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EXPERIMENTAL APPLICATION OF THE CONCEPT OF "TOTAL MAXIMUM DAILY LOAD" IN THE WATERSHED PLANNING UNDER THE WATER FRAMEWORK DIRECTIVE

AGR/10

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APPLICAZIONE SPERIMENTALE DEL CONCETTO DI "TOTAL MAXIMUM DAILY LOAD" NELLA PIANIFICAZIONE DI BACINI IDROGRAFICI NELL'AMBITO DELLA WATER FRAMEWORK DIRECTIVE

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"Only after the last tree has been cut down,

Only after the last river has been poisoned,

Only after the last fish been caught....

Only then you will find that money cannot be eaten"

Cree Indian Prophecy

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Abstract

The Water Framework Directive 2000/60/CE (WFD) was enacted in order to maintain and improve the aquatic environment of the Union. The protection of waters, in terms of quality and quantity, is one of the key aspects of the Directive, which requires the achievement of "good ecological status" for all water bodies by 2015. In many European countries the process of implementation of the WFD has required important changes in the development of the water management plans.

The River Basin Management Plan was indicated as the process to adopt for investigates the current status of the water bodies and define the "Programme of Measures" that permit to reach the objective of "good ecological status".

This dissertation can be part of the definition process of a "Programme of Measures" for impaired waters through the application of a scientifically based method in order to define the "objective" to achieve, identify the measures to be taken and then evaluate their effectiveness.

The method applied fulfills the requirement of the WFD within the directive to manage both types, punctual and diffuse, of pollution sources causing the deterioration of the ecological status of all European water bodies.

The management of punctual and diffuse sources requires to establish a link between input loads and the water quality standards of the receiving water bodies.

In this dissertation, the use of the concept of the "Total Maximum Daily Load" (TMDL) was applied for an Italian river. The TMDL is an instrument required in the Clean Water Act in U.S.A for the management of water bodies classified impaired. The TMDL calculates the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards. It permits to establish a scientifically-based strategy on the regulation of the emission loads control according to the characteristic of the watershed/basin.

The implementation of the TMDL is a process analogous to the Programmes of Measures required by the WFD, the main difference is the analysis of the linkage between loads of different sources and the water quality of water bodies.

The TMDL calculation was used in this study for the Candelaro River, an intermittent Italian river, classified impaired in the first steps of the implementation of the WFD.

The "Load Duration Curves" methodology was adopted for the calculation of nutrient TMDLs due to the more robust approach than the expression based on average long term flow

conditions. This methodology permits to establish the maximum allowable loads across to the different flow conditions of a river.

This methodology allowed: to evaluate the allowable loading of a water body; to identify the sources and estimate their loads; to estimate the total loading that the water bodies can receives meeting the water quality standards established; to link the effects of point and diffuse sources on the water quality status and finally to individuate the reduction necessary for each type of sources.

The loads reductions were calculated for total nitrogen, total phosphorus and ammonia.

The measures simulated gave results that show a remarkable ability to reduce the pollutants, for the Candelaro River. This reduction, anyway, is not enough to achieve the objective of water suitable for fish life.

The use of a mathematical model on a watershed scale, the Soil and Water Assessment Tool (SWAT), was applied in order to obtain a daily flow dataset of the Candelaro River and a daily water quality for a longer period than the measured data. The use of the model permitted to obtain a robust assessment of the present and future water quality status overcoming the lack of measured data.

The results highlighted the critical condition of water quality particularly during the dry periods and the necessity to adopt specific measures for each flow conditions, not related to the seasonality, to restore the water surface quality status of the Candelaro River.

Riassunto

La Direttiva Quadro Europea sulle Acque (2000/60/CE) (*Water Framework Directive - WFD*) è emanata allo scopo di mantenere e migliorare l'ambiente acquatico del territorio dell'Unione. La protezione delle acque, dal punto di vista qualitativo e quantitativo, riveste uno degli aspetti basilari della Direttiva, che richiede il raggiungimento di un buono stato ecologico di tutti i corpi idrici Europei entro il 2015. Per molti Stati Europei il processo di implementazione della WFD ha richiesto l'attuazione di sostanziali modifiche nella predisposizione dei Piani di Gestione delle Acque. Il Piano di Gestione del Bacino Idrografico è indicato come lo strumento da adottare nel processo di pianificazione, in esso è riportata la valutazione dello stato attuale delle acque ed è definito un "Programma di Misure" che permetterà di raggiungere l'obiettivo di "buono stato ecologico".

Questo studio s'inserisce nell'ambito della definizione di un "Programma di Misure", per un bacino italiano, attraverso l'applicazione di un metodo scientifico che stabilisce gli obiettivi da raggiungere, individua le misure da adottare e ne valuta l'efficacia.

