SURFACE WATER QUALITY MODELING FOR BEST MANAGEMENT PRACTICES - A CASE STUDY FROM BAKIRÇAY RIVER BASİN

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ABSTRACT

SURFACE WATER QUALITY MODELING FOR BEST MANAGEMENT PRACTICES - A CASE STUDY FROM BAKIRÇAY RIVER BASİN

This study was carried out to analyze the water quality in the Bakırçay River basin, which is known to be exposed to intense industrial and agricultural pollutant loads. A mathematical model system called AQUATOOL was used to reveal the changes that the effects of anthropogenic and natural events in the basin will cause on the conservative water quality parameters and nutrients. Model results are given in wet (April) and dry (September) periods for 4 points determined from upstream to downstream in the basin on a spatial basis, and temporal evaluation is also given for 1 upstream river water body, 1 downstream river water body, and 1 lake water body. Seven best management practices scenarios were determined and implemented one after the other in the model. Spatially, the results reveal good water status for both the dry period and the wet period at the upstream points, while at the downstream points, all parameters except BOD_5 and Dissolved Oxygen are found to be in poor condition. Besides, similar situations arise in spatial-based results, and despite the scenarios, parameters could not reach good water status except for the lake waterbodies. The improvement in lake results occurs due to dilution, not scenarios. With this study, the pollution load in Bakırçay River Basin and the effects it creates once again revealed that if the anthropogenic loads are not reduced, the water quality of the basin will reach irreversible points for many years. It is thought that this study can constitute a source document for decision-makers, especially in terms of efficiency comparisons in the best management scenarios to be applied.

ÖZET

EN İYİ YÖNETİM UYGULAMALARI İÇİN YÜZEYSEL SU KALİTESİ MODELLEMESİ – BAKIRÇAY HAVZASINDAN BİR ÖRNEK ÇALIŞMA

Bu çalışma yoğun endüstriyel ve tarımsal kirletici yüklerine maruz kalındığı bilinen Bakırçay Nehir havzasındaki su kalitesini analiz etmek için gerçekleştirilmiştir. Havzada gerçekleşen antropojenik ve doğal olayların etkilerinin geleneksel su kalitesi parametreleri ve nutriyentler üzerinde yaratacağı değişimi ortaya koyabilmek adına AQUATOOL adı verilen matematiksel model kullanılmıştır. Model sonuçları mekansal bazda havza içerisinde menbadan mansaba belirlenen 4 nokta için yağışlı (Nisan) ve kurak (Eylül) dönem olarak verilmiştir. Ayrıca zamansal değerlendirme 1 menba nehir su kütlesi, 1 mansap nehir su kütlesi ve 1 göl su kütlesi için sunulmuştur. Literatürden belirlenen ve sıkça su kalitesi çalışmalarında kullanılan en iyi yönetim uygulamaları arasından 7 senaryo belirlenmiş ve modelde birbiri ardınca uygulatılmıştır. Mekansal bazda sonuçlar hem kurak dönem için hem de yağışlı dönem için menba noktalarda iyi su durumunda bulunabiliyorken, mansap noktalarda BOD_5 ve Çözünmüş Oksijen hariç parametrelerin tamamı kötü durumdadır. Öte yandan mekansal bazlı sonuçlarda da benzer durumlar ortaya çıkmakta ve senaryolara rağmen göl su kütlesi sonuçları dışındaki parametreler iyi su durumuna ulaşamamışlardır. Göl sonuçlarındaki iyileşme ise senaryolar kaynaklı değil, seyrelme kaynaklıdır. Bu çalışma ile birlikte Bakırçay Nehir Havzasın'daki kirlilik yükü ve beraberinde oluşturduğu etkileri bir kez daha ortaya konulmuştur.Eğer antropojenik yükler azaltılmaz ise havza su kalitesinin uzun yıllar boyu geri dönülemez noktalara ulaşacağı görülmektedir. Bu çalışmanın karar vericilere özellikle uygulanacak en iyi yönetim senaryolarında verim karşılaştırmaları açısından bir kaynak teşkil edebileceği düşünülmektedir.

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CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Water resources such as rivers and lakes are essential for human existence and biodiversity throughout the world. Typically, freshwater resources are used for drinking, transportation, agricultural irrigation, energy production, and other purposes by mankind. Furthermore, freshwater resources are the host for over 10000 fish species, approximately 40% of global fish diversity, and one-quarter of global vertebrate diversity (Dudgeon et al., 2006; Lundberg et al., 2000). These uses of water resources and the persistence of biodiversity require a certain level of water quality at any moment.

Freshwater resources and their quality have been significantly deteriorated by anthropogenic activities and natural pollutant sources in the last decades. Volcano eruptions, forest fires, and climate change can be considered as natural pollutant sources. On the other hand, along with the start of the industrial revolution, anthropogenic activities such as treated, partially treated, or untreated domestic and industrial wastewater discharges and contaminated return waters from agricultural activities created more damage than natural pollutant sources within the last decades. The consequence of over-exploitation and unsustainable utilization was the destruction of the natural environment and the depletion of resources. Rapid industrialization, urbanization, and intensive farming caused pollution of the soil, air, and water and created global problems such as the depletion of ozone, climate change, and global warming (Singh, 2014). In this era, water is considered one of the most valuable resources, and it is very likely that water-related conflicts are likely to happen between countries about sharing water resources.

Before developing computer systems, many expert human resources and high budgets were required to carry out detailed water quality management practices. Due to advancements in technology, water resources engineers now have a chance to use cutting-edge technologies to achieve their goals in a much faster and reliable way. Mathematical models are effective tools for water quality management and allow the user to save time and money. They also make it easier to solve ecological problems and help choose suitable management alternative for sustainable development. Therefore, mathematical models have a very important role in water resources management practices. These models provide information and insight, which can help improve water resources management and planning. Nevertheless, these approaches face significant uncertainties due to spatial and temporal variation of the watershed properties (i.e., topography, geology, precipitation, etc.) (Fonseca 2006).

The definition of how each of the above-mentioned factors affects water demand and water quality should be well defined. In addition, the mechanisms of occurrence of similar factors and their effects on water use should be well examined. This entails using a holistic approach that integrates hydrological processes at the watershed scale in determining an overall response to both user’s demands and changing climate patterns. Therefore, watershed modeling is used as a method to better understand the flow of surface and subsurface water and the relationships between these water bodies. More importantly, they provide information to support decision-making on the safety of water resources and the required mitigation measures associated with potential threats (Arabi et al., 2005; Singh and Woolhiser, 2002).

Natural organic matter, as well as nitrogen and phosphorous loadings, have a major impact on the water quality of sensitive and vulnerable water bodies; therefore, eutrophication control is one of the major challenges facing those responsible for sustainable development and management of these ecosystems. Consequently, these watershed models can be used to predict the future state of such natural and vulnerable water bodies.

In addition to natural organic matter and nutrients (nitrogen and phosphorous), heavy metals and synthetic organic compounds are other important pollutant sources for water bodies. Along with intense agricultural production, fertilizers and pesticides have increased to enhance crop yields and quality. However, excessive use of these agricultural inputs can result in residues that remain in farmland soil or are transported with rainfall or irrigation water to aquatic ecosystems. Overall these inputs have become a global concern and a challenge to the environment because of their toxicity and accumulation risks to human and ecological life (Aydin and Kucuksezgin, 2012; Ouyang et al., 2018).

1.2. Objectives of the Study

Urbanization, agricultural intensification, and industrialization have serious impacts on the aquatic ecosystems and indirectly on human health. In particular, the deterioration of water quality needs to be determined, and necessary precautions must be taken. Thanks to the convenience provided by the mathematical models, water quality improvement scenarios can be analyzed and evaluated to predict future conditions better.

Accordingly, this thesis focuses on applying a water quality model (AQUATOOL) in one of the heavily polluted river basins in Western Turkey for water quality management. AQUATOOL model is a recently developed modeling platform to simulate basin hydrology and water quality. The model contains hydrological tools to simulate several hydrological and quality-based effects on the basin.

The study presents the application of SIMGES and GESCAL modules of AQUATOOL model to Bakırçay River Basin based on the current pollutant loads and predicted future pollutant load conditions under specific scenarios to predict water quality in the watershed. Bakırçay River Basin is a sub-basin of the Northern Aegean Watershed and has a total catchment area of 3393 km^2. Bakırçay River can also be defined in the category of rivers with continuous flow, low altitude, low average slope, high precipitation area, small drainage area, and low mineralization. The study presents calibration and validation of water quantity and quality. The validated model was then applied to determine the effects of scenarios to make water quality status better.

1.3. Scope of the Study

With the above-mentioned objectives, this thesis is organized into six chapters. In Chapter 1, a problem statement and the purpose of the study are presented. The following section, Chapter 2, addresses the literature review, where the fundamentals of water quality modeling topics are summarized, and the main impacts of anthropogenic pollutant sources and their consequences on surface waters are discussed. In Chapter 3, the methodology implemented for required data assessment, data interpretations, and discretization for model setup is discussed. In Chapter 4, the purpose and development stages of the model system are described, and the study area, field characteristics, and necessary data for the model are explained. The results of the study are presented in Chapter 5, within which temporal and spatial concentration profiles of the system and the effects of load reduction scenarios are discussed. Furthermore, this chapter also provides a comparison of the findings with national legislation. Finally, Chapter 6 discusses the effectiveness of the scenarios and concludes the thesis with major conclusions of the study and recommendations for further works.

CHAPTER 2

LITERATURE REVIEW

2.1. Fundamentals of Hydrology

Hydrology deals with the distribution of water on the Earth's surface and its movement over and below the surface and through the atmosphere (Davie 2002). The global water cycle and all fluxes, which include physical, chemical, and biogeochemical processes within the water cycle, are topics of hydrology. Water is important not only to humans but to all forms of life on Earth. Water's importance for improving quality of life, food production, and support for business are crucial in today's rapidly developing world. Over the past 26 years, the world population has increased from 5.7 billion to 7.7 billion, and it is likely to rise by another 2 billion by 2030 and is expected to reach 10.9 billion by 2100 (United Nations 2019). This means a higher demand for water, which will cause more stress over water resources due to excessive consumption. Because of this excessive consumption, the volume of fresh water in rivers is decreasing and ending up in changes in the balance between fresh and saltwater. As we can see in Figure 2.1 current percentage value of freshwater, which we can reach, and use is 2.5% of total global water on Earth.

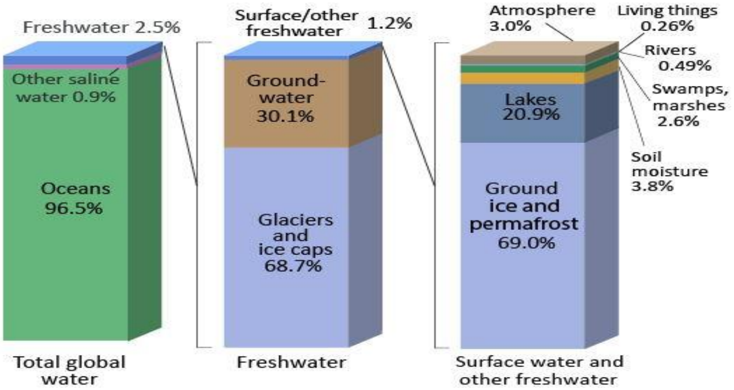

Figure 2.1. Total global water in world

(Survey 2013)

2.2. Hydrologic Cycle

The hydrological cycle (Figure 2.2.) represents the continuous movement of water above, on, and below the Earth's surface, changing its form: as water vapor in the atmosphere; as liquid water in seas, lakes, and rivers; and as ice in polar ice caps and mountain glaciers.

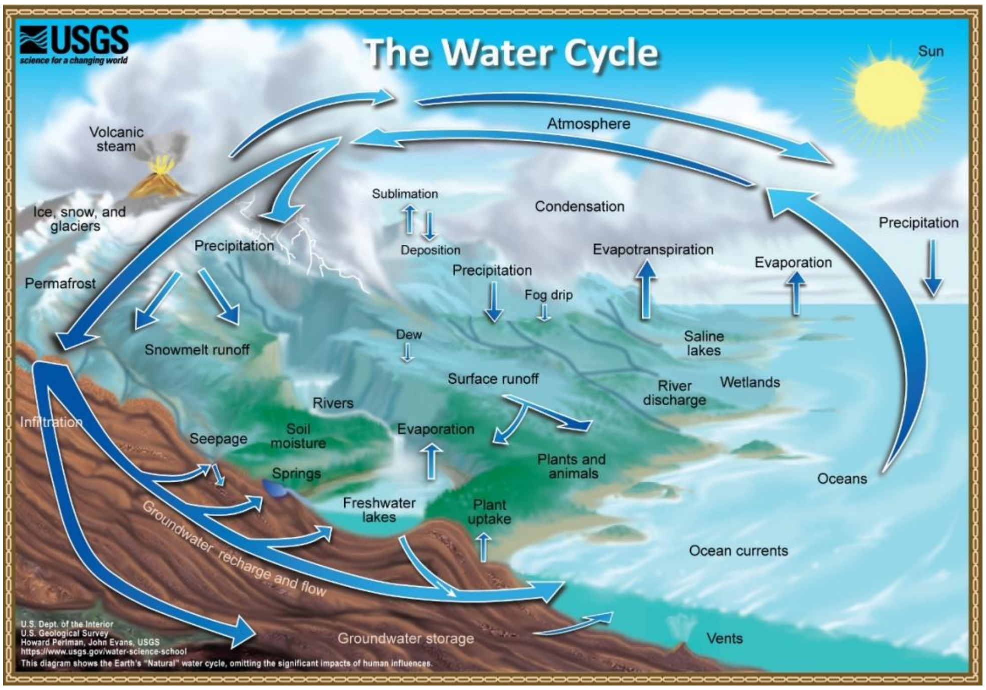

Figure 2.2. The hydrologic cycle

(Source: U.S. Geological Survey, 2013)

The hydrological cycle has no end; it starts and consistently occurs. Water evaporates from the oceans into the atmosphere, where it condensates and precipitates back on the land surface or water bodies. And then, it is moving through the surface as runoff or the subsurface as groundwater flow until it reaches the ocean or the atmosphere by evaporates. Chow et al. (1988) demonstrated that the water cycle begins again, and the water moves continuously because of solar energy.

2.3. Influence of Pollutants on Surface Water Quality

In recent years, the need for healthy and reachable water is raised due to an unbalanced growing population and industrial resource needs. However, it's getting harder for water resources engineers to provide that water for use year by year. The reason for this is that water resources such as rivers, lakes, ponds have been getting more and more polluted every year.

Increases in urbanized areas indicate that the environmental pressure on rivers, especially urban rivers, is rising. Water quality is one of the most often affected environmental indicators of rivers by urbanization.

The simple definition of water pollution is the presence of harmful substances, mostly chemicals or microorganisms, in water. These water pollutants can also be categorized as pathogens, inorganic and organic materials, and macroscopic pollutants. Some sources of water pollution can be seen in Figure 2.3.

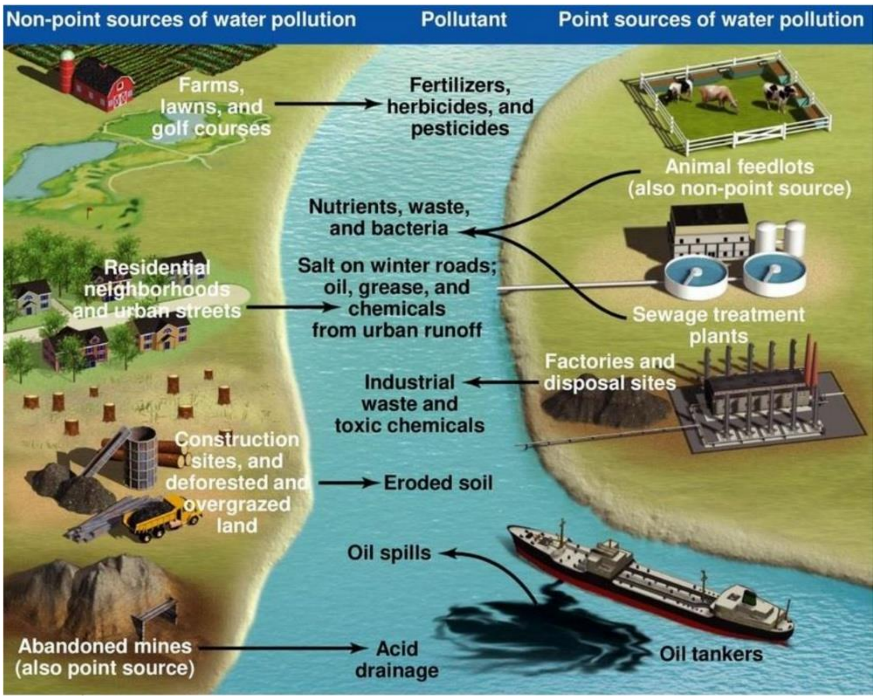

Figure 2.3. Source of water pollution

(Source: Sayed, Ahmed, and Yousef 2019)

Pathogens can be viruses, protozoans, or bacterias, and they can be dangerous for human health. Among these pathogens, bacterias such as coliform and E. coli are commonly found in water. Still, they are not harmful unless their concentrations in water are higher than the regulatory limits. Human wastes, other animal wastes, and medical wastes can be considered as the source of this pollution. Thus, contamination of water bodies with pathogens is one of the most critical water quality issues worldwide.

Inorganic materials such as heavy metals like arsenic, zinc, copper, chromium, etc., also create toxic effects on water bodies if they are concentrated in water resources. In addition, inorganic pollution can occur because of anthropogenic sources like industrial wastes, infiltration from landfills and agricultural activities, or natural sources like geological formations.

Organic material can be defined as materials that contain carbon in their formations. When a large quantity of organic material is discharged to the water bodies, they act like substrates for microorganisms. Oxygen depletes during the decomposition process, and in conclusion, aquatic life gets affected in a bad way. Organic pollution can be originated from domestic sewage, runoffs after stormwater, industrial discharges, and agricultural activities wastes (US EPA 2019).

Nutrients can be counted as one of the organic pollutants. Nitrogen and phosphorus are called nutrients, and living organisms in aquatic life need these nutrients as essentials to grow and survive. But excess of nutrients causes eutrophication or algal blooms, which is known as the uncontrolled increase of the algae. Algal blooms cause decreasing oxygen levels in the aquatic system and block light penetration into the deeper parts of the water bodies because algae cover the surface of the water body (U.S. Geological Survey 1999).

2.4. Pollution Mitigation Options

Pollution control measures should be applied to pollution sources to achieve good water quality status, which may vary according to administrative organisations. Improving water quality with in-river methods generally is not as effective as source prevention methods. Pollution reduction options can be considered separately as point source pollutant reduction and non-point source pollutant reduction. In general, point pollutant sources are located more easily than diffuse pollutant sources in basins, and these sources can be intervened faster (R. Zhang et al. 2014). The control measures for non-point sources are also called Best Management Practices (US EPA 1992), and as Kroll and Oakland (2019) remark, they are designed under the idea of the retention of sediment, nutrients, and other water quality chemicals on the agricultural lands or in buffer zone rather than allowing their transport them to waterbodies.

Point pollutant sources can be identified as the pollution sources which discharge watersheds from easily locatable discharge pipes of wastewater treatment plants, industrial facilities, and canals of tributaries or stormwater drainages. This type of pollution source is generally easily preventable with constructing new or improving the existing end-of-pipe treatment methods or the impermeable ponds.

On the other hand, non-point pollutant sources can be defined as the pollutant sources which come with runoff to watersheds from farms, livestock’s pastures, forests, cities, lawns, mining operations, atmosphere, petrol stations, highways, sediment and leachates from rural fosseptics and landfills. It is known that stormwater runoffs have a significant impact on the transport of non-point natural and anthropogenic pollutants (Ernst 2004).

Water quality management studies are mostly conducted for the waterbody to reach a good water quality status. In order to achieve the goal, it is necessary to determine the polluting sources in the watershed systems and to apply pollution-reducing measures to these sources. With the recent developments in water quality models, we are able to simulate the applicability and efficiency of these measures. As highlighted by Shepherd and Chambers (2007), only with the appropriate spatial and temporal targeting of a combination of measures will the desired environmental targets be achieved.

One of the non-point pollutant sources that need attention is the livestock industry. Directly and indirectly, livestock production influences nearby streams by increased nutrient and sediment loads in the runoff. Animals with access to the streams directly pollute the stream with the waste matter and nutrients in addition to the degradation of stream banks and riparian buffer zones (Strand and Merritt, 1999; Belsky et al., 1999; Scrimgeour and Kendall, 2003; Agouridis et al., 2005; Holmes et al., 2016). Preventing livestock’s stream access by one of best management practices like fencing and livestock-related manure management through off-stream shelters can reduce the livestock-related pollution (Kroll and Oakland 2019). This pollution reduction method, which can also be called Green Belt applications, is the creation of forested areas adjacent to the river banks to form a transition between water and soil. They contribute to the improvement of water quality while providing a habitat for wild animals and fish. Riverside forest buffers play a key role in diffuse pollution control. Tree roots absorb nutrients and other pollutants from the soil with runoff, and according to Campbell et al. (2005), their holding capacity increases as tree roots grow. Another part of the tree where nutrients are stored other than the root is the leaves. Nitrogen stored here in the form of nitrate is converted into nitrogen gas by the denitrification process and is mixed into the air. An example of riparian forest buffers is given in Figure 2.4.

Figure 2.4. A View from the riverside forest buffer

(Source: SYGM, 2019b)

Crop rotations can also be used as best management practices for reducing soil erosion, therefore, reducing the quantities of sediment and other pollutants as nitrogen, phosphorus, and pesticides that transport with sediment. The technique can be defined as changing planted crops in a specified sequence on the same field (Evans and Corradini 2013).

The terracing process, which is another BMPs technique, is the earthen process of channels to prevent pollutants runoff on sloping land parcels. This technique also helps to control soil erosion on cropland, therefore indirectly helps to reduce nutrients and pesticides by preventing sediment runoff to the water column (Evans and Corradini 2013). According to Cestti et al. (2003) and Ritter and Shirmohammadi (2000), soil losses are prevented by 94-95%, nutrient losses by 56-92%, and the runoff volume is reduced by 73-88% with terracing practices. Another study shows that this rate can go up to 95% for sediment, and it varies between 30% and 70% for nutrients (Novotny, 2002). The application example can be seen in Figure 2.5.

Figure 2.5 Aerial views of terracing

(Evans and Corradini 2013)

The vegetated buffer strips technique is also one of the often used BMPs. In this process, by forming strip-shaped areas of land preserved in some form of permanent vegetation such as grasses, shrubs, and/or trees, trapping contaminants found in surface runoff from neighboring land areas are targeted. Vegetative barriers control erosion and hold sediments from runoff, preventing them from reaching the receiving water environments. However, by cutting the velocity of the water coming with the surface flow, they allow sediments to accumulate in the upper sloping parts of the barriers. Another beneficial aspect is that they increase the efficiency of other protective applications, and they are known to reduce the total amount of water that comes with surface runoff by increasing water filtration (Los et al., 2011; US EPA, 2007). Some forms of buffers can be seen in Figure 2.6.

Figure 2.6 Riparian and contour buffer strip

(Source: SYGM, 2019b)

Many more BMP techniques are also available in addition to the mentioned ones above. The effectiveness of some of these BMP techniques can be seen in Table 2.1.

Table 2.1. The effectiveness of non-point source pollution mitigation options

Pollution Mitigation Alternatives for Non-Point Sources	Pollutant	Removal Efficiency Range	References
Creating Buffer Zones	Total Nitrogen	23% reduction	McKergow et al. (2003)
Creating Buffer Zones	Total Nitrogen	75-94% reduction	Heathwaite et al. (1998)
Creating Buffer Zones	Total Nitrogen	10% decrease-217% increase	Borin et al. (2005)
Creating Buffer Zones	Total Nitrogen	47-100% reduction	Dorioz et al. (2006)
Creating Buffer Zones	Total Nitrogen	29-89% reduction	Cho et al. (2010)
Creating Buffer Zones	Total Nitrogen	64% reduction	Du et al. (2016)
Creating Buffer Zones	Total Nitrogen	<65% reduction	Kroll and Oakland, (2019), Simpson and Weammert, (2009)
Creating Buffer Zones	Nitrate	50-100% reduction	Haycock and Burt (1993)
Creating Buffer Zones	Nitrate	No impact (due to macropore flow)	Leeds-Harrison et al. (1999)
Creating Buffer Zones	Nitrate	9% decrease-232% increase	Borin et al. (2005)
Creating Buffer Zones	Nitrate	95% reduction	Hefting and de Klein (1998)
Creating Buffer Zones	Total Phosphorus	6% reduction	McKergow et al. (2003)
Creating Buffer Zones	Total Phosphorus	10–98% reduction	Heathwaite et al. (1998)
Creating Buffer Zones	Total Phosphorus	0–97% reduction	Uusi-Kämppä et al. (2000)

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Table 2.1. (Cont.)

Pollution Mitigation Alternatives for Non-Point Sources	Pollutant	Removal Efficiency Range	References
Creating Buffer Zones	Total Phosphorus	31% reduction	Abu-Zreig (2001)
Creating Buffer Zones	Total Phosphorus	8–97% reduction	Dorioz et al. (2006)
Creating Buffer Zones	Total Phosphorus	27% decrease – 41% increase	Borin et al. (2005)
Creating Buffer Zones	Total Phosphorus	27-100% reduction	Cho et al. (2010)
Creating Buffer Zones	Total Phosphorus	52% reduction	Du et al. (2016)
Creating Buffer Zones	Total Phosphorus	<45% reduction	Kroll and Oakland, (2019), Simpson and Weammert, (2009)
Creating Buffer Zones	Inorganic Phosphorus	16% reduction	VȨȨnȨnen et al. (2006)
Creating Buffer Zones	Inorganic Phosphorus	61% increase	McKergow et al. (2003)
Creating Buffer Zones	Total Phosphorus	50-75% reduction	(Novotny 2002)
Creating Buffer Zones	Total Nitrogen	80-95% reduction	(Novotny 2002)
Creating Buffer Zones	Inorganic Phosphorus	17% decrease – 475% increase	Borin et al. (2005)
Creating Buffer Zones	Inorganic Phosphorus	0–30% decrease	Dorioz et al. (2006)
Creating Buffer Zones	Pesticides (Atrazine)	53% reduction	Arora et al. (2003)
Creating Buffer Zones	Pesticides (Atrazine)	25-49% reduction	Popov et al. (2006)
Creating Buffer Zones	Pesticides (Chlorpyriphos)	83% reduction	Arora et al. (2003)
Creating Buffer Zones	Pesticides (Metolachlor)	54% reduction	Arora et al. (2003)
Creating Buffer Zones	Pesticides (Metolachlor)	30-61% reduction	Popov et al. (2006)
Creating Buffer Zones	Pesticides (Chlorpyriphos)	89% reduction	Zhang and Zhang (2011)
Creating Buffer Zones	Pesticides (Diazinon)	89% reduction	Zhang and Zhang (2011)
Creating Wetlands	Total Nitrogen	5-50% reduction	Alström et al. (2000)
Creating Wetlands	Total Nitrogen	19-100% reduction	Jansson et al. (1998)
Creating Wetlands	Total Nitrogen	3-15% reduction	Braskerud (2002)
Creating Wetlands	Total Nitrogen	7% increase – 40% decrease	Koskiaho et al. (2003)
Creating Wetlands	Total Nitrogen	<25% reduction	Kroll and Oakland, (2019), Simpson and Weammert, (2009)
Creating Wetlands	Nitrate	8% increase – 38% decrease	Koskiaho et al. (2003)
Creating Wetlands	Nitrate	28% reduction	Kovacic et al. (2006)
Creating Wetlands	Nitrate	35-100% reduction	Larson et al. (2000)
Creating Wetlands	Total Phosphorus	6% increase – 72% decrease	Koskiaho et al. (2003)
Creating Wetlands	Total Phosphorus	53% reduction	Kovacic et al. (2006)
Creating Wetlands	Total Phosphorus	<50% reduction	Kroll and Oakland, (2019), Simpson and Weammert, (2009)
Creating Wetlands	Inorganic Phosphorus	<10% reduction	Braskerud (2002)

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Table 2.1. (Cont.)

Pollution Mitigation Alternatives for Non-Point Sources	Pollutant	Removal Efficiency Range	References
Creating Wetlands	Inorganic Phosphorus	33% increase – 33% decrease	Koskiaho et al. (2003)
Creating Wetlands	Pesticides (Atrazine)	25-95% reduction	Stearman et al. (2003)
Creating Wetlands	Pesticides (Chlorpyriphos)	100% reduction	Schulz and Peall (2001)
Creating Wetlands	Pesticides (Chlorpyriphos)	47-65% reduction	Moore et al. (2002)
Creating Wetlands	Pesticides (Metolachlor)	82% reduction	Stearman et al. (2003)
Creating Wetlands	Heavy Metals (Pb)	>50% reduction	Hathaway et al. (2009)
Creating Wetlands	Heavy Metals (Cu, Zn, Cd)	>97% reduction	Polprasert (2004)
Fertilization Control	Total Nitrogen	14-31% reduction	Wang et al. (2011)
Fertilization Control	Total Phosphorus	9-22% reduction	Wang et al. (2011)
Fertilization Control	Total Nitrogen	<40% increase – <14% decrease	Vagstad et al. (2009)
Pesticide Control	Pesticides (Chlorpyriphos)	26% reduction	Zhang and Zhang (2011)
Pesticide Control	Pesticides (Diazinon)	28% reduction	Zhang and Zhang (2011)
Fencing	Total Phosphorus	7% reduction	Miller et al. (2010)
Fencing	Total Phosphorus	7% reduction	McDowell (2008)
Vegetated Filter Strip (Buffer Zones)	COD	46-63% reduction	Fan (1998), Lin and Hsieh (2003)
Vegetated Filter Strip (Buffer Zones)	Total Phosphorus	50% reduction	Borin et al. (2010)
Vegetated Filter Strip (Buffer Zones)	Pesticides	75% reduction	Borin et al. (2010)
Vegetated Filter Strip (Buffer Zones)	Total Phosphorus	57-86% reduction	Duchemin and Hogue (2009)
Vegetated Filter Strip (Buffer Zones)	Total Phosphorus	36% reduction	Watts and Torbert (2009)
Vegetated Filter Strip (Buffer Zones)	Total Phosphorus	92-99% reduction	Mankin et al. (2007)
Vegetated Filter Strip (Buffer Zones)	Total Phosphorus	70% reduction	Bhattarai et al. (2009)
Vegetative Barrier	Nutrients (N and P)	Up to 70% reduction	Blanco-Canqui et al., (2004)
Filter Strip (Buffer Zones)	Metals	63% reduction	Barrett (1999), Lee and Jones-Lee (2002)
Livestock number control	Total Nitrogen	<26% increase – <22% decrease	Vagstad et al. (2009)
Livestock number control	Total Nitrogen	60-70% reduction	Gilboa et al. (2015)
Livestock number control	Total Phosphorus	40-50% reduction	Gilboa et al. (2015)
Livestock control (with nutrient control and dead bird composter)	COD	35-69% reduction	Edwards et al. (1996)
Livestock control (Off-Stream watering with fencing)	Total Nitrogen	25% reduction	Simpson and Weammert (2009)
Livestock control (Off-Stream watering without fencing)	Total Nitrogen	15% reduction	Simpson and Weammert (2009)

(Cont. on next page)

Table 2.1. (Cont.)

Pollution Mitigation Alternatives for Non-Point Sources	Pollutant	Removal Efficiency Range	References
Livestock control (Off-Stream watering with fencing)	Total Phosphorus	30% reduction	Simpson and Weammert (2009)
Livestock control (Off-Stream watering without fencing)	Total Phosphorus	22% reduction	Simpson and Weammert (2009)
Livestock control (with nutrient control and dead bird composter)	Total Phosphorus	0-23% reduction	Edwards et al. (1996)
Land Use Change	Total Nitrogen	<40% reduction	Vagstad et al. (2009)
Land Use Change	Total Nitrogen	95% reduction	Du et al. (2016)
Land Use Change	Total Phosphorus	94% reduction	Du et al. (2016)
Crop rotation	Total Nitrogen	<45% increase – <35% decrease	Vagstad et al. (2009)
Crop rotation	Total Nitrogen	7% reduction	Evans and Corradini (2013)
Crop rotation	Total Phosphorus	40% reduction	Evans and Corradini (2013)
Cover Crop applications	Total Nitrogen	43% reduction	Evans and Corradini (2013)
Cover Crop applications	Total Nitrogen	<45% reduction	Simpson and Weammert (2009)
Cover Crop applications	Total Phosphorus	32% reduction	Evans and Corradini (2013)
Cover Crop applications	Total Phosphorus	<15% reduction	Simpson and Weammert (2009)
Cropland protection	Total Nitrogen	25% reduction	Du et al. (2016)
Cropland protection	Total Phosphorus	36% reduction	Du et al. (2016)
Terracing	Total Nitrogen	44% reduction	Du et al. (2016)
Terracing	Total Phosphorus	42% reduction	Du et al. (2016)
Terracing	Total Nitrogen	44% reduction	Kroll and Oakland (2019)
Terracing	Total Phosphorus	42% reduction	Kroll and Oakland (2019)

2.5. Model Description

Hydrological systems are governed by many processes within watersheds. It is not possible to consider and simulate all processes; however, it’s important to ascertain the amount of water that enters and exits the watershed to ensure that all processes are accounted for in modeling. Mathematical models provide convenience for these processes and simplify them so that the components of the system can be applicable at the watershed or sub-watershed scales in order to use while making water management decisions.

Models have been developed for different pollutants, source (point or diffuse) conditions, and different morphological, hydraulic, and ecological river characteristics. Changes in contaminant concentrations in a specific stretch of the river are calculated to include the assimilative potential accessible through physical, chemical, and biological reactions within the environment (Sharma and Kansal 2013; Cox 2003; Ji 2008a). Water quality models can be commonly categorized as simulation models (to simulate improvements in water quality due to a source of pollution) and optimization models (for optimum resource allocation) based on the objectives (Bowen and Young 1985; Dudley 1988; Kirchner, Dillon, and Lazerte 1993; D. J. Lee and Howitt 1996; Krysanova, Bronstert, and Müller-Wohlfeil 1999; Zoppou 2001). Figure 2.7 describes the different kinds of models of water quality.

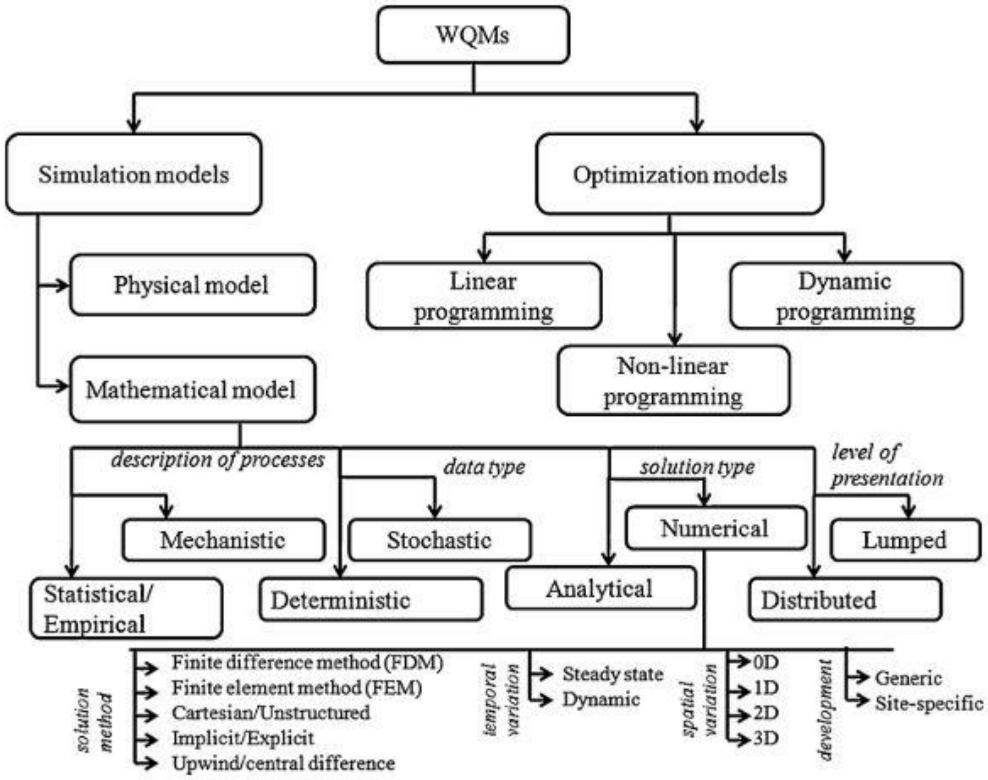

Figure 2.7. The classification types of water quality models (WQMs)

(Source: Sharma and Kansal 2013)

Optimization models can be further categorized into linear programming models (Bowen and Young 1985), non-linear programming models (D. J. Lee and Howitt 1996), and dynamic programming models (Dudley 1988). Simulation models, on the other hand, are categorized as mathematical simulation models and physical simulation models. A physical simulation model is designed to generate a scaled outcome that can be applied to the real system, while a mathematical model is based on a series of governing equations of defining water quality using analytical or numerical solution procedures(Ji 2008a).

Mathematical models can be further categorized as statistical/empirical or mechanistic based on method description; or as deterministic or stochastic according to data type; or as numerical or analytical based on solution types; and as lumped or distributed according to the presentation level (Sharma and Kansal 2013).

2.5.1. Model Types

For simulating natural processes, empirical (statistical), deterministic or stochastic, and numerical or analytical (mathematical) modeling approaches are commonly used. Empirical models estimate concentrations by creating statistical relationships between the observed water quality measurements at different monitoring stations instead of explicitly modeling the underlying processes that govern water quality changes. The created relationship can then be used to predict changes under different model conditions and the variability of those changes. Because empirical models tend to be relatively simple, they are relatively easy to set up and highly usable (Dörnhöfer and Oppelt, 2016). Since empirical models are derived directly from the observations, they are also readily recognized by managers as being fairly practical for the purpose of testing management approaches. Empirical models have been used in many water quality assessment cases (Brezonik et al., 2005; Chen et al., 2007; Chen et al., 2008; Zhengjun et al., 2008; Binding et al., 2010; Sriwongsitanon et al., 2011; Zhao et al., 2011; De la Mare et al., 2012; Tebbs et al., 2013; Chao Rodríguez et al., 2014; Bonansea et al., 2015; Dörnhöfer and Oppelt, 2016; Su, 2017)

In deterministic models, the output of the model is fully determined by the laws of nature as well as parameter values and the initial conditions because deterministic models contain no random (stochastic) components. Each part of and input to the model is strictly calculated by mathematical equations. The behavior of each variable is determined entirely by the governing equations and the initial variable states. A given input always generates the same result and does not allow any random variation (Kıymaz 2017).

A stochastic model includes random (stochastic) elements or inputs into the calculations instead of deterministic models. A stochastic model aims to replicate certain mathematical properties of a water body. The model allows for random, probabilistic elements between two or more variables in the relationship. This randomness is due to model inputs, parameters, or system dynamics (Kıymaz 2017). Entries and results data are generated by statistical analysis and synthesis of time series. Therefore, the same results will not be obtained when these models are operated under the same conditions. Deterministic models are typically structured to represent internal physical processes, allowing a wide range of model applications that stochastic models cannot resolve (Ji 2008b).

Both model types have significant limitations. Deterministic models do not take into account variable uncertainty. Some complex deterministic models may require creating multiple optimum parameter sets where a single parameter cannot be studied as a single solution. On the other hand, stochastic models can be advantageous because they include variable uncertainty in the developed model (Kıymaz 2017; Zoppou 2001). Stochastic models are run only with existing data without detailed process information, and if this data is spaced, it may be insufficient for prediction. In addition, since stochastic models only reveal the current situation with the available data, it is impossible to develop a scenario that aims to see the future situation. Future situations of increasing water pollution can also be examined with deterministic models (Obropta and Kardos 2007).

Mathematical models can be either analytical or numerical. Analytical models provide an exact mathematical solution to the differential equations describing processes in a water body. They can generally be implemented for relatively restrictive conditions such as predicting 1-D, constant parameter systems under steady-state conditions. Analytical models are typically used to check the accuracy of complex numerical models, obtain first-order estimates of relatively simple systems, and to provide information about hydrodynamic and water quality processes in water bodies. However, most models for surface water systems are too complicated to obtain analytical solutions.

On the other hand, numerical models are discrete versions of a series of mathematical equations to describe processes in a water body, such as the continuity equation and momentum equations. The discrete series of equations are then translated into algebraic equations. Then, numerical solutions to the problem can be obtained by inserting initial and boundary conditions and running the program (Ji 2008b).

Numerical models can also be classified according to solution methods, temporal variability, spatial variability, and generic or site-specificity. Some of the commonly applied solution methods are finite difference method, finite element method and finite volume method (Ziemińska-Stolarska and Skrzypski 2012; Brebbia and Walker 2016; Orlob 1983; Connor and Brebbia 2013; Abbott 1979; Steven C Chapra 2008; MAHMOOD and YEVJEVICH 1975). Temporal variability is associated with having steady-state and dynamic models. Steady-state models (static) work with the assumption that dynamic equilibrium conditions have been achieved in a water body and are model parameters and variables are independent of time. The steadystate of a water body is the state of no change in the water body with respect to time. Unchanged properties include parameters such as temperature, pressure, river cross-section salinity and etc. It is also assumed that under steady-state conditions, water quality parameters do not change with time in the water body. Dynamic models, on the other hand, reflect the unstable nature of the system. Therefore, if the change of model parameters according to time is not negligible, dynamic models should be used. Calculations of steady-state models are simpler, and model results can be obtained in a shorter time. These models can be used if the assessment data of the water body of the system is long enough to stabilize (Grimsrud et al. 1976; Kıymaz 2017). For both steady and unsteady (dynamic) models, spatial variations can be exemplified as 0-dimensional, 1-dimensional, 2-dimensional, and 3-dimensional.

Although empirical models are easier to develop and apply, their applications are limited to some aquatic environments because they only provide a statistical approach with historical data. Mathematical models are more flexible in terms of applicability to different water environments (Erturk 2010). Some water quality models can include both empirical and mechanical models. At this point, naming the most dominant model is made according to the type of that model (Riecken and Branch 1995; Kıymaz 2017).

2.5.2. Current Available Models

In this section, the commonly used stream water quality models and their intended use are presented. Simulating complex water quality processes in a variety of environmental conditions has been done using a variety of commercial and open-source models. An overly complex water quality model will increase computation time and cost. However, in the absence of detailed data, uncertainty will increase. Therefore, using complex models is not always the best approach (Ejigu, 2021; Zheng and Bennett, 2002). In other words, model complexity, type of water body, data availability, water quality simulation capabilities, presence of open source code and successful working history of the models are important features to be considered in the selection of models to be used in water quality studies (Zheng and Bennett, 2002).

EPD-RIV1 is one-dimensional model and consisted of the hydrodynamics and water quality module. Basic equations used in the hydrodynamics module are conservation of momentum and continuity. The model solves those equations using the four-point implicit finite difference numerical scheme. The model can predict 16 water quality constitutes based on conservation of mass. The advection transport affected by biogeochemical interactions and diffusion is adapted to the equations (Martin et al., 2002; Tantemsapya et al., 2008).

The EPD-RIV1 water quality model (Martin, Wool, and Olson 2002) has been used to model Pong River, Thailand, for water quality management study (Tantemsapya, Wirojanagud, and Suwannakom 2008). The model has been calibrated manually with the field data of December 2006 and validated with the field data of May 2007 for the parameters of interest, temperature, BOD_5, and DO. In the 2nd segment of the Pong river, which is divided into separate segments according to DO and BOD_5 profiles, low DO levels are thought to be caused by the lagoon, which has nitrogen and phosphorus loads from the surrounding agricultural lands, have been detected. The major pollution sources over the water resource are agricultural activities which use 3,000,000 m^3/day water for irrigation, 218,850 population with the equivalent BOD loading to the river of 12.6 g BOD/person/day and four factories along the lower Pong River with water uses 32,000 m^3/day, 5000 m^3/day, 1000 m^3/day and 13,000 m^3/day, respectively. Different simulations have been made using different flow rates from the Ubolratana Dam in the

1st segment, and as a result, they found that the flow rates had a significant effect on BOD_5 and especially DO and the lowest flow rate that provides DO> 2 mg/L, which is the critical value for aquatic organisms in the river, is 22.65 m^3 /sec.

HSPF is a complex modeling software that consists of various operating modules. RCHRES is counted as one of the modules, and it has a few subroutines that deal with water quality calculations. HSPF uses a kinematic wave approach to calculate water flow in the stream. In HSPF, where many buried water quality variables can be modeled, user-defined variables can also be modeled. In addition, hydrolysis, oxidation with free radical oxygen, photolysis, volatilization, 1st-degree degradation, and biodegradation mechanisms that occur in the system can also be used in calculations (da Fonseca, 2014; Horn et al., 2004).

The HSPF model is used in the USA in 2008 to determine the total maximum daily loads (TMDL) of nutrients, nonionic ammonium, and dissolved oxygen that could be made to Lake Trafford, Florida. The main purpose of the study is to improve the lake water quality, which is known to have excess nutrients, high levels of nonionic ammonium and low dissolved oxygen values. Several load reduction scenarios had been applied until the lake has a trophic state index (TSI) level of 56 and a dissolved oxygen level of 5 mg/L. The reduction rates applied were 60% for TN and 77% for TP, and the long-term average concentrations for the parameters that enable these reduced rates to be achieved were 19.04 μg/L for Chla, 1.09 mg/L for TN, 0.025 mg/L for TP, and TN/TP ratio is used as 44 (Kang and Gilbert, 2008).

Developed by the EPA, Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a watershed scale multi-purpose environmental analysis system that supports the total maximum daily load approach. It is an advantage that data preparation processes can be carried out in the GIS interface in BASINS, which includes geographic information systems and can work in harmony with WASP, QUAL2E, SWAT, AQUATOX, and other similar water quality models (Ambrose et al., 2011; Lahlou et al., 1998).

For the Camp Creek and Little River Basins Assessment Program in Fulton State, Georgia, USA, BASINS 2.0 (Better Assessment Science Integrating Point and Nonpoint Sources) (Lahlou et al. 1998) model is used. Some of the major objectives of the watershed modeling are the representation of the present water quality conditions, quantification of pollutant loads and sources, assessment of water quality response to management alternatives, and prediction of water quality response to future land-use changes. After determining the purpose, modeling programs suitable for the purpose were evaluated, and the BASINS model was selected among eight programs in terms of suitability for in county use (Patwardhan 1999).

Developed to assist in identifying measures to improve water quality in the UK, SIMCAT is a 1-dimensional, equilibrium, and deterministic model. SIMCAT, which can determine the in-river fates and transports of conservative and non-conservative variables, uses Monte Carlo analysis techniques (Tsakiris and Alexakis, 2012).

Crabtree, Seward, and Thompson (2006), have used the SIMCAT model (Warn 2010) to provide underpinning scientific knowledge to make the Environment Agency identify strategies to enable their water quality targets to be achieved on four river catchments, Ehen, Kent, Derwent, and Eden, which they contain some regions are defined as the candidate Special Areas of Conservation (cSAC). Lakes within the river catchments have been included in the models as “black box” linear features to represent the observed behavior of pollutants passing through each lake. 1995-2000 monthly basis monitoring data have been used for model calibration, which has been done manually based on the controlling if the predicted mean values are within the criteria +/- the Standard Deviation (SD) of the observed values of flow and BOD, NH_4-N, DO, TON and PO4-P. A good fit has been achieved for flow and DO, both being well within the criteria of +/-1 SD of the observed values. Other parameters’ calibration results have been found unsuccessful for some modeling locations where the effluent discharge data were not consistent with the observed river quality, and in response to this lack of information, a 12-month data collection program has been carried out to collect additional quality data. After a more successful recalibration process, the model has been used to simulate 3 remediation scenarios to be able to comply with the water quality targets that the Environment Agency defines. Consequently, the study revealed that the reduction in mean daily PO_4-P load (kg/day) for each catchment after scenarios is %27.5, %26.2, %4 and %33.7 for Ehen, Kent, Derwent, and Eden, respectively.

The WASP model, which was developed by EPA and can be used in any size up to 3-dimensional, determines the transport and transformation of pollutants in surface waters. In the model, which has stable and unstable state options, benthic algae and sediment can also be modeled in addition to conventional pollutants. WASP, which offers flow routing and kinematic wave options, is one of the most widely used models (Ambrose and Wool, 2017).

Kaufman (2011) used the Water Quality Analysis Simulation Program (WASP) (EPA 2017) to model concentrations of dissolved nitrogen (DN) in the Altamaha River estuary, Georgia. Calibrated and validated using the Georgia Coastal Ecosystems Long Term Ecological Research project observations, the model yielded an average error of 39.8% for NH_3, 23.6% for NO_3, and 7.8% for DN between estimates and measurements. The results from the calibrated model revealed that the riverside DN inlet had about 6 times greater impact than the flow or temperature on the estimated DN in the estuary. In addition, it can be said that the generally predicted DN concentrations reach their highest levels in the system at high levels of DN inlets, high flows, and low temperatures.

The QUAL2E water quality and in-river flow model developed by the EPA is one of the most widely used models in the world. QUAL2E, which is a 1-dimensional and steady-state model, offers the opportunity to simulate up to 15 parameters, including conventional parameters. In the model, in which daily changes due to meteorology can be simulated in terms of temperature and dissolved oxygen parameters, river flows and pollutant flow rates can be entered as fixed values (Cox 2003). In the model, in which each river branch is represented by dividing it into sub-particles of equal length, it is assumed that the dissolved substances are fully mixed in these parts, advective transport occurs with the average flow, and dispersive transport occurs depending on the concentration gradient (Brown and Barnwell, 1987).

Paliwal, Sharma, and Kansal (2007), applied QUAL2E (U.S. EPA 1995) to determine the pollution loads and examine the influence of different scenarios on the river Yamuna during its course through the national capital territory of Delhi, India. The model was calibrated for the dry season to simulate BOD and DO profiles. The uncertainty analysis has also been performed with first-order error analysis and Monte Carlo simulation. The study stated that the river had low DO and high BOD levels, and out of 14 drains that entered the river at different points, the Najafgarh drain has been found to be the principle source of pollution. The lowest water quality status that can be used as drinking water is Class C, which has been determined by the Central Pollution Control Board, India. 4 scenarios have been used to achieve the water quality of the river corresponding to Class C, but any of those 4 scenarios couldn’t manage to get the water quality of the river reach Class C. This study indicates that without treatment, drains should not be permitted to discharge wastewater. Therefore common treatment plants are indispensable, particularly for all small-scale industries which are unable to afford effluent treatment. In order to meet the requirements, artificial aeration and flow augmentation are also required.

QUAL2K, developed by the EPA and an enhanced version of QUAL2E, is a 1-dimensional and steady-state water quality model. In QUAL2K, where 16 water quality variables can be modeled, including conventional parameters, water column-sediment relationships can also be taken into account. QUAL2K, which differs from QUAL2E with features such as allowing unequal river segments and providing more than one water inlet and outlet from each segment, is one of the most widely used water quality models in the world (Tsakiris and Alexakis, 2012).

The QUAL2K (S C Chapra, Pelletier, and Tao 2008) model was used in the Skudai river basin in Johor Bahru, one of the largest cities in Malaysia, which obtains 80% of its drinking water from river systems. The main reason Ahmad Kamal, Muhammad and Abdullah, (2020) choosing to model the Skudai river basin, which has 7 sub-basins, is that this region is highly developed, urbanized, and densely populated, and the reason they choose QUAL2K is its ability to simulate various scenarios for the branching streams that will mix laterally and vertically using water quality parameters. The model has been developed for extensive temporal water quality index (WQI) and classification analysis, various pollutant discharge scenarios, and NH_3-N mapping selected as the core pollutant using QUAL2K-GIS. The relative percentage difference was used to evaluate the model calibration and validation processes. %10, %50, and %70 of pollution discharge scenarios has been implemented and found out that at least %90 is required to improve the water quality classification to Class II. The study also concluded that a high concentration of NH_3-N had been found in the basin, especially during the dry season.

The HEC-RAS model, which can be operated in 1 and 2 dimensions, developed by the United States Military Engineers Association, can be used for steady and unstable state studies. Although it is generally used in flood studies, it is also used in the analysis of conventional pollutants. In the model using the control volume approach, quality calculations are made by solving the advection-dispersion equation (Fan et al., 2009).

In the Keelung River basin, an important tidal river in Taiwan, biochemical oxygen demand, ammonia nitrogen, total phosphorus, and sediment oxygen demand parameters were modeled using Qual2K and HEC-RAS models (Fan et al., 2009). Keelung River Basin was chosen as the study area because of its population of more than two million and the use of river water for domestic purposes. With the Qual2K model, the effect of pollutant loads on the mentioned parameters has been modeled. The reason for choosing Qual2K is explained as its wide use and ease of use. Since Qual2K does not calculate the tidal effect, the effect of tidal phenomena on water quality has been investigated by using the HEC-RAS model (Brunner 2016). HEC-RAS, which was developed by the US Army Corps' Engineers has been widely used in the estimation of river hydraulic characteristics (Knebl et al. 2005; Patel et al. 2017). Qual2K and HEC-RAS models were used together in order to create an alternative in case of insufficient dynamic monitoring data. It was also stated that the simulation results were compatible with the monitoring data. It has been determined that the most important of pollutant parameter in the basin is the biochemical oxygen demand.

The unstable state MIKE21 model is a comprehensive modeling system that can be applied to any 2-dimensional free-surface flow water bodies where stratification can be neglected. The model developed by the Danish Hydraulic Institute is capable of simulating hydrodynamics, advection-dispersion mechanism, short waves, sediment transport, water quality, eutrophication, and heavy metals (Warren and Bach, 1992).

Li, Huang and Wang (2020) have conducted a study at Donghu Lake in Wuhan, China in order to develop accurate simulation and prediction technology for lake water quality. For this purpose, they preferred the MIKE21 model because of its powerful processing capability in spatio-temporal numerical simulation of the free-surface flow of shallow water and development over decades. The main purpose of this study is to combine the temporal advantages of numerical simulations and the spatial advantages provided by remote sensing satellites to invert the water quality of the lake by creating a multi-source nonlinear regression fitting model (genetic algorithm (GA)-back propagation (BP) model).

WFD-Explorer model developed by an International Consortium intended to support water managers in identifying cost-effective strategies to achieve the ecological objectives in the Water Framework Directive. WFD-Explorer, which can work on a basin or sub-basin basis, has a well-developed graphical interface for its purpose. WFD-Explorer, a 1-dimensional steady-state model with a simplified structure in terms of hydromophology and water quality, attempts to roughly determine the non-living water body characteristics and relate them to ecological quality (Hoang et al., 2013; Mouton et al., 2009).

Water Framework Directive Explorer (WFD Explorer) model has been applied in the Zwalm River basin in Flanders, Belgium in order to analyse the impact of different restoration measures on river ecology based on expert rules embedded in this simulation environment. WFD Explorer reveals the effects of the measures on the water quality situation. WFD Explorer is a decision support system used for the implementation of WFD. Mouton and his colleagues (2009) have modeled the ecological quality of the basin and proposed several water quality and physical habitat restoration options to meet the European Water Framework Directive goals. Model estimates ecological quality ratios of a water body for fish or macroinvertebrates, ranging between 0 and 1, with the several linked ecological expert knowledge rules. There are different rules for different variables in the model. Due to the rules of the lack of flexible rules of the model, users are more reluctant to use this model. The values that the model calculates, the flow velocity, BOD_5, and Total Phosphorus concentration, have been chosen for the calibration process. Error terms of the study ranged between 2.7% and 13.1%. With Chosen 4 scenarios which can be count in briefly increasing connection of household point sources to sewage systems, constructing of wastewater treatment plants, meandering of the river channel and constructing buffer strips along the river channel, Water Framework Directives goals have been achieved in 26 out of the 29 water bodies after application of all scenarios.

AQUATOX, a mechanistic ecological risk assessment model developed by the EPA, is one of the most comprehensive models among surface water quality models. In the model developed in terms of ecotoxicology, in addition to conventional pollutants, organic toxicants, fish, plankton, macrophytes and similar pollutants can be modeled in the sediment and water column. The AQUATOX model, which also offers solutions for stratified systems by connecting fully mixed segments to each other, enables the solution of 3-dimensional systems thanks to this feature. It applies for the fourth and fifth-order Runge-Kutta integration routine by using adaptive step sizes as the solution method of differential equations (Park et al., 2008a).

The AQUATOX (Park et al.2008b; U.S. EPA, 2014) model has been used to demonstrate the ecological impact on the Crow Wing River basin with relatively low nutrients and the Blue Earth River basin with relatively high nutrients, according to the study (Heiskary and Markus 2001, 2003) conducted by the Minnesota Pollution Control Agency (MPCA). The HSPF model has also been calibrated and used to link land-use practices with nutrient concentrations, thereby ensuring upstream boundary conditions to run ecosystem simulations on AQUATOX. Nutrient concentrations have been modeled with AQUATOX in the system whose nutrient loads were determined by HSPF and to correlate these concentrations with response variables (such as chlorophyll-a and water clarity). Another of the aims of the study is to evaluate the creation of standards-based on nutrient criteria. Both AQUATOX and HSPF models have been calibrated using two years (1999-2000) nutrient and biological data. The Blue Earth River basin, which has a higher nutritional value from the two modeled basins, has been used in addition to the other basin study to create a nutrient water quality criterion and to reduce high nutrient values with specified reduction factors. The process of creating water quality criteria was carried out by determining the acceptable chlorophyll-a concentration value in the water column determined by the state or administrations and the nutrient concentrations that would provide the chlorophyll-a value determined in the AQUATOX model. After this process, 7 different mitigation scenarios have been determined and implemented in order to implement the best management practices (BMPs). Under current conditions (scenario A), mean annual chlorophyll concentrations in four out of six modeled years exceed the Method 1 (7.85 g/L) criterion, and in five out of six years, the Method 2 (7.5 g/L) criterion. Under the most stringent mitigation scenario (scenario G) the annual exceedances drop only slightly, to three and four years out of six, respectively (Carleton et al. 2005).

The Environmental Fluid Dynamics Code (EFDC) is a comprehensive model developed by the EPA. Hydrodynamics, sediment transport, water quality, eutrophication and toxic pollutant transport are the contents that can be studied through this model. The EFDC model, which can be used up to 3-dimensional, can perform steady-state and dynamic-state analysis. The EFDC model, which uses finite volume-finite difference spatial discretization as the solution method of differential equations, simulates 21 state variables, including conventional water pollutants, by solving the mass balance equations. It is one of the preferred models, especially in algae simulations.

In Daoxiang Lake, Beijing, Wu and Xu (2011) have used the EFDC (Hamrick 1992; Tetra Tech 2007) model, which was developed by U.S. Environmental Protection Agency, to simulate the eutrophication process and to assess the occurrence of algal blooms by creating a linkage between chlorophyll-a concentrations and algal blooms. The model has been calibrated with the field data from March 2008 to July 2008 and validated with the field data from August 2008 to October 2008. For the calibration process, primary production by algae, decomposition of oxygen-containing material, and the concentration of dissolved oxygen have been chosen as the key parameters. As a consequence, Wu and Xu (2011) found that, among 4 sampling stations, #1, #3 and #4 have more accurate chlorophyll-a predictions with the R^2 of 0.93, 0.45 and 0.46 respectively than #2 with the R^2 of 0.02. Moreover, they stated that the mean accuracy of algal bloom prediction is 63.43% according to chlorophyll-a concentration of 30 μg/L threshold to identify the occurrence of algal bloom.

The Soil Water Management Model (SWMM), a physically-based dynamic model developed by EPA, was developed to analyze the quantity and quality of stormwater flows (Yuan et al., 2020). Developed to simulate the rainfall-runoff relationship, especially in urban areas, SWMM is also widely used for the analysis of the effects of distributed pollutant loads and best management scenarios on watersheds. SWMM can be used as an input to other water quality models by monitoring the water quantity and quality on a sub-basin basis and by monitoring the flow, water depth and water quality on the basis of pipes and channels (Rossman 2015).

