chemical parameters				
1) Temperature (°C)	25	25	30	> 30
2) pH	6.5-8.5	6.5-8.5	6.0-9.0	<6.0 and >9.0
3) Dissolved oxygen (mg O ₂ /L) ^a	8	6	3	< 3
4) Oxygen saturation (%) ^a	90	70	40	< 40
5) Chloride (mg Cl ⁻ /L)	25	200	400 ^b	> 400
6) Sulfate (mg SO ₄ ²⁻ /L)	200	200	400	> 400
7) Ammonia-nitrogen (mg NH ₄ ⁺ -N/L)	0.2 ^c	1 ^c	2 ^c	> 2
8) Nitrite nitrogen (mg NO ₂ ⁻ -N/L)	0.002	0.01	0.05	> 0.05
9) Nitrate nitrogen (mg NO ₃ ⁻ -N/L)	5	10	20	> 20
10) Total phosphorus (mg P/L)	0.02	0.16	0.65	> 0.65
11) Total dissolved substances (mg/L)	500	1500	5000	> 5000
12) Color (Pt-Co birimi)	5	50	300	> 300
13) Sodium (mg Na ⁺ /L)	125	125	250	> 250
B) Organic parameters				
1) Chemical oxygen demand (COD) (mg/L)	25	50	70	> 70
2) Biochemical oxygen demand (BOD) (mg/L)	4	8	20	> 20
3) Total organic carbon (mg/L)	5	8	12	> 12
4) Total kjeldahl-nitrogen (mg/L)	0.5	1.5	5	> 5
5) Oil and grease (mg/L)	0.02	0.3	0.5	> 0.5
6) Methilen blue active substances (mg/L)	0.05	0.2	1	> 1.5
7) Phenolic substances (volatile) (mg/L)	0.002	0.01	0.1	> 0.1
8) Mineral grease and derivatives (mg/L)	0.02	0.1	0.5	> 0.5
9) Total pesticides (mg/L)	0.001	0.01	0.1	> 0.1
C) Inorganic pollution parameters				
1) Mercury (µg Hg/L)	0.1	0.5	2	> 2
2) Cadmium (µg Cd/L)	3	5	10	> 10
3) Lead (µg Pb/L)	10	20	50	> 50
4) Arsenic (µg As/L)	20	50	100	> 100
5) Copper (µg Cu/L)	20	50	200	> 200
6) Chromium (total) (µg Cr/L)	20	50	200	> 200
7) Chromium (µg Cr ⁺⁶ /L)	Not detectable	20	50	> 50
8) Cobalt (µg Co/L)	10	20	200	> 200
9) Nickel (µg Ni/L)	20	50	200	> 200
10) Zinc (µg Zn/L)	200	500	2000	> 2000
11) Total cyanide (µg CN/L)	10	50	100	> 100
12) Fluoride (µg F/L)	1000	1500	2000	> 2000
13) Chloride (µg Cl ₂ /L)	10	10	50	> 50
14) Sulphur (µg S ²⁻ /L)	2	2	10	> 10
15) Iron (µg Fe/L)	300	1000	5000	> 5000
16) Manganese (µg Mn/L)	100	500	3000	> 3000
17) Boron (µg B/L)	1000 ^e	1000 ^e	1000 ^e	> 1000
18) Selenium (µg Se/L)	10	10	20	> 20
19) Barium (µg Ba/L)	1000	2000	2000	> 2000
20) Aluminum (mg Al/L)	0.3	0.3	1	> 1
21) Radioactivity (pCi/L)				
alpha-activity	1	10	10	> 10
beta-activity	10	100	100	> 100
D) Bacteriological parameters				
1) Fecal coliform (EMS/100 mL)	10	200	2000	> 2000
2) Total coliform (EMS/100 mL)	100	20000	100000	> 100000

a: Either concentration values or saturation ratios must be satisfied

b: This concentration ratio should be decreased when chlorine-susceptible plants are irrigated

c: The value of the ammonia-nitrogen should not exceed 0.02 mg/L due to pH value

d: The criteria under this group indicate the total concentrations of chemicals

e: The criteria may have to be decreased down to 300 µg/L when boron-susceptible plants are irrigated

Appendix B-2

The physical, chemical and biological properties of drinking water-TS 266
(Turkish Institute of Standards, 1997).

Water Quality Variables	Unit	Class I		Class II
		Permissible Value	Maximum Value	Maximum Value
Temperature	°C	12	25	25
PH		6.5≤PH≤8.5	6.5≤PH≤9.2	6.5≤PH≤8.5
Color	Pt-Co	1	20	1
Turbidity	Unit	5	25	5
Conductivity	μS/cm	400	2000	650
Chlorides	mg/l	25	600	30
Free Chlorine	mg/l	0.1	0.5	-
Sulfates	mg/l	25	250	25
Calcium	mg/l	100	200	100
Magnesium	mg/l	30	50	30
Sodium	mg/l	20	175	20
Potasium	mg/l	10	12	12
Aluminum	mg/l	0.05	0.2	0.2
Nitrates	mg/l	25	50	25
Nitrites	mg/l	-	0.1	0.1
Ammonium	mg/l	0.05	0.5	0.05
Kjeldahl-nitrogen	mg/l	-	1	1
Permanganate Index	mg/l	2	5	5
Phenoles	μg/l	-	0.5	0.5
Boron	μg/l	1000	2000	1000
Iron	μg/l	50	200	50
Manganese	μg/l	20	50	20
Copper	μg/l	100 or 3000	3000	100
Zinc	μg/l	100 or 5000	5000	100
Phosphorus	μg/l	400	5000	400
Fluorides (8-12 °C)	μg/l	-	1500	1000
Suspended Solids	mg/l	-	1	0.5
Barium	μg/l	100	300	100
Silver	μg/l	-	10	10
Arsenic	μg/l	-	50	50
Cadmium	μg/l	-	5	5
Cyanides	μg/l	-	50	50
Chromium	μg/l	-	50	50
Mercury	μg/l	-	1	1
Nickel	μg/l	-	50	50
Lead	μg/l	-	50	50
Antimony	μg/l	-	10	10
Selenium	μg/l	-	10	10
Pestisides	μg/l	-	0.1	0.1
-PCB's	μg/l	-	0.1	0.1
-Herbisides	μg/l	-	0.1	0.1
Total Coliform	/100 ml	-	-	-
Feacel Coliform	/100 ml	-	-	-

Appendix B-3

Limit values for eutrophication control in lakes, swamps and reservoirs (Official Gazette, 2004).

Desired Characteristics	Purpose of Area Use	
	Natural protection area and recreation	For various uses (including natural salt, soda)
PH	6.5-8.5	6-10.5
COD (mg/l)	3	8
DO	7.5	5
SS	5	15
Total Coliform (MPM/100 ml)	1000	1000
Total nitrogen (mg/l)	0.1	1
Total phosphorus	0.005	0.1
Clorofil-a (mg/l)	0.008	0.025

Appendix C

Standard Normal Distribution Table

F(Z)= Probability (Area) from -∞ to Z

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990