Il metodo sperimentato risponde al principio guida della WFD nell'ambito della gestione integrale delle fonti inquinanti che determinano il deterioramento dello stato ecologico dei corpi idrici dell'Unione. Introducendo la necessità di gestire anche le fonti diffuse, non più solo quelle puntuali, in ciascun bacino idrografico degli Stati membri diviene importante mettere in relazione i carichi derivanti da ciascuna fonte e gli standard di qualità definiti per il corpo idrico recettore.

In questo studio è stato valutato l'utilizzo del concetto di "Total Maximum Daily Load" (TMDL), ovvero carico massimo totale giornaliero, uno strumento richiesto dal Clean Water Act, negli U.S.A, per la gestione dei corpi idrici inquinati. Il concetto base del TMDL è di valutare i carichi totali derivanti, sia dalle fonti diffuse sia da quelli puntuali, che un corpo idrico può ricevere pur mantenendo gli standard di qualità per esso stabiliti. Tale metodo permette di definire una strategia, scientificamente basata, per il controllo delle emissioni dei carichi, in relazione alle caratteristiche del bacino. Il processo di implementazione del TMDL è analogo a quello del Programma di Misure richiesto dalla WFD, la sostanziale differenza si riscontra nel processo di analisi che mette in relazione i carichi derivanti dalle diverse fonti inquinanti e la qualità dei corpi idrici. In questo studio è stato utilizzato il calcolo del TMDL per il Candelaro, un fiume intermittente Italiano, classificato altamente inquinato durante i primi processi di attuazione della WFD. Per il calcolo del TMDL di nutrienti è stata adottata

la metodologia della “Curva di Carico” che permette di definire un carico massimo accettabile in relazione alle diverse condizioni di portata di un fiume, un fattore di particole rilievo nel caso di fiumi intermittenti che mostrano notevoli variazioni di portata durante l’anno.

L’utilizzo della metodologia del TMDL ha consentito di: di identificare le fonti inquinanti e stimare i carichi da esse derivanti; di valutare il carico totale inquinante ammissibile che il corpo idrico può ricevere in base alla destinazione finale assegnata; di individuare quali sono gli effetti che ciascun tipo di fonte ha sulla qualità del corpo idrico e infine di individuare e calcolare le riduzioni necessarie per ciascun tipo di fonte inquinante al fine di raggiungere l’obiettivo stabilito.

I risultati hanno mostrato una notevole capacità di riduzione degli inquinanti ma l’inefficacia a raggiungere uno stato delle acque idonee alla vita dei pesci.

Un modello matematico a scala di bacino, Soil and Water Assessment Tool (SWAT), è stato utilizzato per ottenere una serie di dati giornalieri di portata e di qualità delle acque per un periodo più lungo di quello dei dati misurati disponibili. L’utilizzo del modello ha permesso di effettuare una valutazione più rappresentativa dello stato attuale e futuro del corpo idrico caratterizzato da una assenza o scarsità di dati misurati. I risultati hanno rilevato le condizioni critiche dello stato qualitativo delle acque particolarmente durante i periodi secchi e la necessità di adottare misure diverse in relazioni alle condizioni di portata e non di stagionalità per migliorare lo stato qualitativo delle acque del Candelaro.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

CHAPTER 1 - INTRODUCTION

1.1 GENERAL INTRODUCTION

The fundamental change in the European water policy started on 2000 with the establishment of a legal framework for community action in the field of water management across Europe. The official title of this new water policy is Water Framework Directive 2000/60/CE (WFD); it points out the importance of water protection for the future in all the European States. The goal of the Directive is to achieve a "good status" for all surface waters and groundwater by 2015. The challenges introduced by WFD in the water management require adopting new strategies for all European States.

The introduction of a holistic vision requires to manage all type of sources, punctual and diffuse sources that are responsible of the deterioration or "bad" water quality status. The previously system based on emission control, effluent quality control and nutrient load regulation, was not linked to the water quality status of surface water bodies.

The WFD requires to assess the current status of water bodies, to indentify the objective (e.g. "good ecological status") and the pressures, and finally to establish a "Programme of Measures" that will improve or permit to reach the ecological objective defined for the specific destination of the water body.

In the process of implementation of the WFD, that in many European country is still now in progress, member states had to present the management plans for their river basins by the end of 2009. These plans have to specify the measures to adopt for achieve "good status" (Article 13 and Annex VII of the Directive).

The assessment of current status is a preliminary step before to develop a River Basin Management Plan (RBMP), the evaluation of gaps with the objective of Directive permit to specify the measures to be implemented. The assessment of the actual status of all the water bodies often was conducted using calculation that not permitted to evaluate all the hydrologic aspects. The Directive outlines also the importance of understand the effect of changing pressures, including seasonal, on that status to define programmes that permit really to reach the objective. The Programme of Measures was indicated in many draft of the RBMPs without evaluate the effectiveness of the implementation on the water quality status in the future.