Tuomela, Sillanpää and Koivusalo (2019) have investigated the use of constant source concentrations in modelling pollutant loads by using the water quality package of Storm Water Management Model (SWMM) (Rossman 2015). Total suspended solids, total phosphorus, total nitrogen, lead, copper, and zinc were chosen for modelling process with SWMM using literature event mean concentrations (EMCs) for different land cover types and on-site rainfall and discharge data for a residential area in southern Finland. The study states that simulated loads obtained using literature-based EMCs, were often overestimated in comparison to the monitored loads at the catchment outlet. The exceedance has been explained by the dilution effect of large stormwater volumes on measured EMCs.

The Soil Water Assessment Tool (SWAT), a physically-based, semi-distributed, and dynamic watershed model, was developed in collaboration with the United States Department of Agriculture (USDA) and EPA (Yuan, Sinshaw, and Forshay 2020). The model creates unique hydrological response units (HRUs) by comparing land use and soil types in the watershed and calculates operations at this unit scale. The sum of the outputs generated by each HRUs in the watershed represents the overall situation in the watershed. In SWAT, which can be calculated on daily or hourly time scales, processes such as plant growth, evaporation from plant roots, and water loss, which are not common in other water quality models, can be simulated. In the model in which surface flow and groundwater flow are simulated by the kinematic wave approach, the Manning equation is used for channel flows. With the SWAT model, sediment transport, nutrients, and pesticides can also be simulated (Neitsch et al., 2005).

Kalcic et al. (2019), used the Soil&Water Assessment Tool (SWAT) (Neitsch et al., 2005; Neitsch et al., 2011) with 1 global and 4 regional different climate models to evaluate the state of Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP) in the context of global warming, which has increased in the Maumee River watershed which is the source of almost 50% of Lake Erie’s Western Basin phosphorus load, over last 20 years and caused harmful algal blooms. In the context of the study, the potential pathways have been identified with SWAT for the %40 reduction goal for the watershed. Researchers have calibrated the model for 2001-2005 and validated it for 2006-2010. The study’s findings reveal that due to increases in precipitation are mitigated by warmer temperatures, Maumee River phosphorus loads may decrease from the present by the midcentury. The study also indicated that annual TP and DRP loads would decrease 11% and 6%, respectively.

The summary of above-mentioned water quality models can be seen in Table 2.2.

Table 2.2. The properties of water quality models

(Source: modified from Kıymaz, 2017)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
SIMCAT	Environment Agency (UK)	1D	Steady State	-DO -CBOD -NH_3 -User defined conservative parameters	Windows	-	Stochastic, deterministic, Monte Carlo analysis techniques, requires low computational time with limited data, auto-calibration	Over-simplistic, doesn't account photosynthesis, respiration, sediment oxygen demand, and variation of re-aeration rate with flow	(Cox, 2003; Crabtree et al., 2006; Mateus et al., 2018; Tsakiris and Alexakis, 2012; Warn, 2010)
HSPF	US EPA & USGS	1D	Dynamic	-DO -pH -temperature -alkalinity -Inorganic Suspended Solids -Organic/ Inorganic Sediment -BOD -TIC -NH_3 -TN -NO_2/NO_3 -TP -Total Coliform -Aquatic Organisms -Toxic Chemicals -Pesticides	Windows	No	Conservation of mass balance, simulates the transient hydrological and the hydro-chemical response of a catchment, mostly used for large rural and agricultural areas, also includes flood control operations and planning	needs daily or hourly data, also needs extensive data and expertize modeling skills	(Ambrose Jr et al., 2009; da Fonseca, 2014; Kim and Ryu, 2019; Obropta and Kardos, 2007; Yuan et al., 2020)

(Cont. on next page)

Table 2.2. (Cont.)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
BASINS 4.5	US EPA	Depends on sub modules	Depends on sub modules	Depends on submodules	Windows	No	Multi-purpose environmental analysis systems with point/ non-point loads included, model package includes Hspf, Qual2e, Aquatox, Swmm, Swat and Wasp models		(Moffitt 2019; Yuan, Sinshaw, and Forshay 2020; Ambrose Jr, Wool, and Barnwell Jr 2009)
WASP8	US EPA	1D, 2D, 3D	Both Steady State and Dynamic options	-Temperature -pH -DO -CBOD -TIC -Organic N/ NO_2-NO_3/ NH3 -OP, PO_4 -alkalinity -salinity -phytoplankton -bottom-algae -SOD -detritus -Toxic chemicals	Windows, Linux and Mac	No	Conservation of mass theory solved with finite differences numerical method, converts algal death to CBOD, requires extensive data	Not handles mixing zone processes or non-aqueous phase liquids, potentially large external hydrodynamic file, requires extensive data	(Ambrose Jr et al., 2009; Kannel et al., 2011; Kıymaz, 2017; Mateus et al., 2018; Sharma and Kansal, 2013)
QUAL2E	US EPA & Tufts University	1D	Steady State	-DO -associated water quality determinants (up to 15)	Windows	No	In-stream flow and water quality model has an automatic uncertainty analysis	Unable to have a non-uniform mixing (2D-3D) and unsteady flow, Does not convert algal death to CBOD	(Ambrose Jr et al., 2009; Cox, 2003; Horn et al., 2004; Kannel et al., 2011; Kıymaz, 2017; Wang et al., 2013)

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Table 2.2. (Cont.)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
QUAL2K	US EPA	1D	Steady State	-DO -pH -CBOD -Nutrients -Algae -Various Pathogens -Detritus	Windows	No	Advection-Dispersion content transport and reaction equation, converts algal death to CBOD, has an auto-calibration	Unable to have a non-uniform mixing (2D-3D) and unsteady flow, does not simuşate river branches	(Kannel et al. 2011; Mateus et al. 2018; Q. Wang et al. 2013; Ambrose Jr, Wool, and Barnwell Jr 2009)
HEC-RAS	US Army Corps of Engineers	1D	Both Steady State and Dynamic options	-NO$_3$-N -NO$_2$-N -NH$_4$-N -Org-N -PO$_4$-P -Org P -Algae -DO -CBOD -Temperature	Windows	No	1D Advection-Dispersion equation solved with a control volume approach, generally uses for flood modeling studies, GIS capabilities are successful, Ability to import MIKE11 Cross Sections	Model code is not publicly available, Unable to have a non-uniform mixing (2D-3D), Modeling skews of hydraulic structures is limited to 30 degrees, Cannot currently account for steep slopes above 10% inside the model	(Brunner, 2016; Fan et al., 2009; Kıymaz, 2017; Knebl et al., 2005; Patel et al., 2017)
MIKE21	Denmark Hydrology Institute (DHI)	1D, 2D	Dynamic	-Salinity, DO, Temperature -Diss./ Susp. BOD -Sedimented BOD -NH$_3$, NO$_3$ -PO$_4$ -Faecal/ Total Coliforms -One or more user defined pollutant -12 component with the eutrophication module/5 component with metal module	Windows	Yes	solves the ADE for diss. or susp. substances using a 2-D form of the QUICKEST finite difference scheme has a powerful processing capability in the spatiotemporal numerical simulation of free-surface flow of shallow water	requires extensive data, stratification neglected	(Cox, 2003; da Fonseca, 2014; Li et al., 2020; Wang et al., 2013; Warren and Bach, 1992)

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Table 2.2. (Cont.)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
WFD Explorer	International Consortium	1D	Steady State	-BOD_5 -TP	Windows	No	46 different restoration measure includes in the model	Unable to have a non-uniform mixing (2D-3D) and unsteady flow, simplified description of the hydromorphology and the water quality of the water bodies	(Hoang et al., 2013; Mouton et al., 2009)
AQUATOX	US EPA	1D, 2D, 3D	Both Steady State and Dynamic options	-Nutrients -Organic Chemicals -Suspended and Bedded Sediments -Macrophytes -Algae	Windows	No	MBE-differential equation solved with 4th and 5th order Runge Kutta integration method, mostly used for the aquatic ecosystem, reveals the effects of pollutants over fishes and invertebrates	Assumes each segment is well mixed, does not allow dynamic stratification; Macrophytes and algae are simulated as steady-state	(Park et al., 2008; Sharma and Kansal, 2013; U.S. EPA, 2014)
EFDC	US EPA	1D, 2D, 3D	Both Steady State and Dynamic options	-COD & DO -Coliform&Bacterias -Diatom/Green algae -Refr./Lab. POC, Diss. C -Refr./Lab. POP, Diss. Org P, TP -Refr./Lab. Org N, Diss. Org N, NH_4-N, NO_3-N -Silica & TAM	Windows	No	solves MBEs with a finite volume-finite difference spatial discretization for dissolved and suspended materials. Has also include the sediment diagenesis model for remineralization.	Requires a long period of in-depth study, with a large amount of difficult data acquisition	(Ambrose Jr et al., 2009; Hamrick, 1992; Park et al., 2008; Tetra Tech, 2007; Wu and Xu, 2011)

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Table 2.2. (Cont.)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
SWMM	US EPA	-	Dynamic	-TSS -TP -TKN -NH_3-N -NO_2+NO_3-N -BOD & COD -Pb -Zn -Cu -Other conservative pollutants (up to 10)	Windows	No	Tracks the quantity and quality of runoff generated by stormwaters within each subcatchment and transports that runoff through a system of pipes, channels, storage devices, pumps, and regulators	does not simulate pollutant loads from atmospheric deposition, quality simulation in SWMM is weak in the representation of the true physical, chemical, and biological processes that occur in nature	(Niazi et al., 2017; Obropta and Kardos, 2007; Rossman, 2015; Tuomela et al., 2019)
SWAT	USDA Agricultural Research Service (ARS)&US EPA	-	Dynamic	-Sediments -Nutrients -Pesticide Loads -Crop Growth	Windows	No	Based on the solving of water balance equations, uses HRUs which are lumped land areas within the subbasin that are comprised of unique land cover soil and management combinations, Computationally efficient, enables users to study long-term impacts	lackness of the ability to model flow in a complex sewer network that can operate under partially free-surface and partially pressurized flow and of experience backwater conditions, or subwatersheds, consisting of pervious & impervious areas with the specific configuration of connection to the sewer network	(Neitsch et al., 2005, Neitsch et al., 2011; Niazi et al., 2017)

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Table 2.2. (Cont.)

Model Name	Organization/ Institution	Dim.	Hydrologic State	Modeling Capability	Operating System	License Require-ment	Explanations	Weakness	Reference
EPD-RIV1	Georgia Environmental Protection Division	1D	Both Steady State and Dynamic options	-Temperature -CBOD/ CBOD2 -Nitrogenous BOD -Organic Nitrogen -NH_3-N -NO_2+NO_3-N -DO -Organic P -Phosphates -Algae -Dissolved Fe -Dissolved Manganese -Coliform Bacteria -Arbitrary Constituent 1-2 -Macrophytes	Windows	No	The hydrodynamic model solves the St. Venant equations as the governing flow equations using the widely accepted four-point implicit finite difference numerical scheme, Flexible geometry specification and time-series input available, time varying boundary conditions, lateral inflows, and withdrawals are available	Unable to have a non-uniform mixing (2D-3D), Velocities are assumed to be adequately represented by an average value over the cross-section, The assumption of homogeneity over the cross-section is rarely completely true, and The model does not include sediment transport processes such as scour and deposition and the sediments affecting rates of oxygen demand and nutrient releases	(Adu and Kumarasamy, 2018; Martin et al., 2002; Tantemsapya et al., 2008)

CHAPTER 3

METHODOLOGY

3.1. Modeling Objective and Model Development

Water quality deterioration in watersheds directly affects both people and ecological life in that ecosystem. Bakırçay basin, where industry and agriculture are intensely maintained, is under heavy pollution pressure with the pollutants coming from these sources. Bakırçay River, which also provides irrigation water to many agricultural areas, can be defined as polluted in terms of carbonaceous contaminants, nutrients, and metals' organic pollutants. This pollution also reduces dissolved oxygen levels in the river.

AQUATOOL decision support system's modules, EVALHID, SIMGES, and GESCAL was employed for developing and utilizing scenarios to be able to assess water quality status in Bakırçay watershed. AQUATOOL was preferred over other models due to its ability to have flexibility in the design, implementation, and operation of the system.

3.2. AQUATOOL

3.2.1. General

Developed by the Technical University of Valencia, AQUATOOL is a comprehensive model package that provides decision-making support to users in the planning and managing of water basins in hydrology, water quality, and water allocation. AQUATOOL is an environment for developing and improving the decision support system (DSS) for watershed and water resources planning. As a DSS, it offers tools to aid in the study of different water quality problems. The software allows the configuration of a water supply infrastructure and its related databases (physical features, management conditions) to be planned and graphically implemented for subsequent optimization and simulation, among other things. The model consists of many modules that can work integrated with each other. AQUATOOL makes it possible to choose management alternatives and to use the optimization module to design process parameters, as well as to run management simulations using the simulation model for different alternatives. As a simulation model, it can also be used as a support mechanism for managing resources between conflicting conditions and to analyze the impacts of future system improvements. These modules and their connection can be seen in Figure 3.1 (Andreu, Capilla, and Sanchis 1991). AQUATOOL is extensively applied to basins or water resources systems.

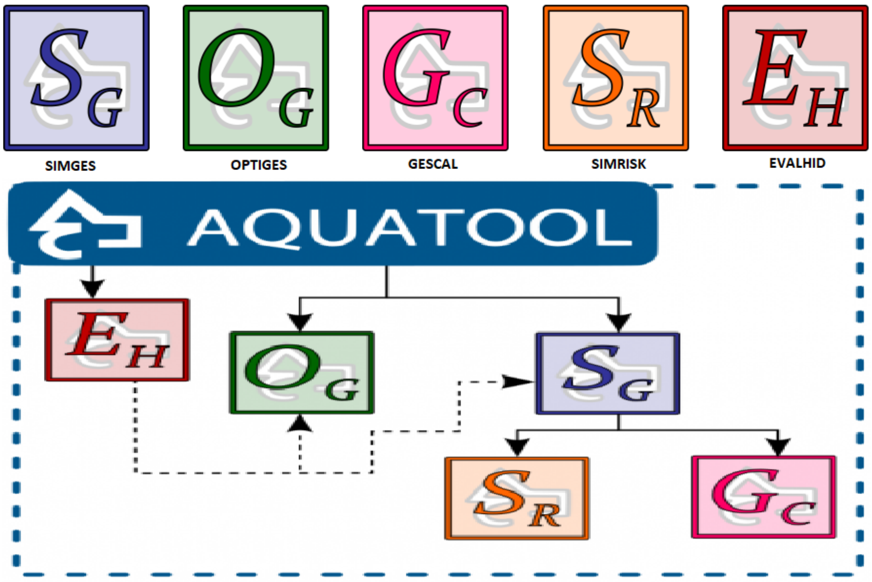
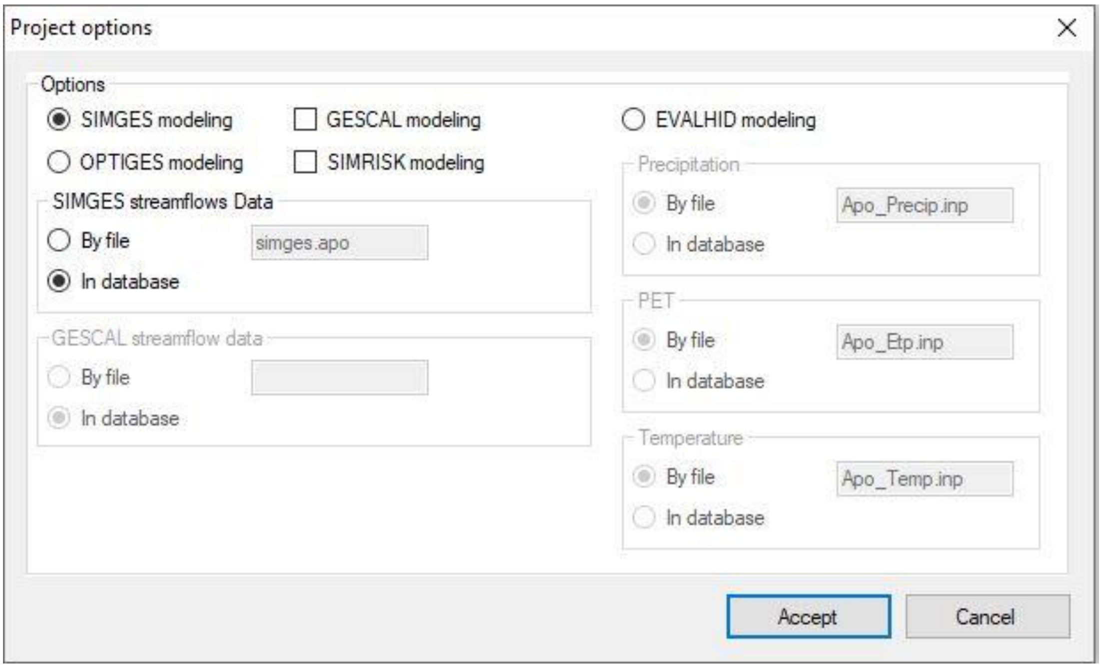


Figure 3.1. Aquatool modules and the relations between modules

The project options window and the main interface of software can be seen in Figure 3.2 and Figure 3.3.



Project options

Options

● SIMGES modeling

☐ GESCAL modeling

○ EVALHID modeling

○ OPTIGES modeling

☐ SIMRISK modeling

SIMGES streamflows Data

○ By file simges.apo

● In database

GESCAL streamflow data

○ By file

● In database

Precipitation

● By file Apo_Precip.inp

○ In database

PET

● By file Apo_Etp.inp

○ In database

Temperature

● By file Apo_Temp.inp

○ In database

Figure 3.2. Aquatool project options

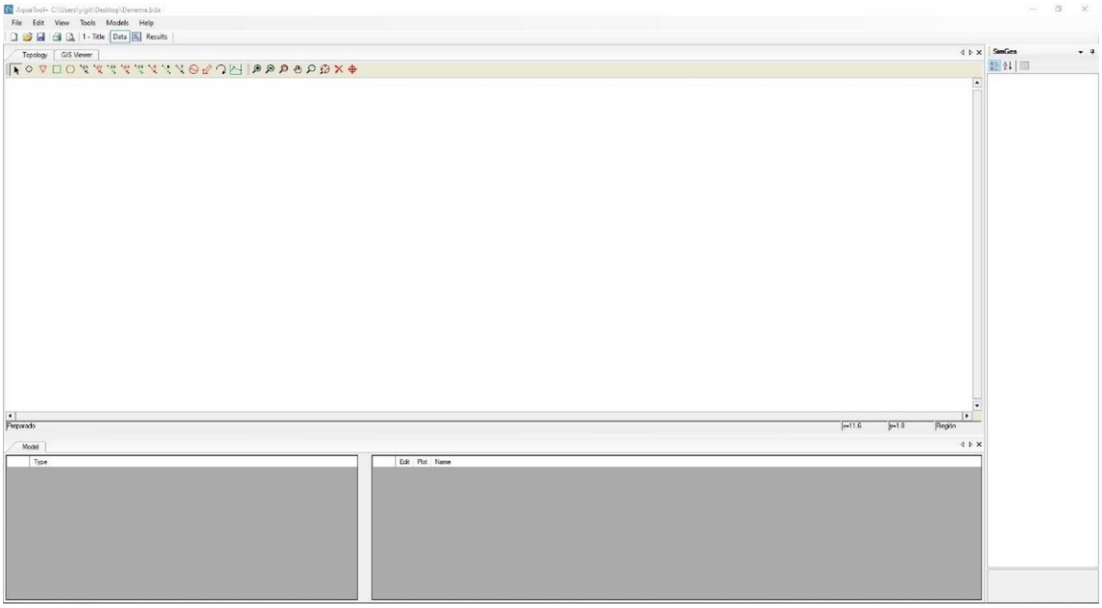


Figure 3.3. Aquatool main interface

3.2.2. EVALHID Module

EVALHID hydrological module is a module that calculates runoff, seepage, and percolation components by modeling the rainfall-flow relationships of basins. The module contains several types of models that can be selected depending on the data availability, the complexity of the basin, and the user's experience in developing and calibrating hydrological models (Pedro-Monzonís et al. 2016). All the models in the EVALHID module are aggregated on a sub-basin basis for semi-distributed implementations. Some of the models in the EVALHID modules can be counted as Témez, HBV, SAC-SMA, GR4J, and GR2M. The Témez model is a model with several parameters for the evaluation of water resources with a long history of application in Spain. Its low number of parameters makes it particularly suitable for basins with less data (Témez 1977).

The HBV model, used frequently in Scandinavian countries, allows hydrological modeling where there are not many parameters, so it is quite versatile in many cases (Bergström 1995), and its scheme can be seen in Figure 3.4.

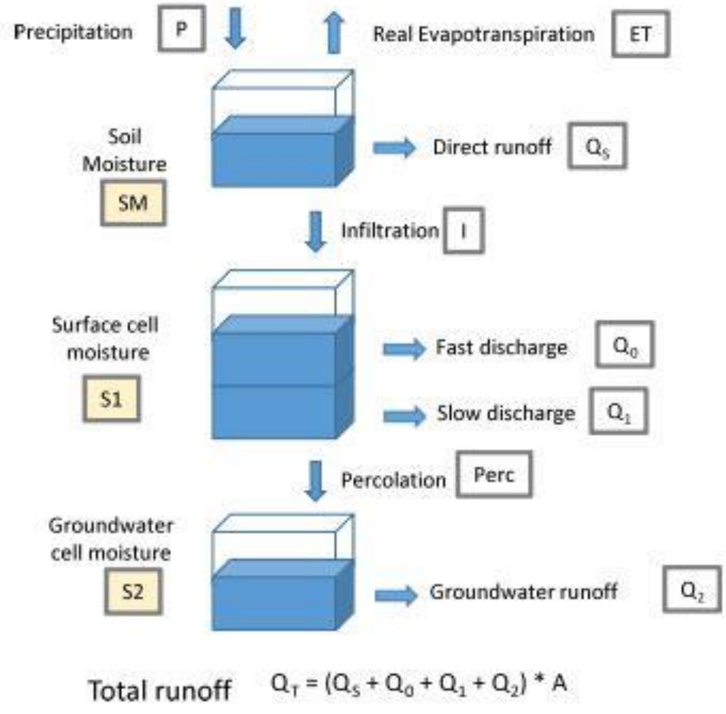


Figure 3.4. Schematic flow and storage of HBV model

(Source: Pedro-Monzonís et al. 2016)

The Sacramento model, also known as "SAC-SMA", is a model with a high number of parameters, up to 16, allowing very detailed modeling of hydrological processes when data are widely available (Burnash, Ferral, and McGuire 1973).

The GR4J model is a global hydrological model with four parameters developed by Perrin et al. (2003). It is an empirical model, but its structure is similar to conceptual models. It considers moisture and consists of two tanks (production and orientation). Unit hydrographs have been correlated to take into account the hydrological behavior of the basin.

And finally, GR2M is a collective model that simulates flows over time intervals. The model converts precipitation into a runoff by applying two functions: a production function and a transfer function (Mouelhi et al. 2006). The diagram of GR2M model can be seen in Figure 3.5.

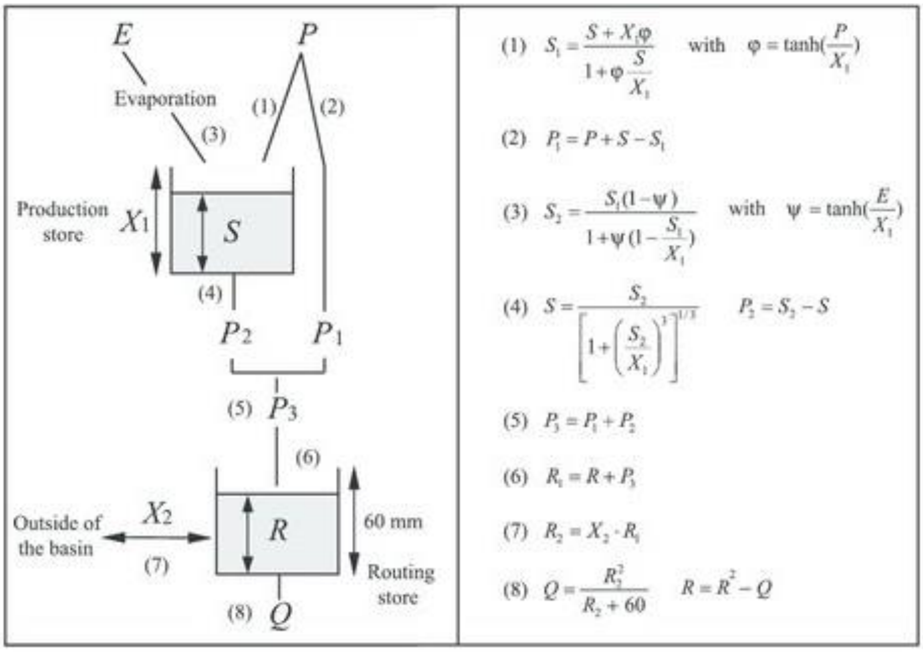


Figure 3.5. Structure of the GR2M model

(Source: Mouelhi et al. 2006)

The EVALHID module requires the following basic hydrological data in order to use the above models in itself; rainfall and temperature as time series, potential evapotranspiration (PET) and natural flows (for calibration purposes).

3.2.3. SIMGES Module

SIMGES is a mathematical model that executes a monthly simulation of system operational management. SIMGES model is based on the conceptualization of water resource systems using elements representing the reach of rivers, channels, reservoirs, aquifers, desalination plants, the direct use of treated wastewater, the artificial drainage of aquifers, the use of water of various kinds (urban, agricultural, industrial, hydroelectric, etc.), and other features of the basin (Paredes-Arquiola et al. 2010). The sub-basin or intermediate basin flows calculated by the EVALHID module are used as input currents in the SIMGES module. In order to find a flow solution compatible with the specified constraints, the SIMGES module simulates the water supply system on a monthly time scale through a simple flow balance in a flow network. The SIMGES module includes aquifers, the relationships between rivers and aquifers, infiltration into groundwater, their return to the surface system, evaporation and seepage losses from reservoirs, environmental flows, and power generation from hydroelectric power plants, as well as taking into account different water use needs. In addition, the SIMGES module helps us to identify operating rules that can help enhance integrated river basin management by reproducing source-demand interactions (Andreu, Capilla, and Sanchis 1991; Pedro-Monzonís et al. 2016). To use the model, a scheme must be constructed by the user with the elements that the user must specify. Nodes with and without storage capacity, 5 types of channels, hydrological inflows, consumptive demands, connections of consumptive demands, hydroelectric plants, aquifers, return elements, artificial recharge facilities and additional pumping facilities can be given as the types of elements (Andreu, Capilla, and Sanchís 1996). For the simulation of water resource systems, different elements may be considered: inflows or impaired flows; streams, rivers, and artificial channels are modelled with flow elements; nodes are intersection points that are used to describe the system's topology or to integrate such elements as inflows, etc.; reservoirs are nodes where storage is permitted; consumptive demands are defined by monthly demand curves; surplus demands can be incorporated into the system by return elements; each demand can be supplied from one or more intakes or sources; non-consumptive demands (e.g. hydropower plants) are defined by objective monthly flows; and various methods can be used to model aquifers, from simple tanks to advanced distributed models (e.g. hydropower plants) (Paredes-Arquiola et al. 2010).

The system 's management is integrated into the model by means of multiple tools. For the reservoirs, zoning and priority structures are specified. The availability of different demands is characterized by another set of priorities. The software has the option of specifying rule curves for single reservoirs or for groups of reservoirs, in addition to the priority scheme. Therefore, if the volume stored is less than the value specified in the curve, it is possible to add restriction coefficients for various elements such as intakes, demands, channels, pumps, etc. A flexible approach to determining the management practices of the systems is the operating rules specified by rule curves (Paredes-Arquiola et al. 2010).

These elements must have some operating policies as well as their physical properties. These operating policies can be counted as target volumes and zoning for reservoirs, inter-reservoir relationships, target supply, target flow, inter-demand relationships, inter-channel relationships, and inter-element relationships(Andreu, Capilla, and Sanchís 1996). The resulting schematic representation of the networks of water resources is converted into a complex network of arcs and nodes consisting of a conservative flow. Arcs are defined by the origin and final node, maximum and minimum flow, and unit flow cost representing either real flows across rivers, channels, etc., or virtual flows required to accurately reflect physical constraints, management policies, and nonlinearities accounting. Mathematically, the simulation process is based on the resolution of the flow network for each time phase (in this process, the monthly time scale is used). This describes a problem of optimization that can be described by an objective function and a series of restrictions (1 and 2) (Paredes-Arquiola et al. 2010):

$$Min \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{1}$$

$$\begin{aligned} &\sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = 0 \qquad \forall i = 1, \dots, m \\ &x_{ij} \geq l_{ij} \quad \forall i = 1, \dots, m \quad \forall j = 1, \dots, m \\ &x_{ij} \geq u_{ij} \quad \forall i = 1, \dots, m \quad \forall j = 1, \dots, m \end{aligned} \tag{2}$$

Where x_{ij} is the flow from node "i" to node "j"; c_{ij} is the flow unit cost, the lower and upper flow limits for the arc from node "i" to node "j" are l_{ij} and u_{ij}. With the Out of Kilter algorithm (Jewell 1962), this question is solved. In the problem formulation, some nonlinearities are directly accounted for by piecewise approximation, and some others by means of successive approximations until convergence is achieved.

One of the differences which separate SIMGES from other network flow models is SIMGES incorporates groundwater components into the water-resource systems. SIMGES provides a wide variety of approaches to groundwater modeling. The user should select from the following types of models, depending on the amount of data available from hydrogeological studies and/or the necessary degree of detail needed to reflect aquifers realistically; reservoir type, aquifer with discharge through a spring, aquifer hydraulically connected to a surface stream, aquifer hydraulically connected to two surface streams and finally distributed model of a heterogeneous aquifer of irregular shape (Andreu, Capilla, and Sanchís 1996).

The model utilizes an optimization algorithm to deal with the different elements' decisions needed each month. Using the data generated by the control unit regarding the scheme and its operating laws, the model builds an internal flow network using the principle of mass conservation. A set of arcs and nodes designed to represent the physical characteristics of the element and the management rules are generated by each element of the scheme. The out-of-kilter algorithm (Jewell 1962) optimizes this internal network, which is transparent to the user. The results take the form of water allocations among the different uses that minimize the weighted deviations from the targets, depending on the priorities for the weights (Andreu, Capilla, and Sanchís 1996).

Simulation of the aquifers is done after initial values for the decisions are obtained via the optimization algorithm. This provides values of the relationships between surface water and groundwater that are modified throughout the network. Before consistency is achieved, the iterative process continues. With iterative solving of the optimization problem, other nonlinear processes such as evaporation, filtration, losses from reservoirs and river reach, nonlinear flows in reaches, etc., which are not solved by internal piecewise approximation, are solved (Paredes-Arquiola et al. 2010).

Under multiple scenarios (including climate change scenarios), the resulting decision support systems can be used to test different alternatives, including vulnerability analysis and risk management. For each element of the scheme, SIMGES generates the normal range of results, consisting of simulated flows and/or storage levels, spanning each month within the time horizon. In addition, a description, including mean values and performance measures, of the simulation is given by the SIMGES. These are created by report files (i.e. plain text and numerical values) or files to be used as input for other AQUATOOL components. A module has been included for visualizing reports and files without having to leave AQUATOOL. This module helps the user to browse through all the papers, hydrological details, and intermediate files before sending them, if necessary, to a printer.

3.2.4. SIMRISK Module

The SIMRISK model is used to assess the risks arising during the actual operational management of the system. The model simulates the management of the system, using the same schema and databases as SIMGES, but with some differences. These differences can be summarized as follows:

- The time period is much shorter (generally months rather than decades) than in the planning mode.
- The model of risk assessment repeatedly simulates the system 's output using synthesized hydrological records suited to the hydrological conditions at the beginning of the time cycle.
- The performance of SIMRISK contains the probabilities of failure for each element of the water resource system in each time period.

The review of SIMRISK 's findings provides the decision-maker an indication of the risks involved if, during the months ahead, the target supplies are kept at their nominal prices. If the findings suggest an unacceptable risk, SIMRISK may conduct a new evaluation of the degree of supply restriction (ranging from zero to unity) in question. In this way, various limitations may, for example, be extended to municipal and agricultural demands.

3.2.5. OPTIGES Module

In the sense that the design of the user interface and its handling are pretty much alike, the optimization element of AQUATOOL is similar to the simulation component. The key difference between the simulation component and the optimization component is that the number of scheme-defining elements available to the user is reduced and restricted to nodes without storage capacity, nodes with storage capacity, channels, hydrological inflows, demands, and return elements. Another difference is that the optimization technique does not include the zoning of the reservoirs. In the optimization model, all the above elements are integrated in a simplified way (Chavez-Jimenez et al. 2013; Andreu, Capilla, and Sanchís 1996).

The optimization model does not give exact results. Instead, the first approaches produced by the optimization model are used in the simulation model. The OPTIGES model allows supply (objective function) to be distributed from the streamflow, regulation, and demand volumes (system variables), with priority parameters being considered as constraints due to the form of demand and depletion by evaporation and environmental flows. The control unit transforms the scheme 's graphical meaning into a numerical description and transfers the necessary data to the optimization model, OPTIGES, including the time horizon. The model then builds an internal flow network based on mass conservation, which contains and optimizes the time dimension via the out-of-kilter algorithm (Bazaraa, Jarvis, and Sherali 2011). Minimizing the weighted sum of the deficits in demands and minimum flows is the objective function. In this process, weights determined by the decision-maker are taken into consideration. The optimization is done in multiple iterative cycles to account, among other factors, for reservoir evaporation and return flows (Andreu, Capilla, and Sanchís 1996).

3.2.6. GESCAL Module

GESCAL is a modeling module for water quality that makes it possible to model water quality in all of the basin's water bodies and for various management alternatives.

Stream flows and storage calculated by the SIMGES flow modeling model can be used as inputs to the water quality model of GESCAL. Although water quality has been considered in all elements of the simulation models, physical-chemical processes have been taken into account only in streams and reservoirs (or lakes). The constituents which can be modelled with GESCAL can be seen in Table 3.1.

Table 3.1. The details of the constituents modelled in the GESCAL module

Constituent	Details
Temperature	The model employs the solution of equilibrium temperature suggested by Edinger and Geyer (1965).
Arbitrary Constituents	Identified as the ones for which it is possible to model degradation as a kinetic first order and/or with a sedimentation velocity. Only computational capacity restricts the maximum number of arbitrary constituents.
Dissolved Oxygen	Divided into 3 possible levels of complexity. The simplest level takes CBOD and dissolved oxygen into account. The second stage considers the nitrogen cycle and the dissolved oxygen effect. They consider ammonia, nitrites and nitrates. The final degree of difficulty makes it possible to model CBOD, the cycle of nitrogen, phytoplankton, and phosphorous, and their interactions and effects on dissolved oxygen. A schema of the processes is considered as shown in Figure 3.6.

Because of the impact of temperature on many systems, it is important to take it into account. On the other hand, it is usually difficult for water temperature simulation to obtain sufficient meteorological data on a basin scale. Thus, the temperature can be modelled in GESCAL, or it can be inserted into each variable as an entry. Later on, this input temperature, or the modelled one, is used to correct the coefficients of the other processes.

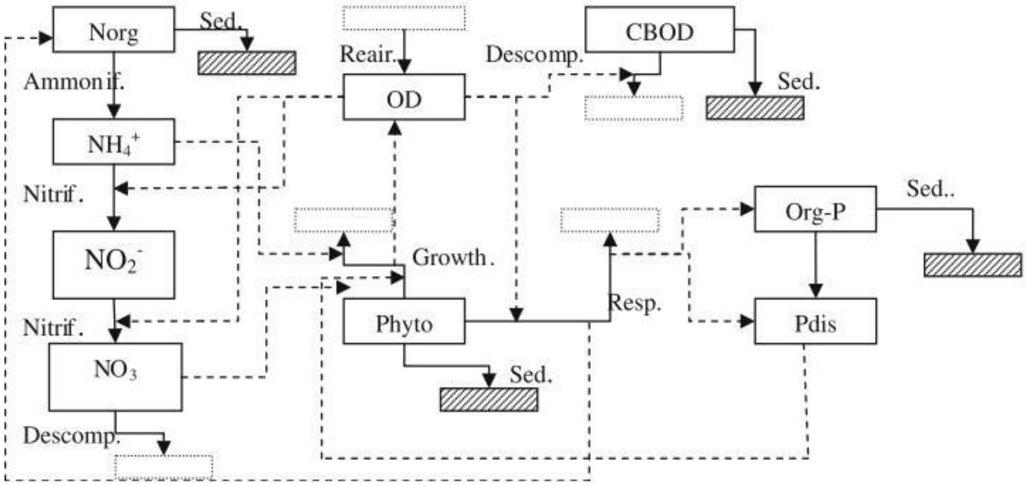


Figure 3.6. Eutrophication processes in the GESCAL

(Source: Paredes-Arquiola et al. 2010)

The physical processes considered when modeling the water quality of rivers are dispersion and advection. For water quality in rivers, one-dimensional and pseudo-stationary conditions are assumed. The water quality model predicts the water quality for each one of the months simulated with the water quantity simulation model. The model is pseudo-stationary since the mass balance equations are iteratively solved for each month until the water quality predictions for the river converge, with given loads, flow, concentrations of data, etc. By power relations or Manning equations, hydraulic components in the rivers are determined. Point loads and dispersed components of pollutants should be considered, and filtration or gaining relationships consider the hydraulic interaction with aquifers. Figure 3.7 represents a model scheme for rivers.

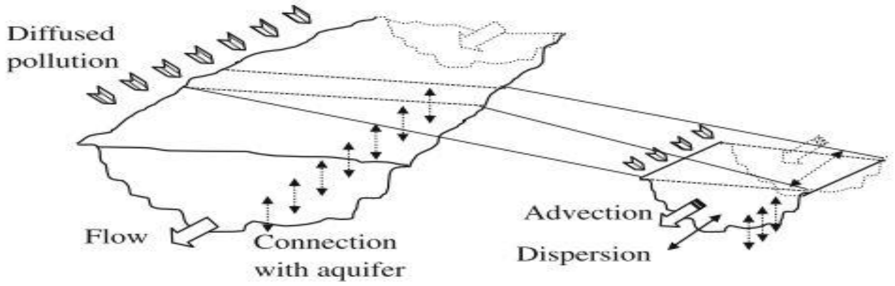


Figure 3.7. River discretization in GESCAL system

(Source: Paredes-Arquiola et al. 2010)

The following equation (3) is constructed for each constituent:

$$0 = \frac{d}{dx}\left(E\frac{dC}{dx}\right) - \frac{d(uC)}{dx} + \frac{S_d + C_e q_e - C q_s + \sum S_i}{V} \tag{3}$$

Where E is dispersion ($m^2 day^{-1}$); C is constituent concentration (mg/l); C_e is aquifer water concentration (mg/l); x is river reach length (m); u is velocity (m day^{-1}); V is volume of the differential element (m^3); q_e is aquifer flow ($m^3 day^{-1}$); q_s is river to aquifer seepage filtration (m^3 day^{-1}); S_d is diffuse pollution (g/day). ΣS_i (g) represents the set of processes that eliminate or add matter to the element. S_i term depends on the constituent being modeled, and it is explained in the Appendix (Paredes, Andreu, and Solera 2007).

By a finite difference method, the differential equations are solved, including fragmentation of the flow into differential parts. Diffuse pollution and hydraulic relationships with any aquifer are considered to be spatially uniform. The numerical resolution of the finite difference consists of a tridiagonal linear equation system being solved (Paredes-Arquiola et al. 2010).

For water quality in reservoirs and lakes, a two-layer model approach representing epilimnion and hypolimnion is used (Figure 3.8). Alternatively, for modeling well-mixed reservoirs, a Continuous Stirred Tank Reactor may be considered. The water quality model is dynamic in time due to the evolution of the storage in the reservoirs. For each reservoir, the monthly distribution of thermocline depth and the distribution of inputs and outputs for each layer must be introduced add as input to the model. The model then calculates if the volume is enough to enable stratification in each month. Water quality can be modelled for each reservoir as a single layer for some months and as two layers for other months due to the reason mentioned above. The diffusion between the two layers is considered in this last scenario. The general formulations for every constituent are expressed by equations 4 and 5.

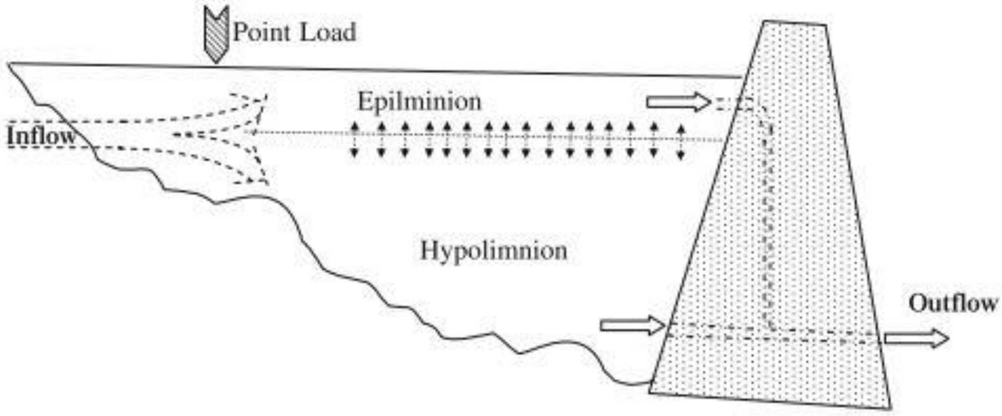


Figure 3.8. Water quality modeling diagram in reservoirs

$$V_1\frac{dC_1}{dt}+C_1\frac{dV_1}{dt}+C_{1/2}\frac{dV}{dt}=Q_{1e}C_e-Q_{1s}C_1+E'_{12}(C_2-C_1)+\sum S_{i1} \tag{4}$$

$$V_2\frac{dC_2}{dt}+C_2\frac{dV_2}{dt}-C_{1/2}\frac{dV}{dt} \\ =Q_{2e}C_e-Q_{2s}C_2+E'_{12}(C_1-C_2)+Sed+\sum S_{i2} \tag{5}$$

Where the subscript “1” represents the epilimnion or upper layer; the subscript “2” represents the hypolimnion or lower layer; V_1 and V_2 are the volumes of the layers (m^3); V is the gain or loss (if negative) in a volume of the epilimnion over the hypolimnion due to heating or cooling throughout the month (m^3); C_1 and C_2 are the concentrations of each layer (mg/l); $C_{1/2}$ is the concentration of the hypolimnion if the volume increase is negative and of the epilimnion, if it is positive (mg/l); C_e is the influent water concentration (mg/l); t represents the variable time; Q_{1e} and Q_{2e} are the flow inputs in the time interval (m3/day); Q_{1s} and Q_{2s} are the outputs in the time interval (m^3/day); Sed is the constituent flux from the sediment (g/day); S_{i1} and S_{i2} are the set of degradation processes or contribution of the constituent in the water body (see Appendix). E'_{12} represents the dispersion coefficient between both layers (m^3/day), which is estimated as following equation 6. It must also be noticed that units with a time interval of 1 day have been written.

$$E'_{12} = \frac{E_{12}A_{12}}{Z_{12}} \tag{6}$$

Where E_{12} represents the vertical diffusion (m^2t^{-1}); A_{12} is the area between the two layers (m^2); Z_{12} is the height of the thermocline (m). For the case of modeling as a completely stirred tank reactor, the equation to be solved is the following equation 7;

$$V_1\frac{dC_1}{dt} + C_1\frac{dV_1}{dt} = Q_{1e}C_e - Q_{1s}C_1 + V_1\sum W_i \tag{7}$$

GESCAL uses the flow results for rivers and reservoir volumes from the SIMGES module. Hence, the simulation time is the same for both models. The GESCAL model 's results are the time series of the concentrations of constituents in each stretch of the river and the time series of the concentrations of constituents in each reservoir layer (Momblanch et al. 2015).

CHAPTER 4

MODEL APPLICATION

4.1. Modeling Objective and Model Development

Water quality deterioration in watersheds directly affects both people and ecological life in that ecosystem. Bakırçay basin, where industry and agriculture are intensely maintained, is under heavy pollution pressure with the pollutants coming from these sources. Bakırçay River, which also provides irrigation water to many agricultural areas, can be defined as polluted in carbonaceous contaminants, nutrients, metals and organic pollutants. This pollution also reduces dissolved oxygen levels in the river.

AQUATOOL decision support system’s modules, EVALHID, SIMGES, and GESCAL was employed for developing and utilizing scenarios to be able to assess water quality status in Bakırçay watershed. AQUATOOL was preferred over other models due to its ability to have flexibility in the design, implementation, and operation of the system.

4.2. Site Description

Bakırçay basin is located in the north of the Aegean Region, between 27°- 28° East longitudes and 39°- 40° North latitudes (Figure 4.1.). The river, which takes its source from Kocadağ, passes through Karakurt Strait and enters into Kırkağaç Plain has a length of 120 km (Danacıoğlu, 2017; SYGM, 2018). In the basin, where the mountain system extending in the east-west direction is observed, the topography is generally undulating, hilly, and cleft, except for small river valleys and bottomlands (Velibeyoglu et al. 2015). Bakırçay River, which takes its resources from Madra Mountain in the north and Yunt Mountain in the south along with its linear flow, is fed by many branches; According to the spatial analysis which is made by the General Directorate of Water

Management (SYGM), it has a basin area of 3393 km^2 (SYGM, 2019). The source streams which feeds the Bakırçay River towards the flow direction are Gelenbe Creek, Aksu, Yağçıllı, Menteşe, Ilıca, Karadere, Kırkgeçit, Gümüş, Kestel, Bergama, Sınır, Boğazasar and Sarıazmak creeks. Connecting with the biggest branch of the Middle Basin, Yağçıllı Creek, Bakırçay passes through the Zeytindağ Plain and flows into the Aegean Sea from Çandarlı Plain (Danacıoğlu 2017).

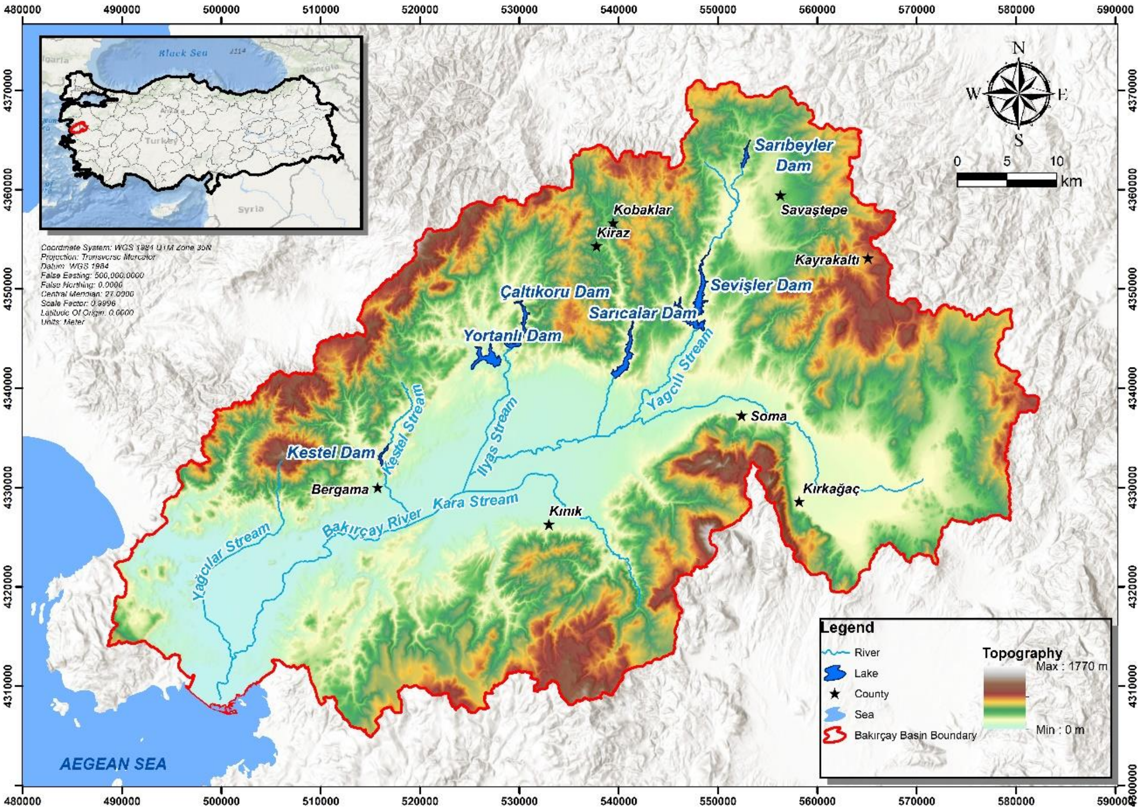


Figure 4.1. The site location map of Bakırçay watershed

4.2.1. Geological Properties

Bakırçay basin consists of Paleozoic, Mesozoic, Tertiary and Quaternary rocks (Danacıoğlu 2017). The geological map of this region is given in Figure 4.2. Most part of the study consists of alluvium, which has an important groundwater potential. The distribution of geological units in the Bakırçay watershed can be seen in Table 4.1. The result shows that most parts of the study area consist of alluvium and terrestrial deposits. In addition, volcanic rocks are also observed in other parts of the study area where these rocks have jointed aquifers.

Table 4.1. The geological unit areas in Bakırçay watershed

Geological Unit	Area (km^2)
Alluvion	707.94
Andesite	654.60
Undivided Terrestrial Deposits	751.01
Basalt	2.85
Flysch	5.82
Granite, granodiorite	69.53
Limestone	323.68
Marble	56.65
Metamorphic units	70.03
Metamorphic series	244.70
ophiolitic melange	0.64
Volcanics	487.58

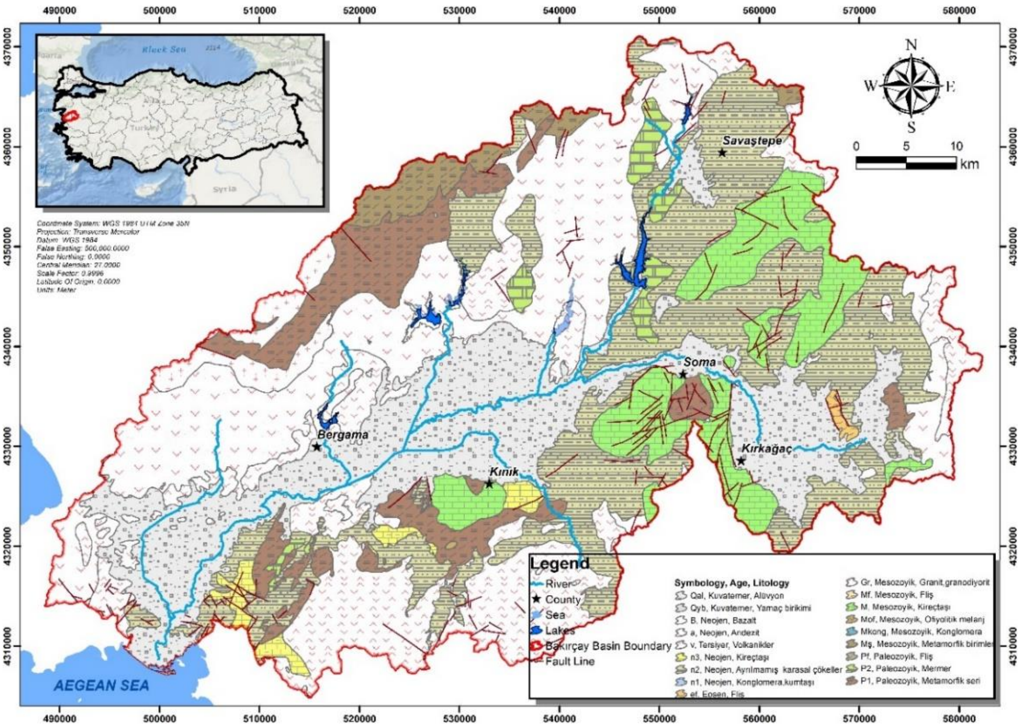


Figure 4.2. The geological map of Bakırçay watershed

(Source: modified from DSİ, 2016a)

4.2.2. Residential Areas

Bergama and Kınık districts of İzmir, Soma and Kırkağaç districts of Manisa, and Savaştepe district of Balıkesir are located within Bakırçay basin. 2011 and 2017 populations of these districts and the rate of increases can be seen in Table 4.2.

Table 4.2 Population and population growth rates of settlements in Bakırçay basin (Source: TUİK, 2011; TUİK, 2017)

Counties	2011	2017	Rate of increase
Savaştepe	9525	18187	47.6%
Kırkağaç	27350	42716	36.0%
Bergama	60559	102961	41.2%
Kınık	11737	28271	58.5%
Soma	76138	108838	30.0%
Settlements belonged to other counties	3113	3180	2.1%

It can be seen that the population growth rates are quite high due to the opportunities in the industrial and agricultural business areas in the basin.

4.3. Watershed Delineation

For the determination of river water bodies, water flow routes were determined by digital elevation model (DEM), and Strahler 3 and above scale rivers were determined as water bodies. In addition, each branch of the river bodies is divided into two segments (upstream and downstream parts), and each segment is systematically numbered by giving the code 1 to the upstream and 2 to the downstream section in order to deal with the water bodies in more detail in the model. If the method mentioned above is schematized, a water body consisting of 3 tributaries and a lake is shown in Figure 4.3. If we consider this water body to be number 8, then the numbering of the river branches and the lake are made as shown in Figure 4.4, and the model topology of this water body can be seen in Figure 4.5.

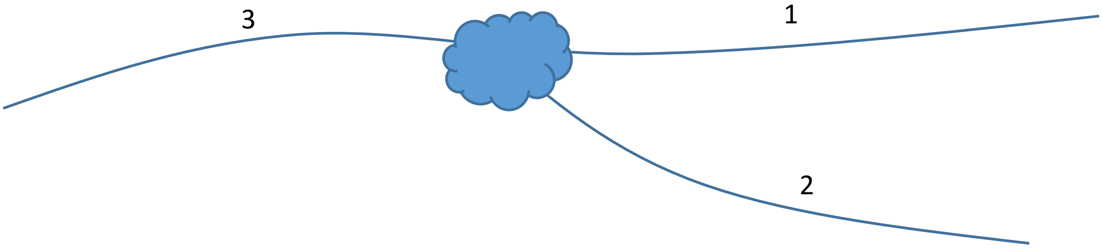


Figure 4.3. Numbering the tributaries of a stream body with water body number 8

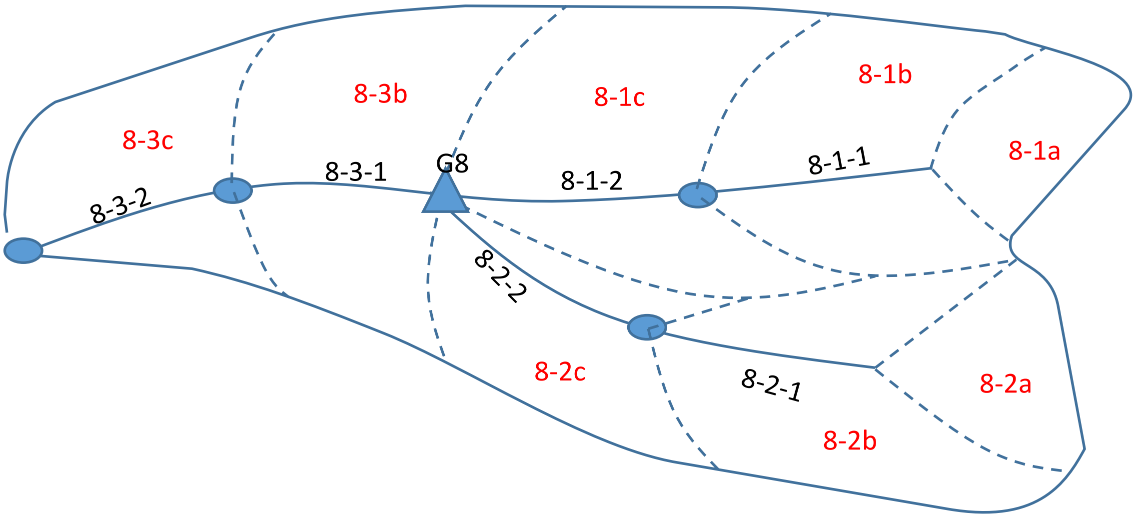


Figure 4.4. Numbering of sub-basins and stream segments in the body of water 8

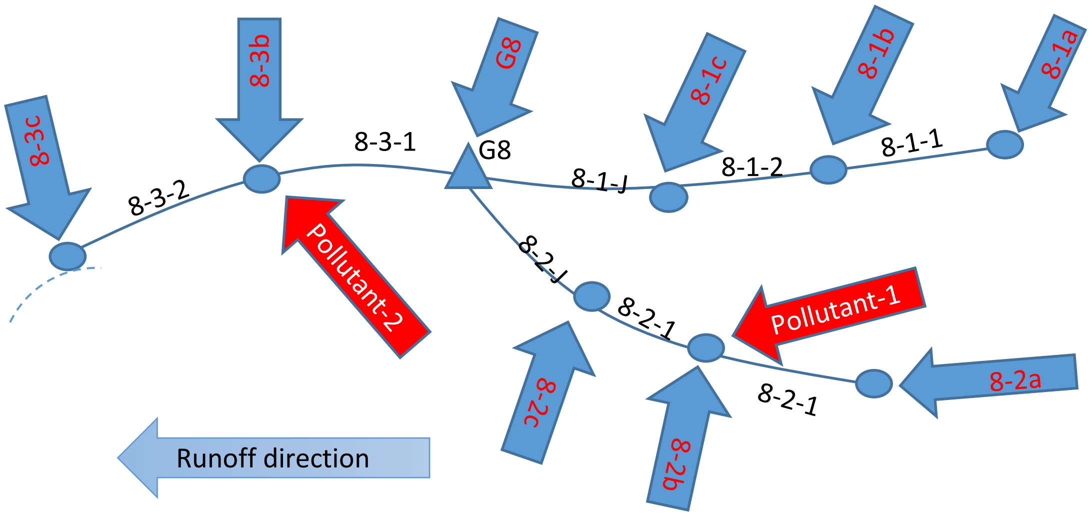


Figure 4.5. Topological representation of sub-basins, stream segments, and pollutants in water body number 8

The "J" extension in the tributaries of the river comes from the initial letter of the word ”Junction”, which was created for the cumulative examination of the quality status of the loads coming to one water body before mixing with the other water body. For all these fictitious branches, 150-meter channel length, 25-meter length step, 0.04 manning roughness coefficient, 8.4-meter channel width, 0.0025 channel slope, 1 lateral slope and dispersion values calculated in one upper river branch were used. According to this delineation method, 12 river and 6 lake water bodies of the Bakırçay watershed can be seen in Table 4.3. and Figure 4.6. The model topology can be seen in Figure 4.7. The dispersion parameter required by the model for each channel and lake are calculated by using the monthly flow results of the SIMGES module of the model and the monthly flow results calculated using the manning velocity formula, and the dispersion (E) values that make these 2 values closest to each other are calculated with the solver add-in of Microsoft Excel. Accordingly, the typical river reaches properties of Bakırçay basin river branches used in the model are given in Table 4.4.