The objective of this dissertation is to apply a methodology, for the first time in Italy and in Europe, as supporting method to develop the Programme of Measures a methodology applied from many years in the U.S.A.

The U.S., within the federal water legislation, Clean Water Act (CWA) adopts a similar approach similar to the European to reduce water pollution but a different method to establish the measures. The method indicated in the CWA, to manage the pressures in the watershed, is the "Total Maximum Daily Load" (TMDL) that establishes the loads that a water body can receive and maintain the water quality standards established.

The overall objective of this dissertation is to study, test and apply the TMDL calculation for an Italian intermittent river as a supporting method for the application of the WFD.

This work will be a part of a European project of the Seventh Framework Programme on environment with the title "MIRAGE - Mediterranean Intermittent River ManAGEment", (see www.mirage-project.eu), aimed to support the development of the RBMP for one of the mirror basins adopted in the project: the Candelaro River. The MIRAGE project aims to provide specific key knowledge for a better assessment of ecological integrity in Mediterranean temporary streams. Within the framework of the project there is the development of practical measures necessary to understand their impact on nutrient dynamics, toxic substances and organic matter and to link these aspects to an integrated flood management. The goal of the project is to co-develop a River Basin Management Plan to support the applicability of the WFD for temporary river. The scientists involved in the project highlighted that an adequate implementation of the WFD and the development of RBMP, including the Programme of Measures for temporary streams, urgently require new concepts of hydrological and ecological characterization, as well as a revised and better integrated understanding of the impact of management measures, both under extreme floods and in the context of seasonal dry periods.

This dissertation will help to assess the current status of the Candelaro River to individuate the critical condition and to assess the main pressures during the different flow conditions. The TMDL is a different approach that can help to individuate the measures and it is a helpful method to asses in the future the progress in the implementation of the measures established. Without adequate characterizations of the problems appropriate solutions for the restoration plans cannot be identified and implemented.

The application of mathematical model, to assist policy, is proved, in many studies, that are useful tool to assist in the understanding of hydrological, chemical transport and processes that occur in watersheds, to understand the response to anthropogenic alterations that affect them and also to evaluate the effect of scenarios. In this study the watershed loading/water quality model, Soil and Water assessment Tool (SWAT) (Arnold et al., 1998) was used to investigate the hydrologic processes, to assess the actual water quality status of Candelaro River and finally to quantify the efficiency of some measures individuate in the Program of Measures developed by the River Basin Authority of Apulia Region, defined without any evaluation of their effectiveness to reach the objectives.

The design standards and the driving legislative frameworks in Europe, Italy and the United States were compared; similarities and differences between the policies were outlined. The protocol to develop the WFD and the transposition into Italian law were described, a detailed implementation process was described only for the Candelaro River Basin due to the differences that can be found among the RBMPs developed in Italy and in Europe.

The protocol to develop a nutrient TMDLs, indicated in the guidance of USEPA for impaired waters in USA, was described. The different TMDL's methodologies used in US to calculate Nutrients were investigated in order to choose the more adequate to apply for the Candelaro River.

Using the TMDLs calculation, for total nitrogen, total phosphorus and ammonia, was possible to analyze the target of the problems, allocate the processes among the sources and finally to calculate the reduction needed for each nutrient. The "Load Duration Curves" methodology was adopted for the calculation of nutrient TMDLs due to the more robust approach than the expression based on average long term flow conditions. This methodology permits to establish the maximum allowable loads across to the different flow conditions of a river; this is particularly relevant for intermittent river. It provides also a visual display for people to better understand: the problem; the TMDL targets; frequency and magnitude of the water quality standards; the allowable loads of each nutrients and the magnitude of loading reduction. The load duration curve is very useful to understand and differentiate the problems between non point sources and point sources.

CHAPTER 2 - WATER POLLUTION LAWS

2.1 EUROPEAN WATER FRAMEWORK DIRECTIVE

The environmental policy concerning water preservation is well established with the EU Water Framework Directive 2000/60/EC (OJ L 327).

The key objective of the Directive is to achieve “good water status” for all European waters by 2015. The intent of WFD is to redesign the overall normative outlines concerning the protection of all water, both above and below ground.

The European water policy began in the 1970s with the adoption of the first directives which focused on water quality objectives.

There was a second wave of European directives in the early 1990s, with several directives (thirteen) based on the emission limit value approach. Several major directives were adopted at that time, including those on urban waste water treatment and on nitrates. However, at the end of the century, European regulations were relatively fragmented and did not provide a clear vision of European water policy. The WFD was prepared with the goal of ensuring the overall consistency of European water policy on the basis of a common objective of “good status”.

The WFD contains the following key points:

– The WFD concerns all the waters in Europe and aims at preventing further deterioration, at protecting and enhancing the status of aquatic ecosystems.

– There is a general objective to attain “good status” for all waters by 2015. This implies characterizing the chemical and ecological status of all waters, the development of measures (including legislation based on a combined approach of emission limit values and quality standards) and management plans to attain this good status.

Innovations in water policy with WFD

The WFD puts water bodies at the center of water policy, rather than water uses or functions. This change in focus can be regarded as a “green” revolution.

Another revolutionary idea reported in the WFD is the attention on all types of waters, not only river and lakes, but also ground water and estuarial and coastal waters.
The Integrated River Basin Management requires a number of changes in comparison with previous water management, namely considering the whole territory of the river basin instead of the lines of the rivers in the landscape. The area of interest of the administration shifts from the territory of the State or of a Region towards the consideration of bioregional catchments areas, one of the effects is the transboundary administration of river basin.
In the past some States only considered chemical parameters to assess water quality, others simply biological parameters and nobody considered morphology. The quality criteria are now based simultaneously on the biology, chemistry, morphology and the flow characteristics of water.
The integration of water quantity and water quality in one single management system is a challenge for many EU countries. Traditionally there were different sectors of the public administration system for the water quality protection and for water quantity management.
The new holistic vision also includes the management of punctual and diffuse sources that are responsible of the deterioration or bad water quality status.
In the past, and in some countries today, the role of water managers was to build the infrastructure systems necessary to protect humans from water or deliver water to the humans, or to collect water for irrigation demand of water supply, generally through pipes or canals. As they were required to fulfill society's needs through engineering works, water managers regarded the protection of ecosystems as an obstacle to their objectives. The WFD requires an integrated approach to watershed management more focused on environmental protection.
Another innovation is the economics arguments; the WFD requires the selection of measures based on economic analysis. It's the first time that an environmental Directive has an impact on the decision making in public finance, normally the public finance was considered very important at political level while environmental had to accept the consequences of the decisions.
Public Participation plays a key role in the implementation of the WFD. During the decision process all stakeholders are invited to contribute actively to the planning process by discussing issues and contributing to the solution.

Implementation guidelines

Member States are obliged to identify their national and international river basins and assign these to so called “River Basin districts”. For all districts, six-yearly River Basin Management Plans (RBMP) and programs have to be developed.

River basin planning is the process of collecting and analyzing river basin data and evaluating management measures in order to achieve the objectives of the WFD within prescribed timescales.

The river basin planning process is followed by implementation of Programme of Measures for the achievement of “good status” and is subject to public consultation, according to the requirement of social participation and transparency during the individuation of measures.

The planning process together with the implementation of the Program of Measures is often referred to as River Basin Management.

According to the Directive, the general approach for water planning contains the following main components:

- Setting the scene (identification of River Basin District).
- Assessment of the current status and analyze preliminary gaps (identification of pressures and assessment of their impacts).
- Setting up of the environmental objectives.
- Establishment of monitoring programs.
- Gap analysis (comparison of the current status with environmental objectives).
- Setting up of the Programmes of Measures (POMs).
- Development of River Basin Management Plans.
- Implementation of the Programmes of Measures and prepare the interim report on the implementation.
- Evaluation the first and the second period.
- Information and consultation of the public, active involvement of interested parties.

The planning process is not a linear process; all the components are involved in a non-linear iterative way (CIS, 2003).

Assessment of current status

In the Annex V of WFD all the elements that permit to classify the surface and groundwater status are reported.

The definition of “good status” for surface water results from a set of criteria concerning the biological and the physico-chemical status specified with their monitoring approaches and threshold values by the Member States.

The status of each surface water body is judged using separate ‘Ecological classification’ and ‘Chemical classification’ systems. The overall status of the water body will be determined by whichever of these is the poorer. To achieve ‘good status’ overall, a water body must achieve both good ecological and good chemical status.

Ecological classification

The Ecological classification system has five classes, from high to “bad”, and uses biological, physico-chemical, hydromorphological and chemical assessments of status.

Biological assessment uses numeric measures of communities of plants and animals (e.g. fish and rooted plants). Physico-chemical assessment considers elements such as temperature and the level of nutrients, expressed in concentration limit value corresponding to the Emission limit value. The hydromorphological assessment looks at water flow and physical habitat.

The Directive only gives definitions for three classes for these quality elements (high, good and moderate status).

Chemical classification for priority substances and other pollutants

The WFD report only two classes, ‘good’ or ‘failing to achieve good’, for the chemical classification for surface waters, that have to be used for the most polluting substances (mercury, cadmium, hexachlorocyclohexane and dangerous substances). The water has to meet *Environmental Quality Standards* (EQSs) for substances listed in Annex IX (Dangerous Substances Directive and associated daughter directives) and Annex X (WFD Priority List Substances). These standards are set on a European-wide basis and are considered a priority because of their high potential for pollution.