Table 4.3. Water Bodies of Bakırçay Watershed

	1	2	3	4	5	6	7	8	9	10	11	12
Bakırçay Lake Water Bodies	G05	G06	G07	G08	G09	G20						
Bakırçay River Water Bodies	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30	N31	N32

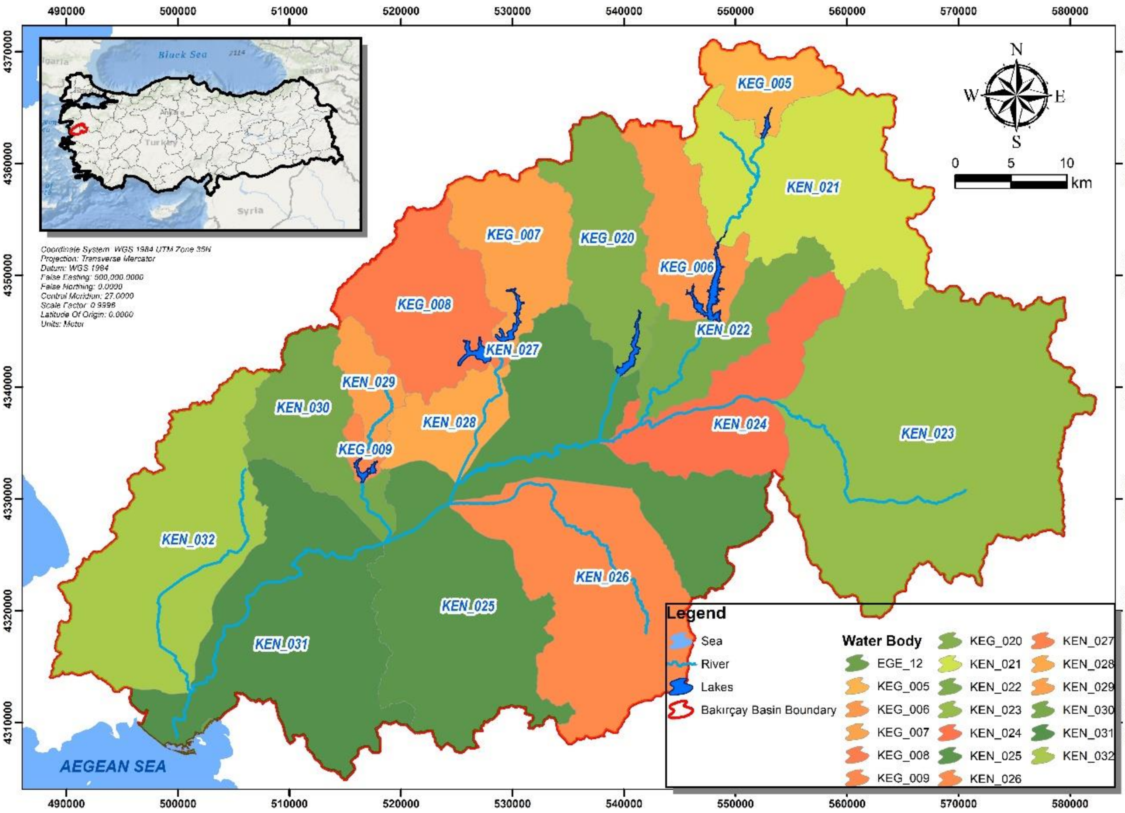


Figure 4.6. Water bodies of Bakırçay watershed

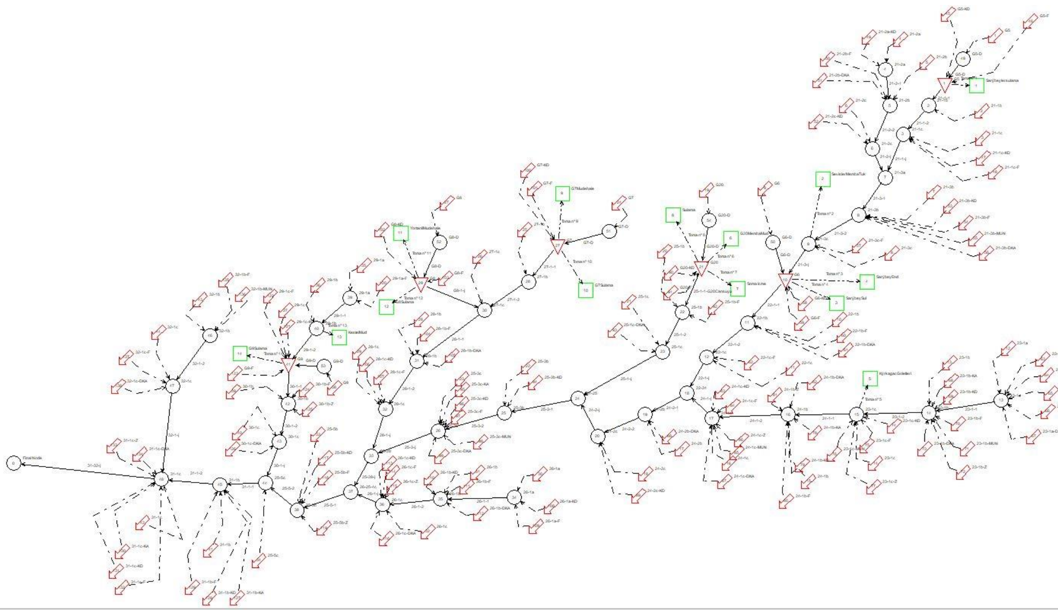


Figure 4.7. Bakırçay watershed model topology

Table 4.4. The typical features of Bakırçay basin river branches

River Branch	Length (km)	Width (m)	Channel Type	Slope (%)	Lateral Slope	Manning Coefficient	Dispersion Coefficient (m^2/s)
KEN_021_01_01	2.338	7.667	trapezium	0.428	1	0.040	11.996
KEN_021_01_02	2.338	8.000	trapezium	0.588	1	0.040	15.410
KEN_021_02_01	2.923	4.000	trapezium	1.369	1	0.040	6.573
KEN_021_02_02	2.923	4.000	trapezium	0.813	1	0.030	8.056
KEN_021_03_01	3.270	8.750	trapezium	0.344	1	0.040	11.740
KEN_021_03_02	3.270	9.500	trapezium	0.459	1	0.040	15.052
KEN_022_01_01	7.103	8.714	trapezium	0.994	1	0.040	20.341
KEN_022_01_02	7.103	18.286	trapezium	0.221	1	0.040	42.844
KEN_023_01_01	12.789	12.900	trapezium	0.274	1	0.030	66.877
KEN_023_01_02	12.789	14.800	trapezium	0.220	1	0.040	28.818
KEN_024_01_01	6.962	19.714	trapezium	0.529	1	0.040	87.097
KEN_024_01_02	6.962	23.714	trapezium	0.298	1	0.030	167.630
KEN_024_02_01	2.493	11.500	trapezium	0.272	1	0.100	2.228
KEN_024_02_02	2.493	12.250	trapezium	0.101	1	0.100	1.434
KEN_025_01_01	3.429	10.800	trapezium	0.948	1	0.030	73.986
KEN_025_01_02	3.429	8.400	trapezium	0.248	1	0.040	9.263
KEN_025_02_01	0.129	8.500	trapezium	0.170	1	0.040	*
KEN_025_02_02	0.129	8.500	trapezium	0.579	1	0.040	*
KEN_025_03_01	9.270	10.800	trapezium	0.165	1	0.040	9.902
KEN_025_03_02	9.270	8.400	trapezium	0.094	1	0.050	2.400
KEN_025_04_01	0.940	6.667	trapezium	0.007	1	0.040	*
KEN_025_04_02	0.940	11.333	trapezium	0.010	1	0.040	*
KEN_025_05_01	3.472	18.800	trapezium	0.067	1	0.030	34.217
KEN_025_05_02	3.472	20.800	trapezium	0.072	1	0.030	42.608
KEN_026_01_01	15.287	9.300	trapezium	1.361	1	0.050	20.427
KEN_026_01_02	15.287	21.900	trapezium	0.187	1	0.030	109.869
KEN_027_01_01	1.939	9.750	trapezium	1.547	1	0.040	39.356
KEN_027_01_02	1.939	9.000	trapezium	0.606	1	0.040	19.571
KEN_028_01_01	6.059	20.500	trapezium	0.384	1	0.040	79.379
KEN_028_01_02	6.059	21.667	trapezium	0.165	1	0.040	53.454
KEN_029_01_01	4.402	9.400	trapezium	1.770	1	0.040	36.948
KEN_029_01_02	4.402	13.400	trapezium	0.909	1	0.030	95.875
KEN_030_01_01	3.496	17.800	trapezium	1.350	1	0.030	184.345
KEN_030_01_02	3.496	21.600	trapezium	0.281	1	0.030	113.402
KEN_031_01_01	17.632	13.583	trapezium	0.099	1	0.030	18.268
KEN_031_01_02	17.632	19.900	trapezium	0.066	1	0.030	34.567
KEN_032_01_01	13.803	7.500	trapezium	6.514	1	0.050	28.679
KEN_032_01_02	13.803	19.900	trapezium	0.020	1	0.030	31.844

* KEN_025_02_01, KEN_025_02_02, KEN_025_04_01, KEN_025_04_02 river tributaries are formed as a result of the mismatch of the data in the GIS analyzes; they are actually non-existent river branches. Therefore these branches were not taken into account in the model schematization.

4.4. Required Data for Model

4.4.1. Precipitation

One of the most important hydro-meteorologic parameters for rainfall-runoff modeling studies is precipitation. Precipitation data obtained by point measurements is an atmospheric parameter with extremely high spatial variability since it is a discrete hydrological measurement (presence/absence of precipitation). When this spatial variability is examined in terms of time, it decreases rapidly from daily precipitation to annual precipitation. For this reason, while the correlation between daily precipitation values of two stations in the same region may be low, the correlation between monthly precipitation values is higher. While this feature makes it difficult to complete the missing data in daily precipitation with correlation and regression analysis, it enables the shortcomings in monthly precipitation to be complemented with highly correlated relationships.

In Bakırçay basin, General Directorate of State Hydraulic Works (DSİ) stations was used in addition to State Meteorological Service (DMİ) stations from Master Plan (DSİ, 2016a, 2016b) to increase both area and space resolution in precipitation data. The list of DMİ and DSİ stations whose data are evaluated within the scope of the study is given in Table 4.5. The areal distribution of these stations is shown in Figure 4.8.

Table 4.5. The meteorology stations used in the modeling study

Station Number	Latitude	Longitude	Elevation (m)	Station Name
1	39.1333	27.1833	53	Bergama Y
2	39.1833	27.8500	250	Gelembe
3	39.0500	26.8833	3	Dikili
4	39.1500	27.2167	185	Kaleardı
5	39.0500	27.1833	130	Karahıdırlı
6	39.0833	27.3833	40	Kınık
7	39.3167	27.3333	310	Kırcalar
8	39.1000	27.6667	250	Kırkağaç
9	39.2167	27.2500	350	Mahmudiye

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Table 4.5. (Cont.)

Station Number	Latitude	Longitude	Elevation (m)	Station Name
10	39.3833	27.6500	300	Savaştepe
11	39.2667	27.5500	130	Sevişler
12	39.1833	27.6000	200	Soma
13	39.2833	27.3333	250	Turanlı
14	39.3667	27.5667	255	Yeşilhisar
15	38.9667	27.0667	125	Zeytindağ
16	39.2500	27.1167	500	Kozak

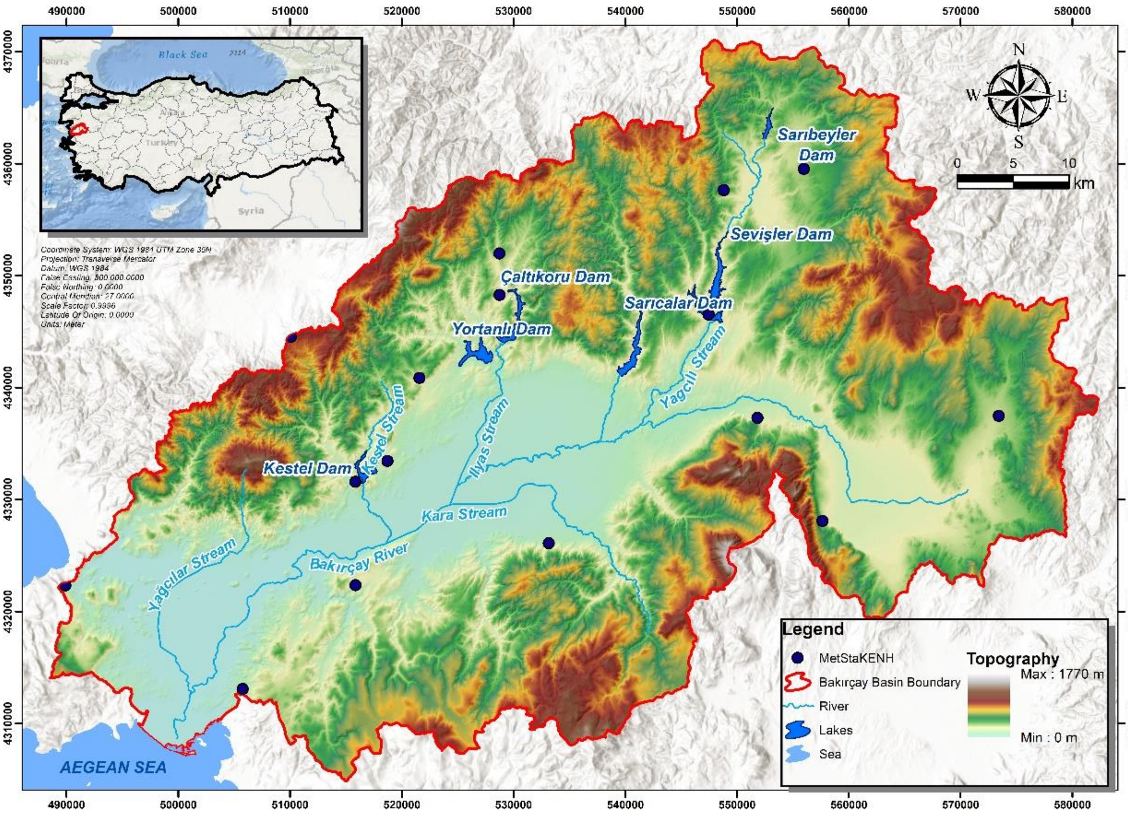

Figure 4.8. The locations of meteorology stations

Within the scope of the study, the inventory information regarding the data availability of 16 rainfall stations for which monthly precipitation data was evaluated is given in Table 4.6. In Table 4.6., in order to complete the missing observations, correlation and regression analyzes were carried out between the monthly precipitation of the stations, and the missing observations at the stations were completed primarily from the stations with the highest correlation, and if there is a deficiency in those stations, another station with the highest correlation with complete data. Correlation and regression analyses between some stations can be seen in Figure 4.9.

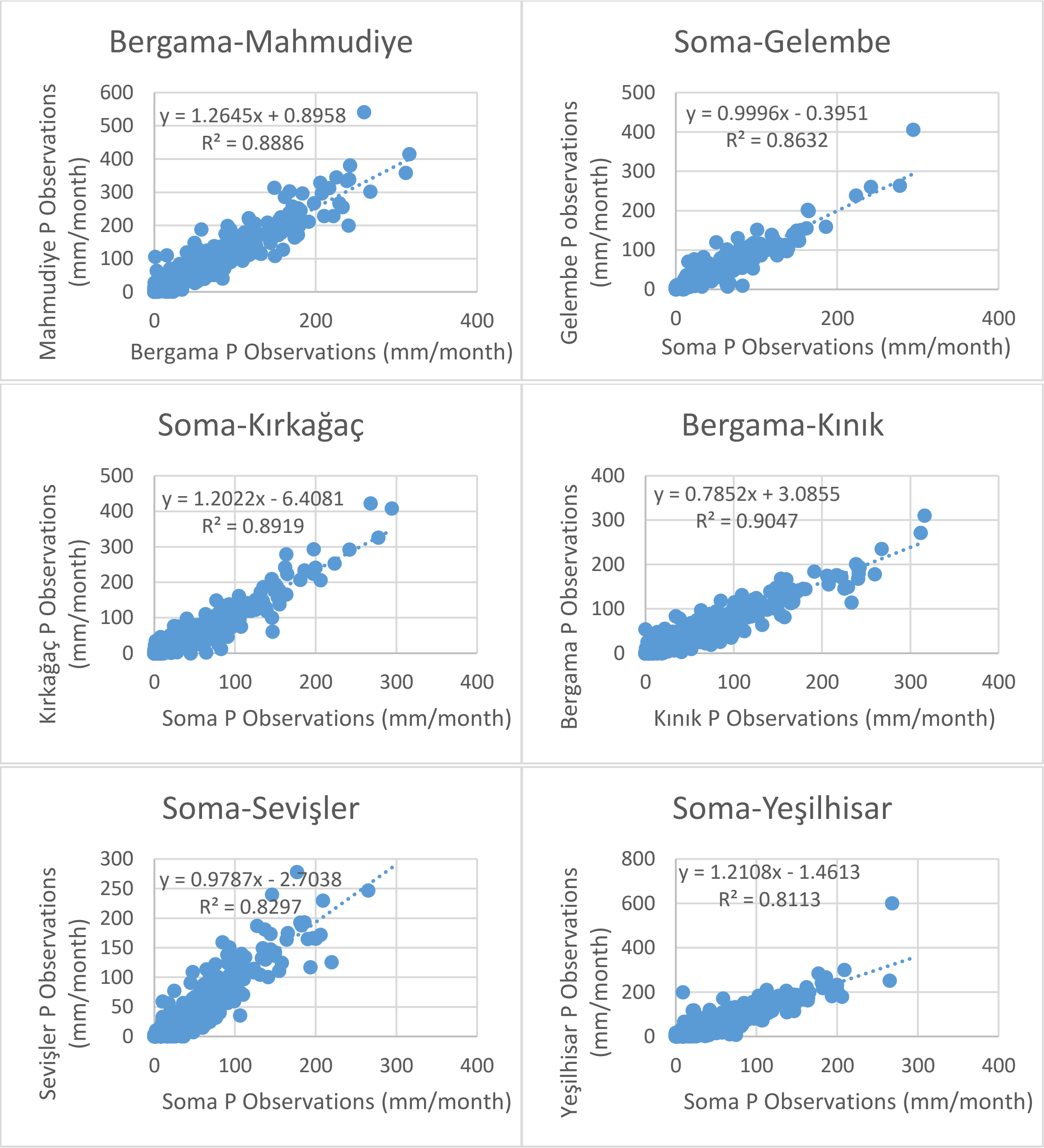

Figure 4.9. The correlation and regression analysis between monthly rainfall observations

Table 4.6. The monthly precipitation record inventory of meteorological stations

Yıl	Bergama	Soma	Gelembe	Dikili	Kaleardı	Karahıdırlı	Kınık	Kırcalar	Kırkağaç	Mahmudiye	Savaştepe	Sevişler	Turanlı	Yeşilhisar	Zeytindağ	Kozak
1963	12	12		12	12		5		8	12	12				3	12
1964	12	12	10	12	11		12		12	12	12		12		12	12
1965	12	12	10	12	12		11		12	12	12		12		12	12
1966	12	12	6	12	12		12		12	12	12		12		12	12
1967	12	12	12	12	12	4	12		12	12	12		12		12	12
1968	12	12	11	12	12	9	12		12	11	12		12		12	12
1969	12	12	10	12	12	12	12		12	12	12		12		12	12
1970	12	12	11	12	12	12	12		12	12	12		12		12	12
1971	12	12	12	12	12	12	12		12	12	12		12		12	12
1972	12	12	12	12	12	12	12		12	12	12		12		12	12
1973	12	12	12	12	11	12	12		12	12	12		12	6	12	12
1974	12	12	12	12	12	12	11		12	12	12		12	12	12	12
1975	12	12	12	12	12	12	12	8	12	12	12		12	12	12	12
1976	12	12	12	12	12	12	12	12	12	12	12		12	12	12	12
1977	12	12	10	12	12	12	12	12	12	12	12		12	12	12	12
1978	12	12	10	12	12	12	12	12	12	12	12		12	12	12	12
1979	12	12	11	12	12	12	12	12	12	12	12		12	12	12	12
1980	12	12	6	12	12	12	12	12	12	12	12		12	12	12	12
1981	12	12		12	12	12	12	12	12	12	12		12	12	10	12
1982	12	12	9	12	12	12	12	12	12	12	12		12	12	11	12
1983	12	12		12	12	12	12	12	12	12	12	12	12	12	10	12
1984	12	12		12	12	12	12	12	7	12	12	12	12	12	12	12
1985	12	12		12	12	12	10	12	2	12	12	12	12	12	12	12
1986	12	12		12	12	12	12	12	12	12	9	12	12	12	12	12
1987	12	12		12	12	12	12	12	6	12	7	12	12	12	12	12
1988	12	12		12	12	12	12	12		12	6	12	12	12	5	12
1989	12	12		12	12	12	12	12		12		12		12		12

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Table 4.6. (Cont.)

Yıl	Bergama	Soma	Gelembe	Dikili	Kaleardı	Karahıdırlı	Kınık	Kırcalar	Kırkağaç	Mahmudiye	Savaştepe	Sevişler	Turanlı	Yeşilhisar	Zeytindağ	Kozak
1990	12	12		12	12	12	12	12		12		12		12		12
1991	12	12		12	12	12	12	12		12		12		12		12
1992	12	12		12	12	12	12	12		12		11		12		12
1993	12	12		12		12	12	12		12		12		12		12
1994	12	12		12		12	12	12		12		12		12		12
1995	12	12		12		12	12	12		12	2	12		12		12
1996	12	12		12		12	12	12		12	1	12		12		12
1997	12	12		12		12	11	12		12	10	12		12		12
1998	12	12		12		12	6	12		12	12	12		11		12
1999	12	12		12		12		12		12	12	12		12		
2000	12	12		12		12		12		12	12	12		12		
2001	12	12		12		12		12		12	12	12		12		
2002	12	12		12		12		12		12	12	12		12		
2003	12	12		12		12		12		12	12	12		12		
2004	12	12		12		12		12		12	12	12		12		
2005	12	12		12		12		12		12	12	12		12		
2006	12	12		12		12				12		12		12		
2007	12	12		12		11				12	12	10		12		
2008	12	12		12						12	12	9		12		
2009	12	12		12							12	12		12		
2010	12	12		12							3					
2011	12	12		12												
2012	12	12		12												
2013	12	12		12												
2014	12	12		12							12					

With the help of quite acceptable correlation and regression relationships ranging from 0.8113 to 0.9047, the long-term precipitation average precipitation values of the stations with missing monthly precipitation are shown in Table 4.7.

Table 4.7. The monthly average rainfall values (mm) for the long term 1963-2014

Station	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Bergama	100.2	87.6	69.6	58.0	32.6	15.6	5.6	6.6	19.0	45.6	88.9	124.6	54.5
Gelembe	95.1	87.6	66.2	57.6	44.1	18.2	5.7	6.6	22.1	43.9	75.7	107.1	52.5
Dikili	99.1	89.6	70.5	49.1	22.2	9.2	2.9	2.4	13.7	41.0	81.5	116.4	49.8
Kaleardı	124.0	107.9	81.3	67.5	35.4	21.6	7.0	6.6	22.5	53.7	111.2	154.8	66.1
Karahıdırlı	91.6	78.6	64.5	53.2	29.4	11.8	5.8	5.6	17.0	44.1	80.8	116.7	49.9
Kınık	82.0	70.8	59.9	50.4	27.3	15.6	8.0	4.9	18.4	41.3	70.1	101.7	45.9
Kırcalar	115.9	103.6	82.9	69.6	38.4	19.0	6.3	8.1	23.9	55.7	113.8	164.1	66.8
Kırkağaç	114.7	102.2	74.4	61.6	39.3	16.9	5.0	6.0	17.9	46.0	82.6	124.1	57.6
Mahmudiye	134.9	115.2	78.9	70.7	40.0	24.4	6.8	5.6	23.6	57.0	116.1	164.2	69.8
Savaştepe	104.2	92.8	72.6	65.3	47.0	21.1	12.8	7.6	24.2	53.0	93.3	128.6	60.2
Sevişler	89.0	84.2	65.9	56.4	34.4	15.7	5.3	4.0	16.3	42.0	71.8	105.7	49.2
Soma	97.5	85.9	67.0	58.0	42.0	17.9	8.7	8.4	22.1	43.9	75.7	107.6	52.9
Turanlı	121.4	97.7	72.6	65.9	38.2	17.9	10.6	6.9	21.9	52.0	106.9	144.3	63.0
Yeşilhisar	115.2	100.3	77.0	66.9	43.8	24.5	8.3	4.3	22.7	54.3	96.5	138.6	62.7
Zeytindağ	90.0	73.9	63.0	47.7	25.8	13.4	5.7	4.4	14.8	37.9	73.3	108.6	46.5
Kozak	151.1	133.2	93.5	72.2	40.7	18.5	10.0	9.2	29.4	64.7	123.1	180.5	77.2

As can be seen from Table 4.7., the lowest long-term average monthly precipitation is seen in Dikili station in August with 2.4 mm/month, while the highest long-term average monthly precipitation is 180.5 mm/month in Kozak station in December.

4.4.2. Temperature

Another important hydro-meteorological parameter needed in rainfall-runoff modeling studies is the temperature parameter. Unlike precipitation observations, temperature observations are more consistent in spatial continuity, so they do not show remarkable variation in area size as rainfall data. While precipitation observations are made at many precipitation stations in the basin, temperature observation is available at very few stations. In terms of the compatibility of Thiessen polygons to be created, it is important that both precipitation and temperature data are obtained specifically for the stations used. For this reason, in addition to the current temperature measurements in the project area, temperature data were also transferred to the precipitation station points without temperature observation. In this way, temperature data were obtained at 16 precipitation station locations, and a Thiessen polygon could be created for the project site. Thanks to the created Thiessen polygons, precipitation and temperature data will be obtained on the basis of sub-basin, which will be used as input to the model. In the process of transferring the temperature data to the stations, the latitudinal temperature corrections are neglected because they are extremely small. For this reason, the temperature values were transferred from the nearest stations depending on the elevation.

Stations and data records that need to be completed from temperature measurements can be seen in Table 4.8. The missing observations in Table 4.8 were completed by correlation and regression analysis, as was done in rainfall data, and made ready for temperature data transfer to stations without temperature measurement. As can be seen from Figure 4.10, the correlation coefficients in the relations between temperatures in all stations are very close to 1, as expected. These values show that the temperature shows a highly defined variation throughout the basin, and this variability can be explained well with a small number of base stations.

Table 4.8. The monthly temperature record inventory of meteorological stations

Year	Bergama	Soma	Kınık	Savaştepe	Year	Bergama	Soma	Kınık	Savaştepe
1963	12	12			1989	12	12	12	
1964	12	12			1990	12	12	12	
1965	12	12			1991	12	12	12	
1966	12	12			1992	12	12	12	
1967	12	12			1993	12	12	12	
1968	12	12			1994	12	12	12	
1969	12	12			1995	12	12	12	2
1970	12	12			1996	12	12	12	1
1971	12	12			1997	12	12	12	10
1972	12	12			1998	12	12	6	12
1973	12	12			1999	12	12		12
1974	12	12			2000	12	12		12
1975	12	12			2001	12	12		12
1976	12	12			2002	12	12		12
1977	12	12			2003	12	12		12

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Table 4.8. (Cont.)

Year	Bergama	Soma	Kınık	Savaştepe	Year	Bergama	Soma	Kınık	Savaştepe
1978	12	12			2004	12	12		12
1979	12	12			2005	12	12		12
1980	12	12			2006	12	12		
1981	12	12			2007	12	12		12
1982	12	12			2008	12	12		12
1983	12	12			2009	12	12		12
1984	12	12			2010	12	12		3
1985	12	12	10	9	2011	12	12		
1986	12	12	12	10	2012	12	12		
1987	12	12	12	10	2013	12	12		
1988	12	12	12	7	2014	12	12		10

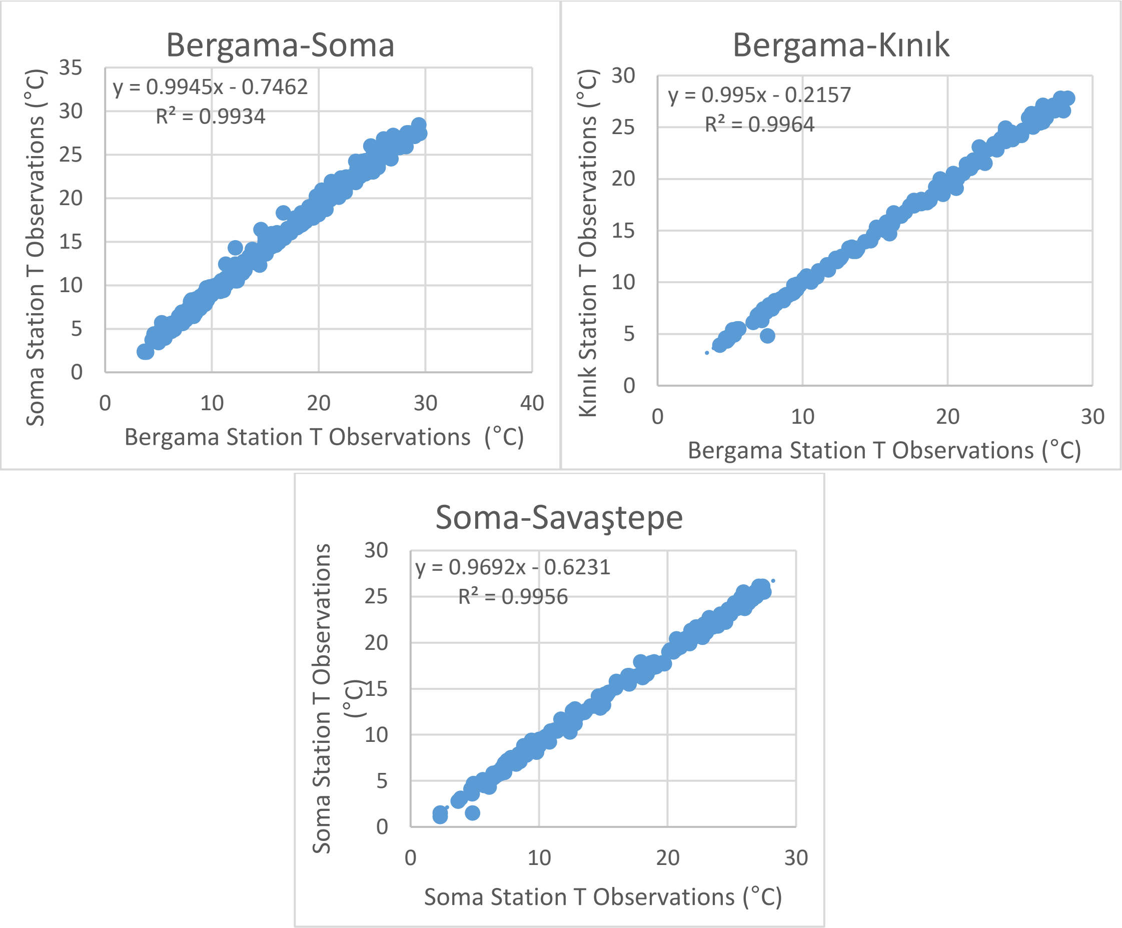

Figure 4.10. The correlation and regression analysis between monthly temperature observations

The correlation between the temperature data of the stations is extremely high as expected as R^2 values of 0.9934, 0.9964, and 0.9956. For this reason, there is no statistical problem in obtaining the temperature values at the points of precipitation observations by correcting the values of the temperature station, which has the closest and sufficient data, according to elevation (-0.5 C°/100 m). The long-term average temperature values of 16 meteorology stations for the period 1963-2014, whose temperature data were completed, are given in Table 4.9.

Table 4.9. The monthly average temperature values (°C) for the long term 1963-2014

Station	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Bergama	6.7	7.6	9.8	14.3	19.5	24.4	26.8	26.3	22.4	17.2	12	8.5	16.3
Gelembe	5.6	6.4	8.8	13.4	18.5	23.2	25.6	25.2	21.2	16.1	10.9	7.4	15.2
Dikili	7.8	8.6	10.6	14.6	19.2	23.8	26.1	25.6	22	17.5	13	9.7	16.5
Kaleardı	6.1	6.9	9.2	13.6	18.8	23.7	26.1	25.6	21.7	16.5	11.4	7.8	15.6
Karahıdırlı	6.3	7.2	9.5	13.9	19.1	24	26.4	25.9	22	16.8	11.7	8.1	15.9
Kınık	6.5	7.3	9.6	13.9	19.1	24.1	26.4	25.9	22.1	16.9	11.8	8.2	16
Kırcalar	5.4	6.3	8.6	13	18.2	23.1	25.5	25	21.1	15.9	10.8	7.2	15
Kırkağaç	5.6	6.4	8.8	13.4	18.5	23.2	25.6	25.2	21.2	16.1	10.9	7.4	15.2
Mahmudiye	5.2	6.1	8.4	12.8	18	22.9	25.3	24.8	20.9	15.7	10.6	7	14.8
Savaştepe	5	5.8	8.1	12.6	17.4	22	24.4	24.1	20.3	15.3	10.3	6.8	14.3
Sevişler	5.9	6.7	9	13.4	18.3	22.9	25.2	24.9	21.1	16.2	11.1	7.7	15.2
Soma	5.8	6.7	9.1	13.6	18.7	23.5	25.8	25.4	21.5	16.3	11.2	7.6	15.4
Turanlı	5.7	6.6	8.9	13.3	18.5	23.4	25.8	25.3	21.4	16.2	11.1	7.5	15.3
Yeşilhisar	5.2	6.1	8.4	12.8	17.7	22.3	24.6	24.3	20.5	15.5	10.5	7.1	14.6
Zeytindağ	6.4	7.2	9.5	13.9	19.1	24	26.4	25.9	22	16.8	11.7	8.1	15.9
Kozak	5.3	5.9	8	12.2	17.2	22	24.4	23.9	20	15	10.4	7.1	14.3

As it can be seen in Table 4.9., the lowest long-term average monthly temperature is seen in Savaştepe station in January with 5 °C, while the highest long-term average monthly temperature is 26.8 °C in Bergama station in July.

4.4.3. Dissolved Oxygen

In this study, which was carried out with the AQUATOOL model, diffuse pollutant sources were also studied with point inputs called "aporticion", which enter the nodal points in the model, as well as point pollutant sources. In short, a distributed load actually means pollution carried by natural flow. Starting from this point, the monthly Dissolved Oxygen value should be defined in the model for each natural flow and point pollutant. At this point, the temperature values in the in-basin stations, whose missing measurements were completed before, were used. First of all, the temperatures of the stations were interpolated to the sub-basins with the help of the geographic information system tool. The temperature values obtained for the sub-basins were used in equation (8), which produces Dissolved Oxygen saturation using temperature, specified by APHA (2005) and Chapra (2008), and thus maximum Dissolved Oxygen saturation values for the sub-basins were obtained. It is not possible to dissolve the full saturation value of Dissolved Oxygen since the Bakırçay basin is known to have an intense pollution pressure.

For this reason, 2mg/L was deducted, and values were rounded before being used in the model. At this point, the lack of data in water quality studies compelled to follow such a method. Dissolved Oxygen data calculated accordingly are given in Table 4.10 for the sub-basins.

$$\begin{aligned}\ln o_{sf} = -139.34411 + \frac{1.575701\times 10^{5}}{T_a} - \frac{6.642308\times 10^{7}}{T_a^2} \\ + \frac{1.2438\times 10^{10}}{T_a^3} - \frac{8.621949\times 10^{11}}{T_a^4}\end{aligned} \tag{8}$$

where o_{sf} is the saturation concentration of dissolved oxygen in fresh water at 1 atm (mg/L) and T_a is the absolute temperature (K).

Table 4.10. The calculated monthly Dissolved Oxygen values in sub-basins (mg/L)

Month# / Sub-Basin	10	11	12	1	2	3	4	5	6	7	8	9
G5	6.0	7.0	8.0	10.0	9.0	8.0	7.0	7.0	6.0	6.0	6.0	7.0
21-1b	7.0	9.0	9.0	9.0	8.0	8.0	8.0	7.0	6.0	6.0	6.0	6.0
21-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0

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Table 4.10. (Cont.)

Month# / Sub-Basin	10	11	12	1	2	3	4	5	6	7	8	9
21-2a	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
21-2b	9.0	9.0	9.0	10.0	8.0	8.0	7.0	6.0	6.0	7.0	8.0	8.0
21-2c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
21-3b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
21-3c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
G6	7.0	8.0	9.0	10.0	9.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
22-1b	6.0	8.0	9.0	9.0	9.0	8.0	8.0	7.0	7.0	8.0	7.0	6.0
22-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
23-1a	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
23-1b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
23-1c	7.0	9.0	11.0	9.0	8.0	7.0	7.0	7.0	6.0	5.0	5.0	6.0
24-1b	7.0	8.0	9.0	9.0	8.0	8.0	7.0	6.0	6.0	5.0	5.0	6.0
24-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
24-2b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
24-2c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
G20	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
25-1b	7.0	8.0	9.0	10.0	8.0	7.0	8.0	6.0	5.0	6.0	6.0	7.0
25-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
25-3b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
25-3c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
G7	7.0	8.0	9.0	10.0	9.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0
27-1b	7.0	8.0	9.0	10.0	9.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0
27-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
G8	7.0	8.0	9.0	10.0	9.0	8.0	8.0	7.0	6.0	6.0	5.0	6.0
28-1b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	8.0	7.0	6.0	6.0	6.0
28-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
26-1a	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
26-1b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
26-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
25-5b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
25-5c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
29-1a	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
29-1b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
29-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
G9	7.0	8.0	9.0	9.0	8.0	8.0	8.0	7.0	6.0	6.0	5.0	6.0
30-1b	6.0	8.0	8.0	10.0	9.0	8.0	8.0	6.0	6.0	6.0	6.0	7.0
30-1c	7.0	8.0	9.0	11.0	8.0	8.0	7.0	7.0	6.0	6.0	5.0	6.0
31-1b	7.0	8.0	9.0	9.0	8.0	7.0	7.0	6.0	6.0	5.0	5.0	6.0
31-1c	7.0	8.0	9.0	10.0	8.0	7.0	7.0	6.0	5.0	5.0	5.0	6.0
32-1b	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0
32-1c	7.0	8.0	9.0	10.0	8.0	8.0	7.0	7.0	6.0	6.0	6.0	6.0

On the other hand, the model also needs monthly Dissolved Oxygen values of point sources. At this point, the dissolved oxygen values selected for the pollutant sources are given in Table 4.11.

Table 4.11. The Dissolved Oxygen values for point pollutant sources

Point Pollutant Source	Dissolved Oxygen (mg/L)	Source
Cesspit Wastewater	4.0	Metcalf et al., (2002)
Municipal Untreated Direct Discharge Wastewater	3.0	Metcalf et al., (2002)
Municipal WWTP Discharge Wastewater	6.0	Metcalf et al., (2002)
Individual and Organized Industrial Zone Wastewater	6.0	
Olive Industry Wastewater	4.0	(Şengül et al. 2003)
Solid Waste Landfill Leachate	3.0	(Tchobanoglous and Kreith, 2002)

4.4.4. Potential Evapotranspiraton (PET)

Potential evapotranspiration (PET), which expresses the amount of water that can return to the atmosphere through evaporation and perspiration from the ground and plant surfaces with sufficient saturation, can be estimated by methods using surface and atmospheric conditions. PET can be calculated by many different methods (Penman-Monteith, Thornthwaite, Blaney Criddle, Kimberly-Penmann, Jensen-Haise, McGuinness) depending on the hydrometeorological adequacy of the data. In this study, the modified Jensen and Haise (1963)/ McGuinness and Bordne (1972) method, which is a modified method based on extra atmospheric solar radiation, was preferred. The Jensen – Haise/ McGuinness method, developed in the study of Oudin et al. (2005), and which can be seen in equation (9), was applied for 16 stations whose monthly average temperature values and non-atmospheric solar radiation values were determined within the scope of the study. Annual totals of precipitation (P) and temperature (T) values, together with PET values determined based on stations, are summarized in Table 4.12.

$$\begin{aligned} PE &= \frac{R_e}{\lambda \rho}\frac{T_a + 5}{100} && \text{if } T_a + 5 > 0 \\ PE &= 0 && \text{any other case} \end{aligned} \qquad (9)$$

In this equation, PE shows daily potential evapotranspiration (mm/day), Re daily extra-atmospheric solar radiation (MJ/day), λ latent heat flux (MJ/kg), ρ water density (kg/m^3) and Ta daily mean air temperature (°C / day).

Table 4.12. Annual total values of precipitation, average temperature and potential evapotranspiration values in 16 meteorology stations examined within the scope of Bakırçay basin

Station	Latitude	Longitude	P (mm/year)	T (°C/year)	PET (mm/year)
Bergama	39.133	27.183	653.7	16.3	1026.6
Gelembe	39.183	27.850	629.9	15.2	978.9
Dikili	39.050	26.883	597.7	16.5	1027.4
Kaleardı	39.150	27.217	793.4	15.6	997.8
Karahıdırlı	39.050	27.183	599.2	15.9	1010.6
Kınık	39.083	27.383	550.3	16.0	1013.6
Kırcalar	39.317	27.333	801.2	15.0	969.2
Kırkağaç	39.100	27.667	690.8	15.2	979.6
Mahmudiye	39.217	27.250	837.4	14.8	961.5
Savaştepe	39.383	27.650	722.5	14.3	937.1
Sevişler	39.267	27.550	590.6	15.2	974.8
Soma	39.183	27.600	634.6	15.4	989.8
Turanlı	39.283	27.333	756.3	15.3	982.6
Yeşilhisar	39.367	27.567	752.4	14.6	946.9
Zeytindağ	38.967	27.067	558.7	15.9	1012.4
Kozak	39.250	27.117	926.0	14.3	934.2

The precipitation, temperature and PET values converted into the sub-watershed base with Thiessen polygons are given in Table 4.13.

Table 4.13. Annual total precipitation, average temperature and potential evapotranspiration values of Bakırçay basin water bodies

Sub-Watershed	P (mm/year)	T (°C/year)	PET (mm/year)
KEG_005	725.1	14.4	937.9
KEG_006	687.8	14.8	958.0
KEG_007	790.7	15.1	972.3
KEG_008	800.0	14.9	966.3

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Table 4.13. (Cont.)

Sub-Watershed	P (mm/year)	T (°C/year)	PET (mm/year)
KEG_009	757.8	15.8	1005.1
KEG_020	723.2	15.0	966.1
KEN_021	729.6	14.4	940.5
KEN_022	611.4	15.1	971.1
KEN_023	649.6	15.2	979.7
KEN_024	624.5	15.4	987.0
KEN_025	608.4	15.7	1000.9
KEN_026	550.2	16.0	1012.1
KEN_027	756.3	15.3	982.6
KEN_028	797.6	15.2	980.9
KEN_029	826.1	15.0	970.8
KEN_030	785.6	15.4	988.6
KEN_031	591.8	15.9	1011.0
KEN_032	633.8	16.1	1013.6

4.4.5. Land Use and Land Cover

One of the most important components affecting the quantity and quality of non-point pollutant loads coming to the basins is land use and land cover. In this study, for the land use and land cover of the basin, the data of CORINE for 2012, which is the last updated data year in the Bakırçay basin, are used.

Generally, half of the Bakırçay basin consists of forests and semi-natural areas. In addition, 2/5 of the basin area is used for agricultural activities and artificial areas, including settlements that occupy 3% of the total watershed area. On the other hand, the total area covered by wetlands and water bodies in the basin is 0.6%. Areas and percentage representation of land use/land cover types can be seen in Table 4.14, and their graphical summary can be seen in Figure 4.11.

Table 4.14. The areas of landuse types

Landuse Type	Area (ha)	Percentage in Bakırçay Basin
Artificial Areas	12264.16	3.1%
Agricultural Areas	159862.01	40.6%
Forests/Semi-natural Areas	219817.77	55.8%
Wetlands	333.56	0.1%
Water Bodies	1951.24	0.5%

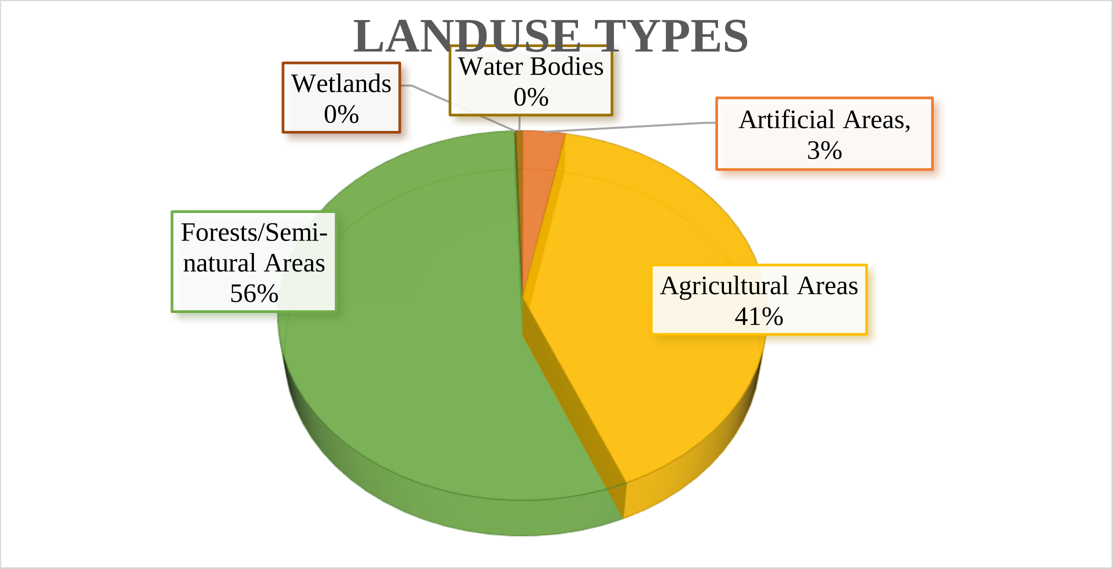

Figure 4.11. The landuse types in the Bakırçay watershed

(Source: CORINE2012)

4.4.6. Water Needs and Uses

Bakırçay basin is an important resource in terms of spring and irrigation water. Therefore, there are aboveground and underground interventions within the basin. These pressure elements are given in Table 4.15 and Table 4.16.

Table 4.15. The surface water uses in the Bakırçay watershed

Sub-watershed	Irrigation Water Use (hm^3/year)	Drinking&Potable Water Use (hm^3/year)	Industrial Water Use (hm^3/year)
KEG05	8.7		
KEG06	9.31 (Upstream Use)		
	32.6		23.2
KEG07	0.82 (Upstream Use)		
	21.13		
KEG08	0.52 (Upstream Use)		
	23.8		
KEG09	0.85 (Upstream Use)		
	13.1		
KEG20	0.54 (Upstream Use)		
	11.3	6.6	
Kırkağaç Ponds	2.7		

Table 4.16. The groundwater uses in the Bakırçay watershed

Sub-watershed	Groundwater recharge (hm^3/year)	Drinking&Potable Water Use (hm^3/year)	Industrial Water Use (hm^3/year)	Agricultural Irrigation Water Use (hm^3/year)	Animal Water Use (hm^3/year)	Total uptake (hm^3/ year)
KEG_005	2.56	0.04	0	0.21	0.1	0.35
KEG_006	5.84	0.1	0	0.28	0.15	0.53
KEG_007	2.63	0.04	0	0.25	0.11	0.4
KEG_008	2.6	0.04	0.01	0.27	0.1	0.42
KEG_009	0.54	0.01	0	0.11	0.02	0.14
KEG_020	5.66	0.1	0	0.38	0.19	0.67
KEN_021	19.64	0.26	0	0.71	0.27	1.25
KEN_022	9.71	0.16	0.04	1.96	0.1	2.27
KEN_023	55.51	5.26	3.01	15.4	0.62	24.29
KEN_024	17.26	0.71	0.38	6.28	0.15	7.52
KEN_025	50.38	1.63	1.23	30.26	0.75	33.86
KEN_026	21.34	0.85	0.79	10.8	0.47	12.91
KEN_027	0.25	0.01	0	0.11	0.01	0.13
KEN_028	8.29	0.26	0.13	5.92	0.11	6.42
KEN_029	1.2	0.02	0.01	0.12	0.05	0.19
KEN_030	6.39	0.15	0.11	2.96	0.14	3.37
KEN_031	30.9	1.02	0.77	20.98	0.5	23.27
KEN_032	28.36	0.87	0.5	18.26	0.47	20.1

4.4.7. Natural Flows

Observed natural flow values are needed for the calibration and verification of the process parameters of the hydrological model established in the modeling study. As in many of our basins, the river basin with natural flow characteristics is almost nonexistent in Bakırçay River Basin. The flows at all flow measurement points in the basin have lost their natural character due to intervention from dams, ponds, and irrigation return flows as well as domestic and industrial wastewater discharges and water extractions. In the flow naturalization process, surface water consumptions (irrigation, drinking water, etc.) and storage (dam storage) are added to the flows observed in the stations. In contrast, upstream groundwater additives (water is withdrawn from the groundwater, used, and discharged back to surface waters) are removed. Therefore, the more healthy the records of surface water consumption information and reservoir operation records, and the return of groundwater use are, the more successful the flow naturalization is. Flows that are not naturalized negatively affect the calibration process due to their effect on their bodies.

In the North Aegean Basins Master Plan (OSIB, 2016a), the above-mentioned naturalization studies were carried out for the dam and flow measurement points, generally for the 1974-2014 water years. However, in some stations, this period is short because data is not available. Within the scope of the modeling study, these naturalized flows were used for model calibration and verification studies. The list of naturalized flows used within the scope of the project is given in Table 4.17.

Table 4.17. Naturalized flows and related water bodies evaluated within the scope of the study and given in the North Aegea river basins master plan

Naturalized Flows	**Sub-watershed**	**Naturalized Period**
Sarıbeyler Dam Natural Flows	KEG_005	1974-2014
Çaltıkoru Dam Natural Flows	KEG_007	1974-2014
Yortanlı Dam Natural Flows	KEG_008	1974-2014
Sarıcalar Dam Natural Flows	KEG_020	1974-2014
D04-24 Station’s Natural Flows	KEN_023	1970-1995
D04-54 Station’s Natural Flows	KEN_025	1974-2014
D04-58 Station’s Natural Flows	KEN_026	1974-2014
Kestel Dam Natural Flows	KEN_029	1974-2014
D04-44 Station’s Natural Flows	KEN_032	1974-2014

4.4.8. Waterbody Natural Flows in Model

In order to use the naturalized flows mentioned above in the model, they need to be converted to a sub-basin base. A spatial relationship has been established between natural flow measurement stations and sub-basins, which can also be seen in Figure 4.12. According to this relationship, if there is no other station above a flow observation station, the naturalized flows of that station are distributed to the water bodies upstream of the same station in proportion to their areas. In the water bodies between two flow observation stations, the differences between the naturalized flow values of these observation stations are distributed in proportion to the areas of water bodies in between. In cases where there is no flow observation station before the confluence of the river water bodies, the flow values of the water bodies up to the confluence were also obtained by using the flow observation stations located at the upstream of those water bodies. Flows on the basis of transformed sub-basins are given in Table 4.18. as a summary table.

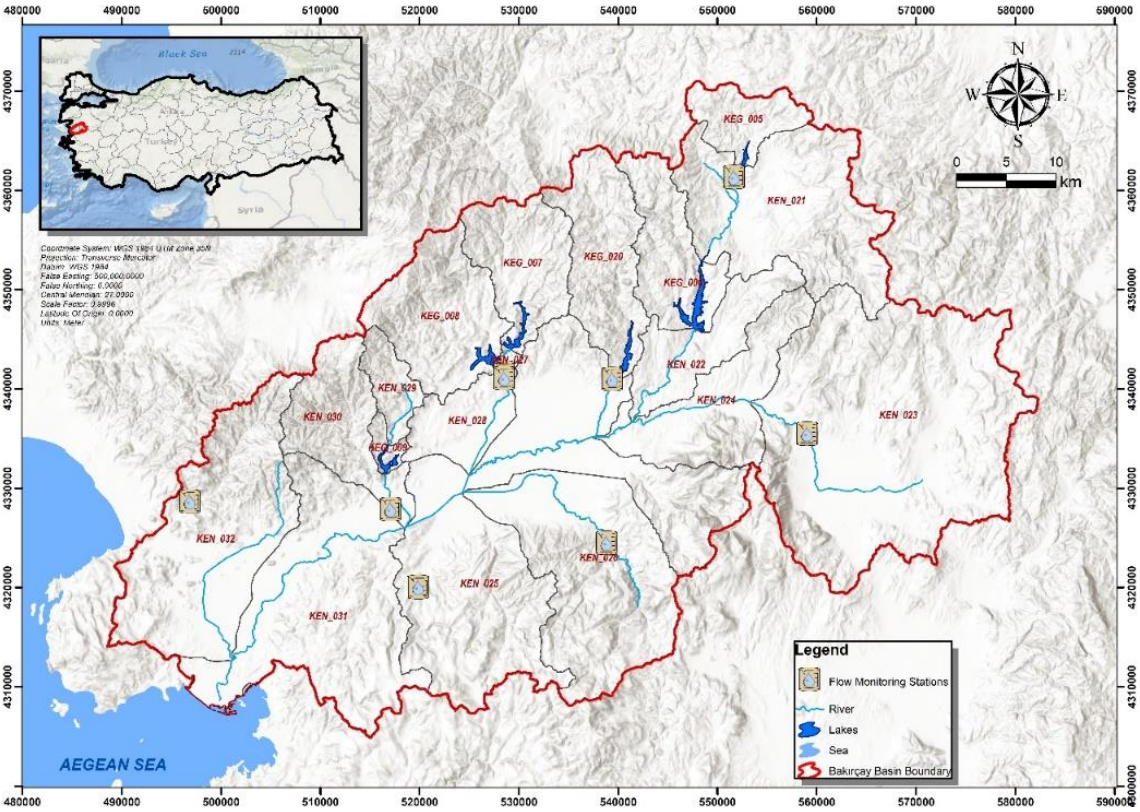

Figure 4.12. The flow monitoring stations given with sub-watersheds

Table 4.18. Sub-watershed based yearly averaged naturalized flows

Sub-watershed	Yearly Average Flow (m^3/year)	Sub-watershed	Yearly Average Flow (m^3/year)
KEG_005	1273033	KEN_027_01b	54992
KEN_021_01b	123092	KEN_027_01c	102658
KEN_021_01c	1532292	KEG_008	3290558
KEN_021_02a	203750	KEN_028_01b	1310800
KEN_021_02b	314092	KEN_028_01c	1549133
KEN_021_02c	133700	KEN_026_01a	1128742
KEN_021_03b	3041208	KEN_026_01b	2122992
KEN_021_03c	137942	KEN_026_01c	1300050
KEG_006	2171050	KEN_025_05b	9559558
KEN_022_01b	549917	KEN_025_05c	158567
KEN_022_01c	147333	KEN_029_01a	604383
KEN_023_01a	1593608	KEN_029_01b	220350
KEN_023_01b	1805608	KEN_029_01c	431250
KEN_023_01c	1123300	KEG_009	356983
KEN_024_01b	691000	KEN_030_01b	2722608
KEN_024_01c	268308	KEN_030_01c	233375
KEN_024_02b	39108	KEN_031_01b	5896158
KEN_024_02c	40475	KEN_031_01c	1732875
KEG_020	2667583	KEN_032_01b	806358
KEN_025_01b	236600	KEN_032_01c	4168175
KEN_025_01c	178700	KEN_025_02b	-*
KEN_025_03b	372517	KEN_025_02c	-*
KEN_025_03c	2632767	KEN_025_04b	-*
KEG_007	2544592	KEN_025_04c	-*

*Sub-watersheds that are formed during digitization with geographic information systems but do not bring significant flow to the basin

4.4.9. Point Pollutant Sources

Pollutant loads originating from urban wastewater occur from 3 different sources in the basin. These are loads from septic tanks of relatively small settlements, loads from urban direct wastewater discharges, and loads from urban treated wastewater discharges. In the calculation of these loads, the generic coefficients shown in Table 4.19 were used. Loads calculated with the help of these coefficients indicate the situation in raw wastewater. For urban wastewater discharged from septic tanks or urban wastewater treatment plants, a load reduction factor has been adopted to consider the treatment performance by using the removal rates given in Table 4.20.

Table 4.19. Coefficients used in calculating pollution loads resulting from urban originated wastewater

(Source: Official Gazette 1991)

Population	Unit flow (L/person/day)	Unit COD Load (gr/person/day)	Unit Total N Load (gr/person/day)	Unit Total P Load (gr/person/day)
<2000	105	55	5	0.9
2000-10000	120	55	5	0.9
10000-50000	135	75	6	1
50000-100000	150	90	7	1.1
>100000	150	90	7	1.1

Table 4.20. Removal efficiencies provided by treatment type

(Source: Metcalf and Eddy, 2002)

Treatment Type	COD removal rate (%)	Total N removal rate (%)	Total P removal rate (%)
Physical Treatment	10	0	0
Biological Treatment	80	25	10
Advanced Biological Treatment (N and P removal)	80	70	70
Natural Treatment	55	20	35
Treatment in a Septic Tank	50	20	30
Treatment in Package Plant	90	40	30
Other	80	20	30

A total of 38 urban direct discharge points have been identified in the basin. The pollutant discharge and load values are given in Table 4.21 according to the sub-watersheds.

Table 4.21. Pollutant loads and discharge rates originating from urban direct discharges on sub-watersheds

Sub-watershed	COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)	Total Discharge (m^3/year)
KEG_005	2.188	0.199	0.036	4177.400
KEG_006	1.024	0.093	0.017	1954.600
KEG_007	9.415	0.856	0.154	17974.400
KEG_008	9.540	0.870	0.160	18204.400
KEG_020	6.826	0.621	0.112	13030.500
KEN_021_01c	188.143	17.104	3.079	410493.600
KEN_021_02a	4.760	0.430	0.080	9083.000
KEN_021_02c	41.796	3.800	0.684	91191.600
KEN_021_03b	17.350	1.580	0.280	33112.800
KEN_023_01a	9.420	0.860	0.150	17974.400
KEN_023_01b	26.057	2.369	0.426	49745.900
KEN_023_01c	8.930	0.810	0.150	17054.600
KEN_024_01c	50.509	4.592	0.827	110200.800
KEN_024_02c	65.404	5.946	1.070	142700.400
KEN_025_03b	23.548	2.141	0.385	44955.200
KEN_025_03c	38.300	3.480	0.630	73124.100
KEN_025_05b	37.560	3.420	0.620	71706.100
KEN_026_01a	20.015	1.820	0.328	38210.000
KEN_026_01b	16.560	1.510	0.270	31618.100
KEN_026_01c	314.190	28.560	5.140	685513.800
KEN_028_01c	22.645	2.059	0.371	43230.600
KEN_029_01c	1.164	0.106	0.019	2222.900
KEN_031_01b	3.694	0.336	0.060	7051.800
KEN_031_01c	77.670	7.060	1.270	164156.900

In the Bakırçay basin, there are 205 septic tanks and the sub-basin-based pollutant load values originating these units are given in Table 4.22.

Table 4.22. Pollutant loads originating from septic tanks on sub-watersheds

Sub-watershed	COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)	Total Discharge (m^3/year)
KEG_005	11.620	1.690	0.270	44380.350
KEG_006	7.250	1.050	0.170	27670.650
KEG_007	30.570	4.450	0.700	116737.950

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Table 4.22. (Cont.)

Sub-watershed	COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)	Total Discharge (m^3/year)
KEG_008	21.450	3.120	0.490	81900.530
KEG_009	1.305	0.190	0.030	4982.250
KEG_020	16.820	2.450	0.390	64232.700
KEN_021_01c	9.490	1.380	0.220	36217.130
KEN_021_02b	0.863	0.126	0.020	3295.950
KEN_021_03b	18.990	2.760	0.440	72510.900
KEN_021_03c	2.290	0.330	0.050	8738.100
KEN_022_01b	13.560	1.970	0.310	51777.080
KEN_022_01c	7.610	1.110	0.170	29050.350
KEN_023_01a	53.540	7.790	1.230	204425.550
KEN_023_01b	18.050	2.630	0.410	68908.350
KEN_023_01c	18.010	2.620	0.410	68755.050
KEN_024_01b	3.920	0.570	0.090	14985.080
KEN_024_01c	4.600	0.670	0.110	17552.850
KEN_025_01b	3.071	0.447	0.070	11727.450
KEN_025_03c	19.540	2.840	0.450	74618.780
KEN_025_05b	30.530	4.440	0.700	116584.650
KEN_026_01a	5.070	0.740	0.120	19354.130
KEN_026_01b	31.330	4.560	0.720	119612.330
KEN_026_01c	10.900	1.590	0.250	41620.950
KEN_028_01b	7.510	1.090	0.170	28667.100
KEN_028_01c	5.200	0.760	0.120	19852.350
KEN_029_01a	0.693	0.101	0.016	2644.430
KEN_029_01c	0.673	0.098	0.015	2567.780
KEN_030_01b	4.850	0.710	0.110	18510.980
KEN_031_01b	49.050	7.140	1.120	187294.280
KEN_031_01c	12.010	1.750	0.280	45875.030
KEN_032_01b	24.840	3.610	0.570	94854.380
KEN_032_01c	29.670	4.320	0.680	113288.700
Total	474.875	69.101	10.901	1813194.140

There are 8 urban wastewater treatment plants in the Bakırçay basin that are actively operating, and the pollutant loads originating from these plants are shown in Table 4.23 according to the treatment type and removal percentages given in previous sections Table 4.20.

Table 4.23. Pollutant loads originating from urban wastewater treatment plants on sub watersheds

Sub-watershed	COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)	Total Discharge (m^3/year)
KEN_023_01a	6.685	2.279	0.492	63811.100
KEN_023_01b	123.510	37.360	7.510	1115629.800
KEN_024_01b	617.698	72.065	11.324	5147485.500
KEN_025_03c	0.365	0.199	0.042	6975.200
KEN_031_01b	389.450	45.560	7.170	3248465.300
KEN_031_01c	1.076	0.587	0.123	20542.200
Total	1138.785	158.050	26.662	9602909.100

Especially in the Soma region of the Bakırçay basin, individual mining activities and related power plants and cement factories exist. In addition, individual factories from food sector (tomato paste and olive) are also active in the basin. Furthermore, there exist Soma, Kınık and Bergama Organized Industrial Zones (OSB) in the basin. These zones do not have wastewater discharge and, no pollutant load originates from these industrial zones to the basin.

In order to calculate the pollutant load coming to the basin from industrial pollutant sources, the discharge standards depicted according to the codes of the sector in the Water Pollution Control Regulation (WPCR) are used (Official Gazette 2004). In Table 4.24., these industrial facilities, their sectors, and related discharge standard tables of the WPCR regulations are presented and calculated, reference pollutant concentrations are given. The locations of these facilities are shown in Figure 4.13.

Table 4.24. Industrial facility wastewater and reference pollutant values

Plant Name	WPCR Table	Wastewater discharge rate (m^3/day)	COD (mg/L) reference	TN (mg/L) reference	TP (mg/L) reference
Be-San Salça Gıda ve Tarım Ltd. Şti.	Table 5.9	480	150		
Ege Turkuaz Zeytin Ve Süt Ür. San. Ve Tic. Ltd. Şti.	Table 5.3	10	170		

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Table 4.24. (Cont.)

Plant Name	WPCR Table	Wastewater discharge rate (m^3/day)	COD (mg/L) reference	TN (mg/L) reference	TP (mg/L) reference
Hidro-Gen Enerji İth.İhc. Dağıtım ve Tic. A.Ş. Kolin Termik Santrali	Table 9.3	72	60		8
Koza Ovacık Altın Madeni	Table 7.1	3600	80		
Nitromak DNX Kimya San.A.Ş. Soma Şubesi	Table 14.7a	40	200	50	35
Soma Çimento Mad. Beton San. ve Tic. A.Ş. Avdan Şubesi	Table 7.5	100			
Soma Elektrik Üretim ve Tic. A.Ş.	Table 21.1	160	180		
Soma İmbat Madencilik	Table 9.1	200	200		
Soma Termik Santral Elektrik Üretim A.Ş. Soğutma suyu-Kül taşıma suyu havuzları	Table 9.6	720			

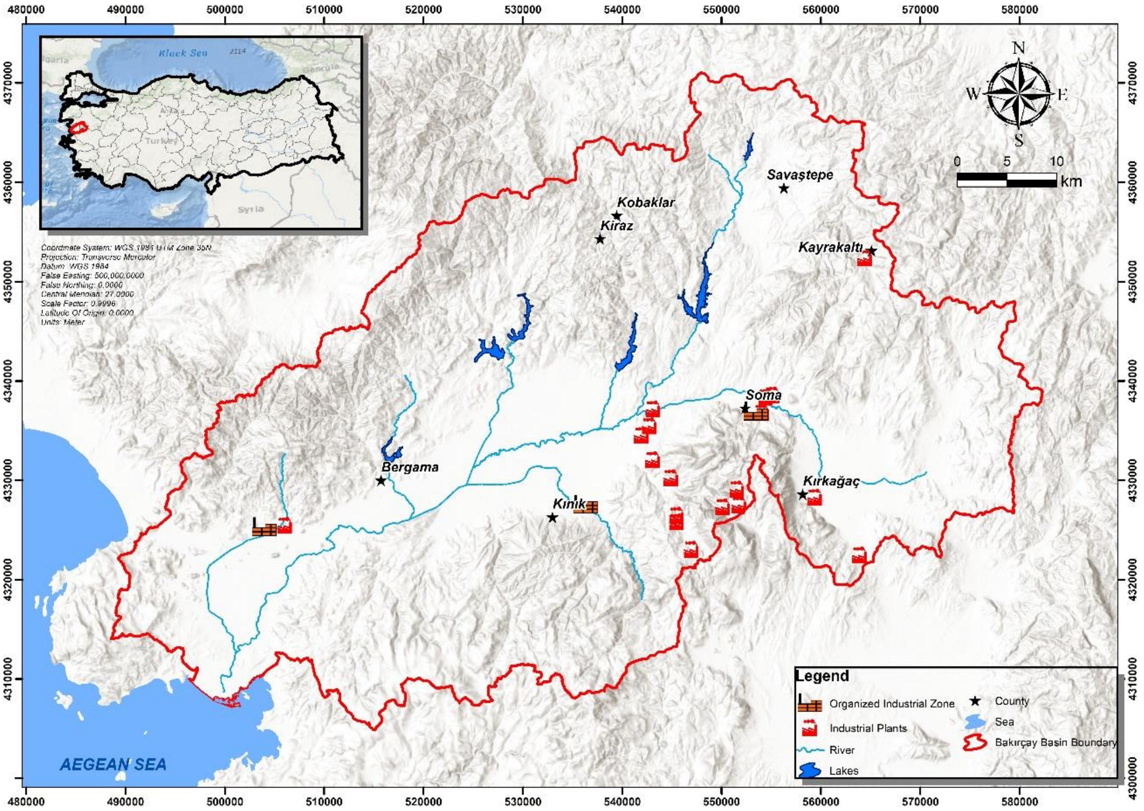

Figure 4.13. Industrial plants and organized industrial zones in Bakırçay river basin

Olive cultivation and olive oil production play an important role in the North Aegean basin, including the Bakırçay basin. Currently, there are 33 olive establishments identified in the basin. The unit pollution loads are given in Table 4.25 and the calculated total pollutant loads of these facilities are given in Table 4.26.

Table 4.25. Unit loads originating from olive industry
(Source: Mekki et al., 2013)

Production method	Generated Wastewater (m^3/ton olive)	COD (mg/L)	TN (mg/L)	TP (mg/L)
Stone Pressed	0.5	130000	1300	87
2 Phase	0.1	15000	150	10
3 Phase	1.1	70000	700	47

Table 4.26. Pollutant loads originating from the olive industry on the sub-watershed basis

Sub-watershed	Total Discharge (m^3/year)	COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)
KEN_023_01a	726.000	50.820	0.508	0.034
KEN_023_01b	2437.000	164.210	1.642	0.110
KEN_023_01c	354.000	23.460	0.235	0.016
KEN_024_01b	676.000	44.020	0.440	0.030
KEN_024_01c	264.000	16.060	0.161	0.011
KEN_025_05b	30.000	0.450	0.005	0.000
KEN_026_01c	175.500	11.275	0.113	0.008
KEN_030_01b	198.000	13.860	0.139	0.009
KEN_031_01c	50.000	0.750	0.008	0.001
Total	4910.500	324.905	3.250	0.219

In this study, contaminant loads originating from leaking uncontrolled solid waste disposal sites, which can also be mentioned as a non-point source by other studies, are considered as point sources. These seepage loads are included in the model from the uncontrolled solid waste site location where they occur. The unit values used to calculate the pollution loads that will arise from the uncontrolled solid waste disposal sites in the basin are given in Table 4.27. While calculating the pollution loads arising from solid waste landfills, the leachate generated by these values has been calculated based on the precipitation value of the site. It was assumed that about 40% of the precipitation will become leakage water. The total loads included in the model system on a sub-watershed basis are given in Table 4.28.

Table 4.27. Unit pollutant values of landfill seepage water

(Source: MoEU, 2006; Service et al., 1977)

Load Type	COD (mg/L)	TN (mg/L)	TP (mg/L)
Landfill Seepage	5000	400	10

Table 4.28. Total pollutant loads from solid waste disposal sites

Sub-watershed	Seepage Flow (m^3/year)	Total COD Load (ton/year)	Total TN Load (ton/year)	Total TP Load (ton/year)
KEN_021_02b	2609.740	13.049	1.044	0.026
KEN_021_03b	3482.165	17.411	1.393	0.035
KEN_022_01b	2780.490	13.902	1.112	0.028
KEN_023_01a	4598.716	22.990	1.840	0.050
KEN_023_01b	20117.542	100.590	8.050	0.200
KEN_024_01b	17657.567	88.288	7.063	0.177
KEN_024_01c	1278.130	6.391	0.511	0.013
KEN_024_02b	544.489	2.722	0.218	0.005
KEN_025_01c	4062.718	20.314	1.625	0.041
KEN_025_03c	2571.369	12.857	1.029	0.026
KEN_026_01b	9602.407	48.012	3.841	0.096
KEN_026_01c	18779.229	93.896	7.512	0.188
KEN_028_01b	2917.827	14.589	1.167	0.029
KEN_030_01c	31284.260	156.421	12.514	0.313
KEN_031_01c	21919.224	109.600	8.770	0.220
KEN_032_01c	28980.573	144.903	11.592	0.290
Total	173186.446	865.935	70.280	1.736

4.4.10. Non-Point Pollutant Sources

Unit loads used in calculating the pollution load due to land use in the Bakırçay basin are given in Table 4.29. As a result of the calculations made, the total TN value arising from land use in the basin is approximately 990 tons/year, while the TP value is 47 tons/year. In Table 4.30., loads can be seen on a sub-basin basis.

Table 4.29. Coefficients used in calculating loads arising from land use
(Source: Dahl and Kurtar, 1993)

Non-Point Source	Unit Loads (kg/ha.year)	
	Total N	Total P
Forest Area	2	0.05
Meadows and Pastures	5	0.1
Urban Area	3	0.5
Rural Area	9.5	0.9

Table 4.30. Land-based pollutant loads originating from sub-watersheds

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEG_005	21.380	1.454	KEN_025_02b	0.000	0.000
KEG_006	43.260	2.267	KEN_025_02c	0.000	0.000
KEG_007	49.129	2.914	KEN_025_03b	0.061	0.002
KEG_008	65.063	3.382	KEN_025_03c	50.147	3.475
KEG_009	4.278	0.086	KEN_025_04b	0.000	0.000
KEG_020	62.322	3.546	KEN_025_04c	0.000	0.000
KEN_021_01b	3.656	0.294	KEN_025_05b	85.007	2.929
KEN_021_01c	22.761	1.652	KEN_025_05c	0.758	0.016
KEN_021_02a	4.567	0.305	KEN_026_01a	31.456	1.207
KEN_021_02b	7.448	0.593	KEN_026_01b	54.073	2.278
KEN_021_02c	3.041	0.220	KEN_026_01c	7.845	0.255
KEN_021_03b	42.851	2.306	KEN_027_01b	0.729	0.057
KEN_021_03c	2.806	0.112	KEN_027_01c	1.345	0.065
KEN_022_01b	21.084	1.097	KEN_028_01b	6.214	0.154

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Table 4.30. (Cont.)

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEN_022_01c	4.212	0.197	KEN_028_01c	7.063	0.376
KEN_023_01a	65.443	3.173	KEN_029_01a	5.577	0.227
KEN_023_01b	41.672	1.623	KEN_029_01b	3.119	0.090
KEN_023_01c	37.030	2.391	KEN_029_01c	5.554	0.163
KEN_024_01b	23.685	1.164	KEN_030_01b	34.730	1.343
KEN_024_01c	5.441	0.185	KEN_030_01c	0.961	0.066
KEN_024_02b	0.929	0.019	KEN_031_01b	75.151	2.817
KEN_024_02c	0.197	0.006	KEN_031_01c	7.499	0.214
KEN_025_01b	2.056	0.064	KEN_032_01b	29.405	0.925
KEN_025_01c	0.299	0.006	KEN_032_01c	47.165	1.559

Total phosphorus and total nitrogen fertilizer consumption per agricultural area in the districts were obtained in the calculation of pollution loads due to the use of fertilizers, and these values were calculated on the basis of districts using 10% for total nitrogen and 4% for total phosphorus. Pollution loads calculated on the basis of districts were converted into the basis of water mass by GIS analysis. As a result of the calculations made, there are approximately 390 tons/year TN and 50 tons/year TP resulting from the use of fertilizers in the basin. Pollutant loads arising from the use of fertilizers on the sub-basin basis are given in Table 4.31.

Table 4.31. Pollutant loads due to the use of fertilizers on a sub-basin basis

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEG_005	7.524	1.006	KEN_025_02b	1.087	0.145
KEG_006	9.004	1.209	KEN_025_02c	0.003	0.000
KEG_007	15.134	2.025	KEN_025_03b	6.096	0.815
KEG_008	14.241	1.906	KEN_025_03c	36.873	4.935
KEG_009	0.569	0.076	KEN_025_04b	0.959	0.128
KEG_020	11.683	1.568	KEN_025_04c	0.066	0.009
KEN_021_01b	0.876	0.117	KEN_025_05b	31.221	4.176
KEN_021_01c	9.969	1.333	KEN_025_05c	0.843	0.113

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Table 4.31. (Cont.)

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEN_021_02a	0.729	0.097	KEN_026_01a	3.729	0.499
KEN_021_02b	1.851	0.247	KEN_026_01b	14.746	1.972
KEN_021_02c	0.915	0.122	KEN_026_01c	28.051	3.751
KEN_021_03b	14.323	1.919	KEN_027_01b	0.091	0.012
KEN_021_03c	1.465	0.197	KEN_027_01c	0.205	0.027
KEN_022_01b	13.281	1.784	KEN_028_01b	2.628	0.352
KEN_022_01c	3.935	0.529	KEN_028_01c	11.104	1.486
KEN_023_01a	11.850	1.587	KEN_029_01a	0.492	0.066
KEN_023_01b	19.146	2.566	KEN_029_01b	0.295	0.039
KEN_023_01c	13.664	1.835	KEN_029_01c	0.584	0.078
KEN_024_01b	11.743	1.577	KEN_030_01b	3.476	0.465
KEN_024_01c	7.376	0.991	KEN_030_01c	2.535	0.339
KEN_024_02b	1.147	0.154	KEN_031_01b	27.991	3.746
KEN_024_02c	1.919	0.257	KEN_031_01c	17.622	2.358
KEN_025_01b	1.579	0.211	KEN_032_01b	7.845	1.050
KEN_025_01c	1.134	0.152	KEN_032_01c	17.634	2.359

In the calculation of pollution caused by animal activities, which is another diffuse source in the Bakırçay basin, the coefficients of pollution reaching the receiving environment were accepted as 15% for TN and 5% for TP, as can be seen in Table 4.32. (Andreadakis et al., 2007; Erturk et al., 2010; NationMaster, 2011). With this assumption, the pollutant loads in sub-basins are shown in Table 4.33.

Table 4.32. Non-point load coefficients resulting from livestock activities

Animal Type	TN (kg/animal/year)	TN dissolution factor	TP (kg/animal/year)	TP dissolution factor
Cattle Farming	8.2	0.15	0.91	0.05
Sheep and Goat Farming	1	0.15	0.05	0.05
Poultry Farming	0.06	0.15	0.008	0.05

Table 4.33. Non-point loads on sub-watersheds resulting from livestock activities

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEG_005	4.332	0.160	KEN_024_01c	8.999	0.386
KEG_006	2.425	0.087	KEN_024_02c	0.432	0.016
KEG_007	10.592	0.334	KEN_025_01b	0.448	0.014
KEG_008	10.960	0.354	KEN_025_03c	13.523	0.464
KEG_009	0.485	0.015	KEN_025_05b	12.426	0.411
KEG_020	4.490	0.152	KEN_026_01a	4.311	0.125
KEN_021_01c	16.199	0.662	KEN_026_01b	4.795	0.150
KEN_021_02a	0.418	0.013	KEN_026_01c	15.228	0.586
KEN_021_02b	3.993	0.149	KEN_028_01b	3.454	0.098
KEN_021_03b	10.619	0.413	KEN_028_01c	4.882	0.172
KEN_021_03c	0.817	0.030	KEN_029_01a	0.388	0.009
KEN_022_01b	4.913	0.203	KEN_029_01c	1.120	0.032
KEN_022_01c	1.141	0.044	KEN_030_01b	16.404	0.602
KEN_023_01a	11.249	0.404	KEN_031_01b	9.216	0.336
KEN_023_01b	6.574	0.210	KEN_031_01c	5.702	0.194
KEN_023_01c	1.638	0.058	KEN_032_01b	9.684	0.332
KEN_024_01b	9.632	0.408	KEN_032_01c	7.522	0.207

The last pollutant source coming to the basin is atmospheric deposition. Total Nitrogen and Total Phosphorus loads from the atmosphere by dry deposition and wet deposition in the basin area were calculated. As a calculation method, it has been assumed that 5% of the basin area will accumulate with 0.4453 ton/km^2/year for TN, 0.04088 ton/km^2/year for TP, and in addition to this, due to the Soma Thermal Power Plant and Lignite mine located in the basin, 30% and 50% additional correction factor has been taken into account in the sub-watershed pollutant load. Pollutant loads resulting from atmospheric deposition as a result of the mentioned method are given in Table 4.34. on a sub-watershed basis.

Table 4.34. Sub-watershed-based pollutant loads caused by atmospheric deposition

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEG_005	1.361	0.125	KEN_025_02b	0.067	0.006
KEG_006	2.463	0.226	KEN_025_02c	0.000	0.000

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Table 4.34. (Cont.)

Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)	Sub-watershed	TN Load Into Water (ton/year)	TP Load Into Water (ton/year)
KEG_007	2.625	0.241	KEN_025_03b	0.330	0.030
KEG_008	3.458	0.317	KEN_025_03c	4.905	0.450
KEG_009	0.291	0.027	KEN_025_04b	0.079	0.007
KEG_020	3.126	0.287	KEN_025_04c	0.005	0.000
KEN_021_01b	0.128	0.012	KEN_025_05b	5.987	0.550
KEN_021_01c	1.608	0.148	KEN_025_05c	0.115	0.011
KEN_021_02a	0.214	0.020	KEN_026_01a	1.569	0.144
KEN_021_02b	0.329	0.030	KEN_026_01b	2.953	0.271
KEN_021_02c	0.141	0.013	KEN_026_01c	1.822	0.167
KEN_021_03b	3.210	0.295	KEN_027_01b	0.032	0.003
KEN_021_03c	0.233	0.021	KEN_027_01c	0.058	0.005
KEN_022_01b	1.769	0.162	KEN_028_01b	0.509	0.047
KEN_022_01c	0.473	0.043	KEN_028_01c	1.073	0.098
KEN_023_01a	4.602	0.422	KEN_029_01a	0.428	0.039
KEN_023_01b	5.214	0.479	KEN_029_01b	0.156	0.014
KEN_023_01c	3.244	0.298	KEN_029_01c	0.306	0.028
KEN_024_01b	3.363	0.309	KEN_030_01b	2.364	0.217
KEN_024_01c	1.133	0.104	KEN_030_01c	0.257	0.024
KEN_024_02b	0.127	0.012	KEN_031_01b	5.350	0.491
KEN_024_02c	0.132	0.012	KEN_031_01c	2.106	0.193
KEN_025_01b	0.210	0.019	KEN_032_01b	2.552	0.234
KEN_025_01c	0.092	0.008	KEN_032_01c	4.160	0.382

4.4.11. Coefficients and Methods Used in the Model

The loads calculated above must be converted into model variables in order to be input into the GESCAL module of the AQUATOOL model. Organic matter load expressed as COD and total nitrogen and total phosphorus loads expressed as TN and TP should be expressed as parameters on which the model can work. In this regard, the calculated COD loads need to be converted to BOD_5 loads; TN loads need to be converted to nitrate, organic nitrogen, and ammonium load; TP loads should be converted to organic and inorganic phosphorus loads. Conversion factors given in Table 4.35 and Table 4.36 were used to convert the relevant loads into BOD_5, nitrate, organic nitrogen, ammonium, organic phosphorus, and inorganic phosphorus parameters, which are the simulation parameters used by the GESCAL model.

Table 4.35. Conversion rates used in expressing the calculated nutrient loads in terms of model parameters (Source: Metcalf et al., 1991)

Pollutant Source	TN Fractions			TP Fractions	
	Organic N	Ammonium	Nitrate	Organic P	Inorganic P
Raw Wastewater	0,4	0,6	0	0,3	0,7
Biologically Treated Wastewaters	0,1	0,1	0,8	0,4	0,6
Solid Waste Landfill Leachate	0,47	0,47	0,06	0,33	0,67
Land Use	0,1	0,2	0,7	0,2	0,8
Fertilizer	0,1	0,2	0,7	0,3	0,7
Livestock	0,1	0,2	0,7	0,2	0,8
Atmosphere	0	0,5	0,5	0	1

Table 4.36. Conversion rates used in expressing the calculated organic loads in terms of model parameters

Pollutant Source	COD/BOD_5
Urban direct discharge	2
Septic tank	4
Urban wastewater treatment plant discharge	6
Organized industrial Zone (OSB) / Individual industrial plant discharge	7
Olive plants	3
Solid Waste Landfill Leachate	1,8

There are two options for the reaeration coefficients to be used in the model. Either the modeler can input the coefficient into the model, or it may be calculated with the COVAR statistical method of the model. In this study, the reaeration coefficient was internally calculated by the model. For this calculation, the water depth (H) and velocity (u) of the water body are used to determine the method to be used. If $H < 0.61$ m model applies Owens-Gibbs formula given in equation 10. If $H > 0.61$ and $H > 3.44 * u^{2.5}$, the O'Connor-Dobbins formula given in equation 11 is applied. In all other cases, the Churchill formula given in equation 12 is applied (Paredes, Andreu, and Solera 2007).

$$K_a = 5.32 \frac{u^{0.67}}{H^{1.85}} \tag{10}$$

$$K_a = 3.93 \frac{u^{0.5}}{H^{1.5}} \tag{11}$$

$$K_a = 5.026 \frac{u}{H^{1.67}} \tag{12}$$

The constant and coefficients used in the models significantly affect biochemical reactions, speed coefficients, directly and indirectly, with coefficients that characterize the life cycle of organisms such as phytoplankton or control light transmission. AQUATOOL provides reference ranges for these coefficients, and these initial values are updated to characterize the study area with calibration studies. Table 4.37. includes the mentioned model parameters and the values and reference ranges used in this study.

Table 4.37. Parameter values used in the model

Parameter Abbreviation	Unit	Recommended Range	Used Value	Parameter
Ka	1/d	0-100	Variable	Reaeration
Kd	1/d	0.02-3.4	0.4	Decomposition of carbonaceous organic matter
VsL	m/d	0.01-0.36	0.01	Sedimentation rate of carbonaceous organic matter
KNoa	1/d	0.02-0.4	0.01	Hydrolysis of organic nitrogen
VSNo	m/d	0.001-0.1	0.001	Settling rate of organic nitrogen
Knai	1/d	0.01-0.1	0.1	Ammonium nitrification
Kno3	1/d	0.001-0.1	0.1	Denitrification
Kg	1/d	1-3	1	Phytoplankton growth
Kresp	1/d	0.05-0.5	0.05	Phytoplankton death and respiration
VSA	m/d	0.15-1.83	0.15	Phytoplankton sedimentation rate
Kmp	1/d	0.01-0.7	0.2	Decay of organic phosphorus
Vsor	m/d	0.001-0.1	0.001	Sedimentation rate of organic phosphorus
-	-	-	250	Light Saturation Intensity

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Table 4.37. (Cont.)

Parameter Abbreviation	Unit	Recommended Range	Used Value	Parameter
-	Langleys	-	350	Radiation mean reference value
-	per unit	-	0.5	Fotoperiod reference value
-	m/d	-	0	Light dampening base constant
-	m/d	-	0	Fitoplancto light dampening coefficient
-	-	-	0	Phosphate degradation constant

Although the Bakırçay watershed is the largest sub-basin of the North Aegean basin, the duration of precipitation-flow-discharge in the surface water bodies forming the basin is 1 day or less. This indicates that the main transport mechanism for the Bakırçay basin model is advection and that biochemical breakdown is a much less effective mechanism on the fate of pollutants, as the time to occur for biochemical reactions is very short. In this context, removal by biochemical reactions has been detected at negligible levels in models.

CHAPTER 5

RESULTS & DISCUSSION

5.1. Calibration and Validation

5.1.1. Parameter Sensitivity

Within the scope of the modeling study carried out in Bakırçay Basin, a sensitivity analysis was carried out to measure the sensitivity of the model parameters. Accordingly, the biochemical degradation rate constant of organic matter, nitrification rate constant of ammonium and mineralization rate constant of organic phosphorus, which are the most important biochemical reactions in the model, were run in the recommended ranges in the model to determine the effects on the model results. The minimum and maximum values determined by the model manual for these parameters and the predicted value to be used in the model are given in Table 5.1.

Table 5.1. Model parameters used in the sensitivity analysis

Values	BOD Degredation rate constant (1/day)	Ammonium (NH_4) nitrification rate constant (1/day)	Organic Phosphorus mineralization rate constant (1/day)
Predicted	0.4	0.1	0.2
The possible minimum	0.02	0.01	0.01
The possible maximum	3.4	1	0.7

The sensitivity analysis results are examined in the river segment named "31-32-J" representing the branch where the basin flows into the sea. In Figure 5.1., the BOD concentrations in the 31-32-J river segment can be seen for the minimum, predicted, and maximum values of the BOD degradation (decay) rate constant. Accordingly, although it is seen that the BOD degradation rate constant affects the model dynamics, it will not cause significant differences in the interpretation of the model results, as all results fall under the "good water condition" criterion in the Water Pollution Control Regulation. Similar graphs are given in Figure 5.2. for ammonium and Figure 5.3. for organic phosphorus. These graphs reveal that these 2 parameters cannot provide good water status in the basin. However, it is clear that this situation is not caused by the ammonium nitrification rate constant and the organic phosphorus mineralization rate constant, which are the subject of the sensitivity analysis. As can be understood from the graphs, the model results using lower and upper velocity constant are within 1 standard deviation confidence interval of the model results using the predicted velocity constant.

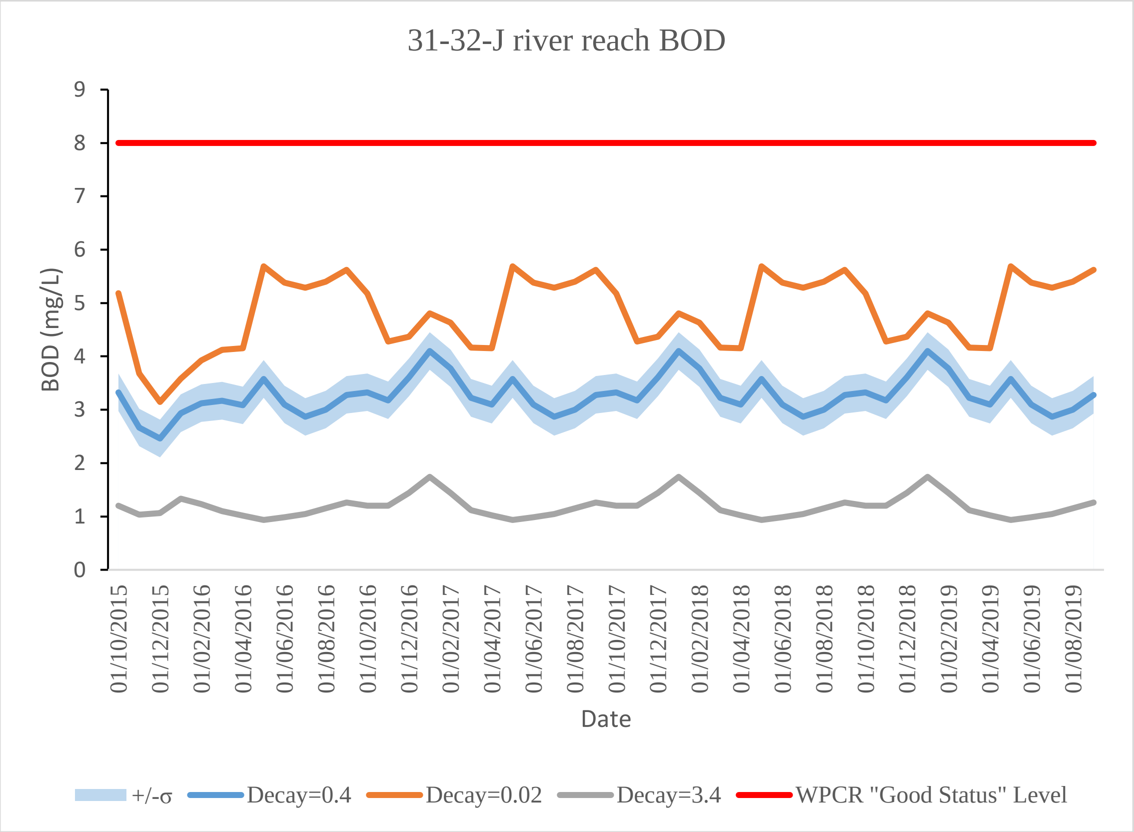


Figure 5.1. Model results and legal limit according to various BOD degradation rate constant in the river section "31-32-J"

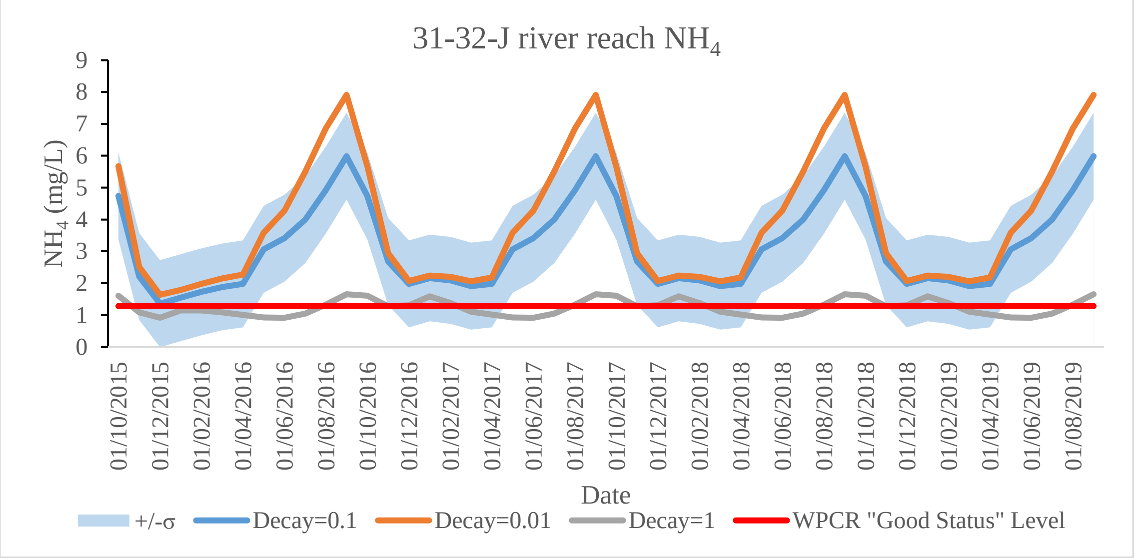


Figure 5.2. Model results and legal limit according to various Ammonium nitrification rate constant in the river section "31-32-J"

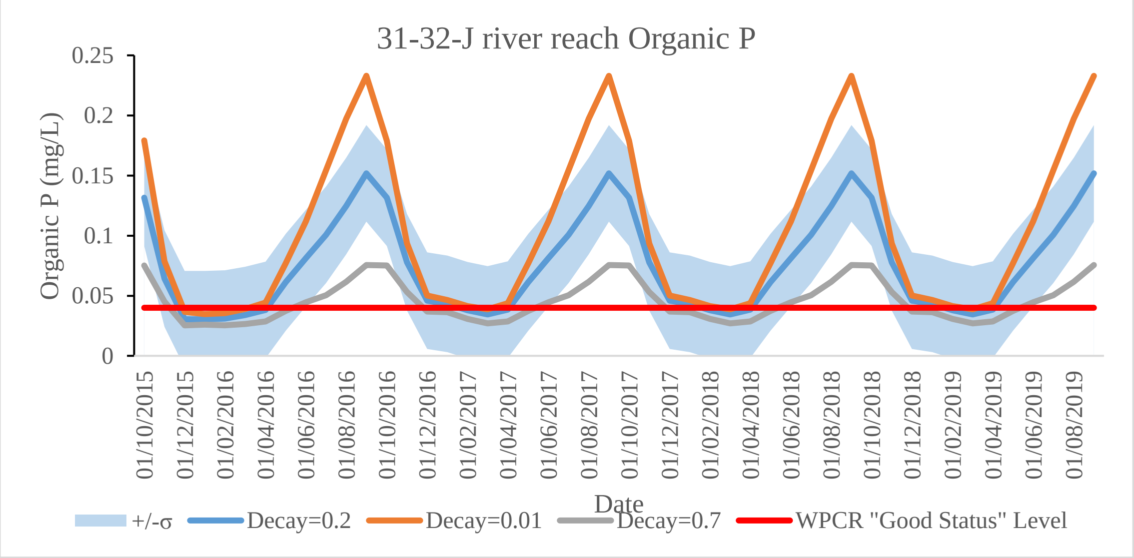


Figure 5.3. Model results and legal limit according to various Organic P mineralization rate constant in the river section "31-32-J"

To summarize, it is understood that the most sensitive of the parameters given above is the BOD degradation rate constant, followed by the ammonium nitrification rate constant and the least sensitive organic phosphorus mineralization rate constant. As can be understood from the figures, parameter changes do not cause statistically significant changes in the model results. For this reason, the use of the values given in Table 5.1., which is currently used in the model, was found appropriate.

5.1.2. Calibration

The AQUATOOL model accepts the quantity and quality values in terms of water years. For this reason, the quality data to be used for calibration processes in the Bakırçay basin were measured in the 2018-2019 water year. However, as the flow observations in the basin ended in 2014, as shown in the precipitation section, the flow completion process had to be applied to compare the quality data. Therefore, the monthly averages of the long-term flow values obtained were extended by 5 years to include the 2019 water year and included in the model process. The results of the model operated using the flow values whose data were completed and evaluated together with the quality measurement values. These evaluations made on the basis of parameters are shown in Figure 5.4, Figure 5.5, and Figure 5.6 for 1 upstream river section, 1 basin outlet river section, and 1 lake.

As can be seen from the calibration results for the 24-1-1 river segment representing the upstream parts of the basin (Figure 5.4), the modeled parameters have been successfully represented in general. With the 90% confidence interval given in the maps, the compatibility of the data and the measurements was demonstrated. Furthermore, it can also be seen that NH_4, NO_3, Organic P and Inorganic P parameters can be represented more successfully than BOD_5, Dissolved Oxygen and Organic N parameters.

The calibration results for the G6 lake part (Figure 5.5) representing the lake water bodies of the basin reveal that the parameters other than the Organic Nitrogen and Organic Phosphorus parameters are successfully represented. In addition, when evaluated together with the limit values, it can be seen that the water quality status of the other parameters except for Organic Nitrogen in the lake water bodies in the basin is not bad.

The calibration results for the 31-32-J river segment, which represents the outlet water body of the basin and the whole of the basin, showed that the model was not very successful in representing the NH_4, Organic N, Organic P, and Inorganic P parameters, but the values of the parameters except Organic N and Organic P from the measurement results were also within limits. According to which indicates that it is not in bad condition.

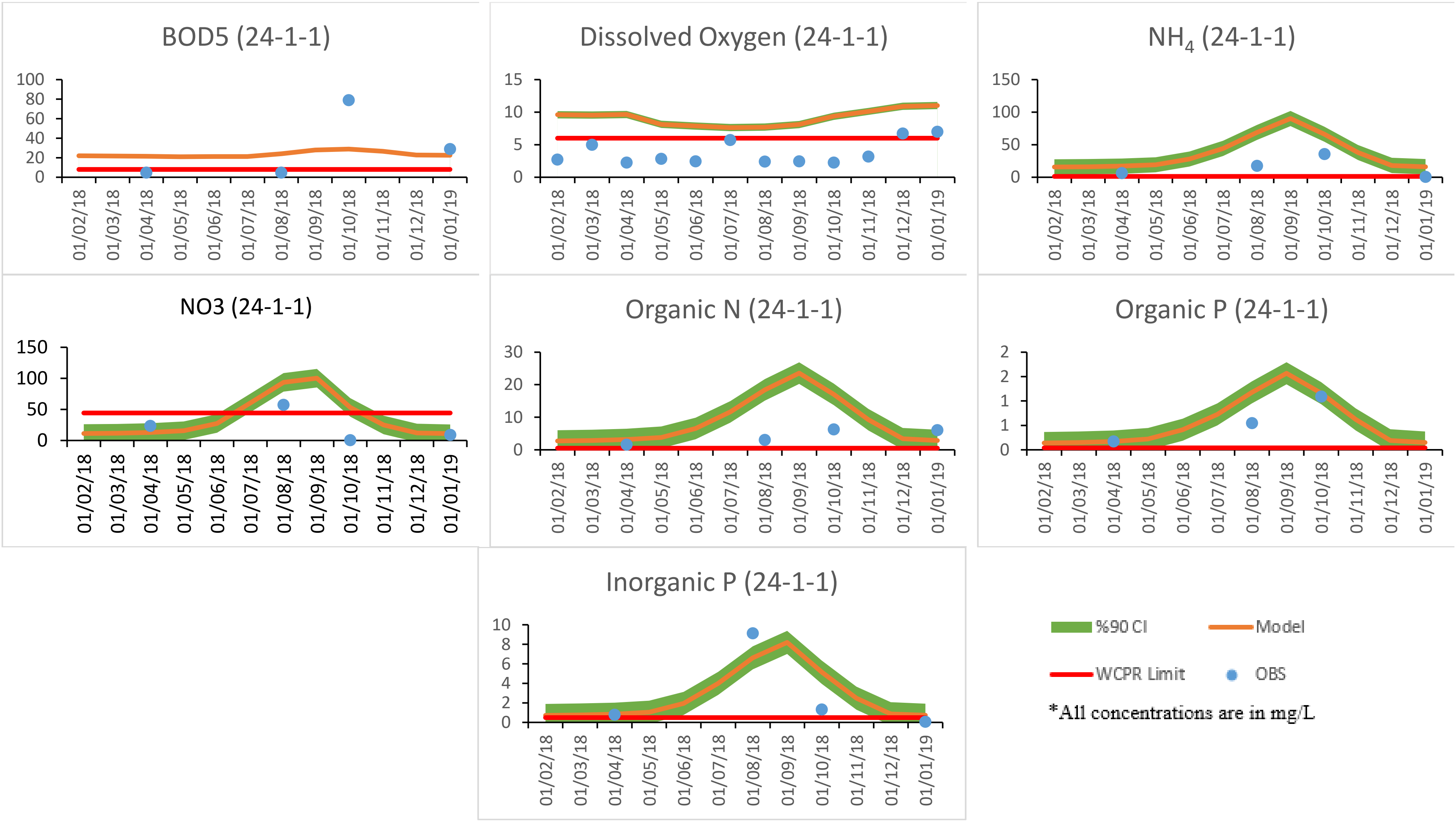


Figure 5.4. Calibration results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P, and Inorganic P at 24-1-1 river reach

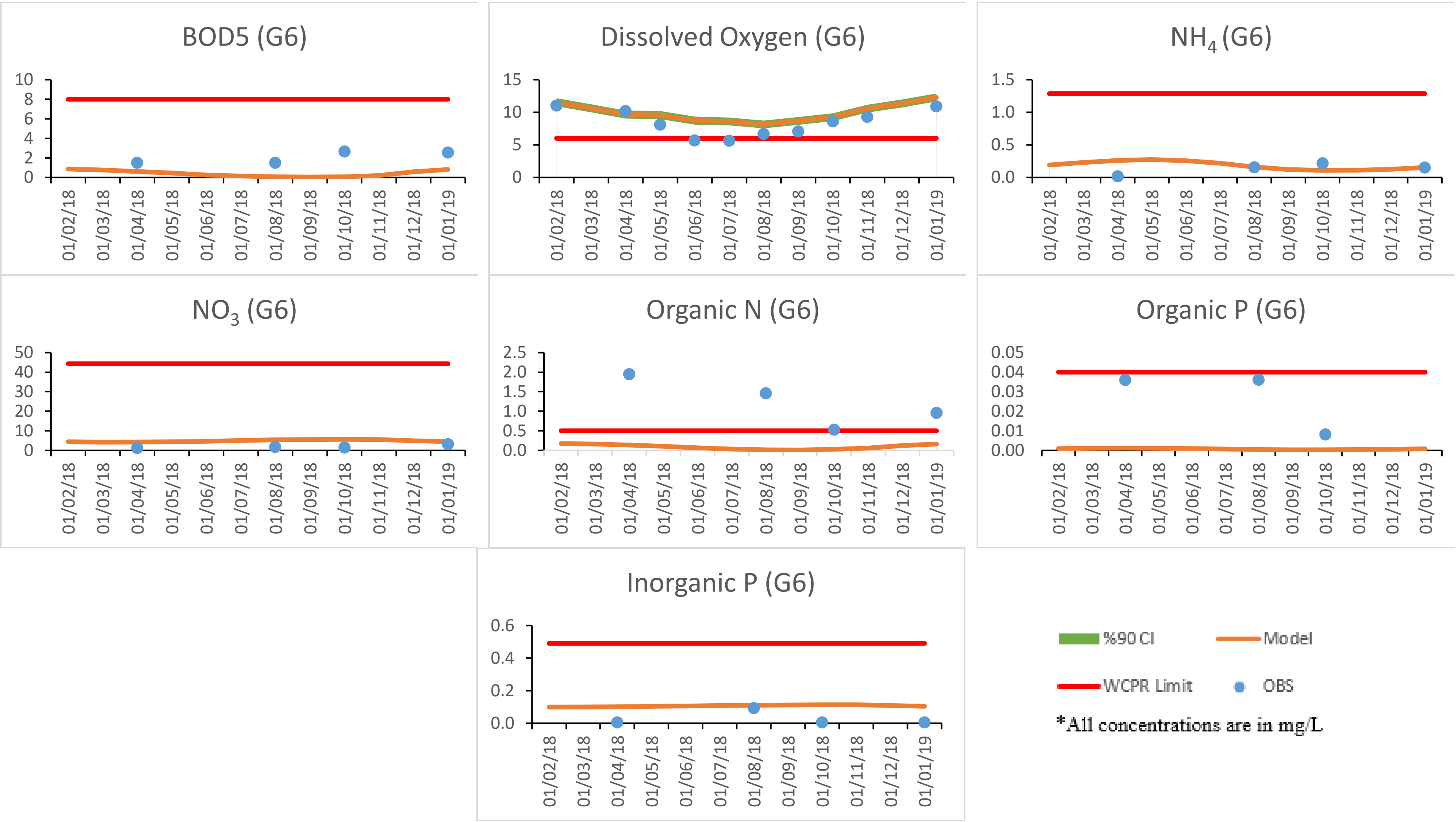
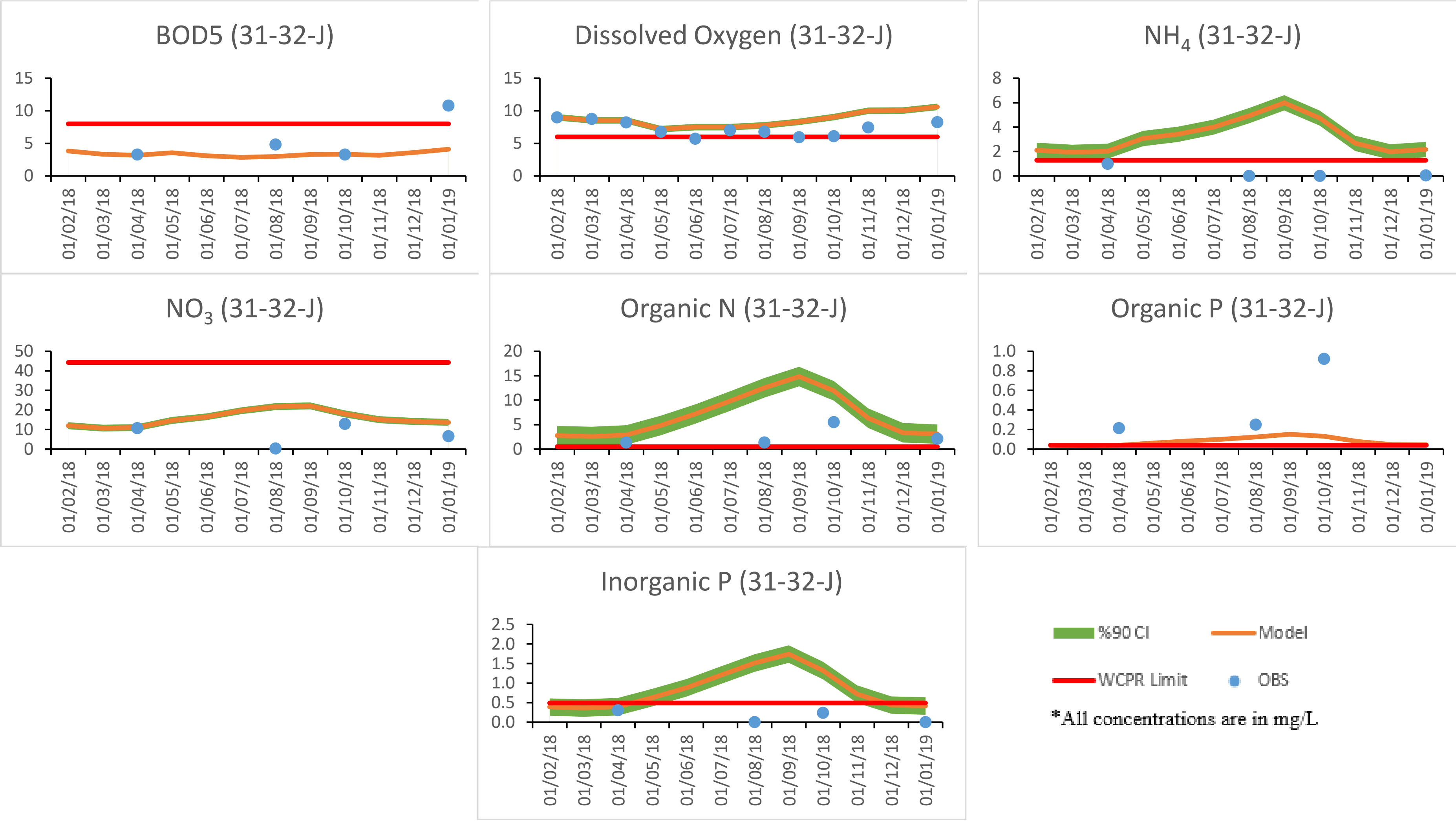


Figure 5.5. Calibration results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P, and Inorganic P at G6 lake point



*All concentrations are in mg/L

Figure 5.6. Calibration results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at 31-32-J river reach

In model studies, mostly high percentage model-measurement compatibility cannot be seen. However, basin water quality models are important in terms of percentage comparison of water quality conditions. As a result, based on Figure 5.4, Figure 5.5, and Figure 5.6, it can be said that the AQUATOOL model represents the Bakırçay basin at a reasonable rate.

5.2. Base Period

The results of the AQUATOOL model run with the data given in the previous section will be explained in 2 different ways. First, the annual average concentrations of selected points on the main stream of the Bakırçay river will be displayed together with the corresponding measurement values so that the fate of the pollutant parameters along the river network can be evaluated. Another method is to present the changes in concentrations over the time of 4 years, which is the model period, at the points used in calibration/verification processes. Thanks to this method, the pressures that the given river points are exposed to can be seen in a temporal context.

5.2.1. Current Pollutant Status

Bar graphs examining the pollution load in the basin can be seen in Figure 5.7. Accordingly, while it can be seen that approximately 80% of the pollutant pressure in the basin comes from diffuse pollutant sources, it has been determined that the largest contributor among diffuse pollutant sources is land use & land cover source for TN pollutant, and chemical fertilizer use for TP pollutant. In point pollutant sources, it has been determined that the biggest contribution in terms of all pollutants comes from urban WWTPs and then from urban direct discharges.

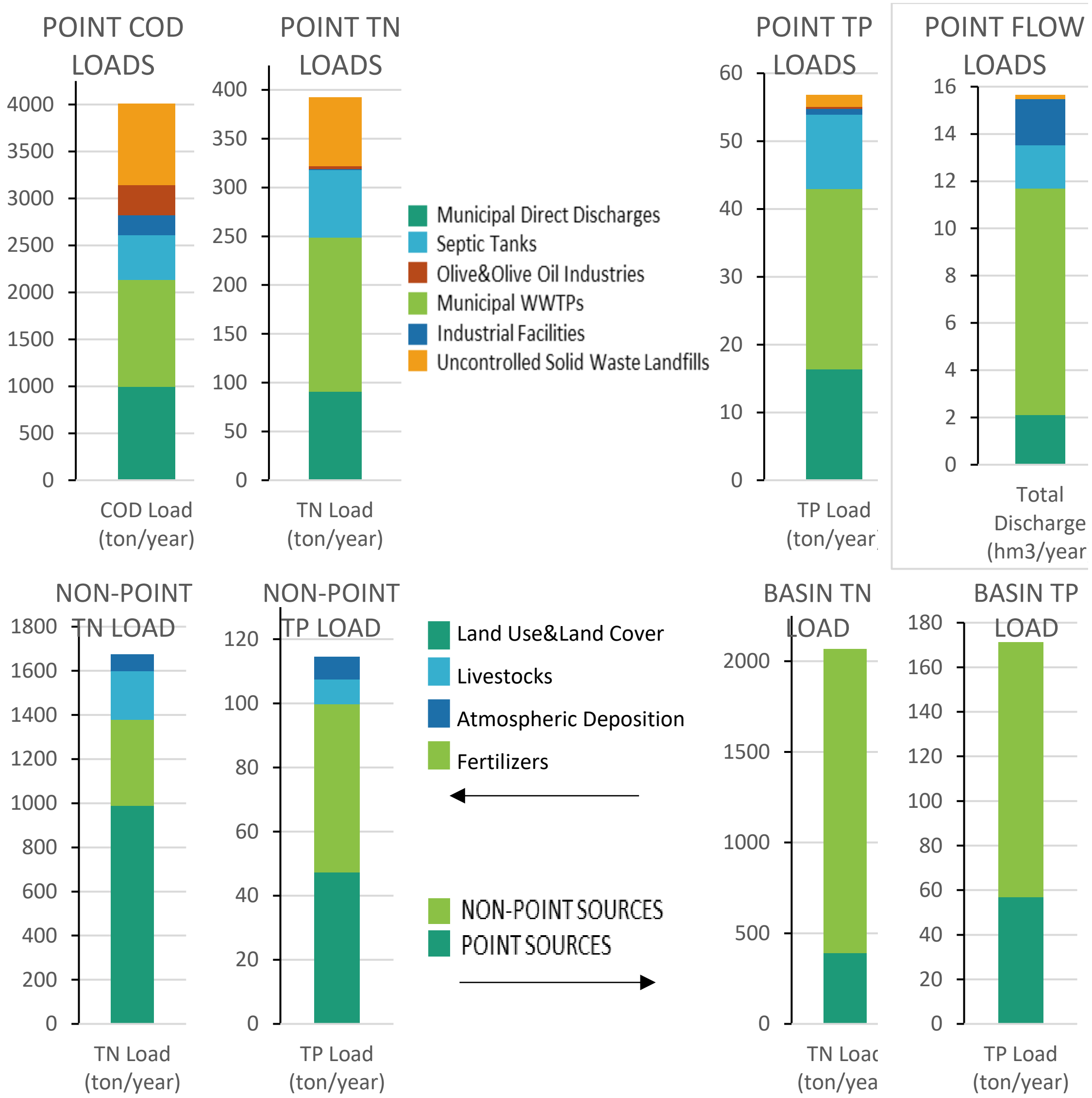


Figure 5.7. The current pollutant status in the basin

5.2.2. Spatially Based Results

For spatial analysis, 21-1-2 river segments representing the upstream, 22-1-2 and 31-1-2 river segments representing inland parts, and 31-32-J river segments representing the downstream were used. The spatial analysis of the model results was carried out with the average values of April results representing the wet period and the average values of September results representing the dry period. Wet period BOD$_5$ and DO results are given in Figure 5.8 and the average flow rates of the related period. BOD$_5$ concentrations, which can be seen between 0.896 and 3.182 in Figure 5.8., reveal that the situation of Bakırçay River in terms of organic pollution is not bad. However, the decrease in dissolved oxygen levels caused by the increasing organic pollution as it moves from the upstream to the downstream side of the river can also be seen in Figure 5.8. The wet period NO_3, NH_4 and organic nitrogen results are given in Figure 5.9. It is thought that the reason for the sharp increase in each of the 3 parameters when it comes to the 31-1-2 part is the tributary from Kırkağaç and Soma regions, which are connected to the river between the two river parts. The wet period organic phosphorus and inorganic phosphorus results are given in Figure 5.10. It is thought that the source of the increase in inorganic phosphorus parameter, which is similar to the sudden rise seen in nitrogenous components at the downstream point of the river, may be Yağcılar Creek, which carries the water of a part of Dikili region and a small part of Bergama region to Bakırçay River.

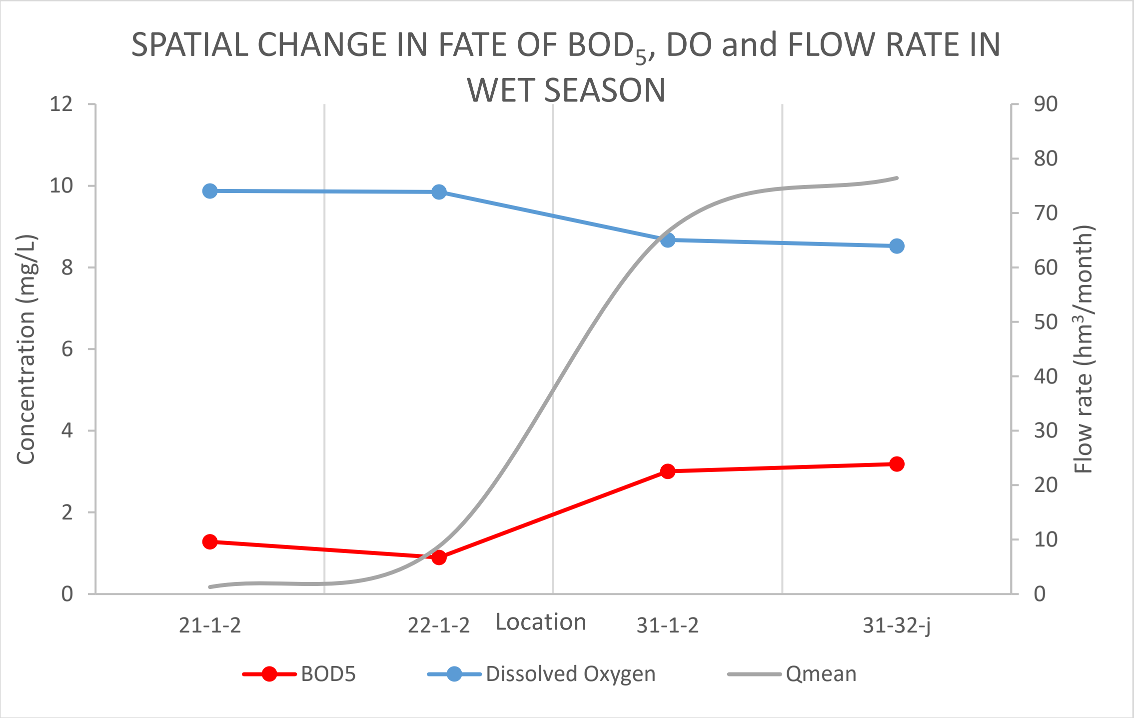


Figure 5.8. The spatial change in fate of BOD_5, DO and flow rate under wet season base period

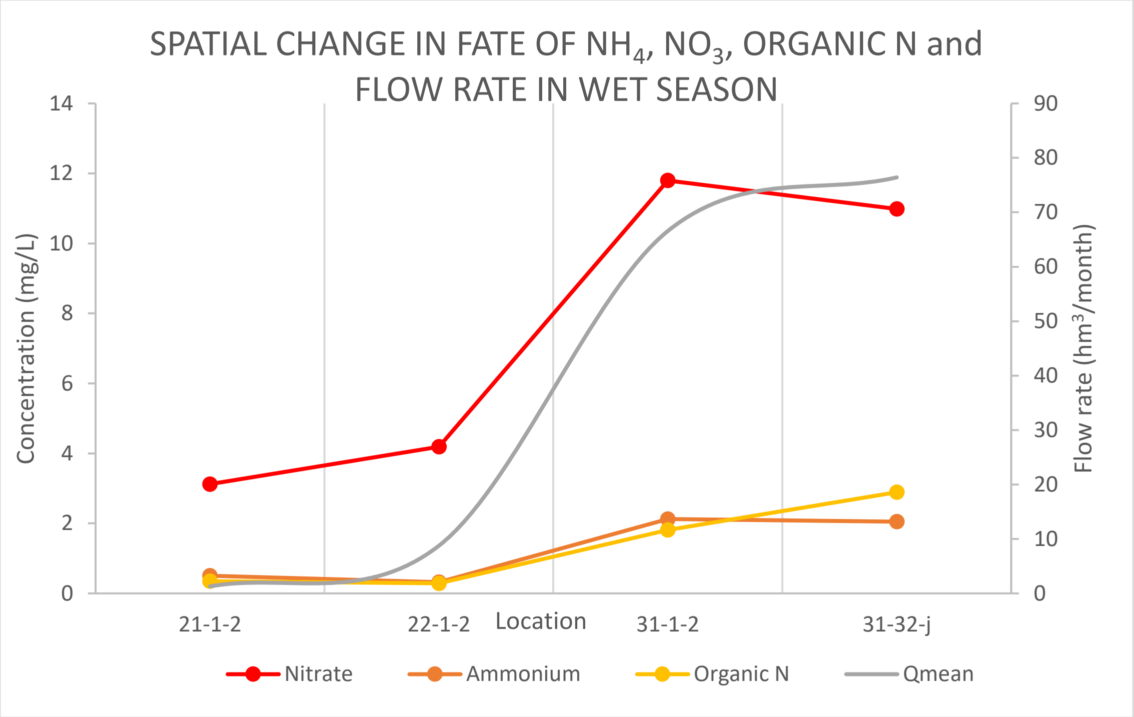


Figure 5.9. The spatial change in fate of NH_4, NO_3, Organic N and flow rate under wet season base period

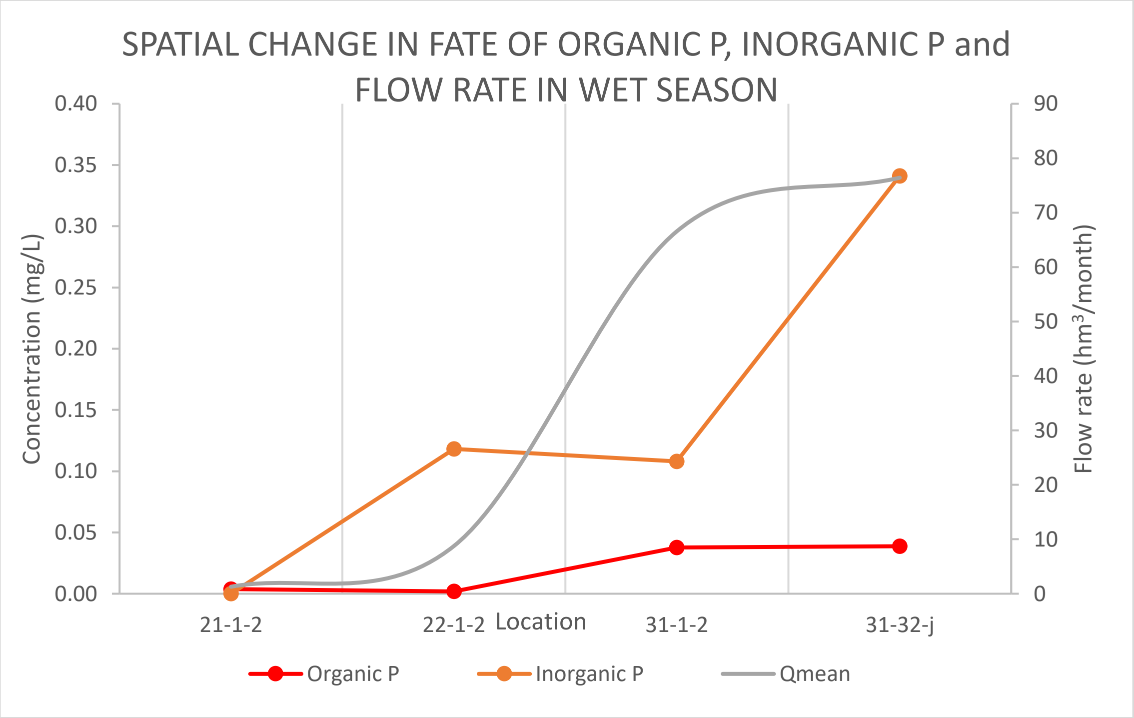


Figure 5.10. The spatial change in fate of Organic P, Inorganic P and flow rate under wet season base period

Dry period BOD_5 and Dissolved Oxygen results are given in Figure 5.11 together with the flow rate averages of the related period. In systems with pollutant discharges that do not change seasonally, it is normal to see higher concentrations due to the reduction of natural flows during dry periods compared to wet periods. However, as shown in Figure 5.11., despite the 10-fold decreasing mean flow compared to the wet period, the dry period BOD_5 results are relatively close to the wet period results, indicating that the Bakırçay River basin is not exposed to high organic pollution. It can be seen that the response to seasonal changes is not high in the dissolved oxygen parameter, which is closely related to the BOD_5 parameter.