Figure 1 provides an example of how to classify the surface waters status derived from the monitoring activities.

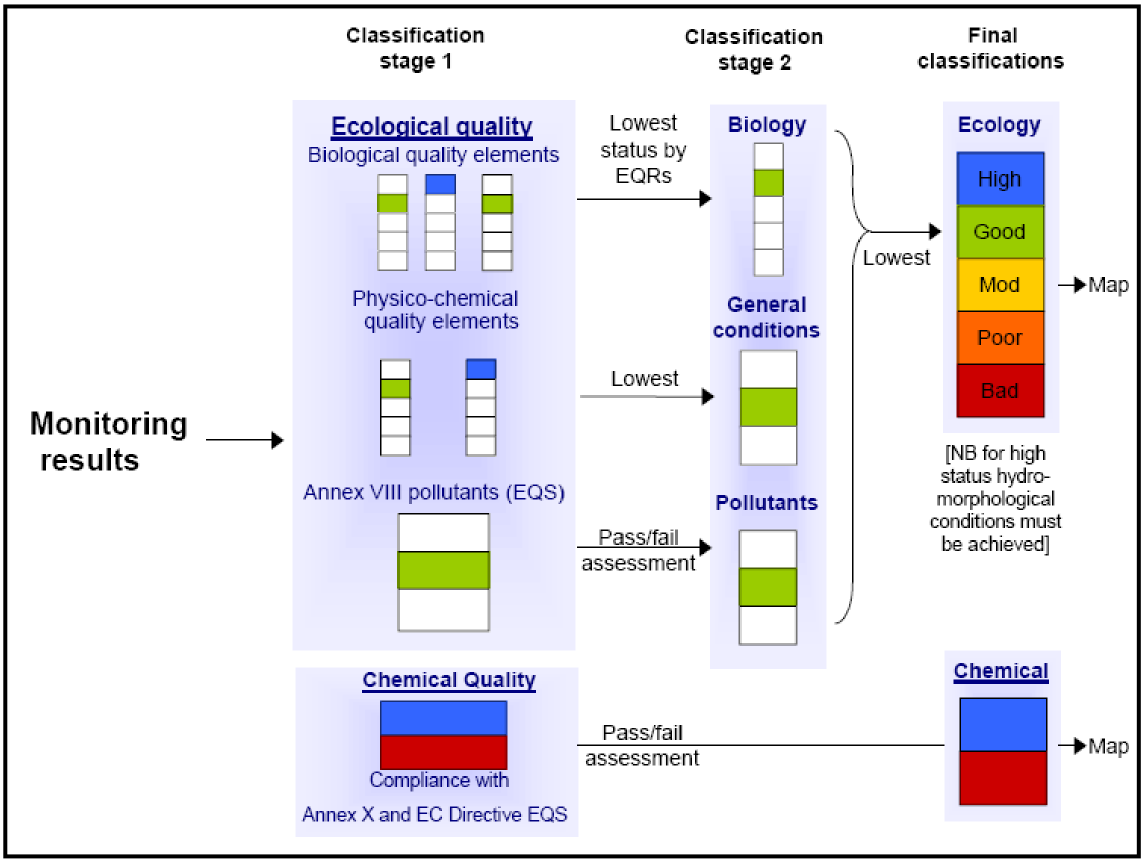


Figure 1: Classification of surface water bodies.

Groundwater classification uses two systems: 'Groundwater quantitative' status, which assesses whether there is sufficient water to maintain the health of the ecosystems it feeds, and 'Groundwater chemical status', which assesses the chemical quality against certain criteria. The Groundwater Daughter Directive details the criteria for chemical status.

The WFD looks at the way groundwater and surface waters interact, so groundwater body cannot be at good status if it causes an associated surface water body to fail its ecological or chemical status objective, or causes significant damage to a groundwater dependant wetland ecosystem. As with surface waters each groundwater body has to be classified.

On the basis of the assessed status, two classes can be defined: good and poor.

Quantitative and chemical status must be good before classifying the groundwater body as good.

Environmental quality standards

Environmental Quality Standards (EQSs) are the values for water quality, water quantity and habitat structure defined to ensure that the right environmental conditions are created to support the biology. The standards will relate to and define the class boundaries for ecological and chemical classification schemes, and helps to decide what measures need to be taken to protect the water environment. For example, water quality standards define the quantity of a pollutant that can safely be present in the water environment without causing harm to the ecology.

This approach is used also for protecting the water environment from pollution and for licensing water abstraction. To implement the WFD, the environmental standards have to be identified and then used to protect the ecology from other pressures, such as over-abstraction and damaging engineering works.

Surface water chemical environmental standards for use in the Chemical classification are the EQSs in existing EU legislation such as the Dangerous Substances Directive, and the new Priority Substances and Priority Hazardous Substances. These standards are being agreed at EU level for a Priority Substances Daughter Directive.

Programme of Measures

According to the water planning, after the assessment of current status of water bodies the settlement of Programme of Measures (POMs) (Article 11 WFD) has to be defined.

The analysis of pressures (e.g. an inventory of significant point and diffuse sources) and impacts (e.g. an assessment of exceedance of national or international environmental quality standards) for priority substances and pollutants is important for the preparation of the programme of measures.

The Program of Measures consist of defining, for each district, the regulatory provisions or basic measures to be implemented in order to achieve the objectives defined for 2015 by the Management Plan in accordance with Community and/or national laws (e.g. extension of sensitive or vulnerable areas, reporting and authorization system, definition of resource protection areas, discharge control etc.). The Directive provides a list of measures that could be included within the POMs, the same required under different previously directives, and provide also a non-exclusive list of measures, which are aimed at either reinforcing the previous provisions or setting up new provisions such as: good practices codes, voluntary agreements, economic and tax instruments etc.

Basic measures include the so-called combined approach (Article 10). This means that water policy should be based on controlling pollution at source through setting emission limit values and environmental quality standards. The effluent limits established for urban or industrial discharge do not take the receiving environment condition and/or dilution ratios into account for derivation of the limits. For point source discharges liable to cause pollution, basic measures can be a requirement for prior regulation (e.g. a prohibition on the entry of pollutants) or a requirement of authorization or registration laying down emission controls for the pollutants concerned.

For diffuse sources liable to cause pollution, basic measures are to prevent or control the input of pollutants or prior regulation, authorization or registration in a similar way to point source discharges. One of the previously directives enhanced in order to control the pollution arising from agricultural activities is the Nitrates Directive (Directive 91/676/EEC) aimed at reducing and preventing water pollution from agricultural sources through a number of steps which shall be fulfilled by Member States: water monitoring with regard to nitrate concentration and eutrophic status, designation of nitrate vulnerable zones and establishment of action programmes and codes of good agricultural practice.

The use of economic instruments is part of the basic measures. The principle of recovery of the costs of water services, including environmental and resource costs associated with damage or negative impact on the aquatic environment should be taken into account in accordance with, in particular, the polluter-pays principle. An economic analysis of water services, based on long-term forecast of supply and demand for water in the river basin district is also necessary for this purpose.

2.2 WFD IMPLEMENTATION IN ITALY

The complete transposition of WFD into Italian law was brought into force in 2006, three years after the deadline defined by the Directive.

The Legislative Decree (L.D.) n. 152, “Norms concerning the Environment” (G.U n.88 14 April 2006) provides rules for the environmental management. The third part of this decree regards the water issues complying with the WFD. All of the previously Italian laws about water resources management are incorporated in the decree n.152/2006. Until the end of

2009, other decrees were originated to review and correct the third part of L.D. 152/2006 and to fulfill the transposition of the WFD into the Italian national legislation.
According to the WFD, 8 Italian River Basin Districts were identified. The River Basin Management Plan of each river basin district was produced by December 2009, according to the Art.13 of WFD.

The RBMPs cover the following main elements:

- Characteristics of river basin districts, analysis of human pressures on the status of waters.
- Environmental objectives established for all surface waters.
- Identification of protected areas.
- Economic analysis of water use.
- List of programmes of measures that have to be adopted to achieve the objectives.

The instruments adopted to develop a draft of the RBMPs are: the "Water Protection Plan" (PTA) and the "Hydrographic District Management Plan" (PGBI) according to the Italian Decree n.152/2006.
The PTA is a regional document, it reports the information that permits to characterize the river basin district territory, to evaluate the human pressures on water quality and quantity, to define the objective of all waters and finally to individuate the measures that have to be adopted.
The analysis of pressures and impact of human activities on water was done so by estimating the following:

- Point sources loads (tons/year or tons/month).
- Diffuse source loads deriving from land uses.
- The pressures on water quantity.

The identification of reference condition, required by WFD to assess the environmental objective, is difficult for many Italian water bodies due to the presence of a lot of hydromodifications and human pressures on water quality status.
The Italian law defines the quality objectives according to the designated uses of surface waters (drinking water, water suitable for fish life, bathing waters, etc). Each pollutant has a maximum allowable concentration that can vary among the surface waters with different designated use of waters.

The monitoring activities began in 2000, according to previously Italian Laws on water quality protection, permitted to assess the surface waters and groundwaters quality status.
A list of measures for river basins classified as “bad” or “poor” must be adopted for each basin according to the WFD.
The process of corrections and reviewing of decree 152/2006 is still going on and is producing a number of new decrees, also taking into account new European directives on water policies.