Dry period NO_3, NH_4, and organic nitrogen results are given in Figure 5.12. Although all three of the nitrogenous components showed the same pattern with the wet period, it can be seen that the levels increase up to 5 times compared to the wet period. This situation is thought to be caused by pollutant discharges that do not change seasonally and are continuous.

The dry period organic phosphorus and inorganic phosphorus results are given in Figure 5.13. As with nitrogenous compounds, phosphorus compounds also increase up to 10 times, and in addition, inorganic phosphorus can be seen to have a higher trend at the point representing the mid-end parts of the river compared to the wet period. It is thought that the reason for this may be that the inorganic phosphorus load from the Soma region may be above natural levels.

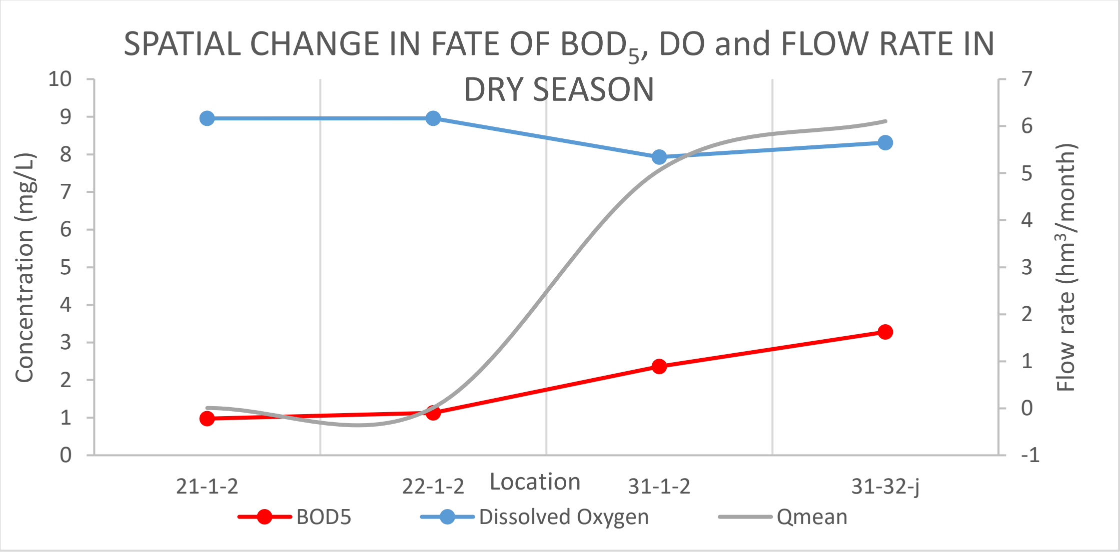


Figure 5.11. The spatial change in fate of BOD_5, DO and flow rate under dry season base period

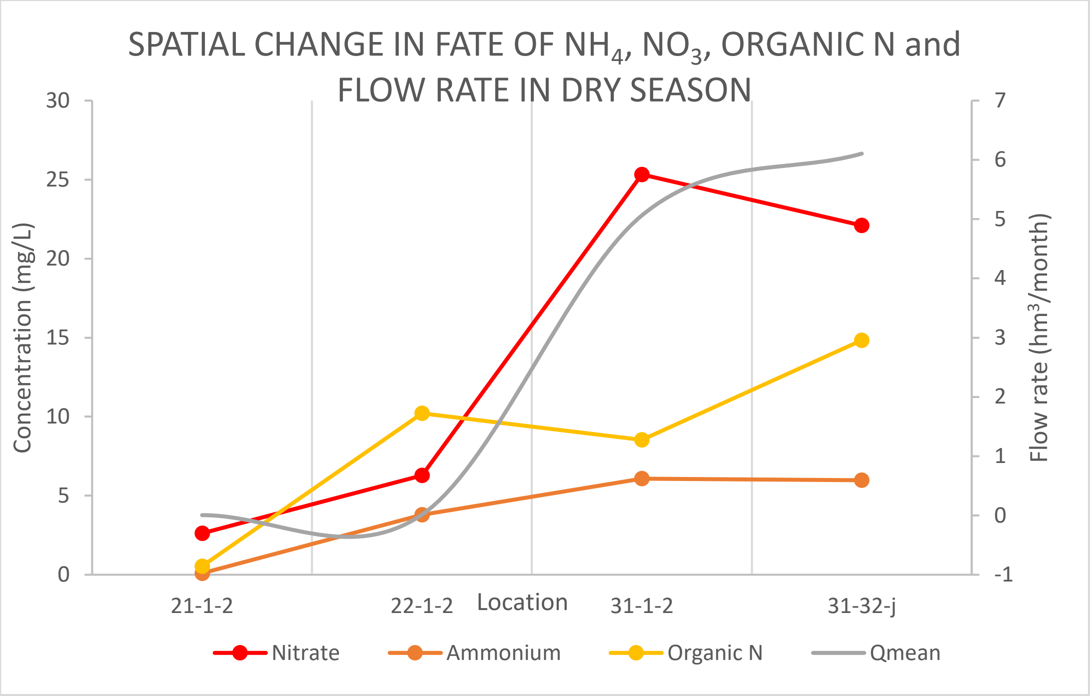


Figure 5.12. The spatial change in fate of NH_4, NO_3, Organic N and flow rate under dry season base period

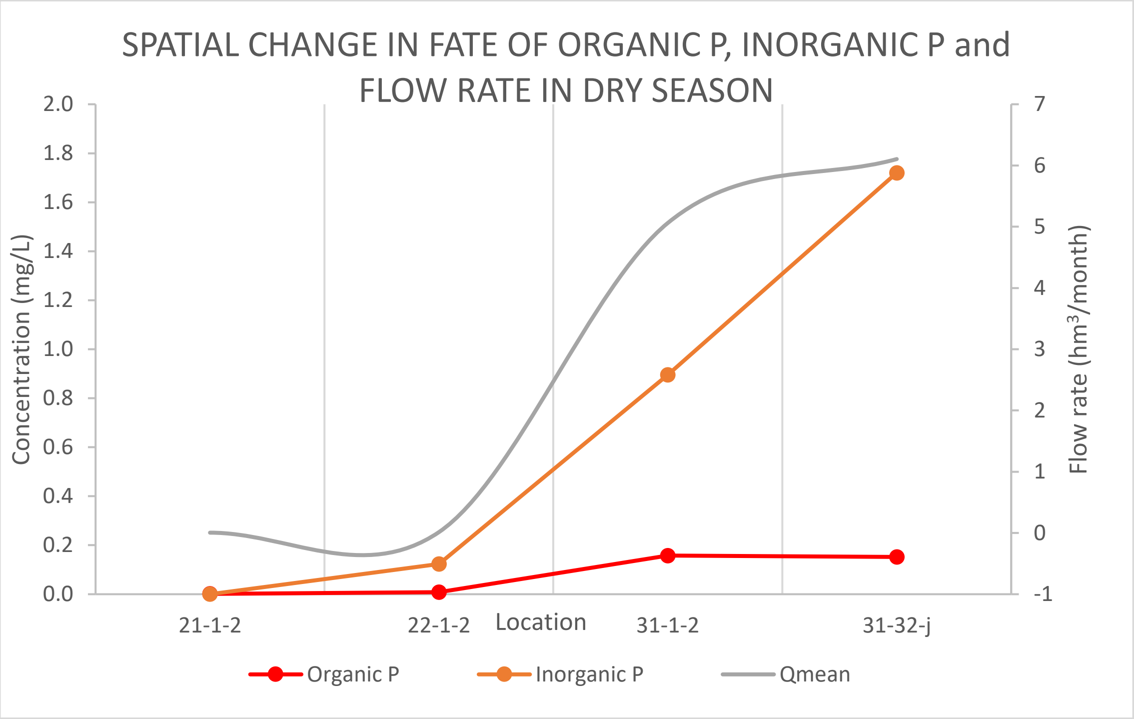


Figure 5.13. The spatial change in fate of Organic P, Inorganic P and flow rate under dry season base period

5.2.3. Time-Dependent Results

The results of the 24-1-1 river branch model, one of the regions where the Bakırçay basin system is exposed to the most anthropological pollution and can be regarded as the upstream region, are given in Figure 5.14. It can be seen from the results that the parameters, except for dissolved oxygen and partially nitrate, are above the permitted regulation limits. These ratios can be approximately 4-7 times for BOD_5, approximately 12-70 times for Ammonium, 5-48 times for Organic Nitrogen, approximately 4-39 times for Organic Phosphorus, and 2-17 times for Inorganic Phosphorus due to the seasonal changes experienced by the system. In addition, it can be understood from the sharpness of seasonal trends in the graphs that the impact of biochemical processes taking place in the river system lacks relative of physical processes. Despite the high nitrogen and phosphorus pollution levels that can be seen in the results, the relatively high dissolved oxygen values observed make the background re-aeration calculations of the model questionable, and it is thought that this may be due to the low organic pollution load relative to the basin capacity or the high values of re-aeration values in the basin.

In order to analyze the lake ecosystem responses in the Bakırçay basin system, the results on G6 water with the name of Sevişler Dam or system in Soma district are given in Figure 5.15. In the G6 water body where stratification is not modeled, the parameter results in general terms are below the regulation limit for pollution, despite the irregular landfill pollution from upstream, septic tank pollution, direct discharge pollution and individual industrial plant treatment discharge pollution, and dissolved oxygen is above the limit as expected. In this case, the effect of the dilution created by the large volume of water in the pollutant parameters is great. The reason for the sharp concentration decreases seen in the first year, especially with the results of Ammonium, Organic Nitrogen, and Organic Phosphorus, is due to the high concentration of the pollutants from the upstream of the lake background concentrations. It can be seen that it takes about 1 year for this pollution difference to be washed out of the system.

The results of the 31-32-J river branch representing the region of the Bakırçay basin flowing into the Aegean Sea, which is the receiving environment, are given in Figure 5.16. The results suggest that the 31-32-j tributary is in a better condition than the

24-1-1 tributary with heavy pollution. Accordingly, the results of BOD_5 released 4 to 7 times above the limit show an oscillation 2 to 4 times below the limit value of 8 mg/L. The results, which were 12 to 70 times higher than the limit in ammonium, decreased to 1 to 6 times above the limit due to dilution and biochemical reactions. In nitrate, the situation was at the limit level, but it fell between 2 and 4 times below the limit. In Organic Nitrogen, the situation has dropped from 5 to 48 times above the limit between 4 and 30 times below the limit. While this decrease in Organic Phosphorus from 4 to 39 times to 1 to 4 times, it decreased from 2 to 17 times to 0.5 to 4 times in Inorganic Phosphorus. However, it can be said that the environmental pollution problem still continues.

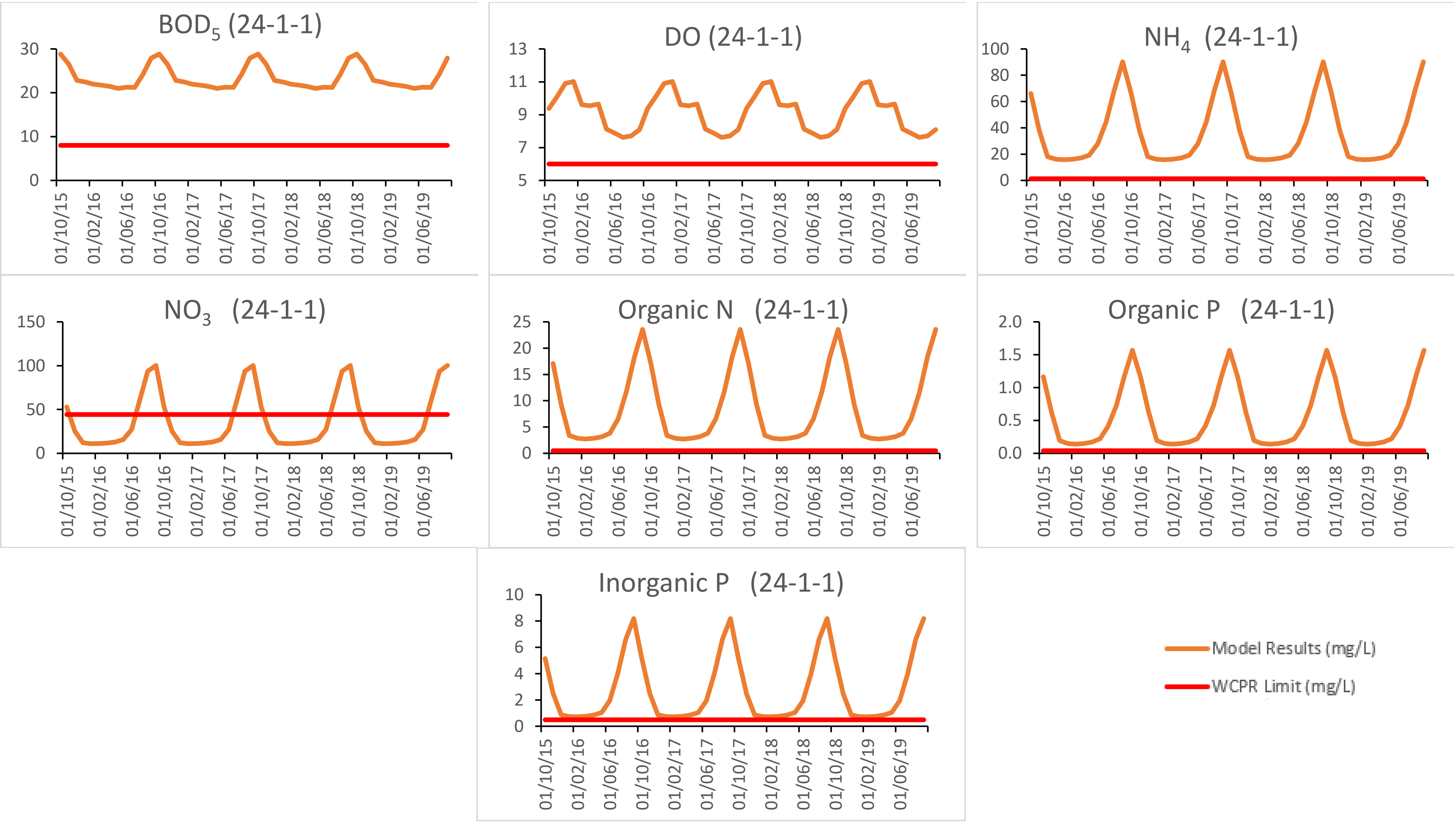


Figure 5.14. Base period results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at 24-1-1 river reach

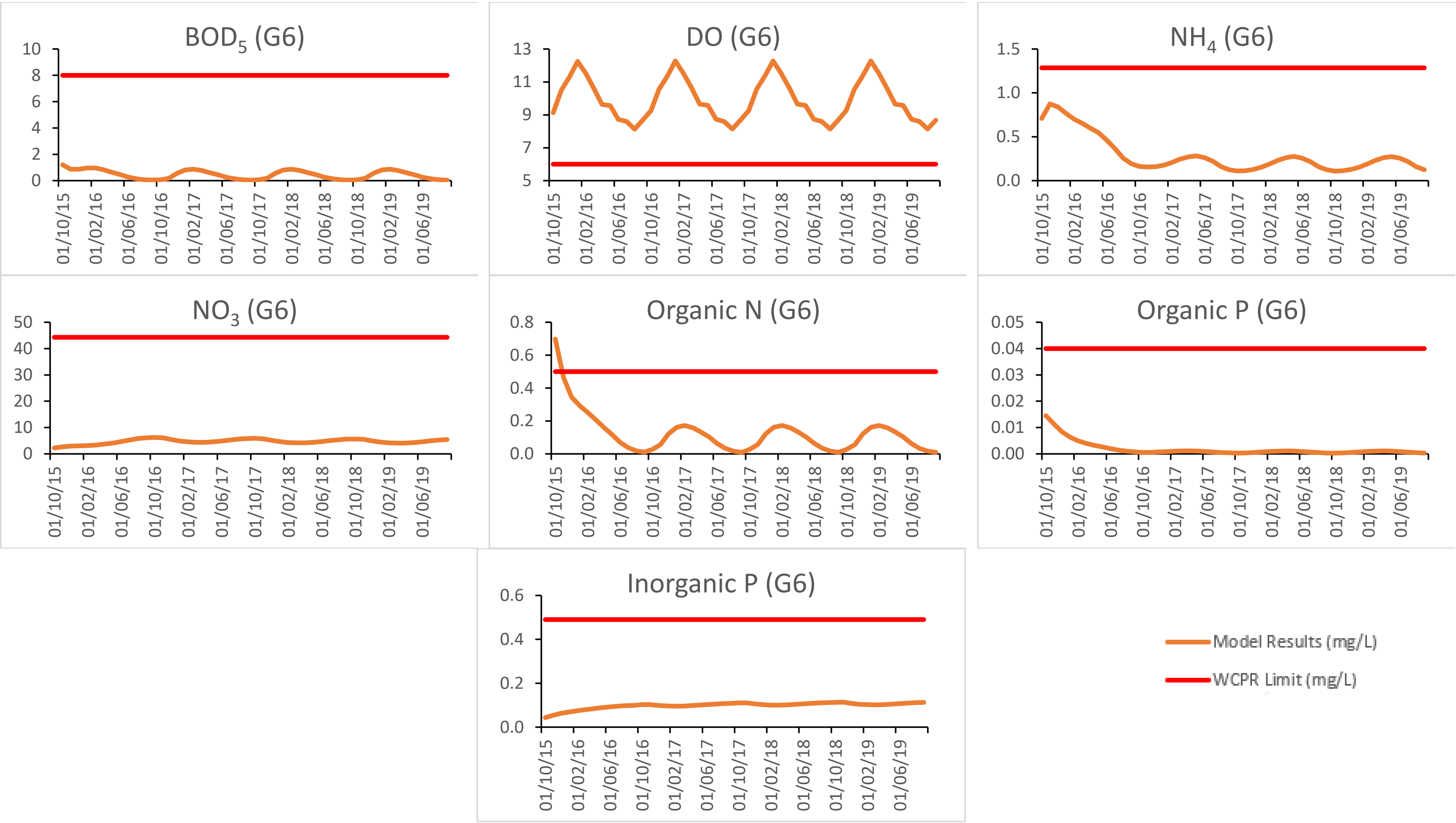


Figure 5.15. Base period results for BOD₅, Dissolved Oxygen, NH₄, NO₃, Organic N, Organic P and Inorganic P at G6 lake point

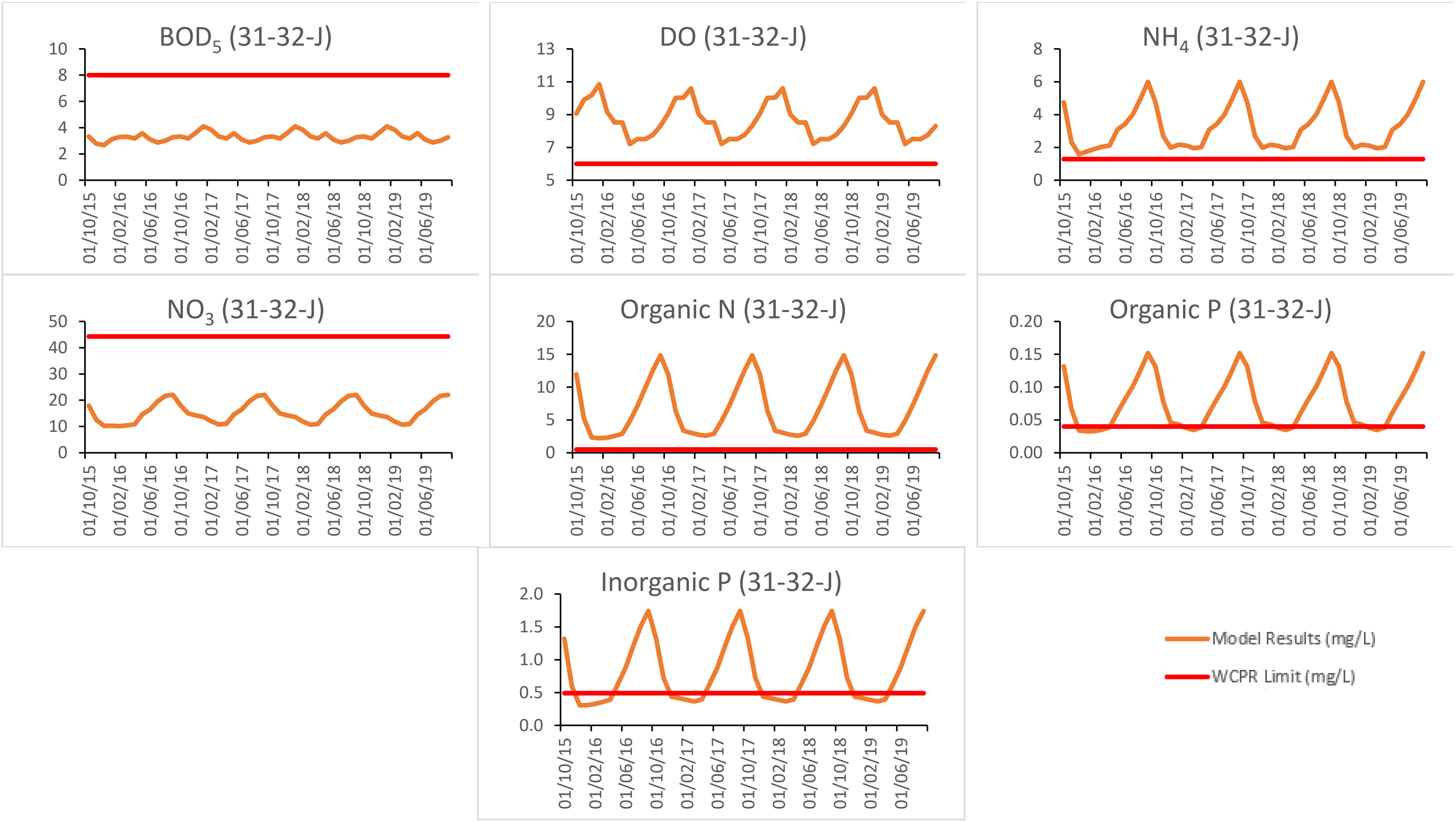


Figure 5.16. Base period results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3. Scenario Applications

Within the scope of this study, a program of measures is planned to improve all water bodies and related parameters that exceed the threshold values specified in the WCPR, and the relative effects of these measures on pollution levels were examined. In Table 5.2., the pollutant removal rates for the different measures used in the scenarios are given.

Table 5.2. Scenarios and pollutant removal efficiencies applied in the model

Scenario Definition	Scenario Name	COD/BOD Removal Rate (%)	TN Removal Rate (%)	TP Removal Rate (%)
Constructing WWTPs to direct discharges (N> 1000)	S1	Variable by facility type	Variable by facility type	Variable by facility type
Constructing septic tanks for direct discharges (N <1000)		Variable by facility type	Variable by facility type	Variable by facility type
Rehabilitation of solid waste uncontrolled landfills		65	65	65
"Zero" discharge for olive and olive oil production		100	100	100
Construction of advanced treatment units for industrial WWTPs	S2	90	90	90
Nutrient Control (Use of animal fertilizers instead of chemical fertilizers)	S3	0	Variable by area	Variable by area
Terracing	S4	50	50	50
Green Belt (Forest buffer to the river and the lake)	S5	50	80	50
Crop Rotation	S6	50	50	30
Herbal Barrier	S7	50	70	70

Among the measures given in Table 5.2., construction of wastewater treatment facilities measure to be made instead of direct discharges, the wastewater treatment facilities measure to be made instead of septic tanks, the rehabilitation of uncontrolled solid waste disposal facilities, and the zero discharge measure in olive cultivation facilities have been applied together, and this combination has been named as basic scenario as S1.

In order to make a cumulative evaluation in the scenario studies, each new scenario application was added to the previous scenario and run. The scenario results produced are compared with the current situation each time.

5.3.1. Scenario #1

With Scenario #1, it is aimed to prevent pollution caused by direct discharges and septic tanks, which are common wastewater disposal methods in small settlements, to prevent pollution from uncontrolled solid waste landfill sites, and to prevent pollution from olive farms, which have special importance in the Mediterranean regions. The reason why these 4 different methods are combined under a single scenario is that these pollution sources can be solved effectively in a shorter time frame with basic structural steps and there are prohibitions/restrictions on these pollution sources for years. The mentioned point pollution sources can be seen in Figure 5.17. In addition, point-source pollutant loads coming to the basin before and after the scenario are given in Table 5.3.

The results in the table reveal that S1 basic measures provide an average of 42% reduction for COD pollutant load, 25.37% for TN pollutant load and 19.73% for TP pollutant load among the total point pollutant loads coming to the basin on the basis of sub-basins. Furthermore, there was a 42.57% reduction in COD pollutant load, 25.57% in TN pollutant load, and 17.72% in TP pollutant load as a point load in the total basin.

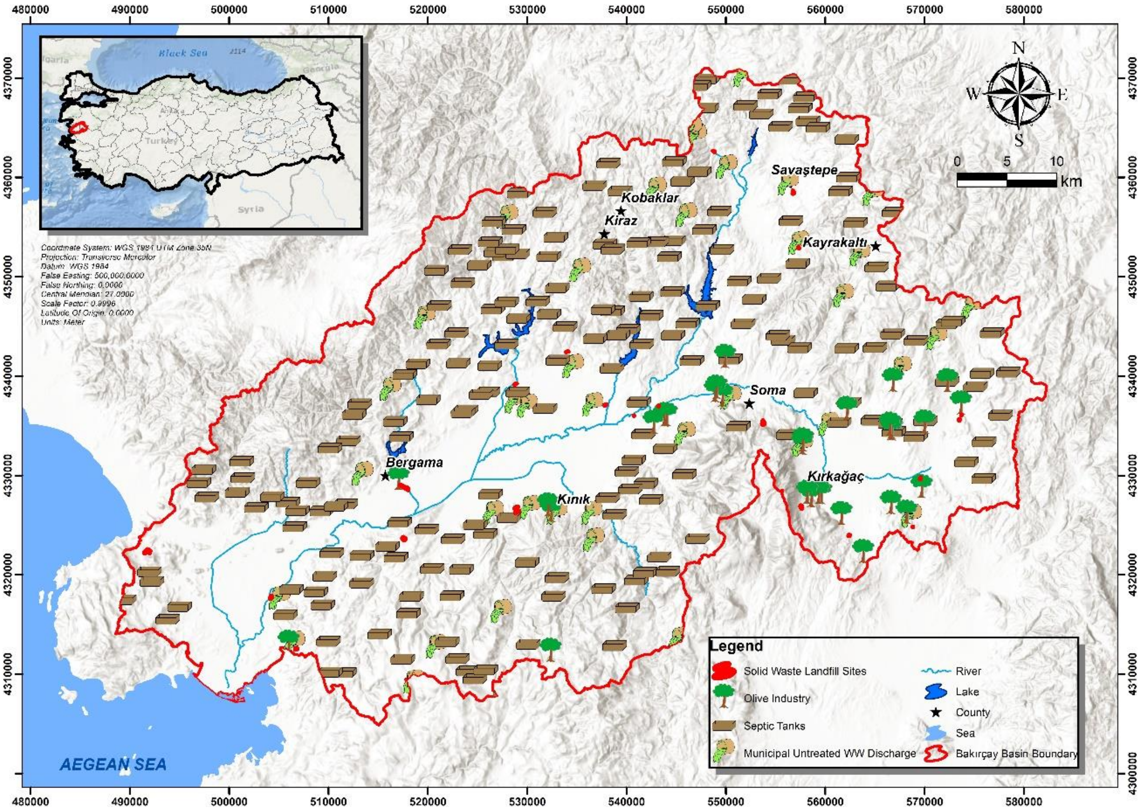


Figure 5.17. Point pollutant source locations where scenario #1 is applied

Table 5.3. Point pollution loads before and after basic measure scenario #1

Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	13.81	12.71	1.89	1.85	0.31	0.30
KEG_006	8.27	7.76	1.14	1.12	0.19	0.18
KEG_007	39.99	35.28	5.31	5.13	0.85	0.81
KEG_008	30.99	26.22	3.99	3.81	0.65	0.60
KEG_009	1.30	1.30	0.19	0.19	0.03	0.03
KEG_020	23.65	20.23	3.07	2.95	0.50	0.47
KEN_021_01b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_021_01c	197.63	47.12	18.48	6.51	3.30	1.14
KEN_021_02a	4.76	2.38	0.43	0.35	0.08	0.05
KEN_021_02b	13.91	5.43	1.17	0.49	0.05	0.03
KEN_021_02c	41.80	4.18	3.80	2.28	0.68	0.48
KEN_021_03b	55.80	35.81	5.73	4.51	1.03	0.92

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Table 5.3. (Cont.)

Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_021_03c	2.29	2.29	0.33	0.33	0.05	0.05
KEN_022_01b	27.46	18.43	3.08	2.36	0.34	0.32
KEN_022_01c	7.61	7.61	1.11	1.11	0.17	0.17
KEN_023_01a	143.45	72.98	13.28	11.39	1.96	1.85
KEN_023_01b	466.58	213.54	52.05	44.23	8.66	8.29
KEN_023_01c	64.07	36.14	3.67	3.27	0.58	0.51
KEN_024_01b	670.03	568.62	70.35	65.32	10.08	9.94
KEN_024_01c	78.37	17.75	5.93	4.29	0.96	0.86
KEN_024_02b	2.72	0.95	0.22	0.08	0.01	0.00
KEN_024_02c	65.40	13.08	5.95	1.78	1.07	0.32
KEN_025_01b	3.07	3.07	0.45	0.45	0.07	0.07
KEN_025_01c	20.31	7.11	1.63	0.57	0.04	0.01
KEN_025_02b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_02c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_03b	23.55	2.35	2.14	1.28	0.39	0.27
KEN_025_03c	93.84	53.38	8.50	6.55	1.81	1.60
KEN_025_04b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_04c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_05b	68.54	40.90	7.86	5.90	1.32	0.95
KEN_025_05c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_026_01a	25.08	7.07	2.56	1.83	0.45	0.35
KEN_026_01b	95.90	56.41	9.91	7.11	1.09	0.94
KEN_026_01c	430.26	106.60	37.77	12.79	5.59	1.86
KEN_027_01b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_027_01c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_028_01b	22.10	12.62	2.26	1.50	0.20	0.18
KEN_028_01c	27.84	7.46	2.82	2.00	0.49	0.38
KEN_029_01a	0.69	0.69	0.10	0.10	0.02	0.02
KEN_029_01b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_029_01c	1.84	1.25	0.20	0.18	0.03	0.03
KEN_030_01b	18.71	4.85	1.06	0.71	0.12	0.11
KEN_030_01c	156.42	54.75	12.51	4.38	0.31	0.11
KEN_031_01b	442.19	440.35	53.04	52.97	8.35	8.33
KEN_031_01c	201.11	65.04	18.19	10.44	1.89	1.56
KEN_032_01b	161.50	161.50	3.61	3.61	0.57	0.57
KEN_032_01c	174.57	80.39	15.91	8.38	0.97	0.78
TOTAL	3927.43	2255.60	381.68	284.09	55.23	45.45

Scenario #1 results for the upstream river segment 24-1-1 of the model are given in Figure 5.18. The results clearly show that Scenario #1 had a very limited impact on phosphorus compounds, meaning that the source of phosphorus in the basin was diffuse sources rather than point sources. Although there have been visible decreases in Ammonium, Nitrate, and Organic Nitrogen, the situation for phosphorus compounds is also valid for Nitrogen compounds, and their main sources are diffuse sources. There has been a significant decrease in BOD_5, the indicator of organic waste; in addition to this, the change in the post-scenario trend of BOD_5 results also indicates that the BOD_5 pollutant is under intense point source pressure. In addition, the Dissolved Oxygen results were almost unchanged when evaluated together with other contaminants due to poor biochemical processes in the basin, as emphasized before.

Scenario #1 results for the lake segment G6 of the model are given in Figure 5.19. It is evident that scenario #1, which aims to reduce point loads, has a low impact on in-lake pollutant concentrations. The reason for this is that the amount of flow affected by scenario #1 is relatively very low compared to the natural flow rates.

The results of the 31-32-J river branch representing the downstream of the Bakırçay River basin are given in Figure 5.20.

The results show that BOD_5 contamination is visibly reduced, but this improvement is not reflected in Dissolved Oxygen concentrations. In addition, it can be seen that the applied point pollutant reduction scenario 1 provides a significant reduction on Ammonium and Organic Nitrogen concentrations. Significant changes in nitrate parameters were not observed, while no significant reductions were observed in both phosphorus compounds.

Scenario #1 results were, in summary, low impact on lakes, leading to significant improvements in in-river concentrations in BOD_5, Ammonium and Organic Nitrogen levels. However, despite the observed improvements, the pollutants did not fall below the threshold values at both the upstream and downstream points.

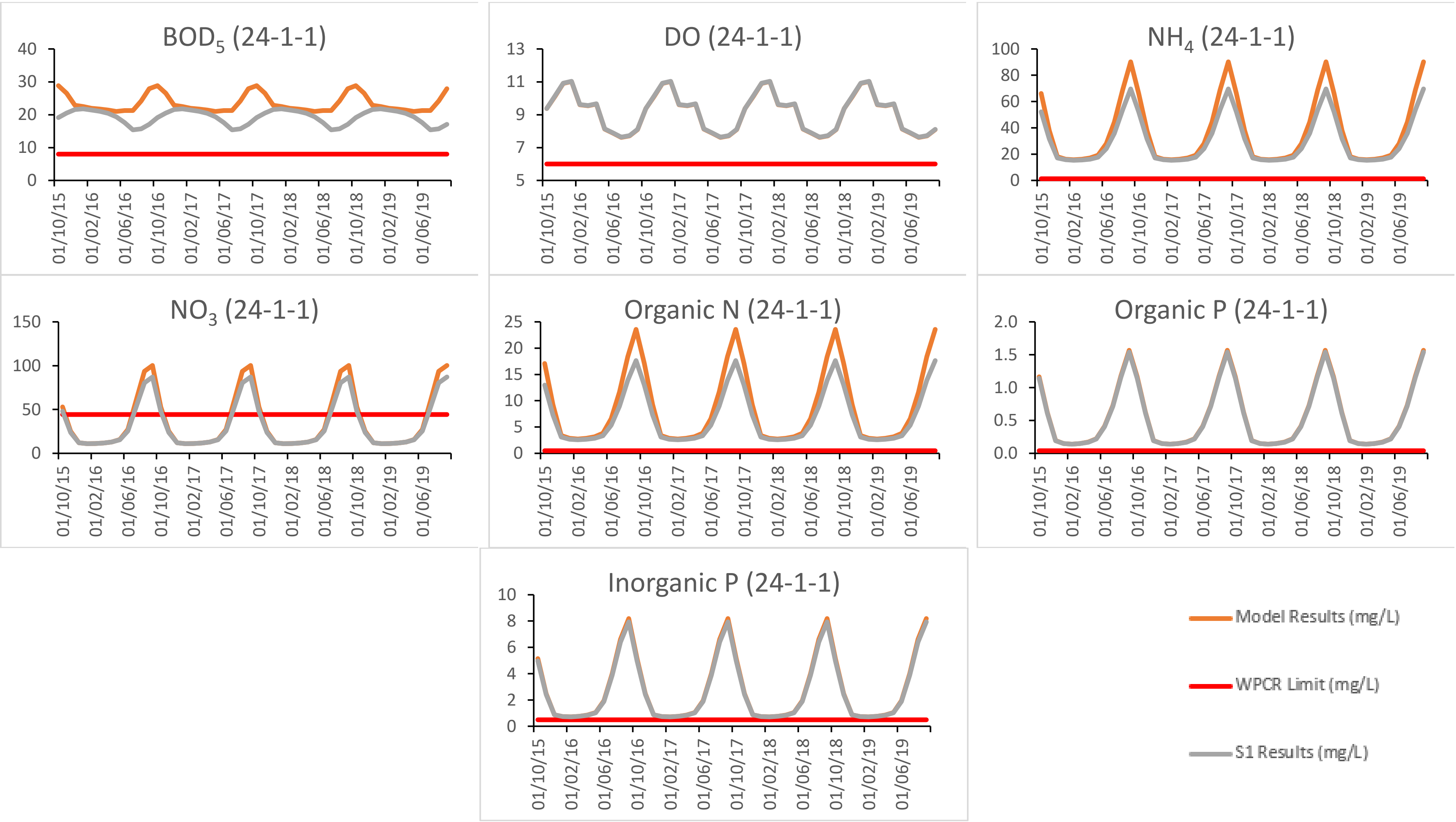

Figure 5.18. Scenario #1 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

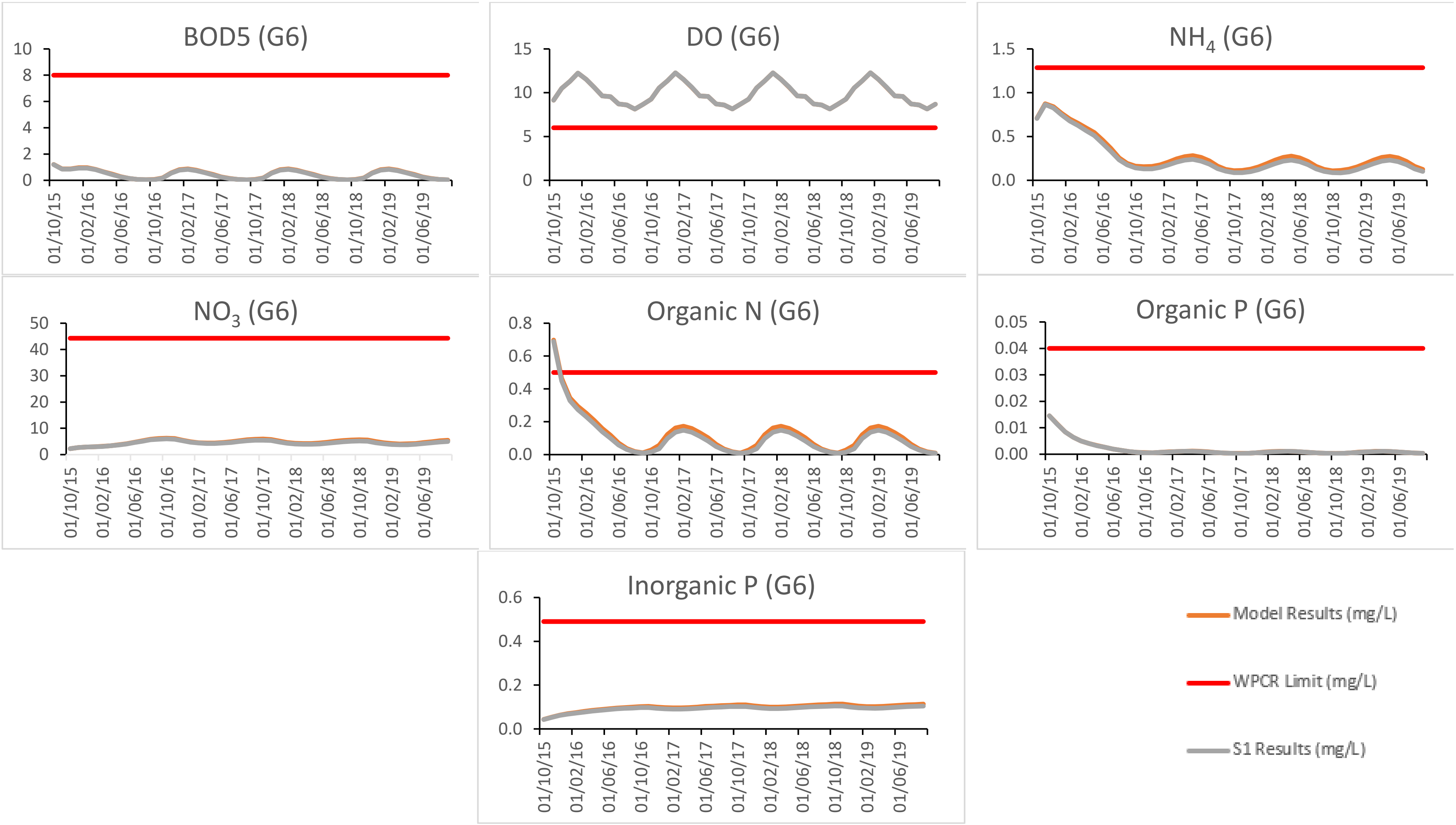

Figure 5.19. Scenario #1 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

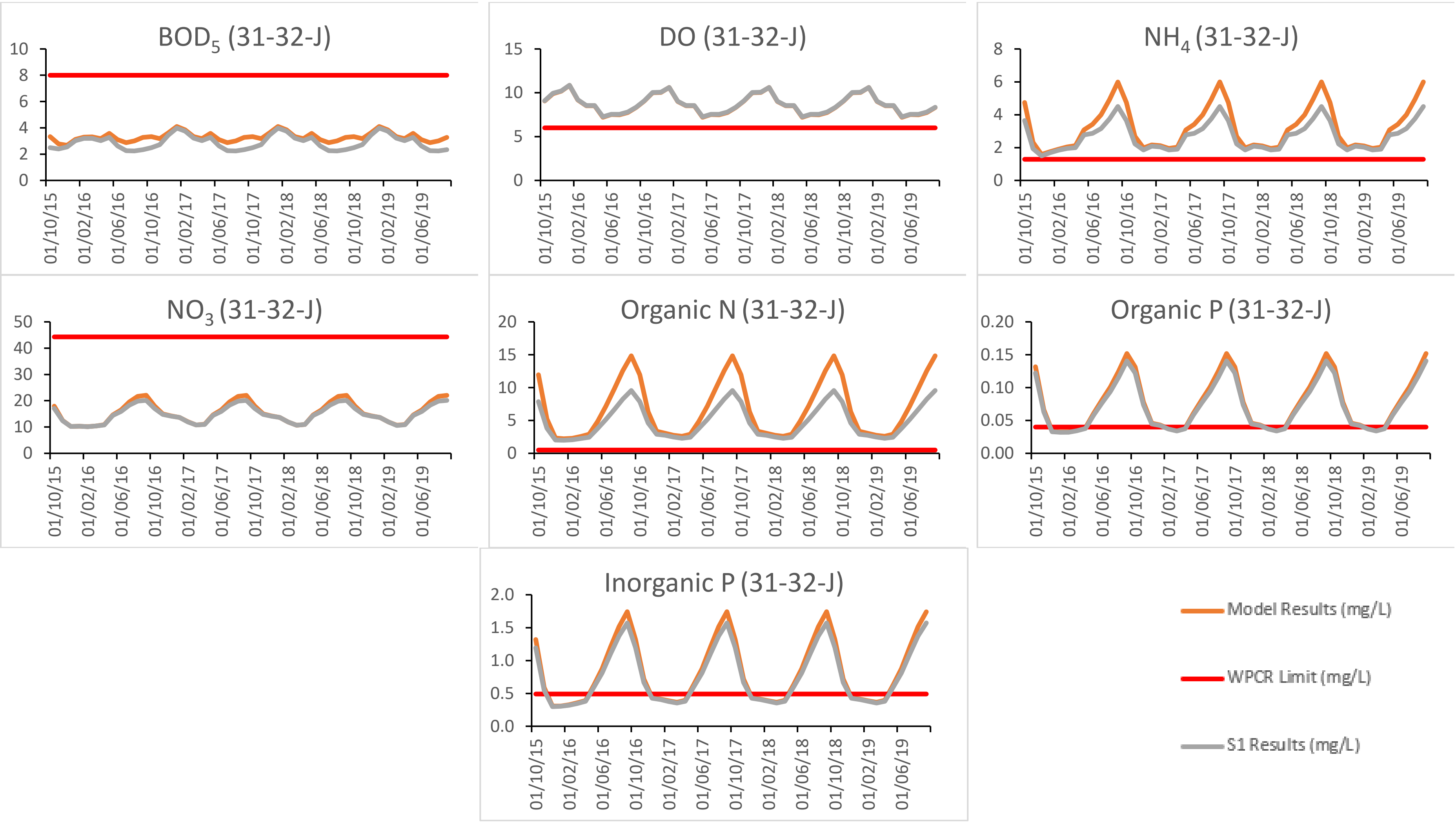

Figure 5.20. Scenario #1 results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.2. Scenario #2

Scenario #2, it is aimed to reduce the pollutants reaching the basin by using the method of developing the treatment technologies of individual industrial facilities and organized industrial zones with old or non-existent treatment technologies. Scenario #2 results are given in Figure 5.22, Figure 5.23, and Figure 5.24, applied to facilities that are located in different sub-basins, which are known to bring about 210.12 tons/year COD, 0.95 tons/year TN, and 0.94 tons/year TP load to the basin with a flow rate of approximately 2 hm^3 per year. Additionally, the facilities where the measure will be implemented are shown in Figure 5.21. Furthermore, Table 5.4 shows the changes in the total point load in the basin before and after scenario #2. As can be seen from the table, although mass reductions of up to 70% are observed in certain sub-basins, significant reductions could not be achieved in many sub-basins. In addition, if we look at the total of the basin, there was a 6.83% reduction in COD load, 0.04% in TN load and 1.04% in TP load in Scenario #2.

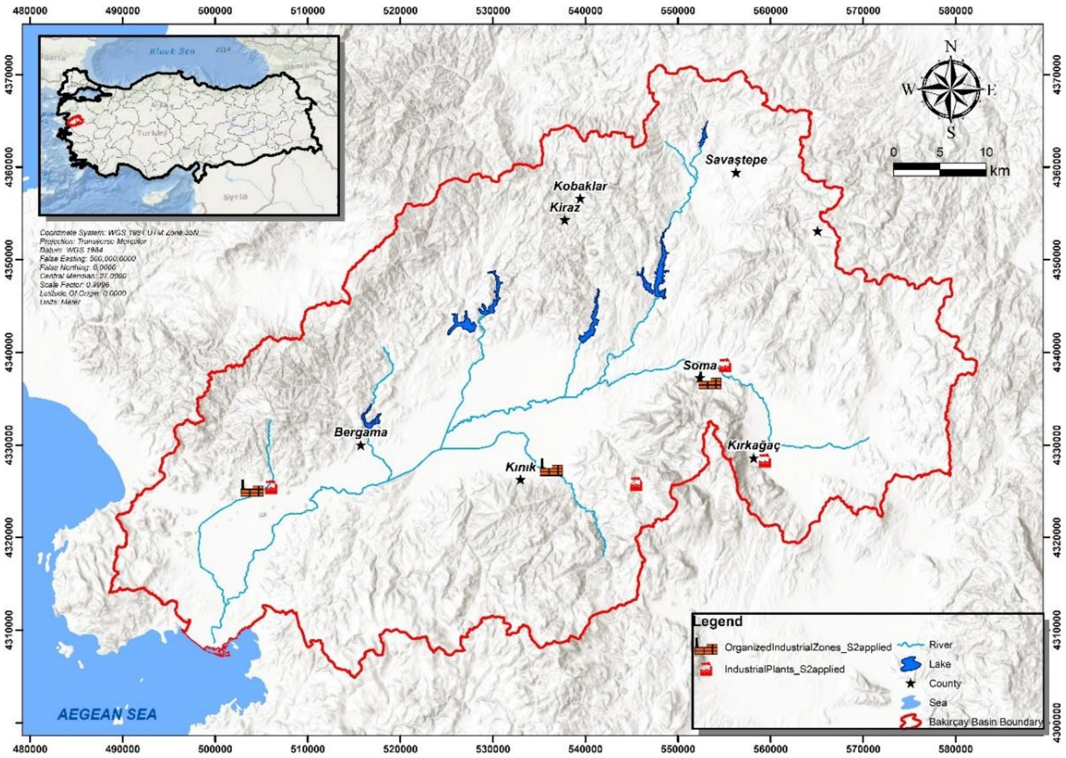

Figure 5.21. Individual industrial facilities and organized industrial zones to which scenario #2 is applied

Table 5.4. Point pollution loads before and after scenario #2

Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	0.83	0.83	5.91	5.91	0.21	0.21
KEG_006	0.45	0.45	2.44	2.44	0.10	0.10
KEG_007	1.05	1.05	9.12	9.12	0.19	0.19
KEG_008	0.81	0.81	6.78	6.78	0.14	0.14
KEG_009	0.06	0.06	0.35	0.35	0.12	0.12
KEG_020	0.78	0.78	8.73	8.73	0.35	0.35
KEN_021_01b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_021_01c	4.65	4.65	6.69	6.69	0.59	0.59
KEN_021_02a	0.26	0.26	0.75	0.75	0.03	0.03
KEN_021_02b	0.60	0.60	1.50	1.50	0.02	0.02
KEN_021_02c	0.46	0.46	1.42	1.42	0.24	0.24
KEN_021_03b	2.80	2.74	10.38	10.38	0.53	0.39
KEN_021_03c	0.13	0.13	0.72	0.72	0.03	0.03
KEN_022_01b	1.34	1.34	5.59	5.59	0.18	0.18
KEN_022_01c	0.42	0.42	2.41	2.41	0.10	0.10
KEN_023_01a	35.56	35.56	261.40	261.40	8.22	8.22
KEN_023_01b	84.77	77.45	1087.00	1087.00	36.90	36.90
KEN_023_01c	14.49	11.56	72.07	72.07	2.28	2.28
KEN_024_01b	11.08	11.08	116.23	116.23	7.49	7.49
KEN_024_01c	0.69	0.68	3.41	3.41	0.58	0.58
KEN_024_02b	0.05	0.05	0.12	0.12	0.00	0.00
KEN_024_02c	0.60	0.60	2.18	2.18	0.22	0.22
KEN_025_01b	0.10	0.10	2.92	2.92	0.19	0.19
KEN_025_01c	0.51	0.51	12.76	12.76	0.04	0.04
KEN_025_02b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_02c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_03b	0.15	0.15	3.74	3.74	0.71	0.71
KEN_025_03c	1.79	1.41	38.80	36.88	4.24	2.66
KEN_025_04b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_04c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_025_05b	1.66	1.66	37.11	37.11	2.50	2.50
KEN_025_05c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_026_01a	0.29	0.29	8.02	8.02	0.92	0.92
KEN_026_01b	2.77	2.77	67.91	67.91	2.49	2.49
KEN_026_01c	6.81	6.81	82.78	82.78	4.92	4.92
KEN_027_01b	0.00	0.00	0.00	0.00	0.00	0.00
KEN_027_01c	0.00	0.00	0.00	0.00	0.00	0.00
KEN_028_01b	0.61	0.61	16.30	16.30	0.48	0.48
KEN_028_01c	0.32	0.32	8.57	8.57	1.00	1.00
KEN_029_01a	0.03	0.03	0.19	0.19	0.06	0.06
KEN_029_01b	0.00	0.00	0.00	0.00	0.00	0.00

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Table 5.4. (Cont.)

Sub-watershed	Before Scenario COD	After Scenario COD	Before Scenario TN	After Scenario TN	Before Scenario TP	After Scenario TP
KEN_029_01c	0.08	0.08	0.34	0.34	0.12	0.12
KEN_030_01b	0.21	0.21	1.31	1.31	0.45	0.45
KEN_030_01c	5.25	5.25	31.19	31.19	0.44	0.44
KEN_031_01b	23.31	23.31	1994.58	1994.58	65.71	65.71
KEN_031_01c	9.34	9.34	255.38	255.38	11.75	11.75
KEN_032_01b	7.68	2.44	123.82	123.82	4.49	4.49
KEN_032_01c	10.63	10.63	303.15	303.15	6.16	6.16
TOTAL	233.44	217.49	4594.06	4592.15	165.21	163.49

Figure 5.22 shows the results of the 24-1-1 river branch representing the upstream part of the Bakırçay basin; There was no improvement as expected for dissolved oxygen, nitrate compounds, and phosphorous compounds, except for the BOD_5 parameter, which experienced an average decrease of 3%. The reason for this situation is that the industrial facility located in the upper parts of the upstream river body, where scenario #2 can be applied, only discharges organic waste.

The results of the G6 lake water body, which can be seen in Figure 5.23, reveal 1% improvements in BOD_5 and phosphorus compounds. However, as expected, no improvement was observed in nitrogenous parameters. The reason for this situation is that the industrial plant in the upper regions of lake G6, where scenario #2 can be applied, only discharges organic waste and Nitrogenous waste.

The 31-32-J river tributary results representing the downstream of Bakırçay Basin, which can be seen in Figure 5.24, reveals that Scenario #2 has performed better results for BOD_5 parameter with the mean improvement percentage of 0.84% and Organic P parameter with the mean improvement percentage of 0.82% than Inorganic P parameter with the mean improvement percentage of 0.4%, NO_3 parameter with the mean improvement percentage of 0.31%, Organic P parameter with the mean improvement percentage of 0.3%, NH_4 parameter with the mean improvement percentage of 0.02% and Dissolved Oxygen parameter with the mean improvement percentage of 0.02%.

In general, if Scenario #2 is evaluated, it is very normal that the effect on the concentration values is low, as the monthly flow rate affected by the scenario is around 3% compared to the natural flow. In addition to this, the boundary condition values could not be obtained either upstream or downstream of the river.

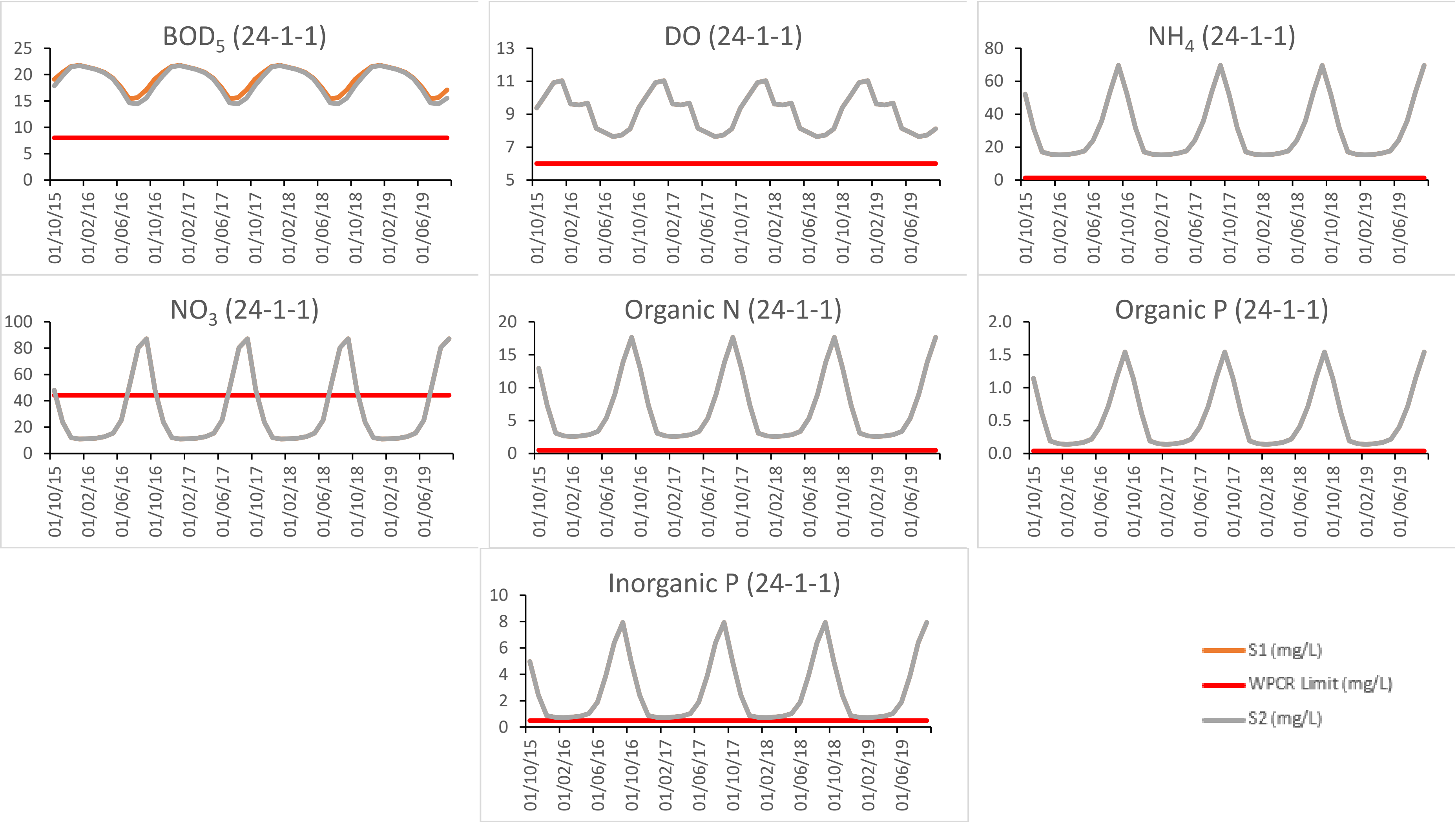

Figure 5.22. Scenario #2 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

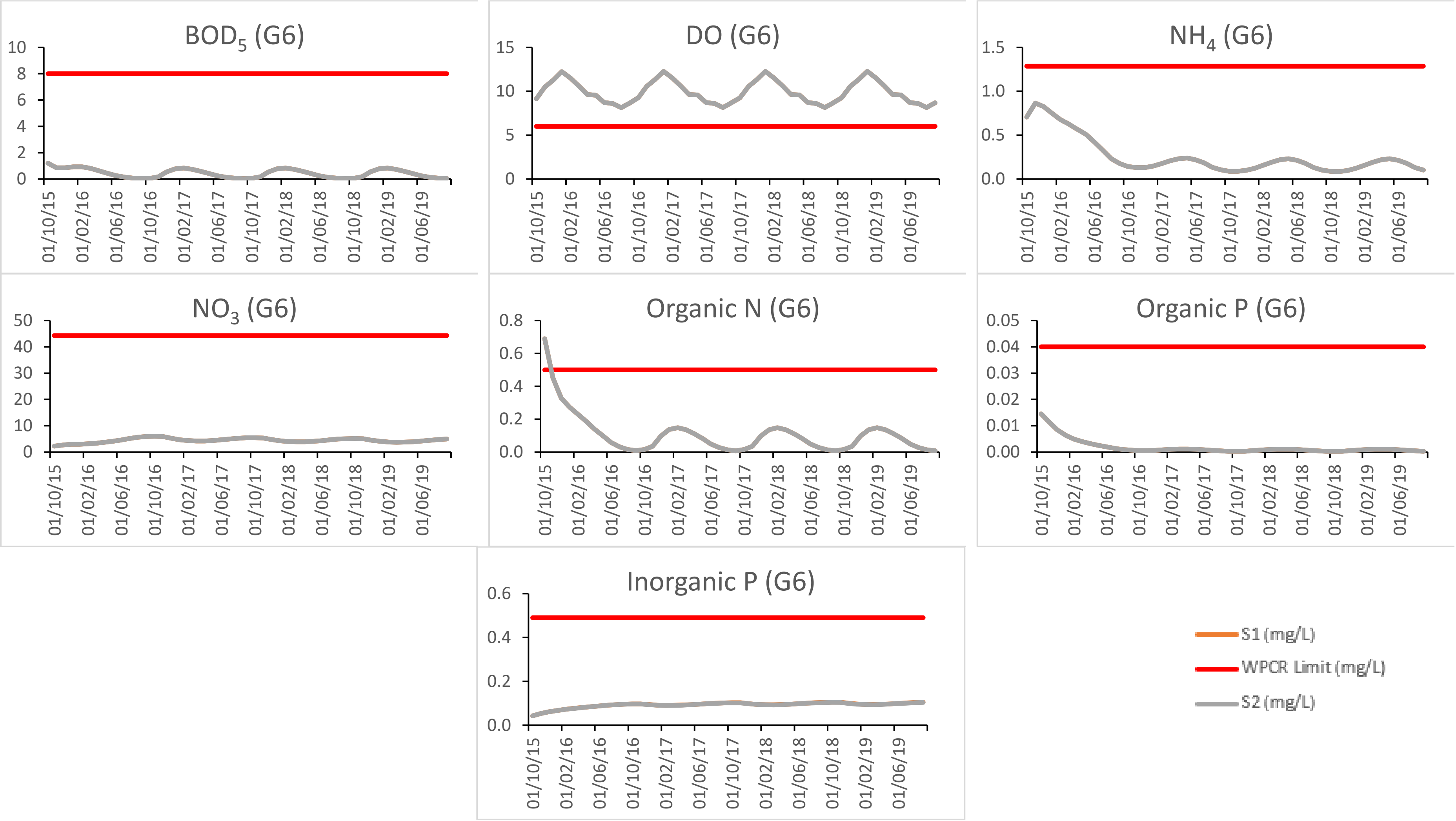

Figure 5.23. Scenario #2 results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at G6 lake point

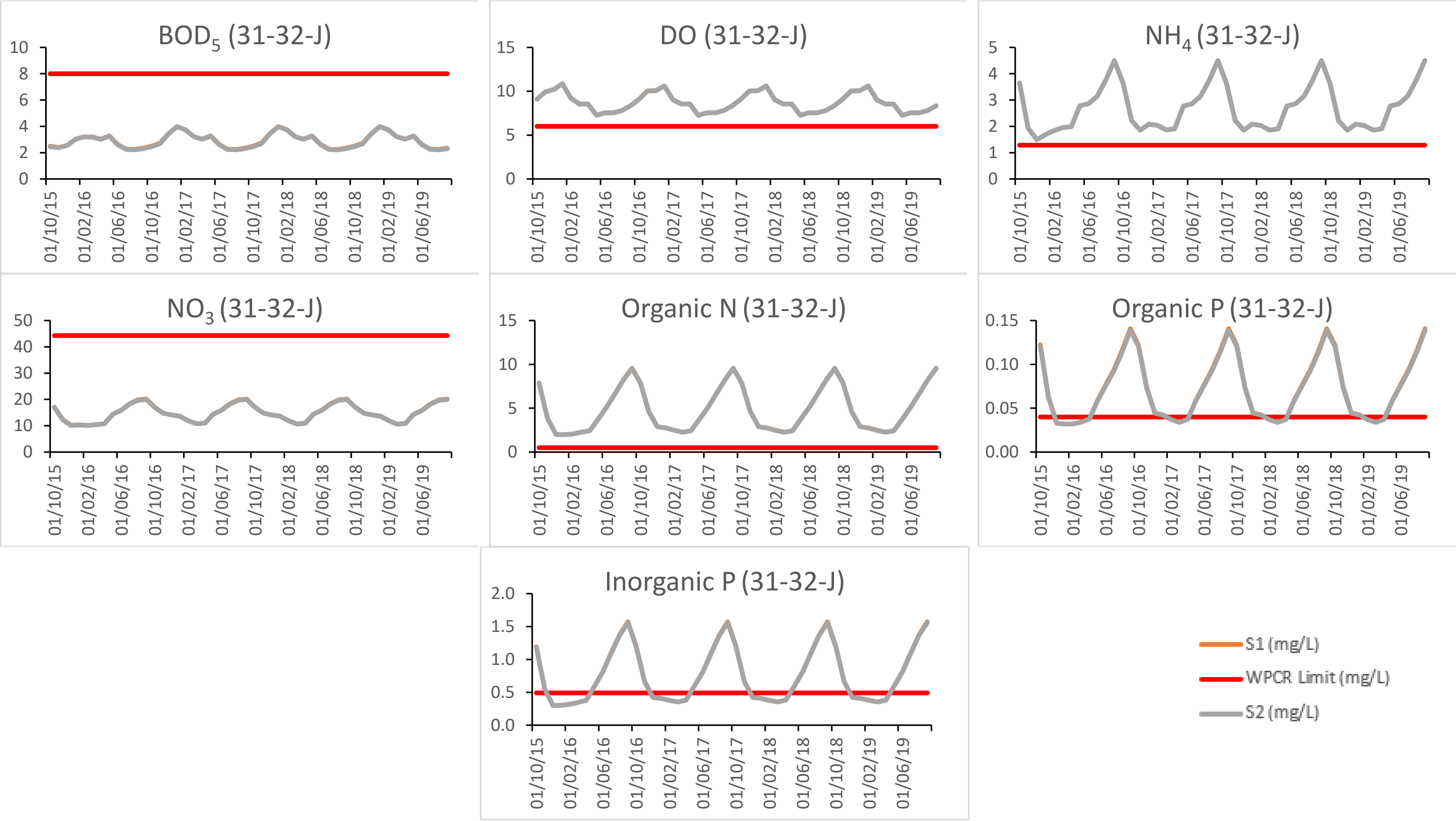

Figure 5.24. Scenario #2 results for BOD₅, Dissolved Oxygen, NH₄, NO₃, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.3. Scenario #3

Scenario #3 is the first scenario applied for diffuse source pollutants in the Bakırçay river basin. With this scenario, it is aimed not only to prevent harmful chemicals such as heavy metals and synthetic organic substances in chemical fertilizers from reaching the soil and then to the groundwater by replacing them with animal fertilizers used in agricultural activities in the basin but also to prevent pollution in the basin by ensuring that the diffuse pollution in the basin originating from livestock is used in agricultural activities. Agricultural areas where nutrient control can be done in the basin are shown in Figure 5.25. The reduction in TN and TP loads of Scenario #3, where no reduction in COD loads can be achieved, is given in Table 5.5. The implementation of Scenario # 3, in which nutrient control was provided, was performed using areal proportions at the scale of water bodies, which is the smallest interface unit of the model system. This method was applied by calculating the ratios of the total diffuse pollutant load values coming to the water bodies after the scenario to the total diffuse pollutant load values coming to the water bodies before the scenario, and multiplying the calculated ratios with the relevant parameter values of the natural flows carrying the diffuse pollution in each water body before the scenario. Multiplication (mult.) coefficients applied to water bodies, in particular for scenario #3 are given in Table 5.6. When the load effect is examined, it can be seen that these rates are 11.48% and 6.72% for TN and TP, respectively, when Scenario #3 Nutrient control provides an average 8.97% TN load and 5.55% TP load reduction in the sub-basins.

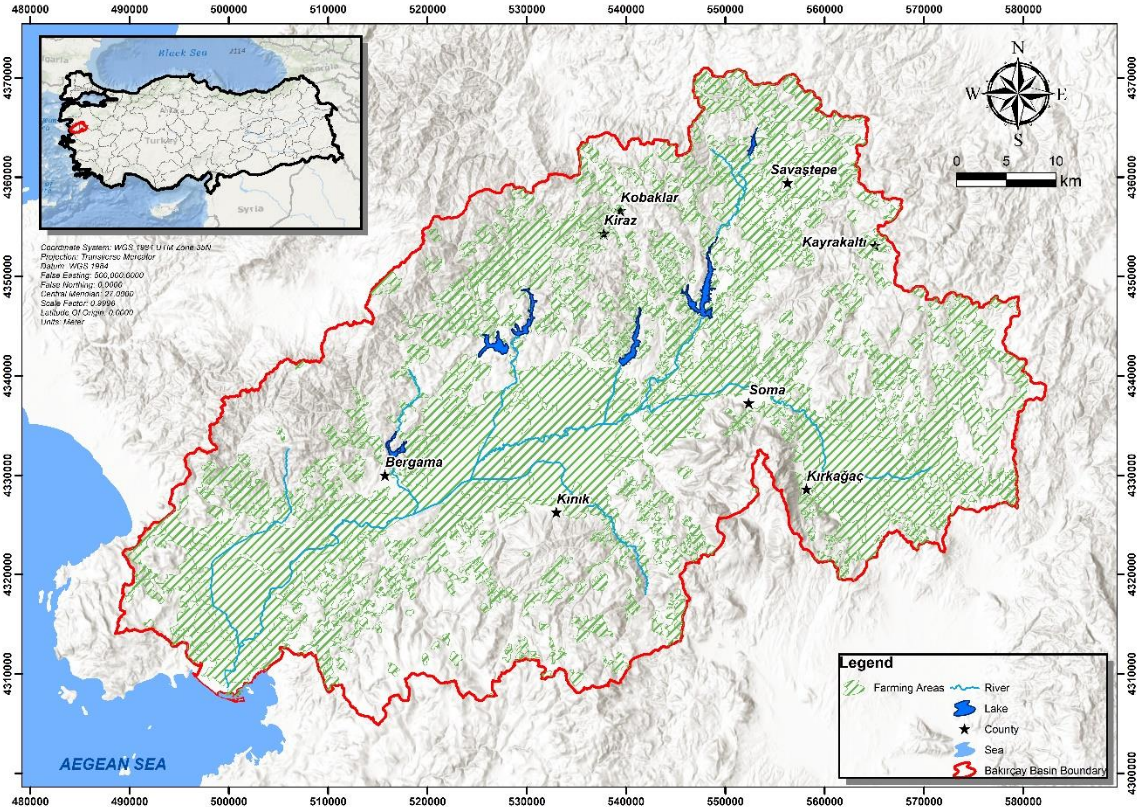

Figure 5.25. Agricultural areas that can be controlled for nutrients under scenario #3

Table 5.5. Non-point pollution loads before and after scenario #3

Non-Point Pollution Loads				
Sub-watershed	Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	34.60	30.26	2.75	2.59
KEG_006	57.15	54.73	3.79	3.70
KEG_007	77.48	66.89	5.51	5.18
KEG_008	93.72	82.76	5.96	5.61
KEG_009	5.62	5.14	0.20	0.19
KEG_020	81.62	77.13	5.55	5.40
KEN_021_01b	4.66	4.66	0.42	0.42
KEN_021_01c	50.54	40.57	3.79	3.13
KEN_021_02a	5.93	5.51	0.44	0.42
KEN_021_02b	13.62	11.77	1.02	0.87
KEN_021_02c	4.10	4.10	0.36	0.36
KEN_021_03b	71.00	60.38	4.93	4.52
KEN_021_03c	5.32	4.50	0.36	0.33
KEN_022_01b	41.05	36.13	3.25	3.04
KEN_022_01c	9.76	8.62	0.81	0.77
KEN_023_01a	93.14	81.89	5.59	5.18
KEN_023_01b	72.61	66.03	4.88	4.67

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Table 5.5. (Cont.)

Non-Point Pollution Loads				
Sub-watershed	Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_023_01c	55.58	53.94	4.58	4.52
KEN_024_01b	48.42	38.79	3.46	3.05
KEN_024_01c	22.95	15.57	1.67	1.28
KEN_024_02b	2.20	2.20	0.18	0.18
KEN_024_02c	2.68	2.25	0.29	0.28
KEN_025_01b	4.29	3.84	0.31	0.29
KEN_025_01c	1.53	1.53	0.17	0.17
KEN_025_02b	1.15	1.15	0.15	0.15
KEN_025_02c	0.00	0.00	0.00	0.00
KEN_025_03b	6.49	6.49	0.85	0.85
KEN_025_03c	105.45	91.92	9.32	8.86
KEN_025_04b	1.04	1.04	0.14	0.14
KEN_025_04c	0.07	0.07	0.01	0.01
KEN_025_05b	134.64	122.21	8.07	7.66
KEN_025_05c	1.72	1.72	0.14	0.14
KEN_026_01a	41.06	37.34	1.97	1.85
KEN_026_01b	76.57	71.77	4.67	4.52
KEN_026_01c	52.95	37.72	4.76	4.17
KEN_027_01b	0.85	0.85	0.07	0.07
KEN_027_01c	1.61	1.61	0.10	0.10
KEN_028_01b	12.80	10.18	0.65	0.55
KEN_028_01c	24.12	19.24	2.13	1.96
KEN_029_01a	6.89	6.50	0.34	0.33
KEN_029_01b	3.57	3.57	0.14	0.14
KEN_029_01c	7.56	6.98	0.30	0.27
KEN_030_01b	56.97	53.50	2.63	2.16
KEN_030_01c	3.75	3.75	0.43	0.43
KEN_031_01b	117.71	108.49	7.39	7.05
KEN_031_01c	32.93	27.23	2.96	2.77
KEN_032_01b	49.49	41.64	2.54	2.21
KEN_032_01c	76.48	68.96	4.51	4.30
TOTAL	1675.44	1483.14	114.53	106.84

Scenario #3 results for the 24-1-1 upstream river branch are given in Figure 5.26. As can be seen from the results, there was an average improvement of 4% in NH_4, 5% in NO_3, 4% in Organic Nitrogen, 2% in Organic Phosphorus, and 2% in Inorganic Phosphorus. In addition, as a result of these improvements in nitrogenous and phosphorus compounds, an increase of 0.03% was observed in the Dissolved Oxygen values. On the other hand, since there is no organic pollution in the animal fertilizer content, no decrease was observed in the BOD_5 parameter. Since the animal manure is transported in the basin by natural flows, Scenario # 3 applied to this pollution has also achieved a noticeable effect on the upstream water body.

Scenario #3 results for lake body G6 are given in Figure 5.27. The results clearly show that Scenario #3, one of the diffuse resource scenarios, reduced the proportion of nitrogenous and phosphorous compounds in the lake. These ratios are on average 7% for NH_4, 7% for NO_3, 8% for Organic N, 3% for Organic Phosphorus, and 5% for Inorganic Phosphorus. In addition to these improvements, the Dissolved Oxygen parameter also improved by 0.01% in relation to these improvements. No change was observed in the BOD_5 parameter in the lake water body as in the upstream water body.

Scenario #3 results of 31-32-J, the downstream river segment of the basin, are given in Figure 5.28. It can be seen that the trend seen at the upstream and lake points is also valid at the downstream point. While the average reduction rates of pollution are 5%, 10%, and 6% for nitrate compounds NH_4, $NO_{3,}$ and Organic Nitrogen, respectively, this rate is equal and 3% for the phosphorus compounds Organic Phosphorus and Inorganic Phosphorus. In addition, there was also a very limited recovery from dissolved oxygen, but as expected, no change was observed in the BOD_5 parameter.

Table 5.6. Nutrient control scenario #3 pollutant removal multiplier values

Sub-Watershed	NH_4 S3 Mult. Value	NO_3 S3 Mult. Value	Organic N S3 Mult. Value	Organic P S3 Mult. Value	Inorganic P S3 Mult. Value	Sub-Watershed	NH_4 S3 Mult. Value	NO_3 S3 Mult. Value	Organic N S3 Mult. Value	Organic P S3 Mult. Value	Inorganic P S3 Mult. Value
KEG_005	0.8818	0.8734	0.8697	0.9229	0.9470	KEN_025_02b	1.0000	1.0000	1.0000	1.0000	1.0000
KEG_006	0.9602	0.9570	0.9557	0.9687	0.9794	KEN_025_02c	1.0000	1.0000	1.0000	1.0000	1.0000
KEG_007	0.8699	0.8620	0.8585	0.9204	0.9451	KEN_025_03b	1.0000	1.0000	1.0000	1.0000	1.0000
KEG_008	0.8892	0.8818	0.8786	0.9196	0.9466	KEN_025_03c	0.8801	0.8700	0.8655	0.9387	0.9540
KEG_009	0.9200	0.9125	0.9091	0.8954	0.9346	KEN_025_04b	1.0000	1.0000	1.0000	1.0000	1.0000
KEG_020	0.9480	0.9444	0.9428	0.9622	0.9755	KEN_025_04c	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_021_01b	1.0000	1.0000	1.0000	1.0000	1.0000	KEN_025_05b	0.9135	0.9065	0.9034	0.9358	0.9532
KEN_021_01c	0.8117	0.8009	0.7963	0.7699	0.8420	KEN_025_05c	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_021_02a	0.9332	0.9288	0.9269	0.9568	0.9727	KEN_026_01a	0.9141	0.9082	0.9056	0.9096	0.9437
KEN_021_02b	0.8689	0.8632	0.8608	0.7997	0.8695	KEN_026_01b	0.9408	0.9367	0.9349	0.9584	0.9709
KEN_021_02c	1.0000	1.0000	1.0000	1.0000	1.0000	KEN_026_01c	0.7265	0.7095	0.7021	0.8640	0.8816
KEN_021_03b	0.8599	0.8485	0.8434	0.8893	0.9242	KEN_027_01b	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_021_03c	0.8560	0.8446	0.8395	0.8975	0.9234	KEN_027_01c	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_022_01b	0.8876	0.8788	0.8749	0.9235	0.9421	KEN_028_01b	0.8063	0.7924	0.7863	0.8118	0.8616
KEN_022_01c	0.8910	0.8814	0.8771	0.9362	0.9492	KEN_028_01c	0.8103	0.7950	0.7882	0.9069	0.9235
KEN_023_01a	0.8876	0.8775	0.8730	0.8983	0.9357	KEN_029_01a	0.9485	0.9427	0.9400	0.9582	0.9762
KEN_023_01b	0.9183	0.9076	0.9025	0.9446	0.9607	KEN_029_01b	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_023_01c	0.9729	0.9700	0.9687	0.9832	0.9885	KEN_029_01c	0.9272	0.9219	0.9195	0.8461	0.9061
KEN_024_01b	0.8199	0.7971	0.7863	0.8448	0.8932	KEN_030_01b	0.9426	0.9383	0.9364	0.7359	0.8448
KEN_024_01c	0.7007	0.6740	0.6619	0.7185	0.7846	KEN_030_01c	1.0000	1.0000	1.0000	1.0000	1.0000
KEN_024_02b	1.0000	1.0000	1.0000	1.0000	1.0000	KEN_031_01b	0.9267	0.9207	0.9180	0.9426	0.9583
KEN_024_02c	0.8499	0.8365	0.8305	0.9409	0.9464	KEN_031_01c	0.8420	0.8236	0.8150	0.9262	0.9374
KEN_025_01b	0.9029	0.8943	0.8904	0.9477	0.9580	KEN_032_01b	0.8529	0.8391	0.8329	0.8240	0.8823
KEN_025_01c	1.0000	1.0000	1.0000	1.0000	1.0000	KEN_032_01c	0.9091	0.9001	0.8960	0.9416	0.9580

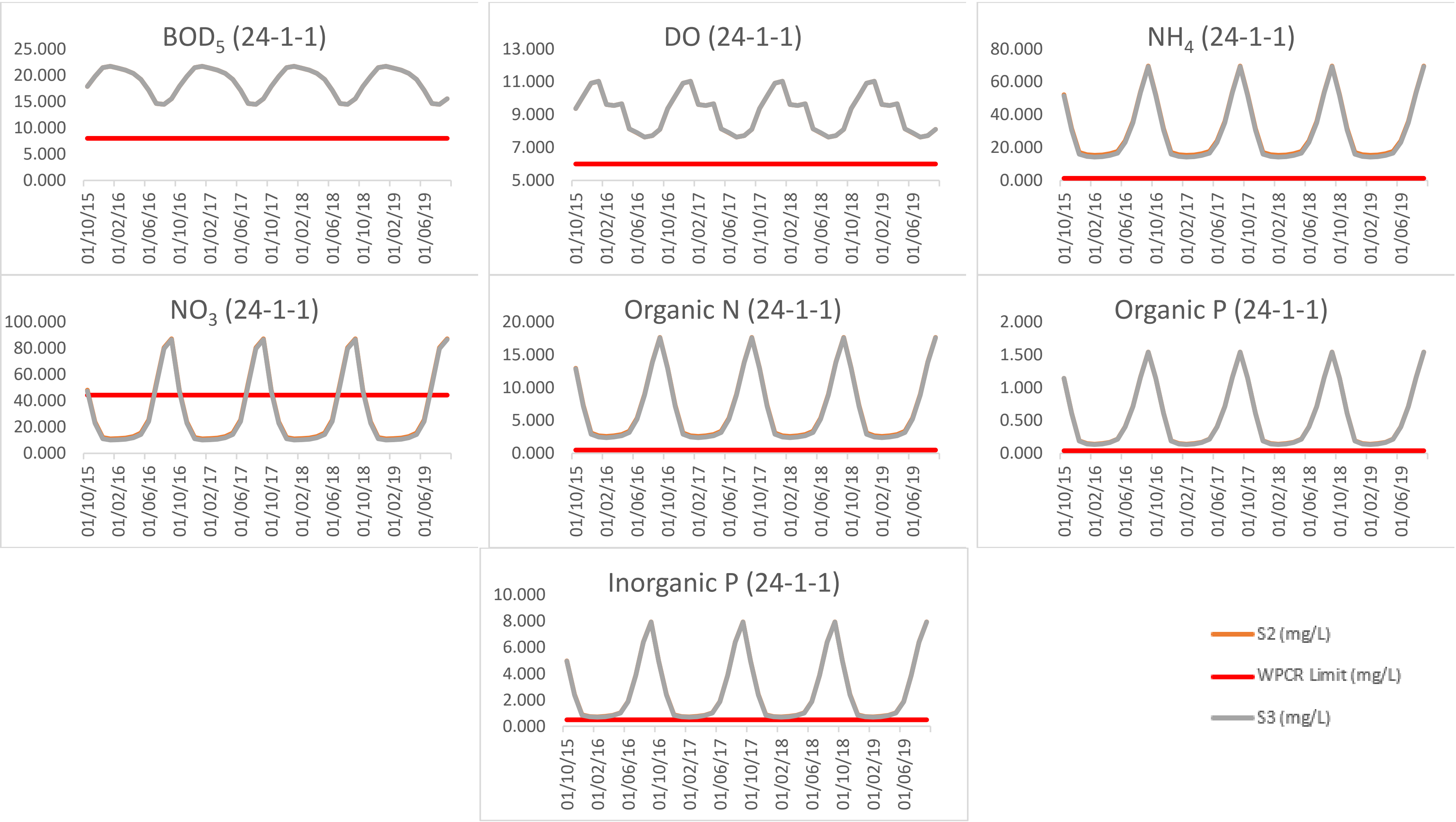

Figure 5.26. Scenario #3 results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at 24-1-1 river reach

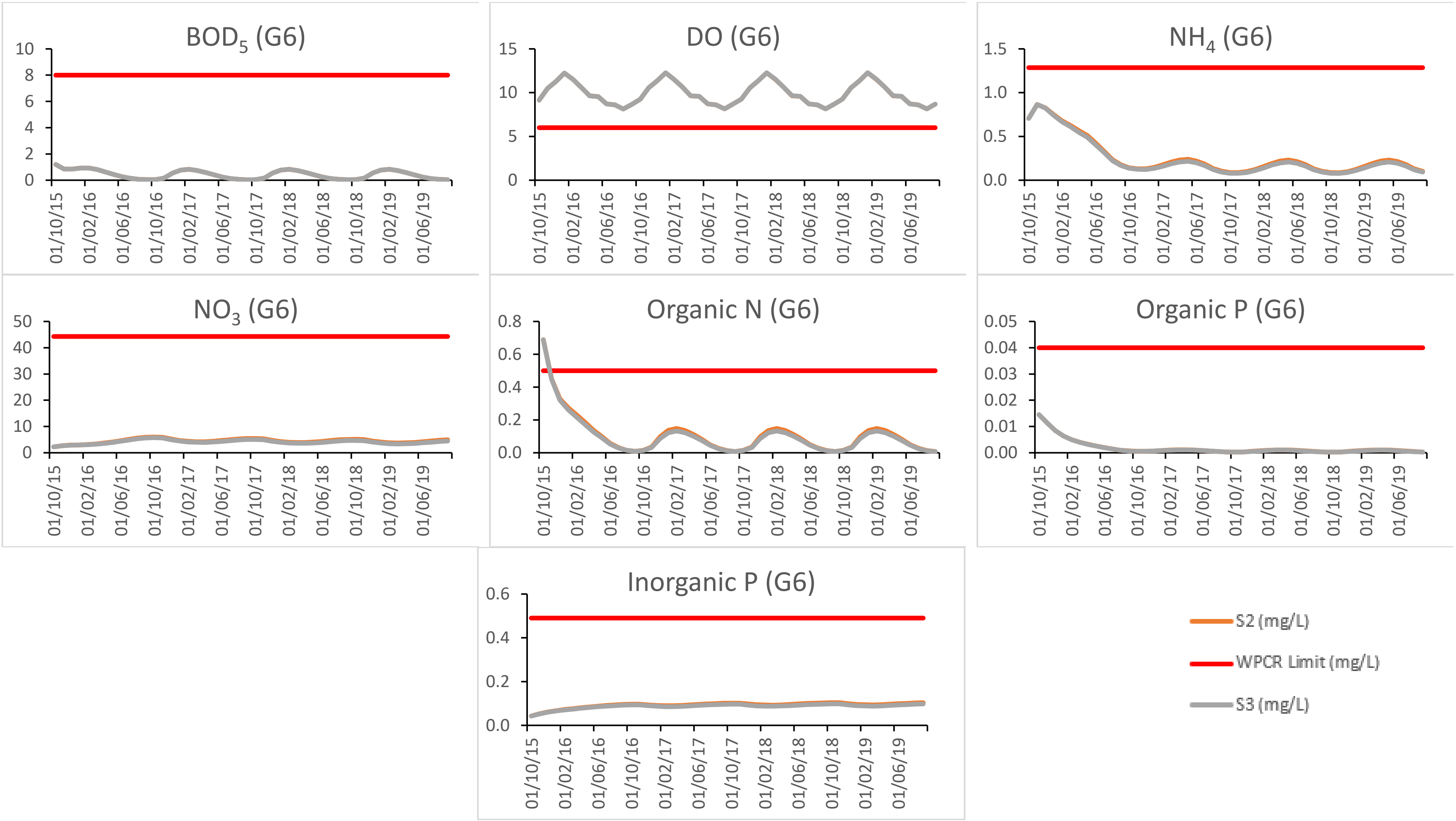

Figure 5.27. Scenario #3 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

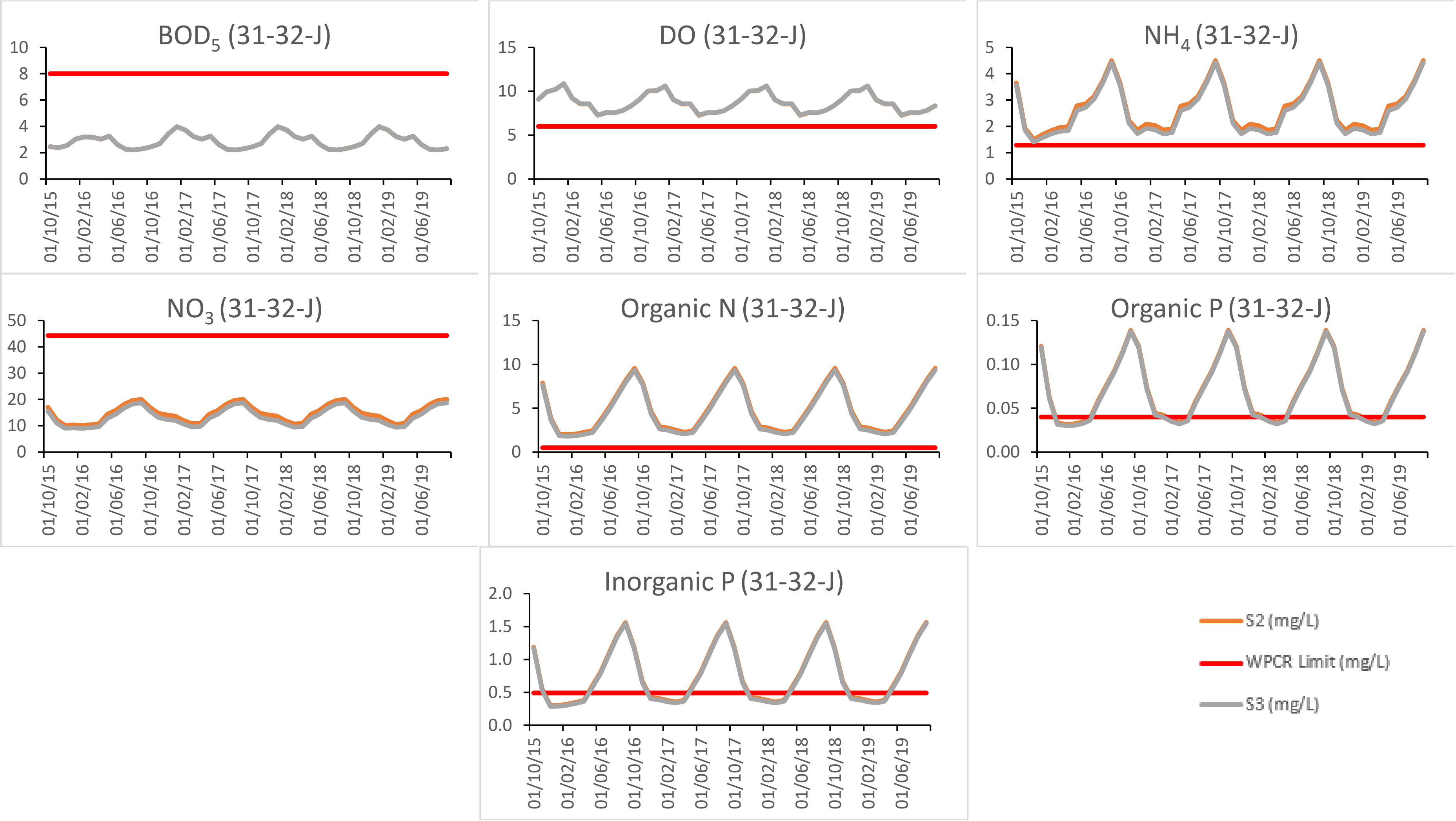

Figure 5.28. Scenario #3 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.4. Scenario #4

Scenario #4, called terracing, is the ground leveling process performed on land with a slope of 12% and higher, causing nutrients to reach water bodies faster. Within the scope of this study, in order for a region to be terraced, it was observed that the slope should be greater than 12% and the ratio of its area to the sub-basin area should be greater than 5%. Farming lands that meet these conditions can be seen in Figure 5.29. With this method, lands with high slopes are leveled within certain height ranges so that they have less slope. Terracing scenario is also applied in the model by using areal pollution reduction factors like the Nutrient control scenario #3. The reductions in COD, TN and TP loads with the terracing measure are given in Table 5.7. Accordingly, COD, TN and TP loads in sub-basins decreased average by 3.14%, 0.64% and 1.14%, respectively. Considering the total of the basin, the COD load decreased by 2.34%, the TN load by 0.75% and the TP load by 1.38%.The method was applied by adding the pollution load to be obtained by multiplying the related parameter reduction coefficient from the ratio of the farming areas with 12% and more slope to the water body areas within the relevant water body area and the existing pollution load from the water body areas where the slope is less than 12%. Thus, the ratio of the total diffuse pollutant load coming to the water body before the scenario to the total diffuse pollutant load coming to the water body after the scenario, Scenario #4 pollution reduction multipliers given in Table 5.8 and used in the model was obtained.

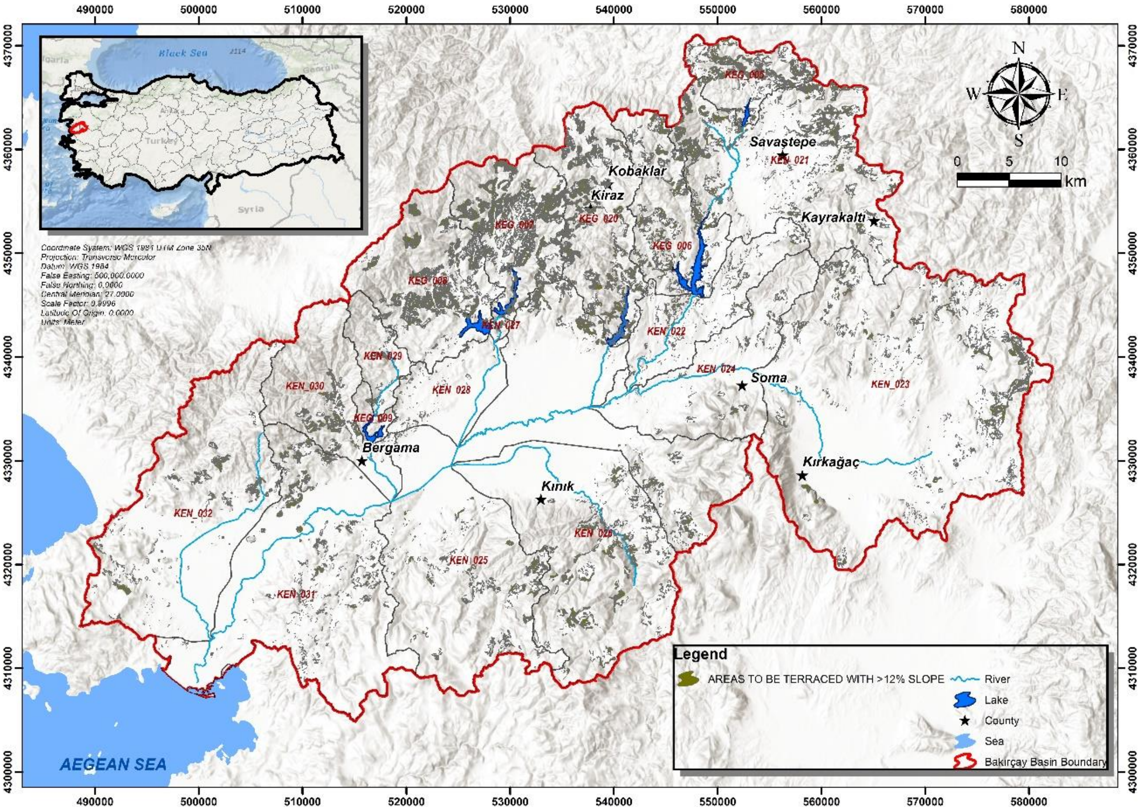

Figure 5.29. Farming lands with the slope of higher and lower than 12%

Table 5.7. Non-point pollution loads before and after scenario #4

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	51.38	46.77	34.60	33.80	2.75	2.64
KEG_006	80.19	76.18	57.15	56.58	3.79	3.72
KEG_007	44.95	39.47	77.48	75.32	5.51	5.24
KEG_008	58.13	54.13	93.72	92.51	5.96	5.81
KEG_009	10.37	10.25	5.62	5.61	0.20	0.20
KEG_020	59.25	54.34	81.62	80.40	5.55	5.40
KEN_021_01b	4.55	4.17	4.66	4.58	0.42	0.41
KEN_021_01c	56.60	53.19	50.54	49.84	3.79	3.71
KEN_021_02a	7.53	6.65	5.93	5.82	0.44	0.42
KEN_021_02b	11.60	10.01	13.62	13.32	1.02	0.98
KEN_021_02c	4.94	4.56	4.10	4.02	0.36	0.35
KEN_021_03b	112.33	110.01	71.00	70.64	4.93	4.89

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Table 5.7. (Cont.)

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_021_03c	5.09	4.70	5.32	5.19	0.36	0.34
KEN_022_01b	20.31	19.91	41.05	40.75	3.25	3.21
KEN_022_01c	5.44	5.41	9.76	9.73	0.81	0.81
KEN_023_01a	446.93	435.27	93.14	92.71	5.59	5.53
KEN_023_01b	506.39	503.04	72.61	72.45	4.88	4.86
KEN_023_01c	315.03	310.31	55.58	55.32	4.58	4.55
KEN_024_01b	10.64	10.53	48.42	48.28	3.46	3.44
KEN_024_01c	4.13	4.11	22.95	22.91	1.67	1.66
KEN_024_02b	0.60	0.60	2.20	2.20	0.18	0.18
KEN_024_02c	0.62	0.62	2.68	2.68	0.29	0.29
KEN_025_01b	5.17	5.12	4.29	4.28	0.31	0.31
KEN_025_01c	3.90	3.90	1.53	1.53	0.17	0.17
KEN_025_02b	-	-	1.15	1.15	0.15	0.15
KEN_025_02c	-	-	0.00	0.00	0.00	0.00
KEN_025_03b	8.14	8.14	6.49	6.49	0.85	0.85
KEN_025_03c	57.52	56.57	105.45	104.76	9.32	9.23
KEN_025_04b	-	-	1.04	1.04	0.14	0.14
KEN_025_04c	-	-	0.07	0.07	0.01	0.01
KEN_025_05b	208.84	205.91	134.64	134.12	8.07	8.00
KEN_025_05c	3.46	3.46	1.72	1.72	0.14	0.14
KEN_026_01a	24.66	24.12	41.06	40.95	1.97	1.96
KEN_026_01b	46.38	44.76	76.57	75.95	4.67	4.59
KEN_026_01c	28.40	28.33	52.95	52.87	4.76	4.75
KEN_027_01b	0.97	0.94	0.85	0.85	0.07	0.07
KEN_027_01c	1.81	1.75	1.61	1.60	0.10	0.10
KEN_028_01b	28.64	28.52	12.80	12.79	0.65	0.65
KEN_028_01c	33.84	33.60	24.12	24.04	2.13	2.12
KEN_029_01a	17.56	17.27	6.89	6.87	0.34	0.34
KEN_029_01b	6.40	6.28	3.57	3.56	0.14	0.14
KEN_029_01c	12.53	12.32	7.56	7.55	0.30	0.30
KEN_030_01b	79.11	76.88	56.97	56.81	2.63	2.61
KEN_030_01c	6.78	6.76	3.75	3.74	0.43	0.43
KEN_031_01b	296.05	290.18	117.71	117.05	7.39	7.31
KEN_031_01c	87.01	86.82	32.93	32.89	2.96	2.95
KEN_032_01b	40.49	39.94	49.49	49.34	2.54	2.52
KEN_032_01c	209.29	207.49	76.48	76.29	4.51	4.48
TOTAL	3023.96	2953.31	1675.44	1662.94	114.53	112.95

Scenario #4 results of the 24-1-1 river branch representing the upstream water body of the Bakırçay River basin are given in Figure 5.30. With the terracing process, 1% improvement was achieved in the BOD_5 parameter, while this ratio was 0.2%, 0.2%, and 0.1% for the nitrogen compounds NH_4, NO_3, and Organic N, respectively. For Organic P and Inorganic P, which are phosphorus compounds, these ratios are 0.2% and 0.3%, respectively.

Scenario #4 results of the water body G6 selected to represent the lakes in the Bakırçay Basin are given in Figure 5.31. According to the results, the parameter with the highest recovery rate is BOD_5 with 4.3%, followed by Inorganic P and Organic P, which are phosphorus compounds with 1.1% and 0.7%. In this order, Nitrogen compounds follow BOD_5 and Phosphorus parameters with 0.6-0.7% recovery levels. It is understood from the 0.01% recovery rate that these reductions have little effect on Dissolved Oxygen.

Scenario #4 results of the 31-32-J river branch, which is the downstream water body of the basin, are given in Figure 5.32. According to the results, the parameter that provided the highest pollution removal efficiency was Organic P with 4.3%, while it was BOD_5 with 1.2%, Inorganic P and NO_3 with 0.4%, NH_4 with 0.3%, Organic N with 0.2% and Dissolved Oxygen with 0.1% is following.

The high removal efficiency of different parameters in different locations is that the rate of sloping land in different locations can vary, and the source and content of pollutants in these lands can also vary.

Table 5.8. Terracing scenario #4 pollutant removal multiplier values

Sub-Watershed	BOD$_5$ S4 Mult. Value	NH$_4$ S4 Mult. Value	NO$_3$ S4 Mult. Value	Organic N S4 Mult. Value	Organic P S4 Mult. Value	Inorganic P S4 Mult.Value	Sub-Watershed	BOD$_5$ S4 Mult. Value	NH$_4$ S4 Mult. Value	NO$_3$ S4 Mult.Value	Organic N S4 Mult.Value	Organic P S4 Mult. Value	Inorganic P S4 Mult. Value
KEG_005	0.910	0.973	0.978	0.980	0.957	0.965	KEN_025_02b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_006	0.950	0.988	0.990	0.992	0.978	0.982	KEN_025_02c	1.000	1.000	1.000	1.000	1.000	1.000
KEG_007	0.878	0.968	0.973	0.975	0.941	0.953	KEN_025_03b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_008	0.931	0.984	0.988	0.989	0.970	0.976	KEN_025_03c	0.984	0.993	0.994	0.994	0.989	0.991
KEG_009	0.988	0.997	0.998	0.999	0.994	0.994	KEN_025_04b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_020	0.917	0.981	0.986	0.988	0.968	0.974	KEN_025_04c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_01b	0.917	0.979	0.983	0.984	0.969	0.976	KEN_025_05b	0.986	0.995	0.996	0.997	0.991	0.992
KEN_021_01c	0.940	0.984	0.987	0.988	0.972	0.978	KEN_025_05c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_02a	0.884	0.977	0.983	0.985	0.964	0.970	KEN_026_01a	0.978	0.996	0.997	0.998	0.992	0.993
KEN_021_02b	0.863	0.974	0.979	0.981	0.954	0.965	KEN_026_01b	0.965	0.990	0.992	0.993	0.981	0.984
KEN_021_02c	0.924	0.978	0.981	0.982	0.966	0.973	KEN_026_01c	0.997	0.998	0.999	0.999	0.998	0.998
KEN_021_03b	0.979	0.994	0.995	0.996	0.989	0.991	KEN_027_01b	0.971	0.994	0.996	0.997	0.993	0.994
KEN_021_03c	0.923	0.972	0.976	0.978	0.948	0.955	KEN_027_01c	0.963	0.992	0.994	0.995	0.986	0.988
KEN_022_01b	0.980	0.992	0.993	0.993	0.987	0.989	KEN_028_01b	0.996	0.999	0.999	0.999	0.997	0.998
KEN_022_01c	0.994	0.997	0.997	0.997	0.995	0.996	KEN_028_01c	0.993	0.996	0.996	0.997	0.994	0.995
KEN_023_01a	0.974	0.994	0.996	0.997	0.990	0.991	KEN_029_01a	0.983	0.997	0.998	0.999	0.995	0.995
KEN_023_01b	0.993	0.997	0.998	0.998	0.996	0.996	KEN_029_01b	0.980	0.996	0.998	0.998	0.992	0.993
KEN_023_01c	0.985	0.995	0.996	0.996	0.992	0.993	KEN_029_01c	0.983	0.997	0.998	0.999	0.994	0.994
KEN_024_01b	0.990	0.996	0.997	0.997	0.994	0.995	KEN_030_01b	0.972	0.996	0.997	0.998	0.993	0.993
KEN_024_01c	0.996	0.998	0.998	0.998	0.997	0.997	KEN_030_01c	0.997	0.997	0.997	0.998	0.997	0.997
KEN_024_02b	0.999	0.999	0.999	0.999	0.999	0.999	KEN_031_01b	0.980	0.993	0.995	0.995	0.987	0.989
KEN_024_02c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_031_01c	0.998	0.999	0.999	0.999	0.998	0.998
KEN_025_01b	0.991	0.996	0.996	0.996	0.992	0.993	KEN_032_01b	0.986	0.996	0.997	0.998	0.992	0.993
KEN_025_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_032_01c	0.991	0.997	0.998	0.998	0.994	0.995

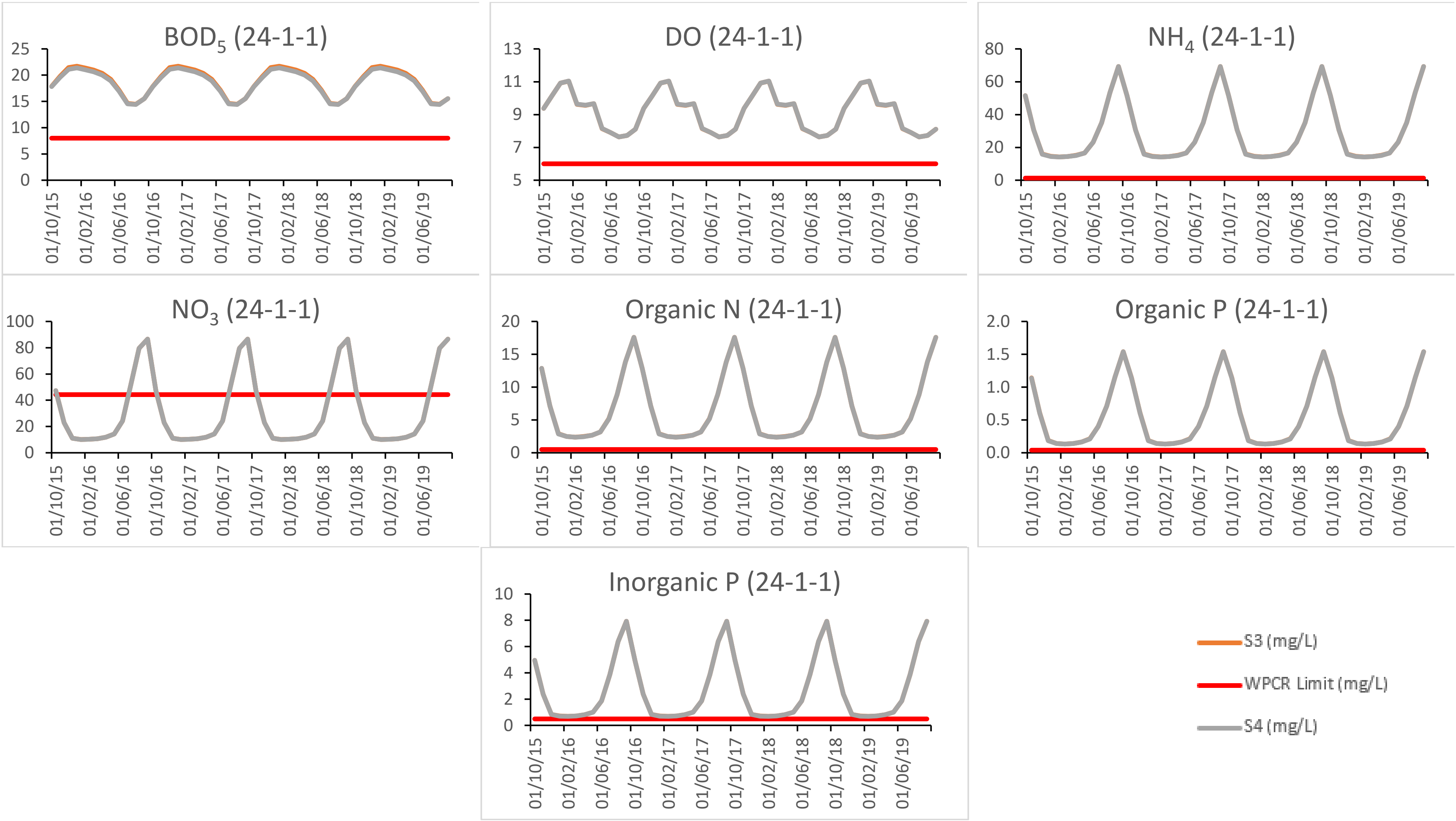

Figure 5.30. Scenario #4 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

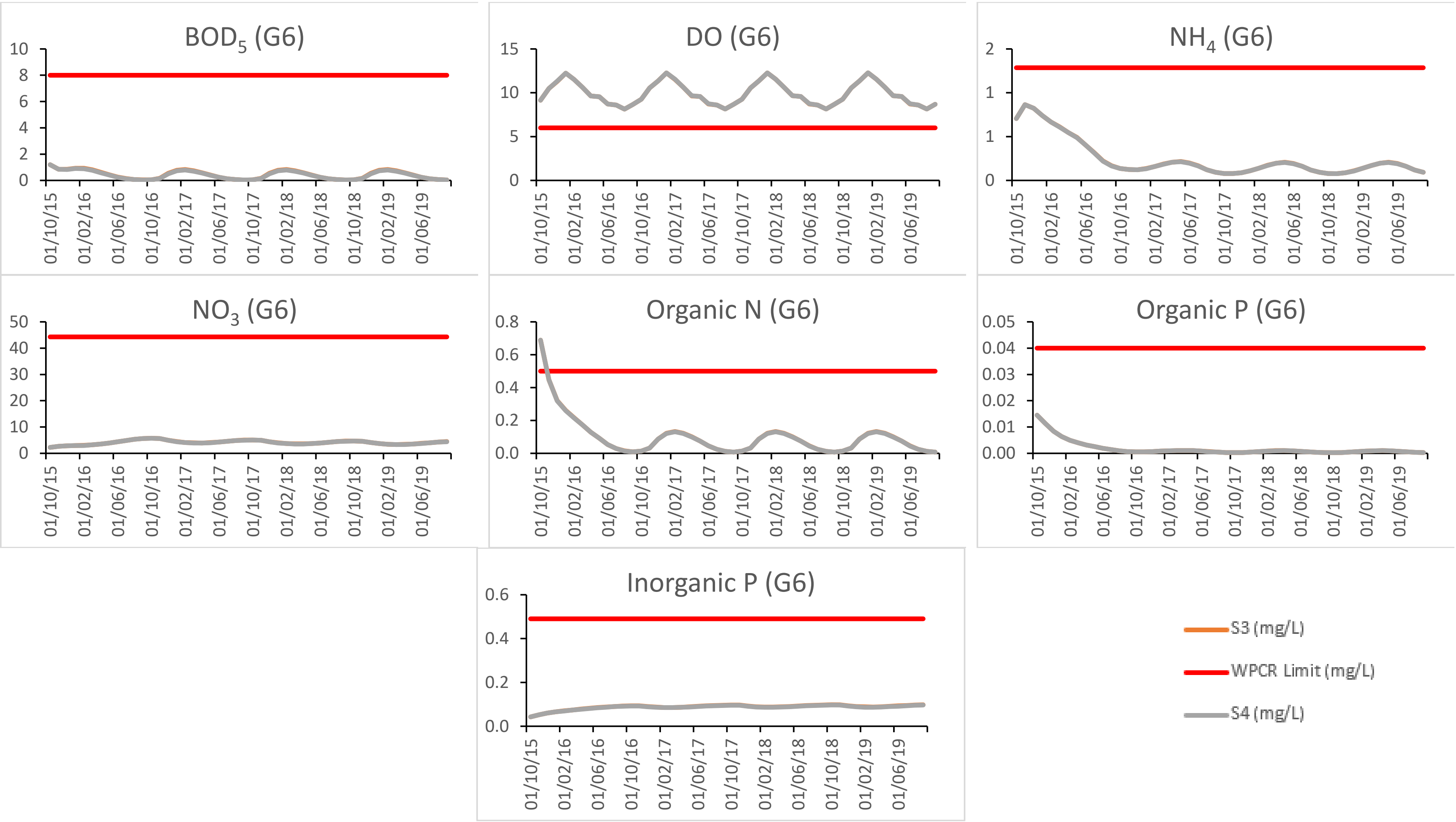

Figure 5.31. Scenario #4 results for BOD₅, Dissolved Oxygen, NH₄, NO₃, Organic N, Organic P and Inorganic P at G6 lake point

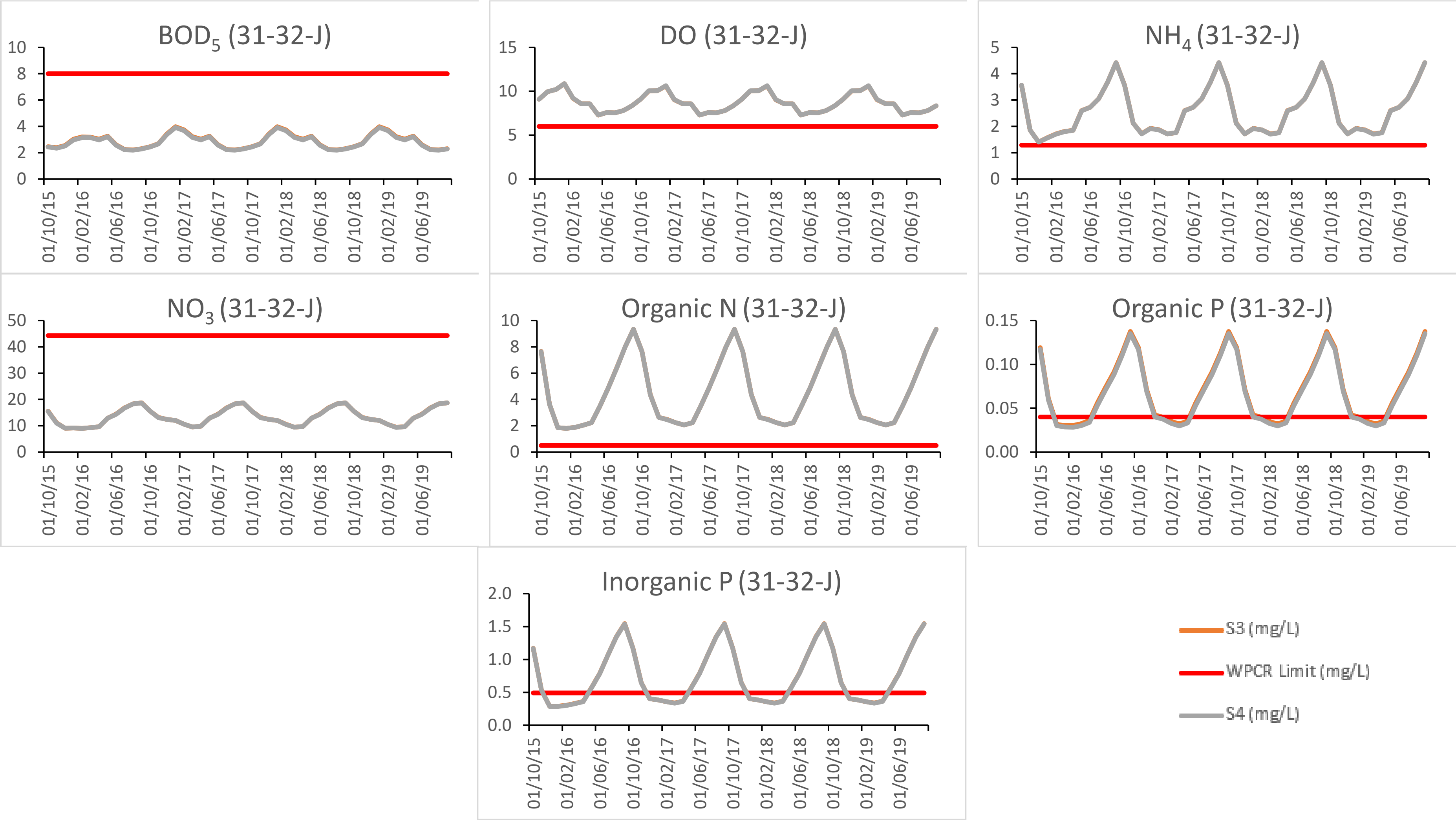

Figure 5.32. Scenario #4 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.5. Scenario #5

With Scenario #5, which can also be named as the Green Belt application, it is aimed to protect and improve the water quality of water bodies used as drinking water by creating a green belt by planting plants and trees 30 meters wide around all water structures such as dams, lakes and river reaches above them. With this method, it is ensured that organic, nitrogen, phosphorus, and heavy metal pollution, which enters drinking water dams and lakes with natural flows, is prevented from entering water bodies with the principle of keeping some of them in green belt structures. Although the green belt applied distance is 30 meters, it is assumed that the effect of the measure will be seen in the runoff from within the 500 meter area. For this reason, a buffer area of 500 meters was used in the operations, and it was thought that the pollutant loads coming over this distance could enter the basin with channel currents. The areas where the measure will be applied are shown in Figure 5.33. In addition, the load reductions that the scenario implementation will create in the basin are given in Table 5.9. The green belt measure, which provides a load reduction of up to 47% in the sub-basins where it is applied, but whose effect cannot be seen in most sub-basins, reduced the COD load by 0.18%, the TN load by 0.48%, and the TP load by 0.29% when looking at the basin total.The Green Belt scenario was also implemented using the areal multiplication coefficients given in Table 5.10., as in the previous scenarios. While calculating the pollutant reduction multiplication coefficients, the pollutant reduction that will assumed take place in the 500 meter buffer area around the water bodies used for drinking water, which the scenario should be applied, is calculated in proportion to the water body area.

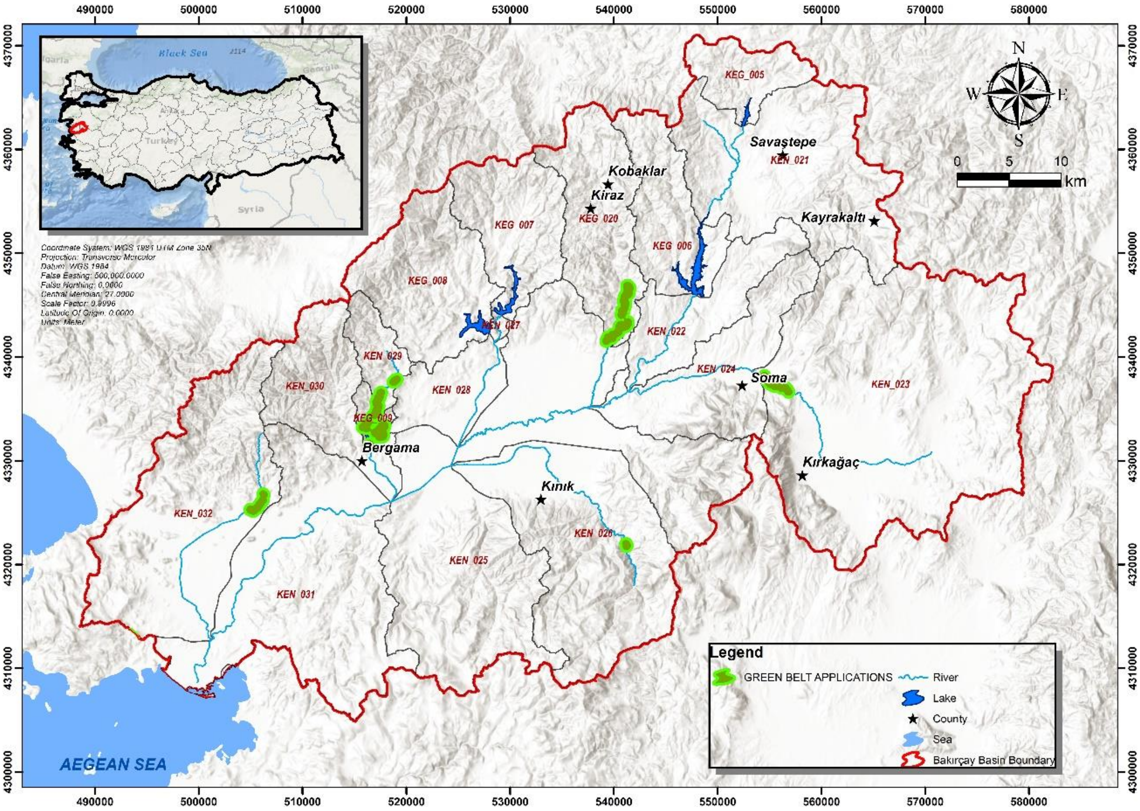

Figure 5.33. Agricultural areas and impact zones where the green belt scenario #5 is applied

Table 5.9. Non-point pollution loads before and after green belt scenario #5

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	46.77	46.77	34.60	34.60	2.75	2.75
KEG_006	76.18	76.18	57.15	57.15	3.79	3.79
KEG_007	39.47	39.47	77.48	77.48	5.51	5.51
KEG_008	54.13	54.13	93.72	93.72	5.96	5.96
KEG_009	10.25	8.06	5.62	3.71	0.20	0.16
KEG_020	54.34	52.91	81.62	78.18	5.55	5.41
KEN_021_01b	4.17	2.95	4.66	2.48	0.42	0.30
KEN_021_01c	53.19	53.19	50.54	50.54	3.79	3.79
KEN_021_02a	6.65	6.65	5.93	5.93	0.44	0.44
KEN_021_02b	10.01	10.01	13.62	13.62	1.02	1.02
KEN_021_02c	4.56	4.56	4.10	4.10	0.36	0.36
KEN_021_03b	110.01	110.01	71.00	71.00	4.93	4.93

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Table 5.9. (Cont.)