2.3 WATER LEGISLATION IN USA

United States has a major and lengthy history of federal water legislation which dates back to Nineteenth century.
The Clean Water Act (CWA), passed in 1972, is the primary federal regulation for protecting water bodies in the United States. The most fundamental goal of CWA is to achieve a level of water quality which provides for the protection and propagation of fish and wildlife and for recreation in and on the water (Gallagher, 2003).
The main objective of the CWA is to restore and maintain chemical, physical, and biological integrity of the United States’ waters. The objectives and the goal of CWA are the same reported in the WFD.
CWA is extremely comprehensive, covering everything from water quality standards, antidegradation, water body monitoring, and assessments to pollution discharge permitting programs, point sources and non point sources funding, and provisions for citizen lawsuits.
The control of point sources in the U.S. is regulated by a program called National Pollutant Discharge Elimination System (NPDES) in which discharges of pollutants from a point source is allowable only if the discharger has a NPDES permit.
The NPDES permit sets numerical concentration limit for a specified pollutant and requires monitoring activities on discharges into waters with relative report that have to be submitted to permitting authority.
Effluent limits specified in the NPDES permit consider both the technology available to treat the effluent (e.g. technology-based effluent limits) and protection of designated uses of the receiving water (water quality-based effluent limits). Effluent limits are specified in the NPDES permit to ensure that receiving water discharges do not exceed the State Water Quality Standards (WQS) criteria.

The CWA does not enforce the non point source control through regulatory means rather through volunteer implementation. A revision of the statue on 1987 created provision for the states to identify measures to reduce non point source contribution, develop a management plan for implementing actions to maintain and attain water quality standards, and identify the best management practices (BMP) that will address nonpoint source pollution.
The strategy adopted in U.S. for the management of surface water quality is the Water Quality Standards.

The three main elements of water quality standard are:

1. Include provisions for restoring and maintaining the chemical, physical and biological integrity of State waters.
2. Provide, wherever attainable, water quality for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water (fishable/swimmable).
3. Consider the use and value of State waters for public water supplies, propagation of fish and wildlife, recreation, agriculture, industrial purposes and navigation.

The WQS are composed of three key parts:

1. The first part of the WQS involves use designations for water bodies based on an assessment of beneficial uses of those water bodies. The CWA describes various “desirable” uses for water bodies that should be protected, including public water supply, recreation and propagation of fish and wildlife. More specific uses (e.g., cold water aquatic life, agricultural and other sub-classifications) or uses not indicated in the CWA may be designated according to State values, as long as they support the defined “fishable/ swimmable” goals.
2. The second part of the WQS includes numerical and/or narrative water quality criteria sufficient to protect each of the designated uses assigned to the specific receiving water body. Numerical criteria define the magnitude (the allowable concentration of a specific parameter), duration (the period of time over which the in-stream concentration is averaged for comparison with criteria concentrations) and frequency (how often criteria may be exceeded) for each of up to 126 priority parameters as summarized in the US EPA Gold Book.
3. States may establish numerical criteria using EPA guidance (e.g., US EPA, 1991) modified to reflect site-specific conditions or other scientifically defensible methods,

or use EPA derived limits. The WQS numerical water quality criteria may be values expressed as levels (e.g. pH), constituent concentrations or mass loadings (e.g. metals, organic compounds), toxicity units (e.g. whole effluent toxicity) or numbers deemed necessary to protect designated uses (e.g. biological indices). The EPAs criteria for the protection of aquatic life addresses both short-term (acute) and long-term (chronic) effects on both freshwater and saltwater species. Human health criteria are designed to protect people from exposure resulting from consumption of water or fish/shellfish.

The WQS narrative criteria may supplement numerical criteria or provide the basis for limiting discharge of specific parameters where the State has no numerical criteria.

The third part of the WQS includes adoption of an antidegradation policy that includes the methods used to implement the policy.

After the implementation of the directives of CWA, there is, however, some water bodies that do not meet water quality standards, these water bodies are listed in section 303 of CWA and a formulation of Total Maximum Daily Load (TMDL) is required. A TMDL allocates pollution control responsibilities among pollution sources in a watershed, and is the basis for taking the actions needed to restore a water body.

2.4 WHAT IS A TOTAL MAXIMUM DAILY LOAD (TMDL)?

The TMDL is a tool for implementing water quality standards (designated uses, numeric and narrative criteria and antidegradation requirements) under the Clean Water Act and is based on the relationship of pollution sources and in stream and lake water quality condition. It is the summation of waste load allocations (WLA) for point sources and load allocations (LA) for nonpoint sources included natural background conditions.