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_021_03c	4.70	4.70	5.32	5.32	0.36	0.36
KEN_022_01b	19.91	19.91	41.05	41.05	3.25	3.25
KEN_022_01c	5.41	5.41	9.76	9.76	0.81	0.81
KEN_023_01a	435.27	435.27	93.14	93.14	5.59	5.59
KEN_023_01b	503.04	503.04	72.61	72.61	4.88	4.88
KEN_023_01c	310.31	310.31	55.58	55.58	4.58	4.58
KEN_024_01b	10.53	10.53	48.42	48.42	3.46	3.46
KEN_024_01c	4.11	4.11	22.95	22.95	1.67	1.67
KEN_024_02b	0.60	0.60	2.20	2.20	0.18	0.18
KEN_024_02c	0.62	0.62	2.68	2.68	0.29	0.29
KEN_025_01b	5.12	4.77	4.29	3.82	0.31	0.29
KEN_025_01c	3.90	3.90	1.53	1.53	0.17	0.17
KEN_025_02b	-	-	1.15	1.15	0.15	0.15
KEN_025_02c	-	-	0.00	0.00	0.00	0.00
KEN_025_03b	8.14	8.14	6.49	6.49	0.85	0.85
KEN_025_03c	56.57	56.57	105.45	105.45	9.32	9.32
KEN_025_04b	-	-	1.04	1.04	0.14	0.14
KEN_025_04c	-	-	0.07	0.07	0.01	0.01
KEN_025_05b	205.91	205.91	134.64	134.64	8.07	8.07
KEN_025_05c	3.46	3.46	1.72	1.72	0.14	0.14
KEN_026_01a	24.12	24.12	41.06	41.06	1.97	1.97
KEN_026_01b	44.76	44.76	76.57	76.57	4.67	4.67
KEN_026_01c	28.33	28.33	52.95	52.95	4.76	4.76
KEN_027_01b	0.94	0.94	0.85	0.85	0.07	0.07
KEN_027_01c	1.75	1.75	1.61	1.61	0.10	0.10
KEN_028_01b	28.52	28.52	12.80	12.80	0.65	0.65
KEN_028_01c	33.60	33.60	24.12	24.12	2.13	2.13
KEN_029_01a	17.27	17.27	6.89	6.89	0.34	0.34
KEN_029_01b	6.28	6.28	3.57	3.57	0.14	0.14
KEN_029_01c	12.32	12.32	7.56	7.56	0.30	0.30
KEN_030_01b	76.88	76.88	56.97	56.97	2.63	2.63
KEN_030_01c	6.76	6.76	3.75	3.75	0.43	0.43
KEN_031_01b	290.18	290.18	117.71	117.71	7.39	7.39
KEN_031_01c	86.82	86.82	32.93	32.93	2.96	2.96
KEN_032_01b	39.94	39.94	49.49	49.49	2.54	2.54
KEN_032_01c	207.49	207.49	76.48	76.48	4.51	4.51
TOTAL	2953.31	2948.12	1675.44	1667.43	114.53	114.20

Table 5.10. The green belt scenario #5 pollutant removal multiplier values

Sub-Watershed	BOD_5 S5 Mult. Value	NH_4 S5 Mult. Value	NO_3 S5 Mult. Value	Organic N S5 Mult. Value	Organic P S5 Mult. Value	Inorganic P S5 Mult.Value	Sub-Watershed	BOD_5 S5 Mult. Value	NH_4 S5 Mult. Value	NO_3 S5 Mult.Value	Organic N S5 Mult. Value	Organic P S5 Mult. Value	Inorganic P S5 Mult. Value
KEG_005	1.000	1.000	1.000	1.000	1.000	1.000	KEN_025_02b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_006	1.000	1.000	1.000	1.000	1.000	1.000	KEN_025_02c	1.000	1.000	1.000	1.000	1.000	1.000
KEG_007	1.000	1.000	1.000	1.000	1.000	1.000	KEN_025_03b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_008	1.000	1.000	1.000	1.000	1.000	1.000	KEN_025_03c	1.000	1.000	1.000	1.000	1.000	1.000
KEG_009	0.787	0.659	0.659	0.659	0.787	0.787	KEN_025_04b	1.000	1.000	1.000	1.000	1.000	1.000
KEG_020	0.974	0.958	0.958	0.958	0.974	0.974	KEN_025_04c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_01b	0.708	0.532	0.532	0.532	0.708	0.708	KEN_025_05b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_025_05c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_02a	1.000	1.000	1.000	1.000	1.000	1.000	KEN_026_01a	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_02b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_026_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_02c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_026_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_03b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_027_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_03c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_027_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_022_01b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_028_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_022_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_028_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_023_01a	1.000	1.000	1.000	1.000	1.000	1.000	KEN_029_01a	1.000	1.000	1.000	1.000	1.000	1.000
KEN_023_01b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_029_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_023_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_029_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_024_01b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_030_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_024_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_030_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_024_02b	1.000	1.000	1.000	1.000	1.000	1.000	KEN_031_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_024_02c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_031_01c	1.000	1.000	1.000	1.000	1.000	1.000
KEN_025_01b	0.931	0.890	0.890	0.890	0.931	0.931	KEN_032_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_025_01c	1.000	1.000	1.000	1.000	1.000	1.000	KEN_032_01c	1.000	1.000	1.000	1.000	1.000	1.000

The results of the upstream river water body 24-1-1, which can also be seen in Figure 5.34, reveal that there is no improvement in the parameters of the 24-1-1 upstream river water body of Scenario #5 applied to drinking water lakes and dams. The reason for this is that there is no lake or dam water body on or over this water body; that is, there is no change in the pollutant loads coming into the system.

Scenario #5 results of the G6 lake water body selected to represent the lake and dam water bodies in the Bakırçay Basin are given in Figure 5.35. According to the results, the highest removal efficiency was observed in the Organic N parameter with 0.7% in the G6 water body, while other Nitrogen compounds NO_3 and NH_4 followed with 0.6%. These parameters are followed by Inorganic P with 0.5%, BOD_5 with 0.4%, and Organic P with 0.2%. In Dissolved Oxygen, the level of recovery is negligible.

The results of Scenario #5 of the downstream water body 31-32-J of Bakırçay basin are given in Figure 5.36. The results show that the parameter with the highest removal efficiency is NO_3 with 0.92%, followed by Inorganic P with 0.025%. The observed removal efficiencies for NH_4, Organic N, and Organic P, which are other Nitrogen and Phosphorus compounds, are 0.016%, 0.015%, and 0.012%, respectively. Observed removal efficiency for BOD_5 is the 3rd best removal efficiency for this scenario and its average value is 0.02%. In the Dissolved Oxygen parameter, the removal efficiencies observed in Scenario #5 are at a negligible level.

Although improvements have been observed in the lake water body and downstream of the basin, it is clear that Scenario #5 is insufficient in terms of reaching the limit values.

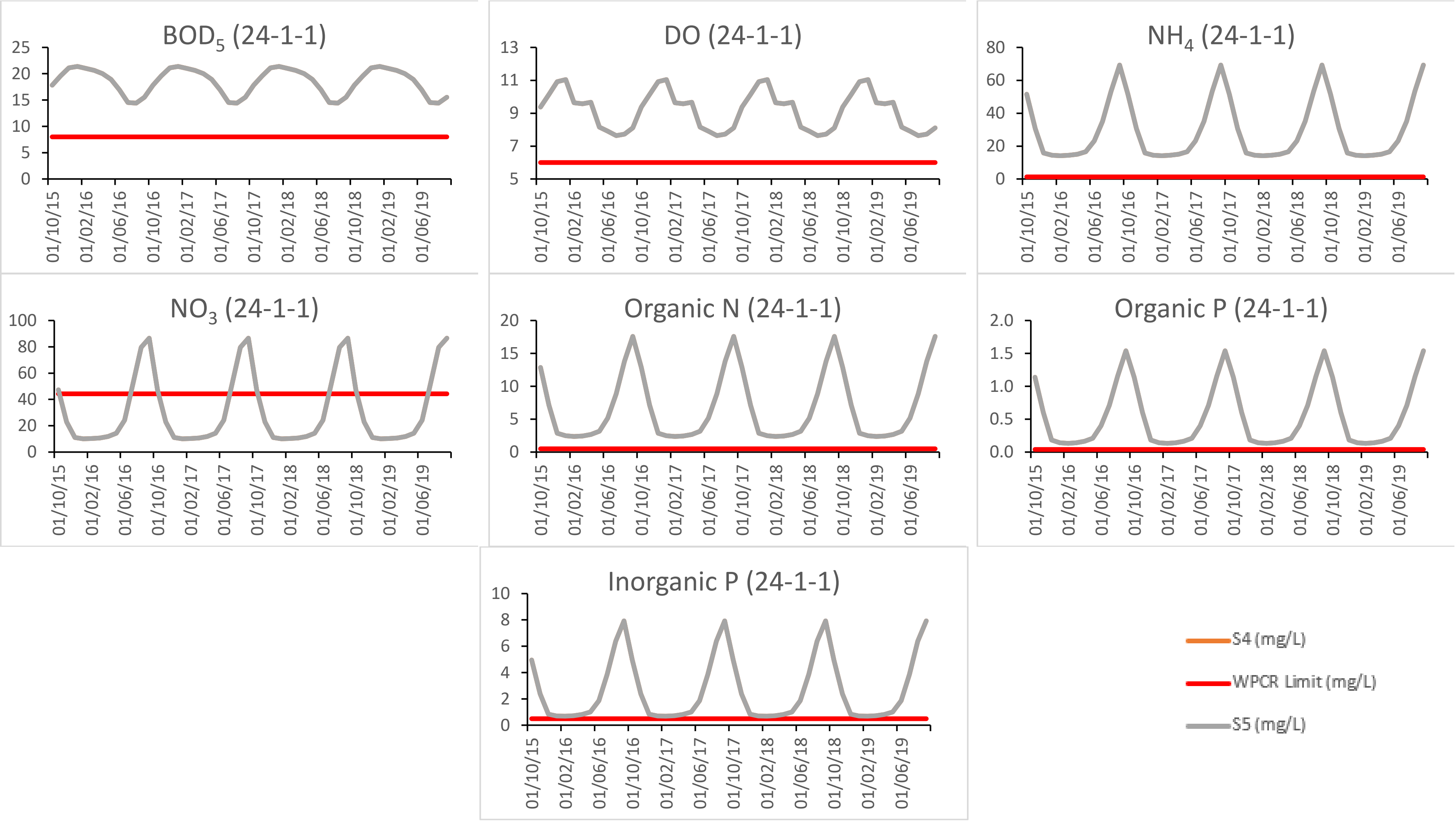

Figure 5.34. Scenario #5 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

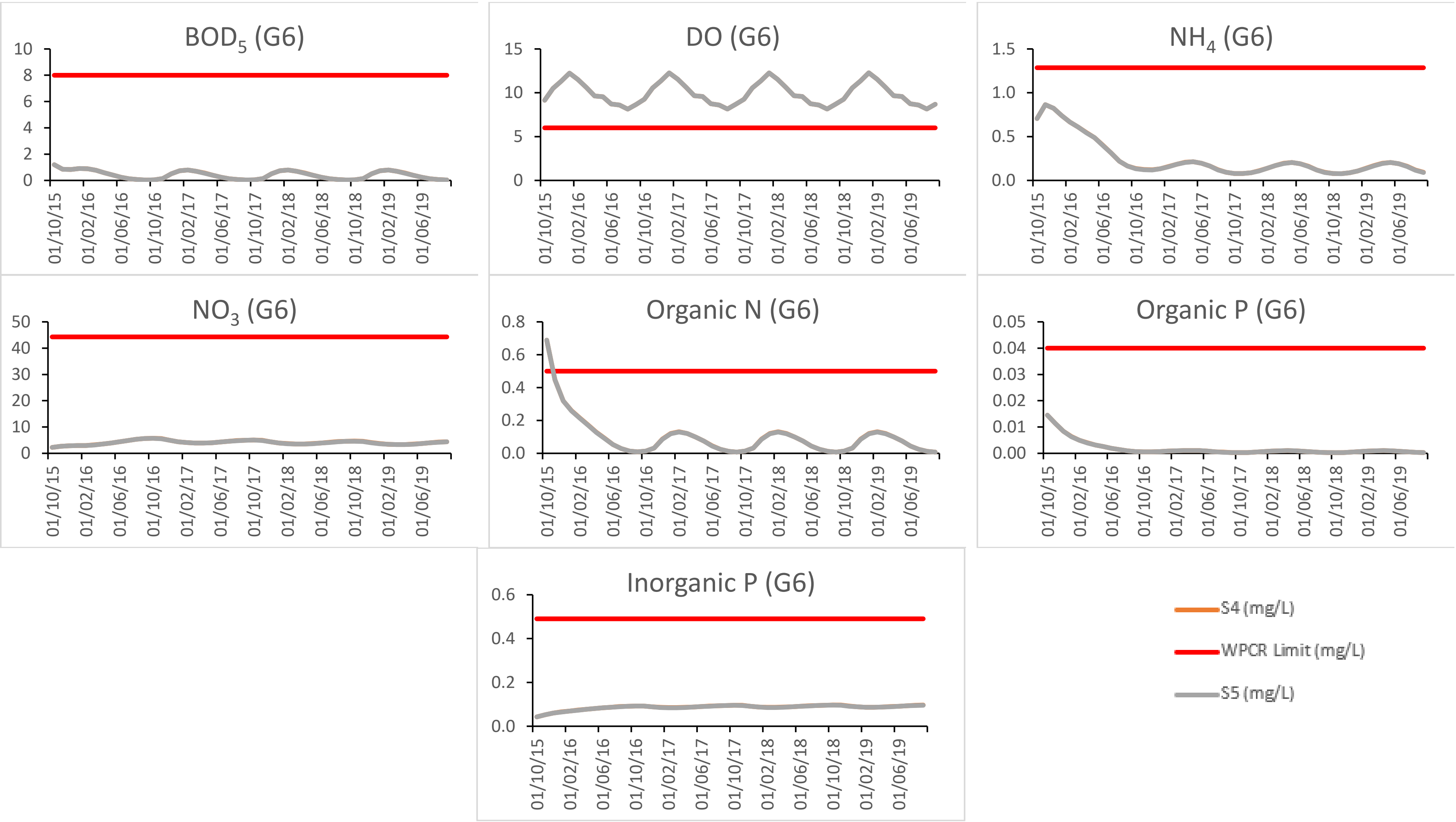

Figure 5.35. Scenario #5 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

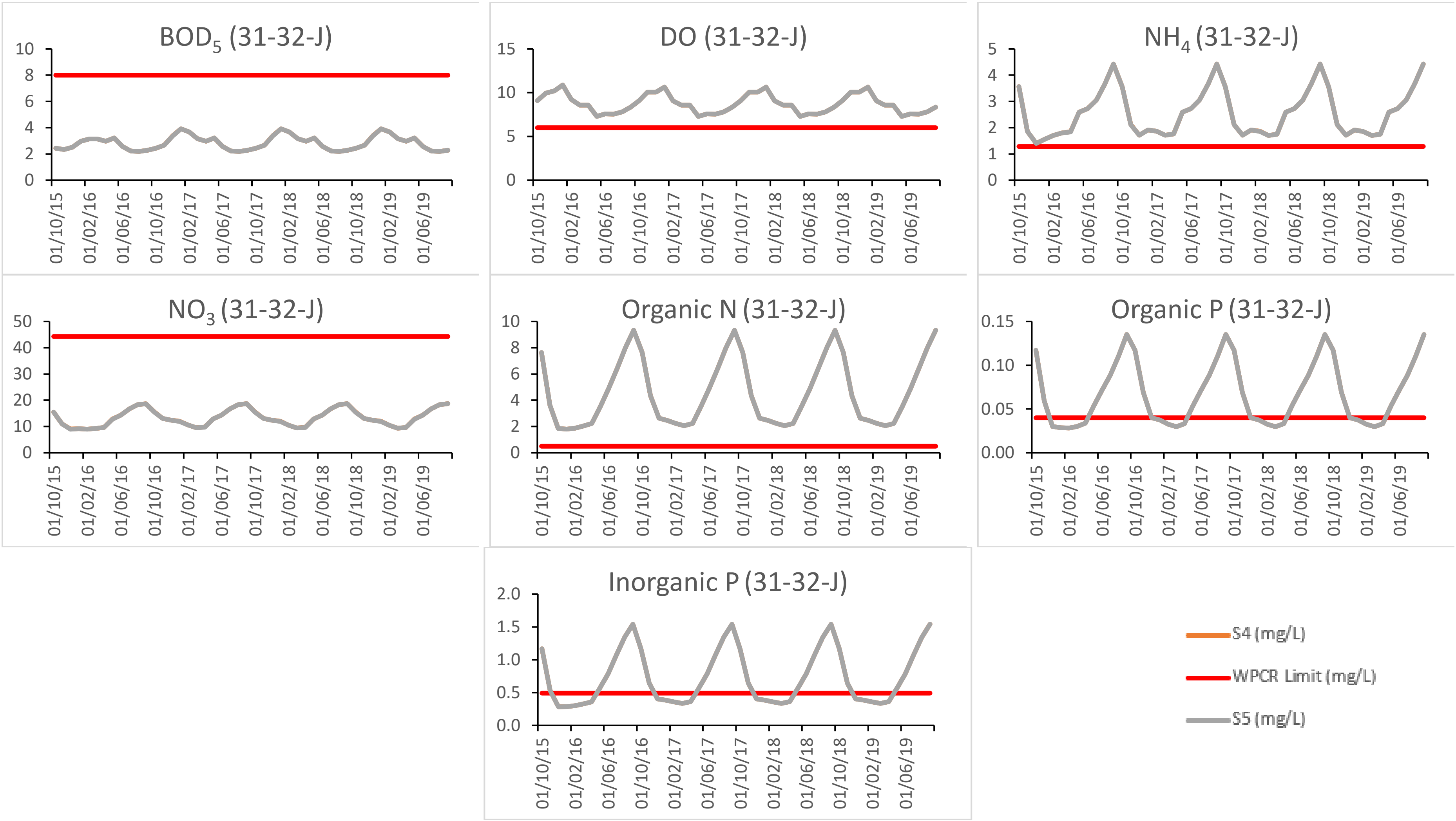

Figure 5.36. Scenario #5 results for BOD₅, Dissolved Oxygen, NH₄, NO₃, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.6. Scenario #6

Crop rotation, which is the name given to the process of planting different crops on the same land with a planned sequence on an annual or periodic basis, was applied as the 6th scenario in the model. While this practice improves soil quality, it also reduces the use of fertilizers by the natural breakdown of insects, weeds, and other residues. Hairston, (2001) and Cestti et al. (2003) stated that the inclusion of greens (grass, green grass) or legumes in the crop rotation will reduce the formation of erosion while increasing the quality of the soil. In addition, Cestti et al. (2003) stated that the need for the use of chemical N fertilizers would be eliminated due to the fact that legumes meet their N needs themselves and that they provide extra N to the soil with fixation, which is the process of converting the free nitrogen in the atmosphere into ammonium forms that can be used by plants, and it will be sufficient to use less fertilizer in the planted products. Another inference obtained by Cestti et al. (2003) in her study is that crop rotation practices improve surface water quality by reducing sediment loss, pesticide applications, and dissolved or soil-bound particulate nutrients and pesticide losses. In another study carried out by Lauringson et al. (2004) in Estonia, it was determined that the phosphorus requirement in the soil decreased by 12-33% in a crop rotation by planting clover first and then potato. In his study in 2003, Novotny, (2002) observed reductions of up to 50% in TN and 30% in TP with this method. Considering the yields in Table 5.2 in the previous sections, in the Bakırçay Basin, the reduction rates to be observed in pollutants with crop rotation were applied as 50% for BOD_5, 50% for TN and 30% for TP. The pollutant load values before and after the application of the measure are given in Table 5.11. Crop rotation measure, which can achieve a mass reduction of up to 48% in some sub-basins, provides a reduction of 11.12% in COD pollutant load, 4.73% in TN pollutant load and 5.56% in TP pollutant load throughout the basin.

These rates were not applied for loads coming from all sub-basins, and reduction rates were obtained on the basis of sub-basins by using the areal approach used before. For this approach, the ratio of the total greenhouse areas and unirrigated mixed agricultural areas in the continuously irrigated areas to the total agricultural area in the sub-basin was found from the CORINE land use data in the Bakırçay Basin which shown in Figure 5.37 and applied to the fertilizer distributed load from the sub-basin. The determined pollution reduction factors are given in Table 5.12.

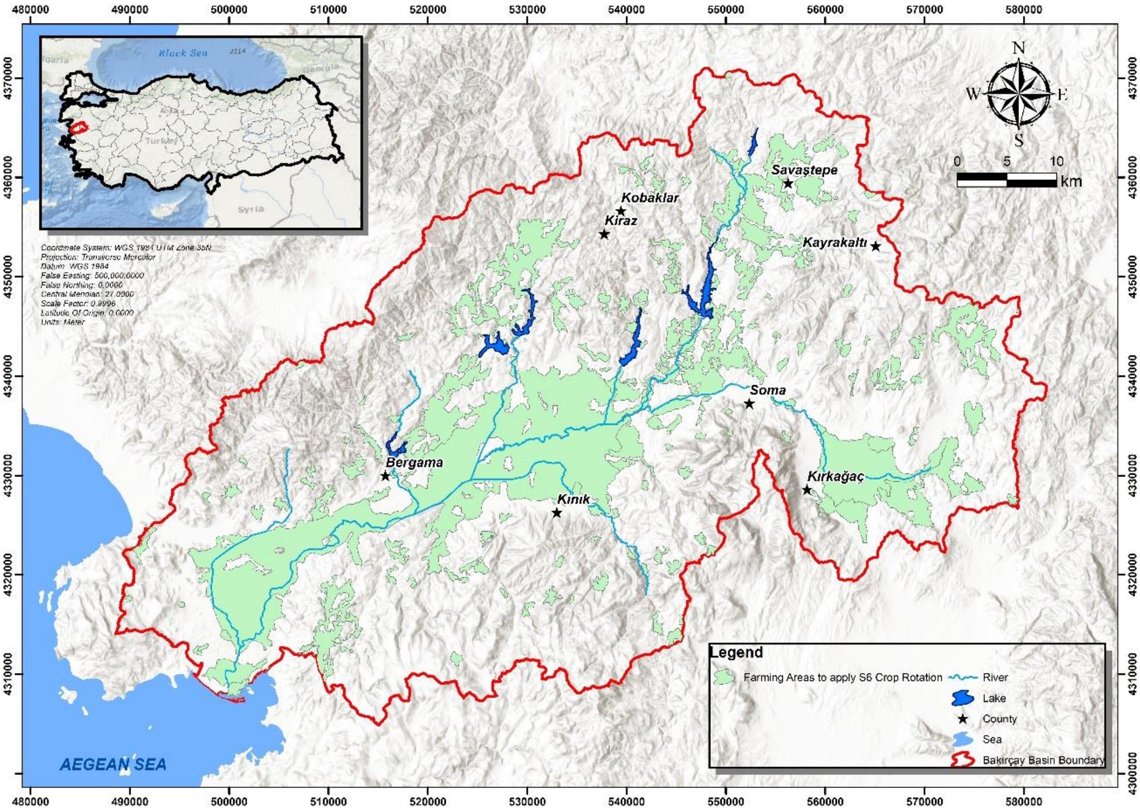

Figure 5.37. Agricultural areas where crop rotation measure is applied

Table 5.11. Non-point pollution loads before and after crop rotation scenario #6

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	46.77	46.65	34.60	34.56	2.75	2.74
KEG_006	76.18	72.34	57.15	55.52	3.79	3.66
KEG_007	39.47	34.79	77.48	73.67	5.51	5.21
KEG_008	54.13	50.90	93.72	91.20	5.96	5.76
KEG_009	8.06	7.52	5.62	5.38	0.20	0.18
KEG_020	52.91	51.41	81.62	80.51	5.55	5.46
KEN_021_01b	2.95	2.68	4.66	4.55	0.42	0.41
KEN_021_01c	53.19	44.34	50.54	48.00	3.79	3.59

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Table 5.11. (Cont.)

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_021_02a	6.65	6.63	5.93	5.92	0.44	0.44
KEN_021_02b	10.01	9.34	13.62	13.41	1.02	1.00
KEN_021_02c	4.56	3.98	4.10	3.94	0.36	0.34
KEN_021_03b	110.01	99.23	71.00	67.48	4.93	4.65
KEN_021_03c	4.70	3.72	5.32	4.70	0.36	0.31
KEN_022_01b	19.91	16.50	41.05	36.87	3.25	2.91
KEN_022_01c	5.41	4.25	9.76	8.34	0.81	0.70
KEN_023_01a	435.27	397.22	93.14	91.12	5.59	5.42
KEN_023_01b	503.04	424.35	72.61	67.60	4.88	4.48
KEN_023_01c	310.31	294.78	55.58	53.78	4.58	4.44
KEN_024_01b	10.53	9.75	48.42	46.14	3.46	3.27
KEN_024_01c	4.11	3.67	22.95	21.68	1.67	1.56
KEN_024_02b	0.60	0.45	2.20	1.76	0.18	0.15
KEN_024_02c	0.62	0.38	2.68	1.77	0.29	0.22
KEN_025_01b	4.77	3.65	4.29	3.66	0.31	0.26
KEN_025_01c	3.90	2.47	1.53	1.11	0.17	0.13
KEN_025_02b	-	-	1.15	0.76	0.15	0.12
KEN_025_02c	-	-	0.00	0.00	0.00	0.00
KEN_025_03b	8.14	4.21	6.49	3.44	0.85	0.60
KEN_025_03c	56.57	45.82	105.45	91.53	9.32	8.21
KEN_025_04b	-	-	1.04	0.56	0.14	0.10
KEN_025_04c	-	-	0.07	0.04	0.01	0.01
KEN_025_05b	205.91	186.58	134.64	124.54	8.07	7.26
KEN_025_05c	3.46	2.33	1.72	1.30	0.14	0.11
KEN_026_01a	24.12	23.58	41.06	40.67	1.97	1.94
KEN_026_01b	44.76	43.09	76.57	74.10	4.67	4.47
KEN_026_01c	28.33	20.53	52.95	41.90	4.76	3.87
KEN_027_01b	0.94	0.94	0.85	0.85	0.07	0.07
KEN_027_01c	1.75	1.65	1.61	1.61	0.10	0.10
KEN_028_01b	28.52	24.11	12.80	12.80	0.65	0.65
KEN_028_01c	33.60	22.51	24.12	24.12	2.13	2.13
KEN_029_01a	17.27	17.14	6.89	6.89	0.34	0.34
KEN_029_01b	6.28	6.28	3.57	3.57	0.14	0.14
KEN_029_01c	12.32	12.17	7.56	7.56	0.30	0.30
KEN_030_01b	76.88	75.25	56.97	56.97	2.63	2.63
KEN_030_01c	6.76	5.25	3.75	3.75	0.43	0.43
KEN_031_01b	290.18	250.95	117.71	117.71	7.39	7.39
KEN_031_01c	86.82	66.96	32.93	32.93	2.96	2.96
KEN_032_01b	39.94	37.69	49.49	49.49	2.54	2.54
KEN_032_01c	207.49	182.37	76.48	76.48	4.51	4.51
TOTAL	2948.12	2620.40	1675.44	1596.24	114.53	108.17

Table 5.12. The crop rotation scenario #6 pollutant removal multiplier values

Sub-Watershed	BOD_5 S6 Mult. Value	NH_4 S6 Mult. Value	NO_3 S6 Mult. Value	Organic N S6 Mult. Value	Organic P S6 Mult. Value	Inorganic P S6 Mult. Value	Sub-Watershed	BOD_5 S6 Mult. Value	NH_4 S6 Mult. Value	NO_3 S6 Mult. Value	Organic N S6 Mult. Value	Organic P S6 Mult. Value	Inorganic P S6 Mult. Value
KEG_005	0.997	0.999	0.999	0.999	0.999	0.999	KEN_025_02b	0.641	0.689	0.656	0.641	0.785	0.797
KEG_006	0.950	0.973	0.971	0.970	0.953	0.969	KEN_025_02c	0.500	0.550	0.515	0.500	1.000	1.000
KEG_007	0.881	0.953	0.950	0.949	0.927	0.950	KEN_025_03b	0.517	0.563	0.523	0.505	0.700	0.716
KEG_008	0.940	0.975	0.973	0.972	0.954	0.969	KEN_025_03c	0.810	0.877	0.866	0.862	0.852	0.889
KEG_009	0.932	0.960	0.956	0.955	0.865	0.915	KEN_025_04b	0.502	0.586	0.529	0.502	0.701	0.723
KEG_020	0.972	0.987	0.986	0.986	0.978	0.986	KEN_025_04c	0.500	0.585	0.528	0.500	0.700	0.722
KEN_021_01b	0.907	0.977	0.976	0.975	0.971	0.981	KEN_025_05b	0.906	0.930	0.924	0.921	0.873	0.908
KEN_021_01c	0.834	0.952	0.949	0.948	0.929	0.951	KEN_025_05c	0.673	0.779	0.752	0.739	0.728	0.770
KEN_021_02a	0.997	0.999	0.999	0.999	0.998	0.999	KEN_026_01a	0.978	0.991	0.990	0.990	0.977	0.986
KEN_021_02b	0.933	0.985	0.984	0.984	0.977	0.985	KEN_026_01b	0.963	0.970	0.967	0.966	0.945	0.961
KEN_021_02c	0.872	0.963	0.961	0.960	0.953	0.968	KEN_026_01c	0.725	0.802	0.789	0.784	0.794	0.821
KEN_021_03b	0.902	0.954	0.950	0.948	0.924	0.948	KEN_027_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_021_03c	0.791	0.890	0.881	0.877	0.828	0.871	KEN_027_01c	0.945	1.000	1.000	1.000	1.000	1.000
KEN_022_01b	0.829	0.904	0.897	0.894	0.873	0.904	KEN_028_01b	0.845	1.000	1.000	1.000	1.000	1.000
KEN_022_01c	0.786	0.864	0.852	0.847	0.833	0.867	KEN_028_01c	0.670	1.000	1.000	1.000	1.000	1.000
KEN_023_01a	0.913	0.980	0.978	0.977	0.959	0.974	KEN_029_01a	0.992	1.000	1.000	1.000	1.000	1.000
KEN_023_01b	0.844	0.938	0.930	0.926	0.894	0.925	KEN_029_01b	1.000	1.000	1.000	1.000	1.000	1.000
KEN_023_01c	0.950	0.970	0.967	0.966	0.958	0.971	KEN_029_01c	0.987	1.000	1.000	1.000	1.000	1.000
KEN_024_01b	0.926	0.957	0.952	0.949	0.930	0.952	KEN_030_01b	0.979	1.000	1.000	1.000	1.000	1.000
KEN_024_01c	0.893	0.949	0.944	0.942	0.926	0.943	KEN_030_01c	0.777	1.000	1.000	1.000	1.000	1.000
KEN_024_02b	0.746	0.816	0.797	0.788	0.787	0.816	KEN_031_01b	0.865	1.000	1.000	1.000	1.000	1.000
KEN_024_02c	0.615	0.685	0.657	0.645	0.732	0.757	KEN_031_01c	0.771	1.000	1.000	1.000	1.000	1.000
KEN_025_01b	0.766	0.863	0.850	0.845	0.807	0.845	KEN_032_01b	0.944	1.000	1.000	1.000	1.000	1.000
KEN_025_01c	0.632	0.749	0.721	0.709	0.785	0.804	KEN_032_01c	0.879	1.000	1.000	1.000	1.000	1.000

Scenario #6 results of 24-1-1 river water body representing the upstream of Bakırçay Basin are given in Figure 5.38. The results reveal that the highest removal efficiency was observed in the parameter BOD_5 with 7.2%, followed by NO_3 with 2.2%. In addition, other parameters and removal rates were obtained as 2% for Organic N, 1.9% for NH_4, Organic N and Inorganic P, and 0.2% for Dissolved Oxygen, respectively.

If the Scenario #6 results of the G6 lake water body given in Figure 5.39 are analyzed, it can be seen that the removal rates are similar to those of the upstream water body results. To give a number, BOD_5 had the highest removal with 8.3%, followed by Organic N with 2.5%, while this rate was 2.3% for NH_4 and Inorganic P. While the ratio is 2% in NO_3, which has a relatively lower removal rate than other parameters, this ratio is 1.2% in Organic P and 0.02% in Dissolved Oxygen.

If the Scenario #6 results of the 31-32-J river water body, which is given in Figure 5.40., representing the basin downstream are analyzed, it would not be wrong to say that the crop rotation scenario has more successful removal efficiencies than the other scenarios applied to diffuse source pollutants. One of the reasons for this is that agricultural lands occupy an important place in the basin. From this point of view, it can be said that the effect of agricultural activities on water resources affects water quality more than most other factors. When the removal efficiencies are examined, the rates of 10.7% in BOD_5, 5.8% in NO_3 and 2.9% in Organic P can be evaluated as high, while 1.9% obtained in NH_4, 1.8% obtained in Inorganic P, 1.2% obtained in Organic N and the 0.4% obtained in Dissolved Oxygen removal rates remained relatively low.

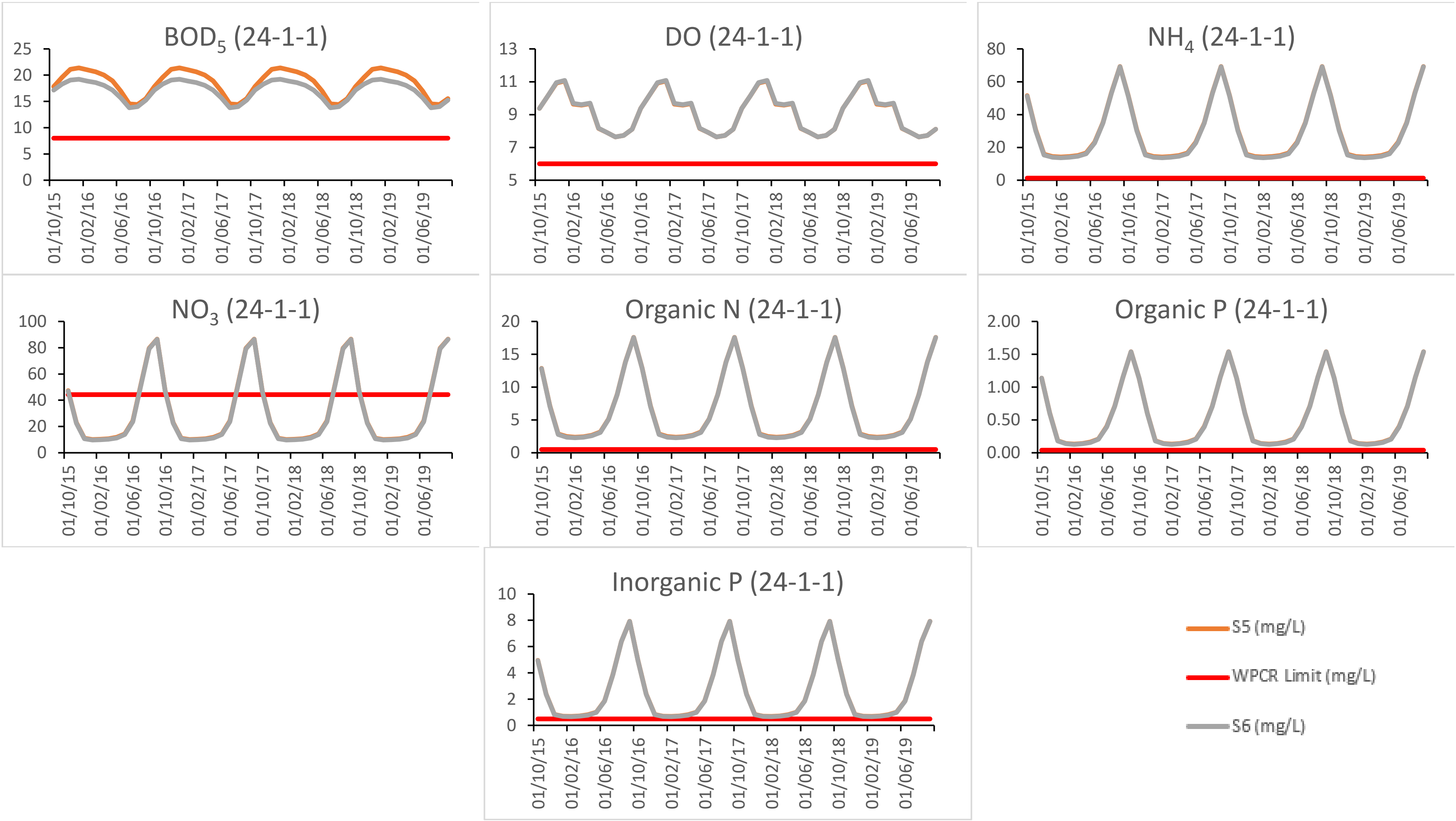

Figure 5.38. Scenario #6 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

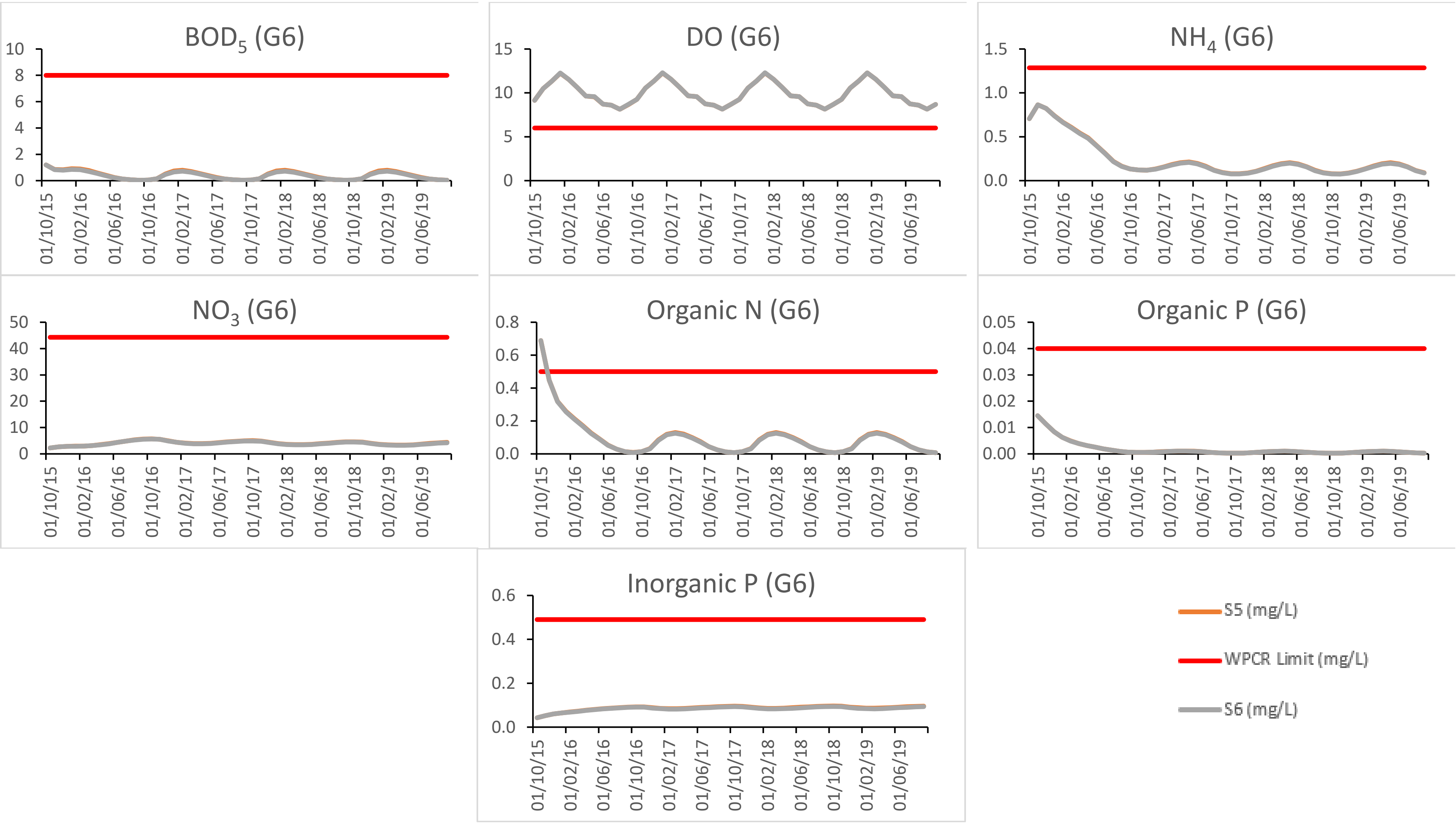

Figure 5.39. Scenario #6 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

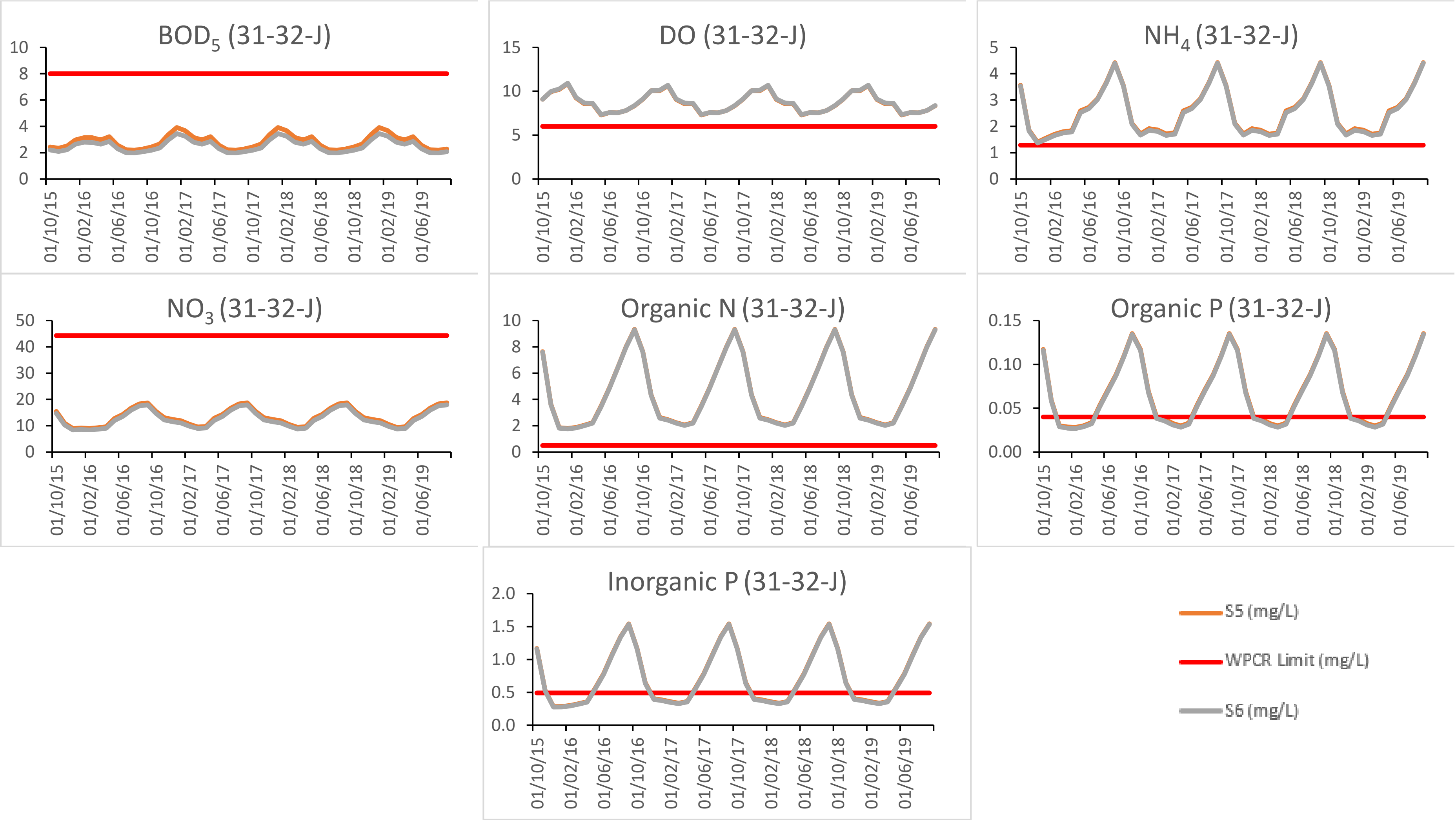

Figure 5.40. Scenario #6 results for BOD₅, Dissolved Oxygen, NH₄, NO₃, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.7. Scenario #7

Vegetative barriers are narrow parallel strips of densely planted plants that are perpendicular to land boundaries (US EPA, 2007). With the Vegetative Barrier measure discussed in Scenario #7, flooding and overflow events are also reduced on heavy rainy days by keeping the nutrients that come with the sediment carried by the surface flow, thus improving the water quality and increasing the water filtration. The vegetative barrier application in Bakırçay basin will be applied by placing 1 meter wide plants at the borders where agricultural areas intersect with water bodies. As assumed in the green belt measure, it is assumed that the area of influence in the applied areas will be 350 meters in this measure. The areas where the measure will be applied are given in Figure 5.41, and in Table 5.13, the distributed total loads in the basin before and after the measure can be seen. According to this table, with the vegetative barrier measure, an average of 12.6% decrease in COD pollutant load, an average of 9.13% in TN pollutant load and 13.34% in TP pollutant load was achieved in the sub-basins, while these rates were 10.72%, 5.32% and 10% for COD, TN and TP, respectively, in the basin total.

The vegetative barrier-based pollutant removal efficiency, which was selected considering the purpose and removal efficiencies described in the literature and shown in Table 5.2, is 70% for TN and TP, and 50% for BOD_5. While these removal efficiencies were applied to the model, as in other diffuse pollutant prevention scenarios, the areal reduction coefficients were calculated and reduction processes were applied. For the calculation of the coefficients, firstly, 350 m buffer areas were created around the agricultural areas in the sub-basins and their areas were calculated. The ratios of these buffer areas to the areas of agricultural lands in the sub-basin and the sub-basin areas were obtained. The obtained buffer area / agricultural area ratio has been reduced by using the ratio of 70% within the fertilizer load, which is one of the components of the current distributed pollutant load to the basin. Atmospheric load, another dispersed pollutant load component, has been updated to reduce the buffer area/sub-basin area ratio by 70%. Thus, the reduction coefficients given in Table 5.14. were calculated.

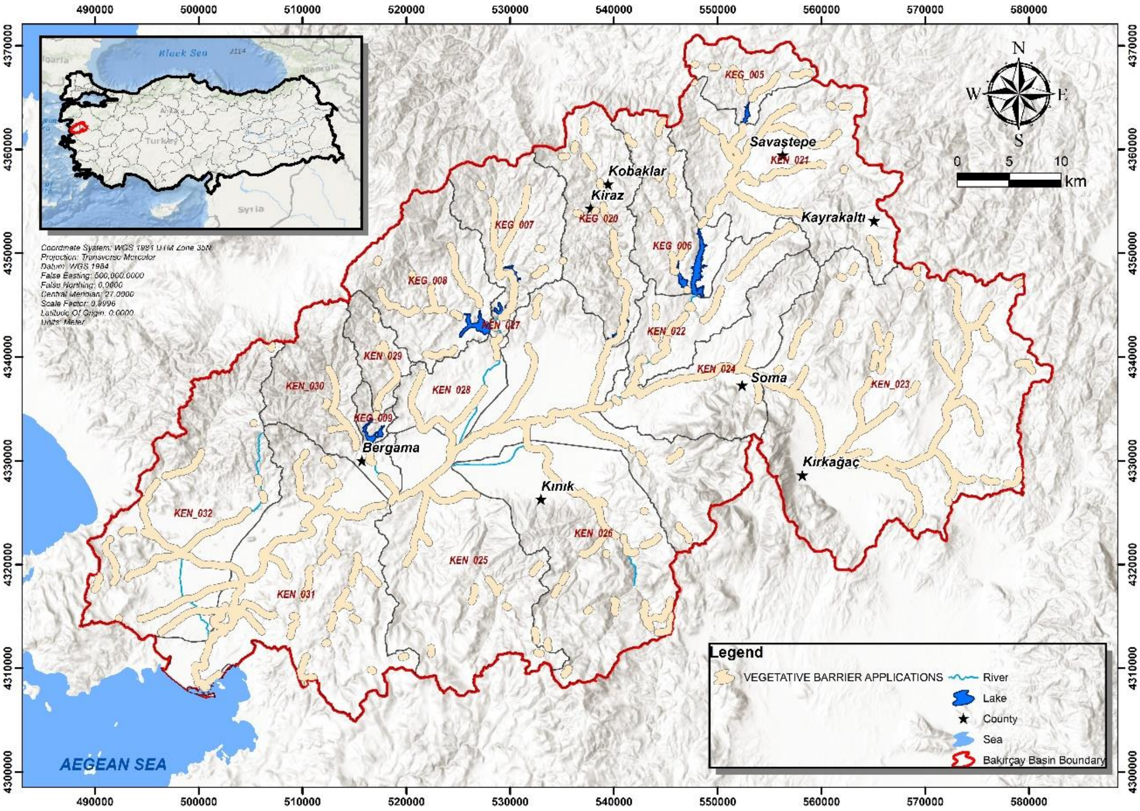

Figure 5.41. Agricultural areas and impact zones where the vegetative barrier scenario #7 is applied

Table 5.13. Non-point pollution loads before and after vegetative barrier scenario #7

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEG_005	46.65	42.20	34.60	33.71	2.75	2.64
KEG_006	72.34	63.52	57.15	55.56	3.79	3.59
KEG_007	34.79	30.41	77.48	73.11	5.51	4.95
KEG_008	50.90	45.30	93.72	90.37	5.96	5.53
KEG_009	7.52	6.76	5.62	5.57	0.20	0.20
KEG_020	51.41	46.28	81.62	79.41	5.55	5.27
KEN_021_01b	2.68	2.29	4.66	4.41	0.42	0.39
KEN_021_01c	44.34	38.59	50.54	48.39	3.79	3.52
KEN_021_02a	6.63	6.20	5.93	5.88	0.44	0.43
KEN_021_02b	9.34	8.51	13.62	13.39	1.02	0.99

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Table 5.13. (Cont.)

Non-Point Pollution Loads						
Sub-watershed	COD Loads (Ton/year)		Total N Loads (Ton/year)		Total P Loads (Ton/year)	
	Before Scenario	After Scenario	Before Scenario	After Scenario	Before Scenario	After Scenario
KEN_021_02c	3.98	3.74	4.10	3.98	0.36	0.34
KEN_021_03b	99.23	88.21	71.00	67.61	4.93	4.50
KEN_021_03c	3.72	3.17	5.32	4.93	0.36	0.31
KEN_022_01b	16.50	14.73	41.05	38.38	3.25	2.90
KEN_022_01c	4.25	3.74	9.76	8.84	0.81	0.69
KEN_023_01a	397.22	360.05	93.14	90.49	5.59	5.26
KEN_023_01b	424.35	382.76	72.61	68.16	4.88	4.31
KEN_023_01c	294.78	258.71	55.58	51.75	4.58	4.09
KEN_024_01b	9.75	8.81	48.42	46.11	3.46	3.17
KEN_024_01c	3.67	3.33	22.95	21.46	1.67	1.47
KEN_024_02b	0.45	0.38	2.20	1.93	0.18	0.15
KEN_024_02c	0.38	0.35	2.68	2.43	0.29	0.26
KEN_025_01b	3.65	3.19	4.29	3.80	0.31	0.24
KEN_025_01c	2.47	1.80	1.53	1.06	0.17	0.11
KEN_025_02b	-	-	1.15	1.07	0.15	0.14
KEN_025_02c	-	-	0.00	0.00	0.00	0.00
KEN_025_03b	4.21	3.81	6.49	5.60	0.85	0.73
KEN_025_03c	45.82	40.63	105.45	97.17	9.32	8.25
KEN_025_04b	-	-	1.04	0.58	0.14	0.08
KEN_025_04c	-	-	0.07	0.07	0.01	0.01
KEN_025_05b	186.58	165.36	134.64	127.44	8.07	7.14
KEN_025_05c	2.33	1.85	1.72	1.34	0.14	0.09
KEN_026_01a	23.58	21.67	41.06	40.54	1.97	1.91
KEN_026_01b	43.09	38.21	76.57	72.93	4.67	4.20
KEN_026_01c	20.53	18.04	52.95	45.81	4.76	3.82
KEN_027_01b	0.94	0.58	0.85	0.78	0.07	0.06
KEN_027_01c	1.65	1.28	1.61	1.50	0.10	0.08
KEN_028_01b	24.11	21.69	12.80	12.36	0.65	0.59
KEN_028_01c	22.51	20.58	24.12	22.40	2.13	1.91
KEN_029_01a	17.14	15.67	6.89	6.76	0.34	0.33
KEN_029_01b	6.28	5.15	3.57	3.36	0.14	0.12
KEN_029_01c	12.17	10.42	7.56	7.25	0.30	0.26
KEN_030_01b	75.25	67.41	56.97	55.38	2.63	2.43
KEN_030_01c	5.25	4.14	3.75	2.86	0.43	0.31
KEN_031_01b	250.95	223.85	117.71	111.51	7.39	6.59
KEN_031_01c	66.96	60.49	32.93	29.84	2.96	2.56
KEN_032_01b	37.69	34.18	49.49	47.11	2.54	2.24
KEN_032_01c	182.37	161.36	76.48	71.87	4.51	3.92
TOTAL	2620.40	2339.40	1675.44	1586.26	114.53	103.08

Table 5.14. The vegetative barrier scenario #7 pollutant removal multiplier values

Sub-Watershed	BOD$_5$ S7 Mult. Value	NH$_4$ S7 Mult. Value	NO$_3$ S7 Mult. Value	Organic N S7 Mult. Value	Organic P S7 Mult. Value	Inorganic P S7 Mult. Value	Sub-Watershed	BOD$_5$ S7 Mult. Value	NH$_4$ S7 Mult. Value	NO$_3$ S7 Mult. Value	Organic N S7 Mult. Value	Organic P S7 Mult. Value	Inorganic P S7 Mult. Value
KEG_005	0.905	0.968	0.976	0.979	0.955	0.961	KEN_025_02b	0.948	0.928	0.928	0.928	0.928	0.928
KEG_006	0.878	0.963	0.974	0.979	0.943	0.950	KEN_025_02c	0.500	0.300	0.300	0.300	0.300	0.300
KEG_007	0.874	0.938	0.945	0.948	0.875	0.904	KEN_025_03b	0.905	0.863	0.863	0.863	0.862	0.862
KEG_008	0.890	0.958	0.966	0.969	0.914	0.933	KEN_025_03c	0.887	0.916	0.923	0.925	0.867	0.890
KEG_009	0.899	0.982	0.993	0.999	0.993	0.972	KEN_025_04b	0.684	0.558	0.558	0.558	0.558	0.558
KEG_020	0.900	0.967	0.974	0.977	0.941	0.952	KEN_025_04c	0.948	0.927	0.927	0.927	0.927	0.927
KEN_021_01b	0.855	0.940	0.947	0.950	0.903	0.928	KEN_025_05b	0.886	0.940	0.948	0.951	0.869	0.891
KEN_021_01c	0.870	0.951	0.959	0.962	0.914	0.932	KEN_025_05c	0.794	0.774	0.782	0.786	0.627	0.655
KEN_021_02a	0.936	0.987	0.992	0.994	0.986	0.986	KEN_026_01a	0.919	0.982	0.988	0.991	0.966	0.969
KEN_021_02b	0.911	0.979	0.984	0.985	0.965	0.973	KEN_026_01b	0.887	0.946	0.954	0.957	0.882	0.906
KEN_021_02c	0.940	0.969	0.972	0.974	0.949	0.961	KEN_026_01c	0.878	0.863	0.866	0.866	0.788	0.807
KEN_021_03b	0.889	0.945	0.954	0.957	0.896	0.917	KEN_027_01b	0.612	0.890	0.920	0.933	0.853	0.881
KEN_021_03c	0.852	0.918	0.928	0.933	0.842	0.866	KEN_027_01c	0.774	0.922	0.938	0.945	0.838	0.873
KEN_022_01b	0.893	0.930	0.936	0.939	0.878	0.898	KEN_028_01b	0.900	0.960	0.967	0.970	0.905	0.917
KEN_022_01c	0.879	0.900	0.906	0.909	0.835	0.857	KEN_028_01c	0.914	0.926	0.929	0.931	0.885	0.898
KEN_023_01a	0.906	0.964	0.973	0.977	0.931	0.944	KEN_029_01a	0.915	0.974	0.984	0.989	0.958	0.959
KEN_023_01b	0.902	0.931	0.940	0.945	0.868	0.889	KEN_029_01b	0.821	0.929	0.943	0.949	0.766	0.825
KEN_023_01c	0.878	0.923	0.933	0.937	0.873	0.899	KEN_029_01c	0.857	0.950	0.961	0.966	0.840	0.879
KEN_024_01b	0.903	0.944	0.954	0.959	0.905	0.919	KEN_030_01b	0.896	0.965	0.973	0.977	0.905	0.929
KEN_024_01c	0.908	0.931	0.936	0.938	0.868	0.889	KEN_030_01c	0.789	0.757	0.764	0.767	0.716	0.735
KEN_024_02b	0.851	0.869	0.877	0.881	0.801	0.810	KEN_031_01b	0.892	0.941	0.949	0.952	0.877	0.897
KEN_024_02c	0.918	0.905	0.906	0.907	0.883	0.888	KEN_031_01c	0.903	0.903	0.907	0.909	0.857	0.867
KEN_025_01b	0.873	0.882	0.887	0.890	0.771	0.801	KEN_032_01b	0.907	0.946	0.953	0.957	0.855	0.888
KEN_025_01c	0.730	0.690	0.698	0.701	0.632	0.638	KEN_032_01c	0.885	0.932	0.941	0.945	0.851	0.875

Scenario #7 results of 24-1-1 river water body representing the upstream of Bakırçay Basin are given in Figure 5.42. The results reveal that the parameter with the highest removal efficiency with an average of 7.1% is BOD_5, followed by Inorganic P and Organic P with 3.7% and 3.4%. In addition, average removal efficiencies of 3%, 2.6% and 1.9% were observed for nitrogen compounds NH_4, NO_3 and Organic N, respectively. However, the aforementioned pollutant removals resulted in a 0.2% improvement in Dissolved Oxygen.

Scenario #7 results of G6 representing lake water bodies in Bakırçay Basin are given in Figure 5.43. The results reveal that the highest removal efficiency was achieved with an average of 10.3% in the BOD_5 parameter, followed by Inorganic P with 3.5%. Following these two parameters, the highest average removal efficiency parameters are Organic N, NO_3, NH_4, Organic P, and their ratios are 1.9%, 1.8%, 1.7%, and 1.4%, respectively. These removal efficiencies led to an improvement of 0.02% in the Dissolved Oxygen parameter.

Scenario #7 of the 31-32-J river water body, which represents the downstream of Bakırçay Basin given in Figure 5.44., reveals that the highest average removal efficiency is seen in the BOD_5 parameter with 8.9%, as in the upstream and lake water body. This average removal value is followed by Inorganic P and Organic P parameters, which are Phosphorus compounds with 5.6% and 4.9%. The average removal efficiencies of nitrogen fractions NH4, NO3 and Organic N were obtained as 3.2%, 4.7% and 2.7%, respectively. These removals in the pollutant parameters led to an average improvement of 0.4% in Dissolved Oxygen values.

It is obvious that the vegetative barrier scenario has a high impact both upstream and downstream of the basin. This is because most of the pollutant load coming into the basin comes from agricultural activities. The same reason is also valid for the high removal efficiencies seen in the results of the previous scenario, crop rotation. The reason why vegetative barrier scenario removal efficiency results are higher than crop rotation scenario removal efficiencies is the potential of vegetative barriers to retain pollutants precipitated from the atmosphere, unlike crop rotation.

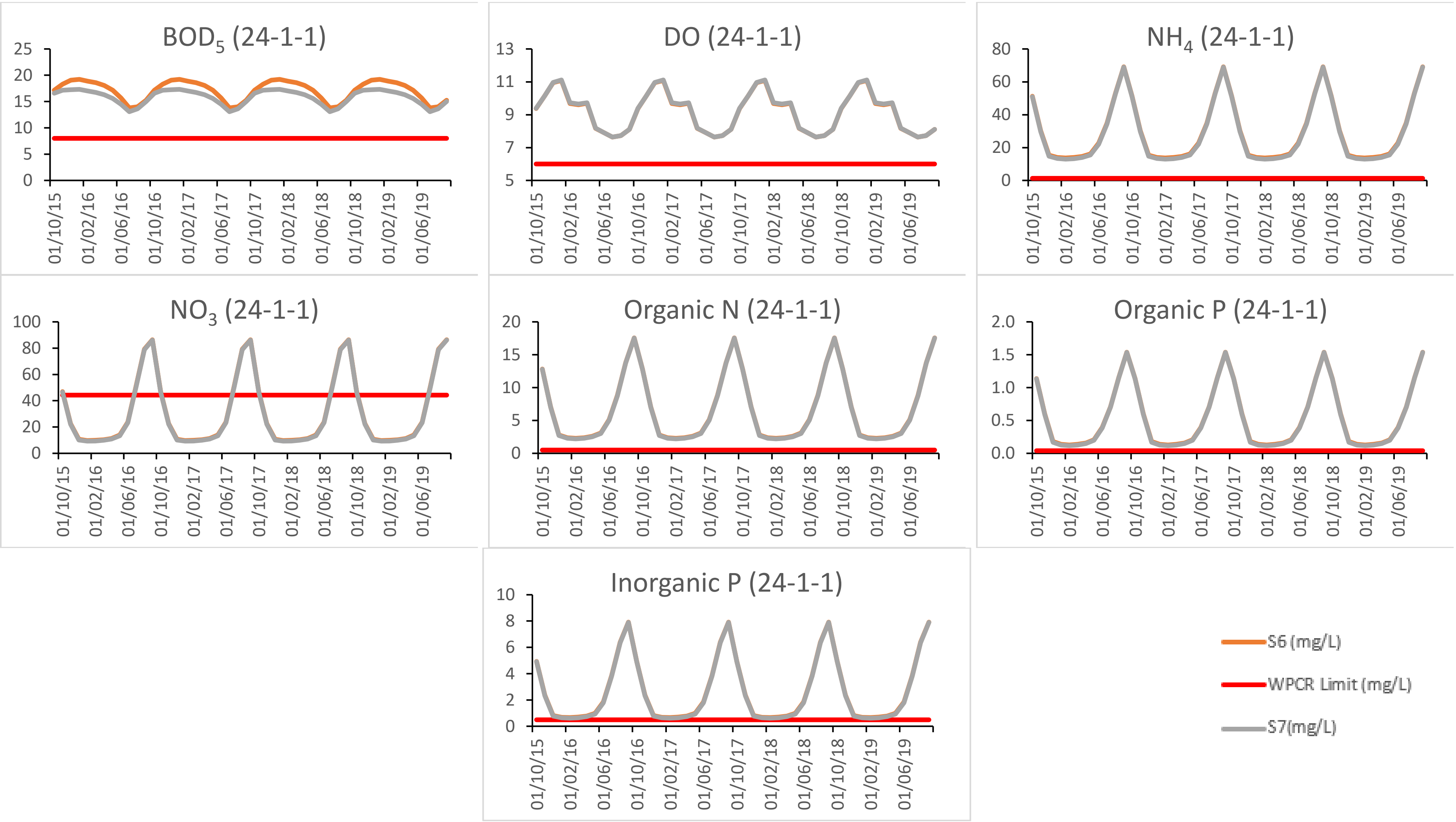

Figure 5.42. Scenario #7 results for BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P and Inorganic P at 24-1-1 river reach

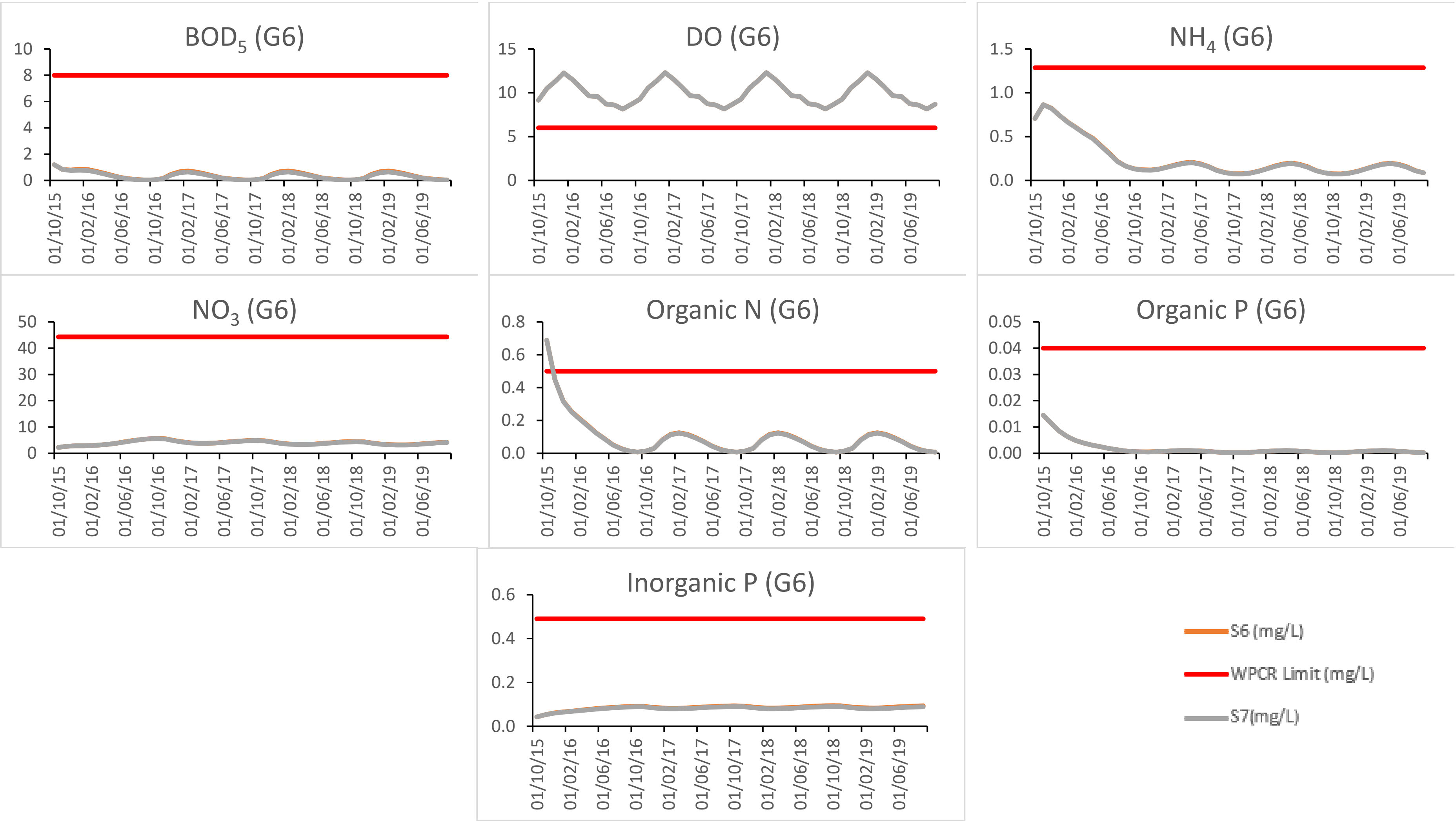

Figure 5.43. Scenario #7 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

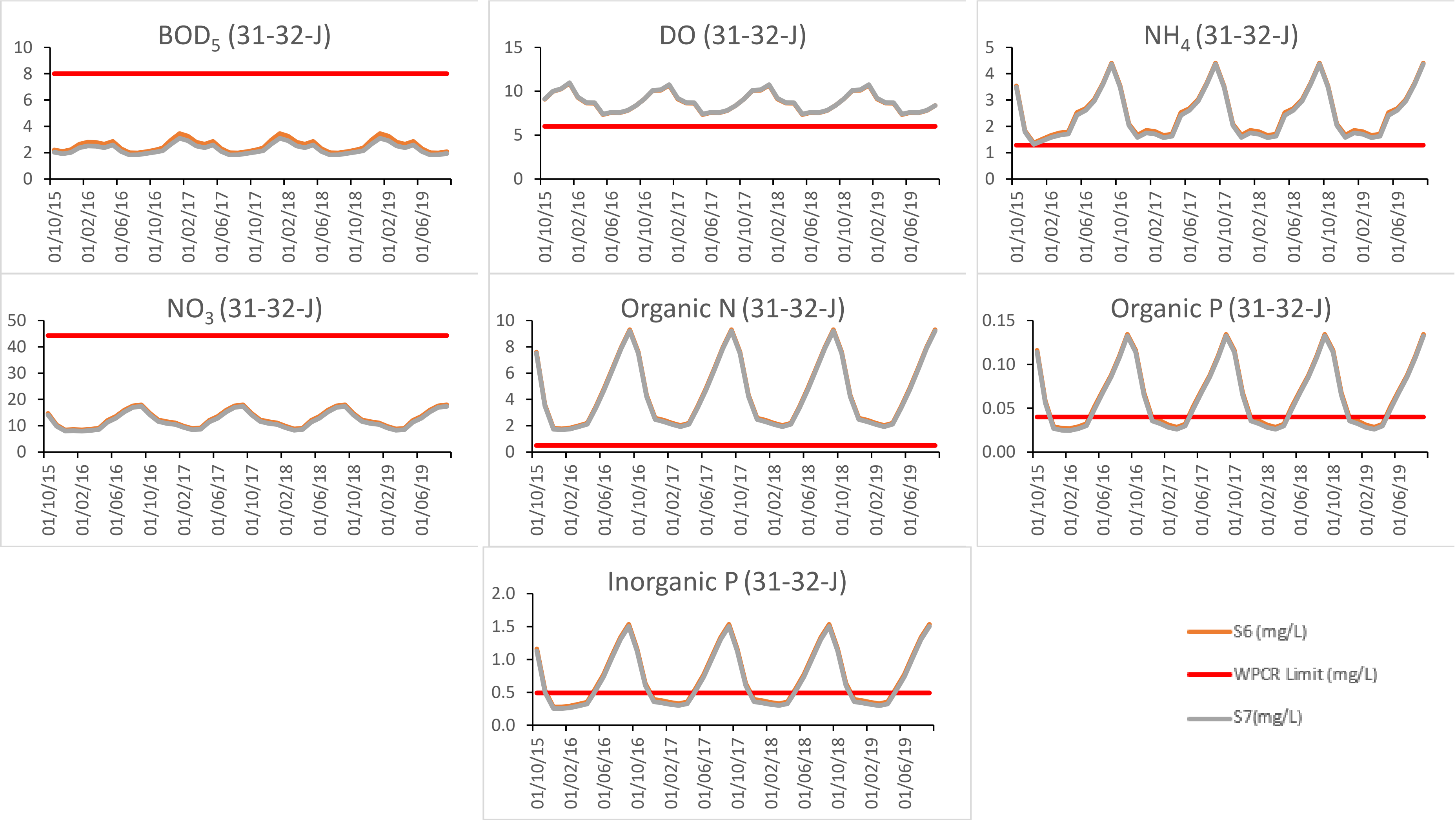

Figure 5.44. Scenario #7 results for BOD$_5$, Dissolved Oxygen, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 31-32-J river reach

5.3.8. Cumulative Scenarios

In order to make cumulative evaluations of the scenario implementations in the basin, the current situation and the Scenario#7 model results are given in Figure 5.47, Figure 5.48. and Figure 5.49. for the upstream river water body 24-1-1, lake water body G6 and downstream river water body 31-32-J. Tabulated representation of the same results is given in Table 5.15. In addition, the cumulative removal effects of the scenarios on the pollutant parameters can be seen in Figure 5.45 and Figure 5.46.

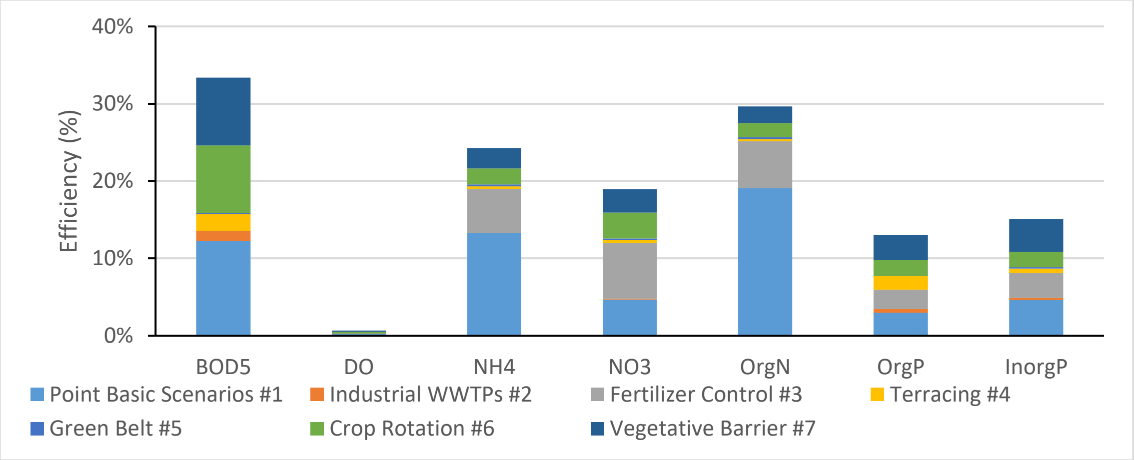

Figure 5.45. Removal efficiencies of the applied scenarios on the basis of pollutant parameters

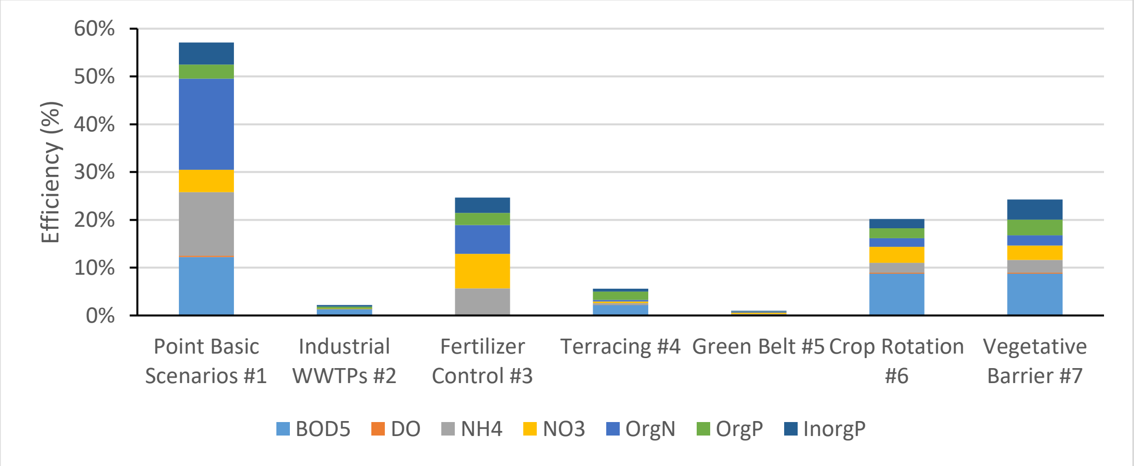

Figure 5.46. Scenario-based comparison of the removal efficiencies of the applied scenarios

Table 5.15. The cumulative average removal yields for upstream, lake water body and downstream

	BOD_5	Dissolved Oxygen	NH4	NO3	Organic N	Organic P	Inorganic P
24-1-1	31.7%	0.6%	20.4%	15.0%	22.2%	8.6%	9.3%
G6	26.8%	0.1%	24.8%	16.0%	29.4%	9.0%	17.0%
31-32-J	30.9%	1.4%	22.4%	22.1%	31.0%	19.0%	16.3%
Basin Mean	29.8%	0.7%	22.6%	17.7%	27.5%	12.2%	14.2%

According to the results, all scenarios provided an average of approximately 30% removal for the BOD_5 parameter from upstream to downstream. As can be seen from the results, this ratio was insufficient to provide the good water condition limit value in river water bodies (upstream and downstream). It is thought that the reason for this situation is that the emitted from the sources of BOD_5 pollution cannot be prevented from entering the water body in sufficient quantities. However, the results show an average improvement of 0.7% in the dissolved oxygen parameter. Although this rate of improvement was expected, sharper trends should have been captured given the reductions of organic, nitrogenous, and phosphorus pollutants in almost every scenario application. It is thought that the reason why this trend is not caught, or in other words, the inadequate response to biochemical activities, is an overestimation of the background dissolved oxygen levels given to the system together with the flow elements in the infrastructure of the model due to lack of dissolved oxygen data. Despite this setback, the fact that dissolved oxygen levels remain above the good water condition limit value is a positive situation in terms of the water quality of Bakırçay River.

Suppose the results are evaluated in terms of Nitrogen fractions. In that case, the highest average removal efficiency is Organic Nitrogen, which gives consistent results to the scenarios in both upstream, downstream, and lake water bodies and has an average decrease of 28%. The reason for this situation is that the ratio of Organic Nitrogen among the fraction ratios of the TN loads calculated for the Bakırçay basin, which can also be seen in Table 4.35, is lower than the other components, in short, less Organic Nitrogen load enters the basin than other nitrogenous compounds. Another reason for this situation is that higher yields can be obtained due to the incorporation of Organic N into plant structures in plant and tree-oriented scenarios such as crop rotation, green belt, and vegetative barrier. Despite this, it is obvious that the limit value of good water conditions in river water bodies cannot be reached below. In NH_4, another Nitrogen fraction, the basin average stands out as 22.6%, and the reason for the higher removal rate in the lake water body is that the nitrification process is observed at higher rates in the lake water bodies and, as a result, higher removals are observed in NH_4. Again in NH_4, good water status could not be reached in river water bodies such as Organic N. It was observed that the removal efficiency of NO_3, the last of the nitrogen fractions, remained at an average of 17.7% in the basin. It is thought that the reason for this ratio to remain at these levels is that the NH_4 pollutant in the basin and especially in the lake water bodies turns into NO_3 as a result of the nitrification process and creates an extra resource in the basin. Despite this situation, NO_3 seems to be the only parameter among the nitrogen fractions that provides good water status in river and lake water bodies.

It can be seen that the average removal results of the phosphorus fractions are lower than the results of the nitrogen fractions. This is unexpected. It is thought that the reason for the lower percentages of organic phosphorus in upstream and lake water bodies compared to the average removals of Inorganic Phosphorus may be that a large fraction of the TN load coming to the basin comes to the basin as Inorganic P, as in the Organic Nitrogen example. However, since most of the TP load coming to the basin is due to land use and fertilizer use, and these loads are heterogeneously distributed in the basin, the difference in the upstream and downstream average removal results is normal.

While the results once again reveal the importance of basic measures based on point source pollution prevention, fertilizer control, vegetative barrier and crop change measures should be given priority according to the removal efficiencies obtained for diffuse source pollutants. However, it can be said that improvements, terracing and green belt applications in industrial facilities provide relatively less removal efficiency. As a result of the scenarios applied in the same context, the highest removal efficiency was found in BOD_5, followed by nitrogen and then phosphorus fractions.

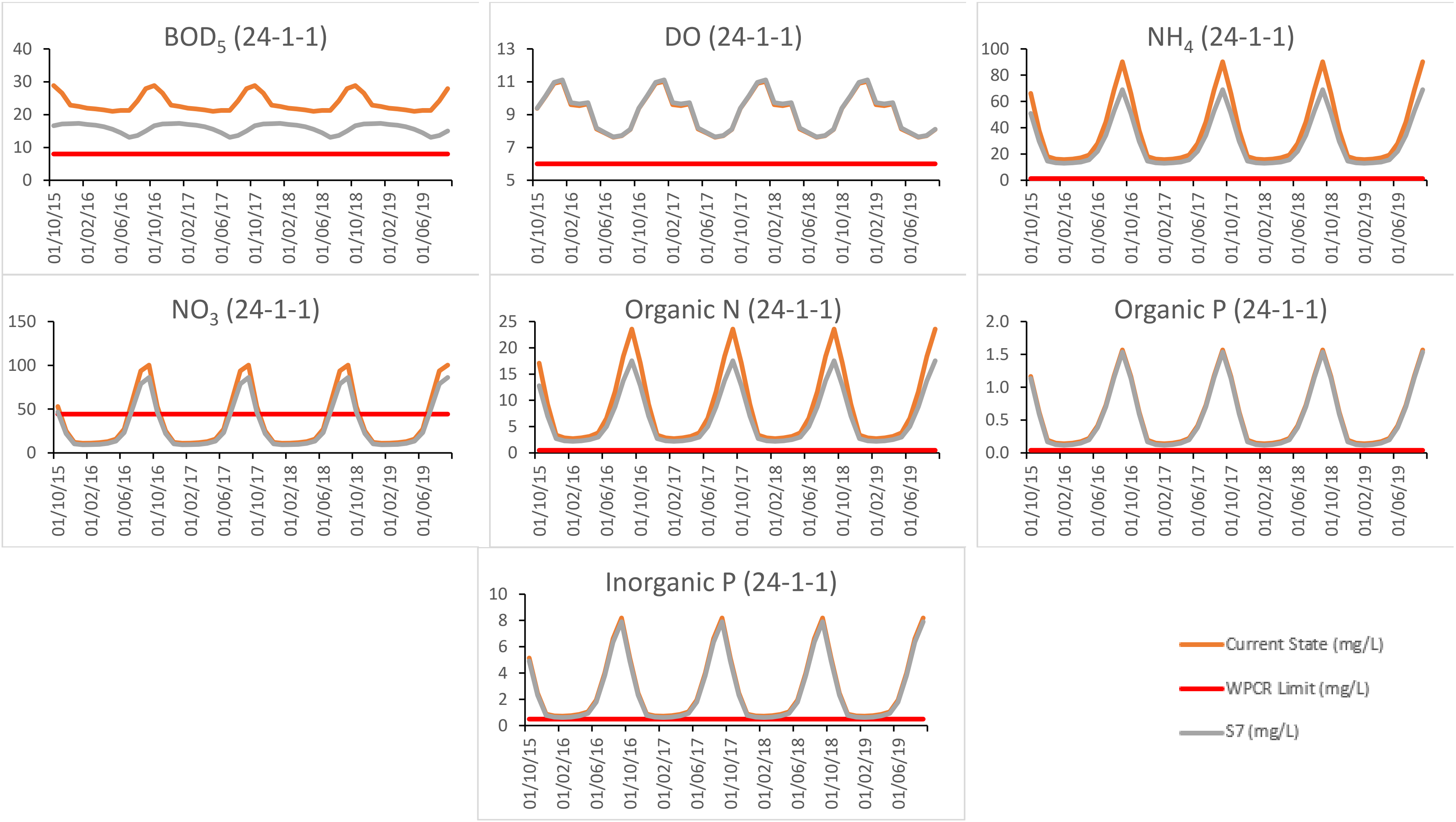

Figure 5.47. Current state and scenario #7 results for BOD$_5$, DO, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at 24-1-1 river reach

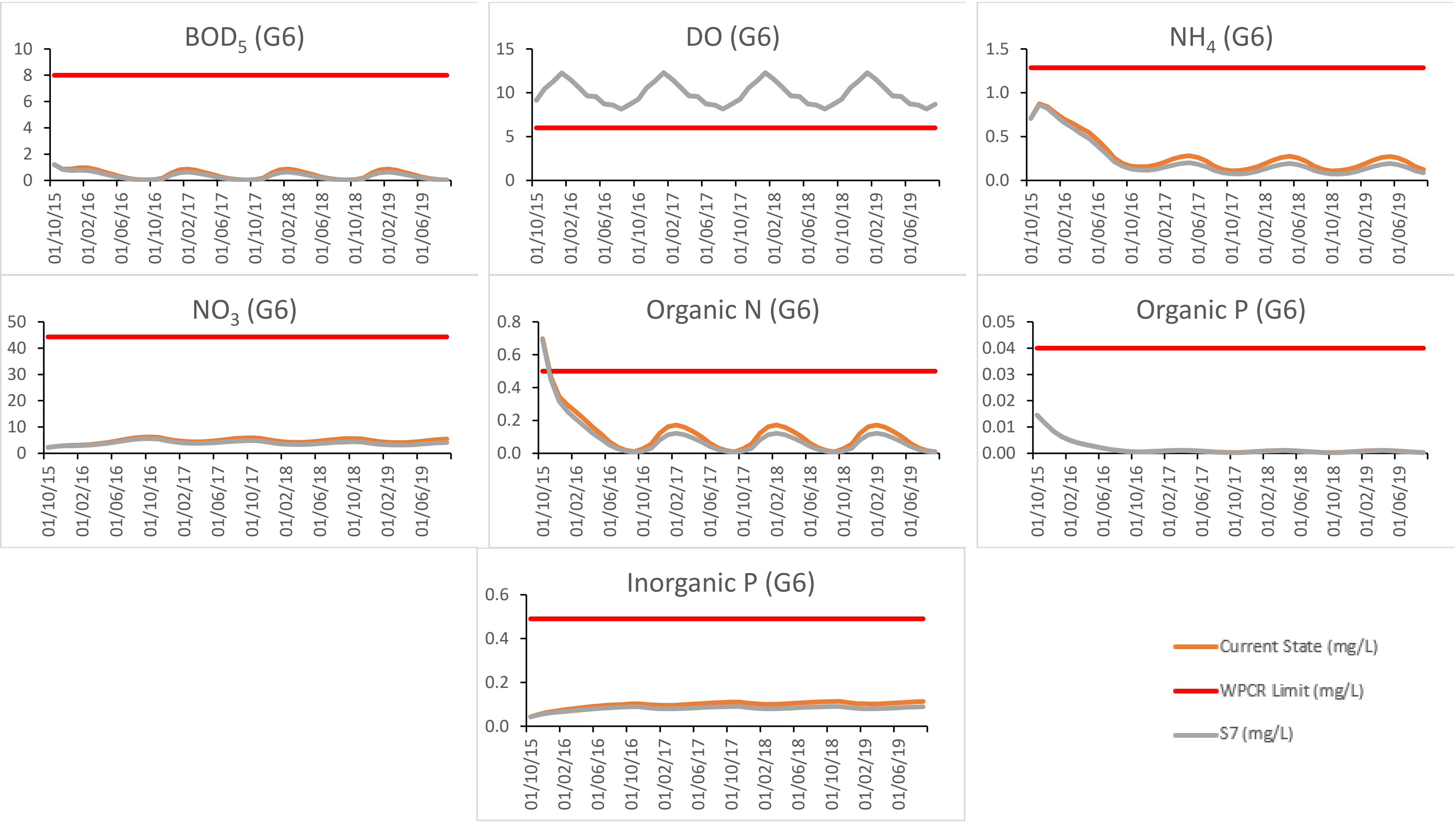

Figure 5.48. Current state and scenario #7 results for BOD$_5$, DO, NH$_4$, NO$_3$, Organic N, Organic P and Inorganic P at G6 lake point

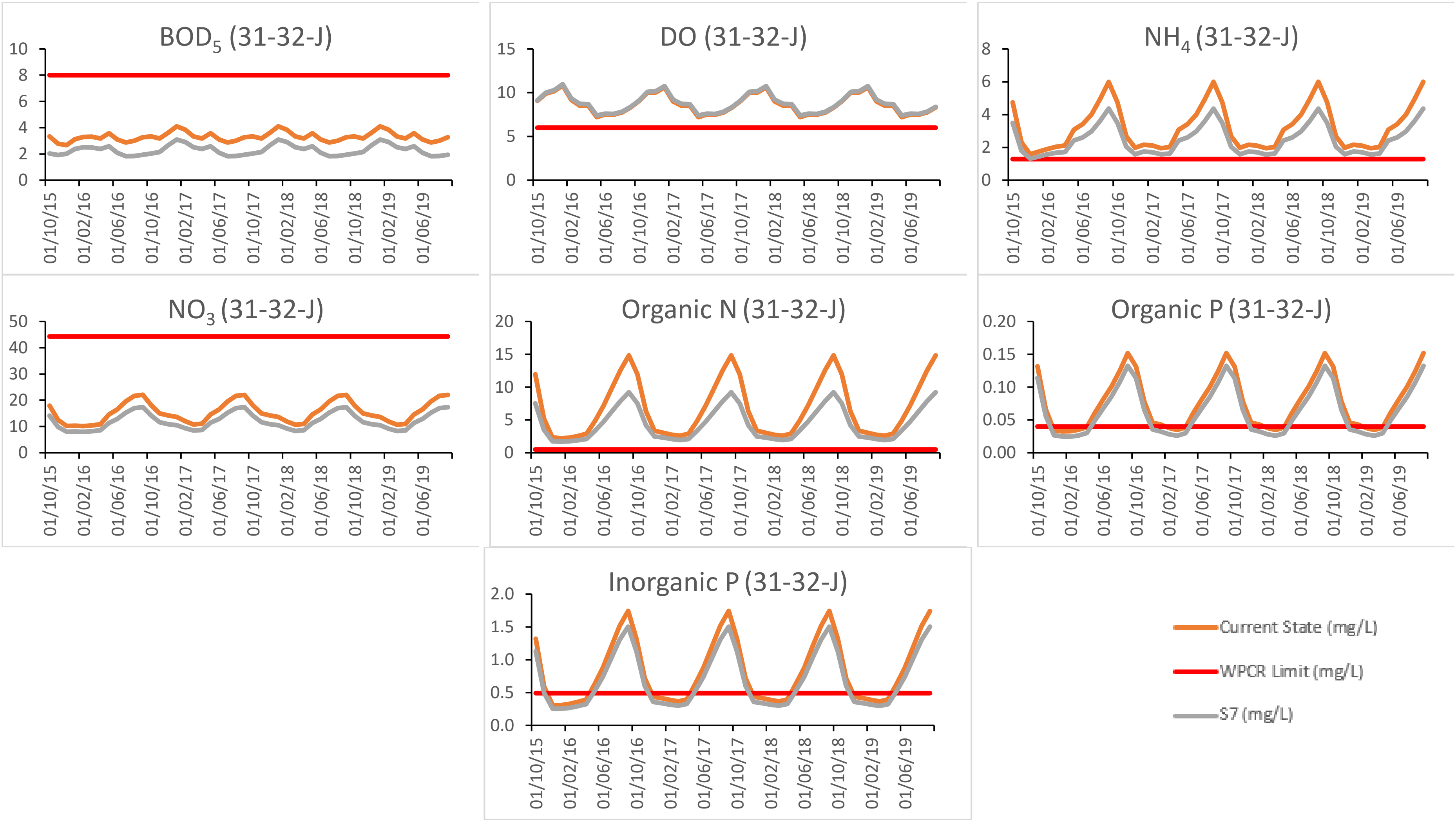

Figure 5.49. Current state and scenario #7 results for BOD_5, DO, NH_4, NO_3, Organic N, Organic P and Inorganic P at 31-32-J river reach

Finally, in order to spatially and seasonally determine the cumulative scenario results applied in the Bakırçay basin, Figure 5.50. I was showing the BOD_5-Dissolved Oxygen relationship, Figure 5.51. showing the Nitrogen fractions together, and Figure 5.52. showing the Phosphorus fractions together for the dry season were prepared.

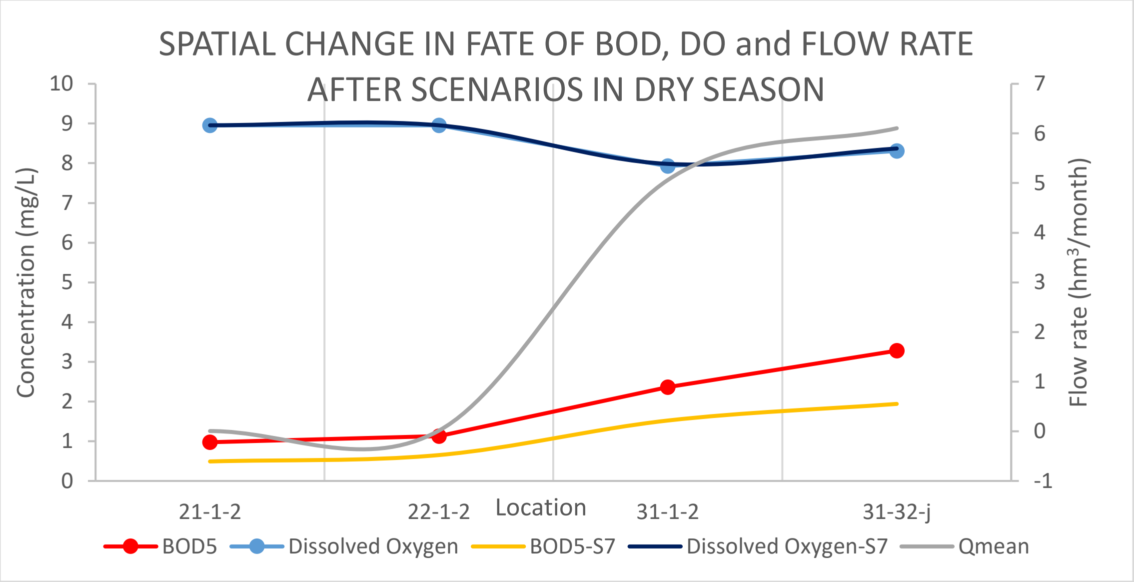

Figure 5.50. Spatial BOD_5-DO results for dry season before and after scenarios

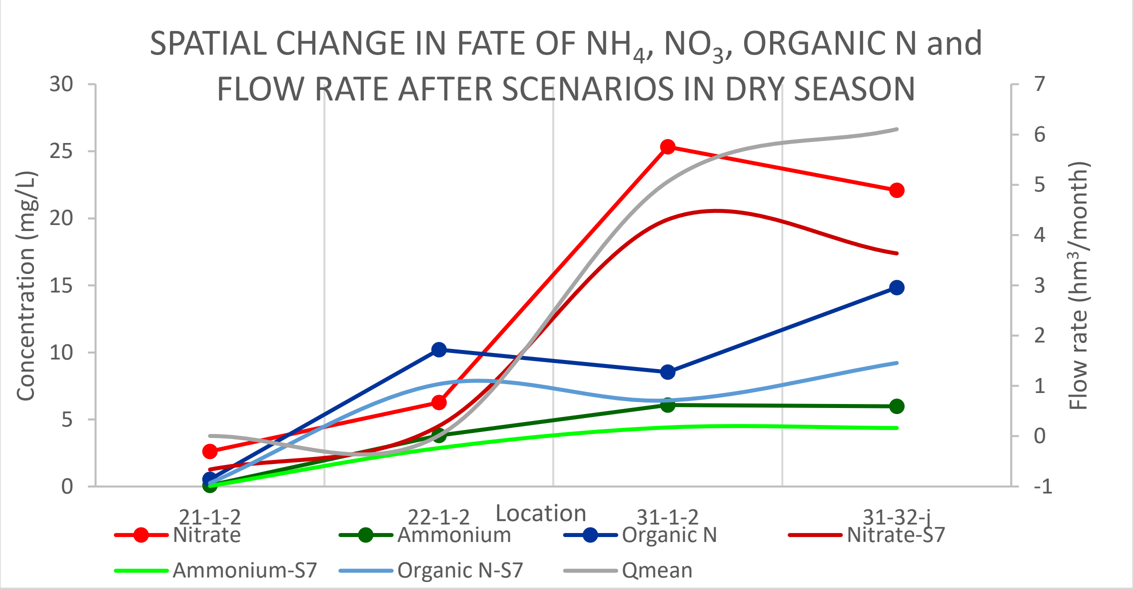

Figure 5.51. Spatial NH_4-NO_3-Organic N results for dry season before and after scenarios

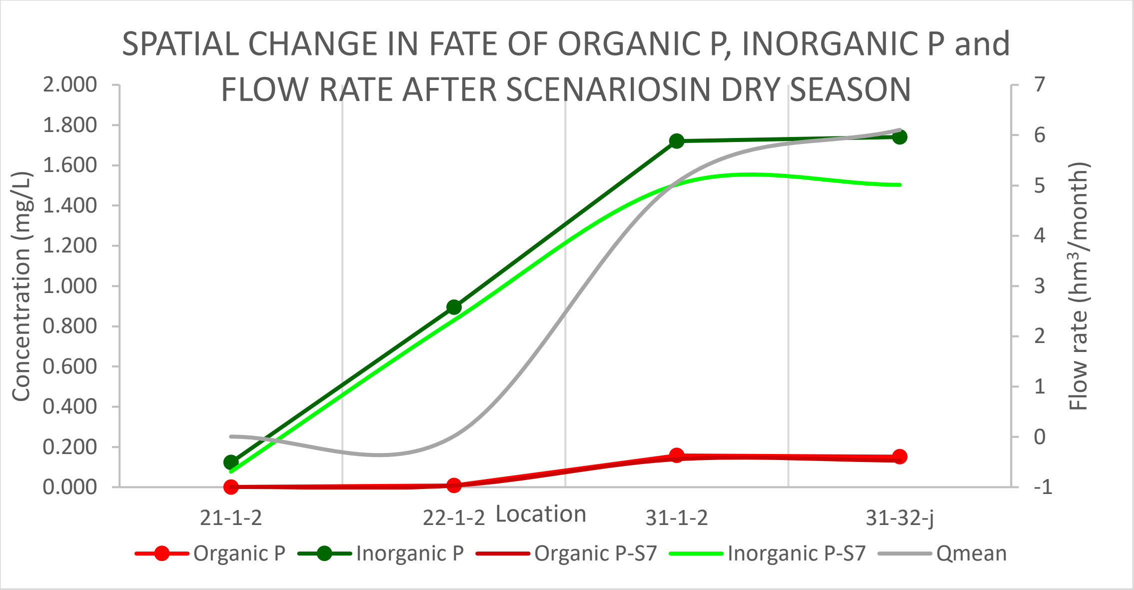

Figure 5.52. Spatial Organic P-Inorganic P results for dry season before and after scenarios

When the spatial results are examined, it is revealed that the increasing trend, especially in NO_3 and Inorganic P, is higher than the other parameters. It is thought that the reason why these two parameters are high is the land use that brings the highest nutrient load to the basin and the intense use of NO_3 and Inorganic P in fertilizer resources. This is proof that the basin is under pressure in terms of these two parameters. Although the improvements resulting from the scenarios applied are striking, it can be seen that the trends have not changed. For this, more structural prevention options should be discussed.

The wet period model-scenario results of BOD_5 and Dissolved Oxygen parameters are given in Figure 5.53. The model-scenario results of Nitrogen fractions are given in Figure 5.54 and model-scenario results Phosphorus fractions are given in Figure 5.55.

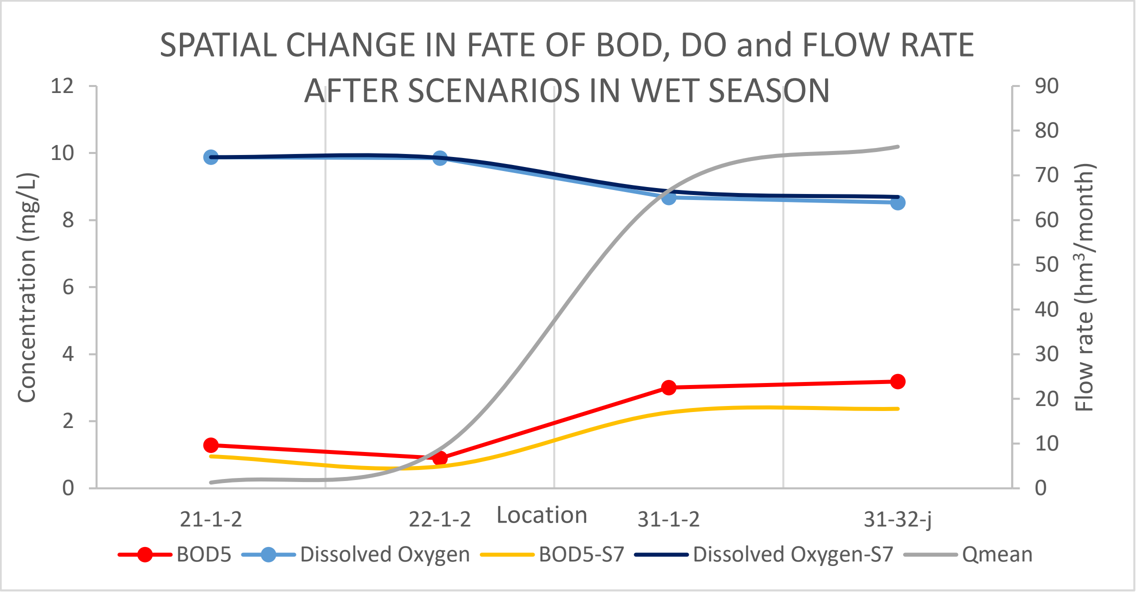

Figure 5.53. Spatial BOD_5-DO results for wet season before and after scenarios

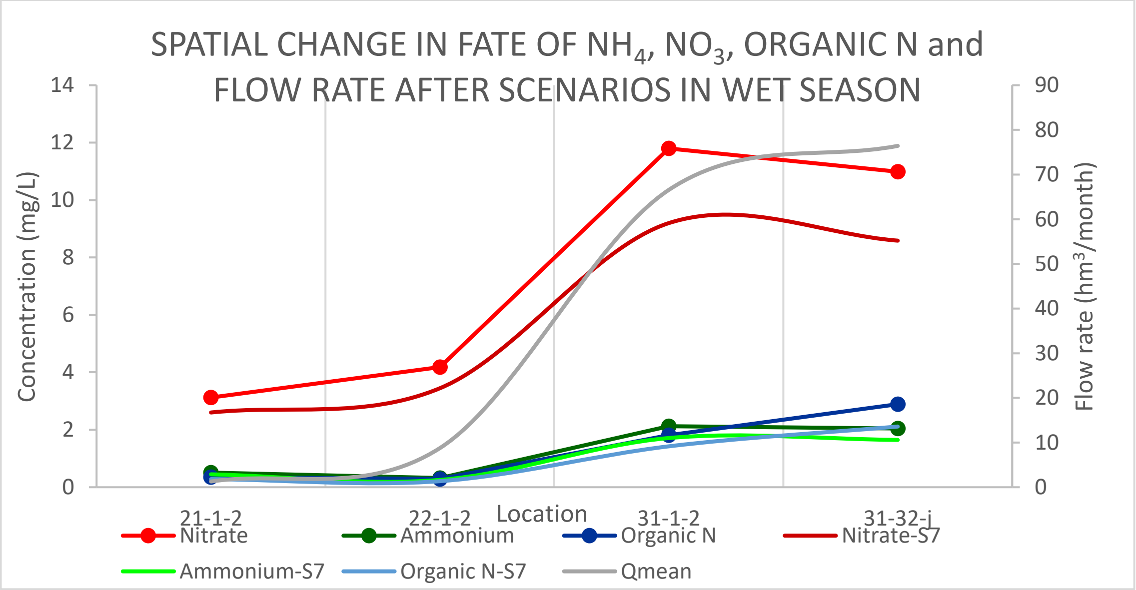

Figure 5.54. Spatial NH_4-NO_3-Organic N results for wet season before and after scenarios

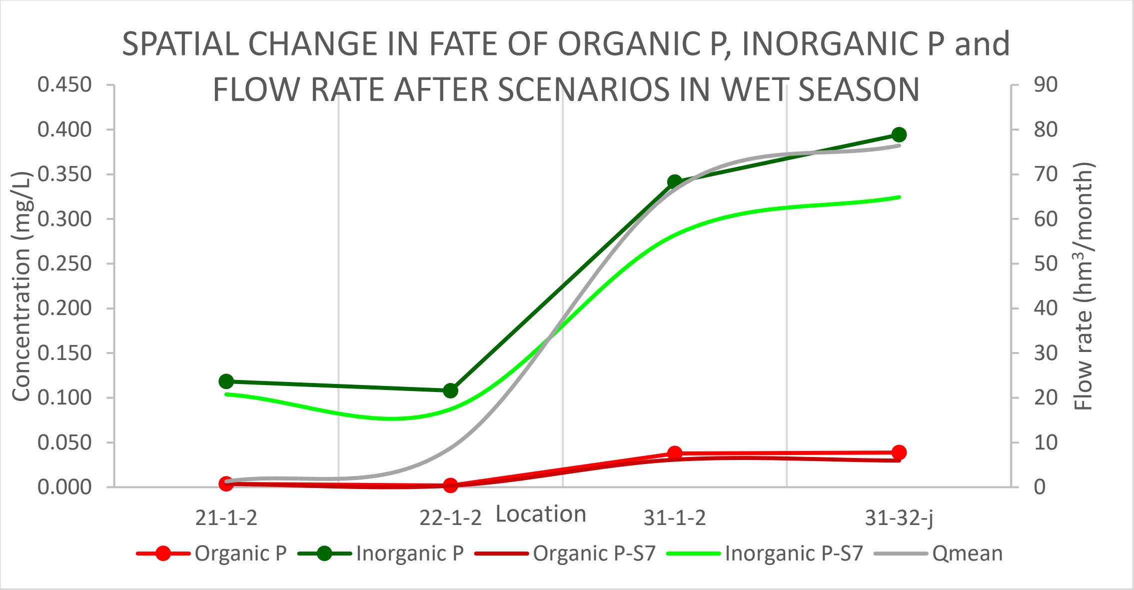

Figure 5.55. Spatial Organic P-Inorganic P results for wet season before and after scenarios

When the wet and dry period results are examined, it can be said that BOD_5 and Dissolved Oxygen parameters are at close levels in all selected locations of the basin. However, the concentrations as a result of removal in the dry period are slightly more successful than in the wet period. It is thought that the reason for this is that the point source pollutant prevention scenarios applied as a result of the decrease of organic pollutants entering the basin widely with streamflow give more successful results.

Let's compare the dry period with the wet period in nitrogen fractions. The removal efficiency is around 20% on average in all 3 fractions in the wet period, while this value is around 35% on average for the dry period. In addition, the removals up to 50% seen in the results of 21-1-2, which is the upstream water body in the dry period, are also proof that the effectiveness of point pollutant prevention scenarios has increased with the decreasing streamflow. Despite the high removal efficiencies observed in the dry period, it is seen that the in-water concentrations are higher than in the wet period, which is thought to be because the point pollutant load coming to the basin creates higher concentration results against the decreasing streamflow.

When the wet and dry period results of the phosphorus fractions are examined, it can be said that the average removal efficiencies obtained in both periods are 17% for both Organic P and Inorganic P. As an important detail at this point, it was determined that the removal efficiencies seen in 21-1-2, which is the upstream water body, in the dry period results were around 40% for both fractions. This indicates that the success of point pollutant prevention scenarios has increased thanks to low stream flows in upstream water bodies, which is also valid for nitrogen and organic pollution

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

In this study, the AQUATOOL model system was run to examine the effectiveness of a set of best management practices (BMP) on 2 rivers and 1 lake sub-basins selected in the Bakırçay River basin, where has an arid and slightly humid climate, is located within the borders of İzmir, Manisa and Balıkesir provinces. The basin is under intense pollutant pressure due to the existence of the Soma industrial zone and the intense agricultural activities, especially within the borders of Manisa province. As a result of the measurements, it has been determined that the water quality is under threat, especially in river water bodies. For this reason, SIMGES, one of the modules of the AQUATOOL model system, was used to model the flow in the basin while the GESCAL module was used to simulate the water quality parameters of BOD_5, Dissolved Oxygen, NH_4, NO_3, Organic N, Organic P, and Inorganic P. Since the measurement results obtained from the flow measurement stations were used as the model stream flow values, the stream flows were not calibrated. Instead, sensitivity analysis and calibration processes for the water quality parameters were performed manually. The reason for the unreasonable statistical method results such as PBIAS up to -1178%, NSE up to -70 and R^2 up to -47 in some parameters is the inadequacy and discontinuity of the quality data, which is also a limitation factor in many water quality studies. Unfortunately, it is challenging to achieve high statistical success in water quality studies with insufficient data and many assumptions. In addition, water quality modeling results are published less frequently than, for example, precipitation-runoff model results due to these insufficient statistical achievements.

The calibrated AQUATOOL model was used to simulate 7 different BMP applications. While the prevention of domestic and industrial point pollution was prioritized in the first 2 scenarios, measures were taken to prevent agricultural and other diffuse pollutants with the nutrient control, terracing, green belt, crop rotation, and vegetative barrier scenarios as of the 3rd scenario. The results were obtained for the sub-basins of Bakırçay River basin, 24-1-1 upstream river water body, G6 lake water body and 31-32-J downstream river water body. The monthly load inputs that will occur as a result of the scenarios were calculated, and the models were run again. The obtained scenario results were compared with the current situation model results of Bakırçay Basin. The results reveal that each BMP scenario provides different removal efficiencies at different parameters and at different locations. However, it is clear that BMP applications do not provide sufficient removals to achieve good water status when applied alone. For this reason, BMP applications have been applied successively and have been evaluated cumulatively last. If evaluated separately, 12.2%, 0.2%, 13.3%, 19.1% and 4.6% rates were obtained for BOD_5, Dissolved Oxygen, NH_4, Organic N and Inorganic P parameters, respectively, with the S1 scenario where anthropogenic pollutant sources are restricted. These ratios are the best removal efficiencies compared to other scenarios. As a difference, NO_3 parameter had the highest removal efficiency with 7.2% thanks to nutrient control (S3), while the highest removal efficiency in the Organic P parameter was found after vegetative barrier application with 3.2%. In addition, the removal efficiencies of up to 50% in nitrogen fractions and 40% in phosphorus fractions, which were revealed in the spatial analysis and especially in the dry period scenario results, are an important indicator that the pollutants can be significantly reduced with point pollutant restriction scenarios in periods when the effect of natural flows is low. These results once again prove that the Bakırçay basin is under the pressure of intense anthropogenic pollution. In addition to these results, the increasing trend towards the end of the basin, especially in the Nitrogen and Phosphorus fractions, has been revealed more clearly, thanks to the graphic created to examine the water quality situation spatially.

This study suggests that all point and diffuse BMPs should be applied to achieve good water quality. However, for the implementation of BMPs in the Bakırçay basin, it would be appropriate to perform a price-performance analysis. Especially scenarios to prevent diffuse pollutants require working in coordination with a large number of farmers and can be very costly. With such studies, different management scenarios specified in the integrated watershed management planning in the European Union Water Framework Directive are implemented and evaluated. Decision-makers can decide which BMP application is economically effective and reduce pollution in the basin. With the 7 different scenarios proposed in this study, the water quality of Bakırçay River has been improved, but long-term pollution monitoring and new scenario trials should be developed according to developing technologies for success in this basin.

6.2. Recommendations

Considering the problems encountered during the study, the biggest problem is that the observation results representing the basin are incomplete and discontinuous. In this context, the number of meteorological and water quality monitoring stations in the basin should be increased to represent the important junction points in the basin, and the measurement process should be done at least once a week, if not every day. In this study, as in other water quality studies, the most challenging part was data discontinuity. Since there were not enough measurements for the warm-up period, calibration and verification processes at the measurement stations used in the model, the only calibration could be performed, and the study had to be carried out assuming that the same river flow and water quality data did not change for 4 years. The results, which can be seen to take about 1 year for the high background levels in the lake water bodies to stabilize, are actually enough to explain the importance of the warming period in the models.

The fertilizer-based nutrient loads calculated within the scope of this study is a calculation method based on the areas of agricultural lands. One of the methods to be followed is to calculate the load according to the types of crops planted on each agricultural land. Also, farmers habits of fertilizer use are important. If there is sufficient data for this, these load values should be updated, and the study should be improved.

Another necessary watershed management study is to simulate the transport of pesticides, heavy metals, and micro-pollutants in water bodies. However, the water quality values that can be used in accordance with the river flow data for these studies should be measured as often as possible with the necessary confidence intervals.

In the Bakırçay basin, it is necessary to open parenthesis for lakes, dams and ponds. Within the scope of this study, 6 lake water bodies modeled with a model that works with a 1-dimensional unmixed storage logic should definitely be developed by operating with mixed lake models. In addition, water withdrawals for humanitarian needs in large river basins such as Bakırçay should definitely be recorded in detail. Especially in the last decades, the waters drawn from underground wells opened unregistered and used are left intentionally to the basin systems as wastewater. This raises the problem that the flow calculations of the models do not match the observations.

6.3. Limitations

The preferred methods in the scope of this study were chosen considering the limitations of the study. Perhaps the most important of these limitations is the absence of flow measurements at water quality measurement stations and the absence of any concentration measurement for pollutant loads. The absence of these data has led to the use of naturalized flows at different measurement stations in terms of flow rates and the use of unit loads in the literature in terms of pollutant concentrations. These assumptions undoubtedly increased the uncertainties in the study. However, these conditions do not constitute an obstacle to the relative evaluation of the pollution prevention scenarios presented in the study.

APPENDIX A

GESCAL MODEL EQUATIONS

Temperature

$$\sum S_i = \phi_{net} = K_{eq}\left(T_{eq} - T\right) \tag{13}$$

Arbitrary constituent

$$\sum S_i = -K(\theta^{T-20})C - \frac{VS}{h}C \tag{14}$$

Biochemical oxygen demand

$$\sum S_i = -K_d\theta_d^{T-20}\frac{O}{O + K_{d1/2}}L - \frac{VS_L}{h}L \tag{15}$$

Organic nitrogen

$$\sum S_i = -K_{Noa}\theta_{noa}^{T-20}N_o - \frac{VS_{No}}{h}N_o + r_{na}K_{resp}\theta_{resp}^{T-20}A \tag{16}$$

Ammonia

$$\sum S_i = +K_{Noa}\theta_{noa}^{T-20}N_o - \left(K_{Nai}\theta_{nai}^{T-20}\frac{O}{O + K_{n1/2}}\right)N_a + -r_{na}F_nK_g'A \tag{17}$$

Nitrates

$$\begin{aligned}\sum S_i = \left(K_{Nai}\theta_{nai}^{T-20}\frac{O}{O + K_{nai1/2}}\right)N_a - \left(K_{No3}\theta_{no3}^{T-20}\frac{O + K_{no31/2}}{O + K_{n031/2}}\right)N_{o3} \\ - r_{na}(1 - F_n)K_g'A\end{aligned} \tag{18}$$

Chlrophylla

$$\sum S_i = +\left[K_g' - K_{resp}\theta_{resp}^{T-20}\right]A - \frac{VS_A}{h}A \tag{19}$$

$$K_g' = K_{gmax}\theta_{resp}^{T-20}F_lF_N \tag{20}$$

$$F_N = Min\left(\frac{N_{aio3}}{N_{aio3} + K_{NF1/2}}; \frac{P}{P + K_{P1/2}}\right) \tag{21}$$

$$FL = \frac{e \cdot f}{K_e \cdot H_1}\left(e^{-I_0\frac{AtI_0}{I_{sat}}e^{-K_eH_1}} - e^{-I_0\frac{AtI_0}{I_{sat}}e^{-K_e\cdot 0}}\right) \tag{22}$$

$$K_e = Ke_0 + \alpha_{at}A \tag{23}$$

Organic phosphorous

$$\sum S_i = -K_{mp}\theta_{mp}^{T-20}P_{or} + f_p r_{pa} K_{resp}\theta_{resp}^{T-20}A - \frac{VS_{or}}{h}P_{or} \tag{24}$$

Soluble reactive phosphorous (Phosphates)

$$\sum S_i = +K_{mp}\theta_{mp}^{T-20}P_{or} - r_{pa}K'_g A + \left(1-f_p\right) r_{pa} K_{resp}\theta_{resp}^{T-20}A \tag{25}$$

Dissolved oxygen

$$\begin{aligned}\sum S_i = {} & +K_a\theta_{Ka}^{T-20}(O_{sat}-O) - K_d\theta_d^{T-20}L \\ & - r_a\left(K_{Nai}\theta_{nai}^{T-20}\frac{O}{O+K_{n\frac{1}{2}}}\right)N_a \\ & + r_{ocrec}\left(K_{gmax}\theta_g^{T-20}F_l Min\left(\frac{N_{aio3}}{N_{aio3}+K_{NF1/2}};\frac{P}{P+K_{P1/2}}\right)\right)A \\ & - r_{oresp}K_{resp}\theta_{resp}^{T-20}A\end{aligned} \tag{26}$$

Where :

α_{at}	Specific extinction coefficient for chlorophyll a (1/mg.m)
θ_{ij}	Temperature correction coefficient;
A	Chlorophyll a concentration (mg/l);
C	Constituent concentration (mg/l);
f	Photoperiod;
F_1	Attenuation light factor;
F_N	Nutrient limit factor;
F_n	Preference factor for ammonia
f_p	Factor for organic phosphorus produced for phytoplankton respiration;
h	Depth of the water body (m);
I	Light intensity (Langleys);
I_0	Surface light intensity (Langleys/day);
I_{sat}	Saturation light intensity;
K	Rate coefficient of arbitrary constituent degradation (1/day);
K_a	Rate coefficient of reaeration (1/day);
K_d	Rate coefficient of CBOD breakdown (1/day);
K_e	Extinction coefficient (1/m);
Ke_0	Background extinction coefficient (1/m);
K_{eq}	Heat interface coefficient (W/m^2.°C);
K'_g	Rate coefficient for phytoplankton growth (1/day);
K_{gmax}	Rate coefficient for maximum phytoplankton growth (1/day);
K_{mp}	Organic phosphorus mineralization parameter (1/day);
$K_{n1/2}$	Semi saturation constant for nitrogen (mg/l);
K_{Nai}	Half saturation for nitrification (1/day);
$K_{NF1/2}$	Half saturation for nitrogen uptake (mg/l);

K_{noa}	Rate coefficient for ammonification (1/day);
K_{no3}	Rate coefficient for denitrification (1/day);
$K_{No31/2}$	Half saturation for the dependence of denitrification on dissolved oxygen (mg/l)
$K_{p1/2}$	Half saturation for phosphorus uptake (mg/l);
K_{resp}	Rate coefficient for phytoplankton death and respiration (1/day);
L	Biochemical oxygen demand (mg/l);
N_a	Ammonium (mg/l);
N_{aio3}	Inorganic concentration (mg/l);
N_o	Organic nitrogen (M/T);
N_{o3}	Nitrate concentration (mg N/l);
P	Concentration of dissolved reactive phosphorus (mg/l);
P_{or}	Concentration of organic phosphorus (mg//l);
O	Dissolved oxygen concentration (mg/l);
O_{sat}	Dissolved oxygen concentration at saturation (mg/l);
r_a	Stoichiometric ratio of oxygen to nitrogen for nitrification (mgO/mgN);
r_{na}	Factor of conversion of nitrogen to chlorophyll a (mgN/mgA);
r_{ocrec}	Rate of oxygen produced for phytoplankton growth (1/day);
r_{oresp}	Rate of oxygen consumed for phytoplankton death and respiration (1/day);
r_{pa}	Factor of conversion of phosphorus to chlorophyll a (mgP/mgA);
T	Temperature of the water body (°C);
T_{eq}	Equilibrium temperature of the water body (°C);
VS	Sedimentation rate (m/day);
VS_A	Sedimentation rate of chlorophyll a (m/day);
VS_L	Sedimentation rate of CBOD (m/day);
VS_{NO}	Sedimentation rate of organic nitrogen (m/day);
VS_{or}	Sedimentation rate of organic phosphorus (m/day)
$WQMs$	Water Quality Models

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