The TMDL process takes a holistic view of identifying pollutants, calculating load reductions, and formulating an action plan for both point sources and nonpoint sources to attain water quality standards. The TMDL takes also into account seasonal and spatial variability of load and impact.

TMDLs are set with public consultation, and while not explicitly following an Ecological Quality Ratio approach relative to Reference Conditions as required by the WFD, in practice estimations of reference conditions are often relevant in setting targets of TMDL (Heiskary, 1989).

In the U.S., it is common that "reference sites" are identified as either the upper 75 percent of "high quality" sites, or the upper 25 percent of all sites. This statistical approach based in frequency data is not the same as the concept of reference state defined in the WFD. Nevertheless, the TMDL approach has many similarities to the policies of the WFD.

The point and nonpoint pollution programs managed separately, before the formulation of TMDL, resulted in a large number of water bodies that didn't meet the water quality standards.

The objective of the TMDL process is to systematically identify impaired or threatened water bodies and the pollutant(s) causing the impairment and ultimately establish a scientifically-based strategy for correcting the impairment or eliminating the threat and restoring the waterbody.

A TMDL implementation plan is analogous to the WFD Programmes of Measures. It requires measurable indicators, in appropriate units, and target values to evaluate attainment of water quality standards; monitoring activities. The mathematical models are used to determine effectiveness of control measures.

The US EPA (US EPA, 1999; US EPA, 1999; US EPA, 2001) has developed protocols for developing TMDLs in response to a number of pollutants. TMDLs are site specific and must include the total of all point and diffuse loads and incorporate a margin of error. They must also take into account seasonal and spatial variability of load and impact, and in its development characterize the catchment to identify all sources of pollutants as well as background loads.

To be effective in improving water quality, a TMDL must be more than an estimation of necessary pollutant reductions; it must be implemented. Therefore, every approved TMDL must include an implementation plan that explains the techniques that will be used to meet the load reductions identified.

The plan also provides the mechanism for tracking the implementation of management measures and point source controls and monitoring the various relevant indicators of water quality conditions. Evaluation of the milestones identified in the implementation plan can be used to determine whether progress is being made toward meeting water quality standards.

Ten distinct elements are required as part of a TMDL submittal:

1. The name and geographic location of the impaired or threatened waterbody for which the TMDL is being established, as well as the geographic location of upstream waterbodies that contribute the pollutant for which the TMDL is being established.
2. Identification of the pollutant for which the TMDL is being established and quantification of the target load of the pollutant that may be present in the waterbody and still ensure attainment and maintenance of water quality standards.
3. Identification of the amount or degree by which the current pollutant load in the waterbody deviates from the target representing attainment or maintenance of water quality standards.
4. Identification of the source categories, source subcategories, or individual sources of the pollutant for which the waste load allocations and load allocations are being established consistent.
5. Waste load allocations to each industrial and municipal point source permitted, discharging the pollutant for which the TMDL is being established; waste load allocations for storm water, combined sewer overflows, abandoned mines, combined animal feeding operations, or any other discharges subject to a general permit may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated to attain or maintain water quality standards (minor or remotely located) may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that waste load allocations when implemented, will attain and maintain water quality standards.
6. Load allocations, ranging from reasonably accurate estimates to gross allotments, to nonpoint sources of a pollutant, including atmospheric deposition or natural background sources; if possible, a separate load allocation should be allocated to each source of a pollutant, where this is not possible, load allocations may be allocated to categories of sources, subcategories of sources; pollutant loads that do not need to be allocated (minor or remotely located) may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that load allocations, when implemented, will attain and maintain water quality standards.
7. A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric

targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant.

8. Consideration of seasonal variation such that water quality standards will be met for the allocated pollutant during all seasons of the year.
9. An allowance for future growth, which accounts for reasonably foreseeable increases in pollutant loads.
10. An implementation plan, which may be developed for one or a group of TMDLs.

CHAPTER 3 - DEVELOPMENT OF NUTRIENTS TMDLs

3.1 PROTOCOL TO DEVELOP A NUTRIENT TMDL

The development of a TMDL is necessary to formulate a strategy that addresses the causes and potential sources of the water quality impairment and available management options. Generically the TMDL is described by the equation:

$$TMDL = LC = \Sigma WLA + \Sigma LA + MOS$$

Where:

LC = Loading Capacity, or the greatest loading a waterbody can receive without violating water quality standards.

WLA = Waste Load Allocation, or the portion of the TMDL allocated to existing or future point sources.

LA = Load Allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background.

MOS = Margin of Safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

In the framework for TMDL development seven components have to be completed:

1. Problem identification.
2. Identification of water quality indicators and targets.
3. Source assessment.
4. Linkage between water quality targets and sources.
5. Allocations.
6. Follow-up monitoring and evaluation.
7. Assembling the TMDL.

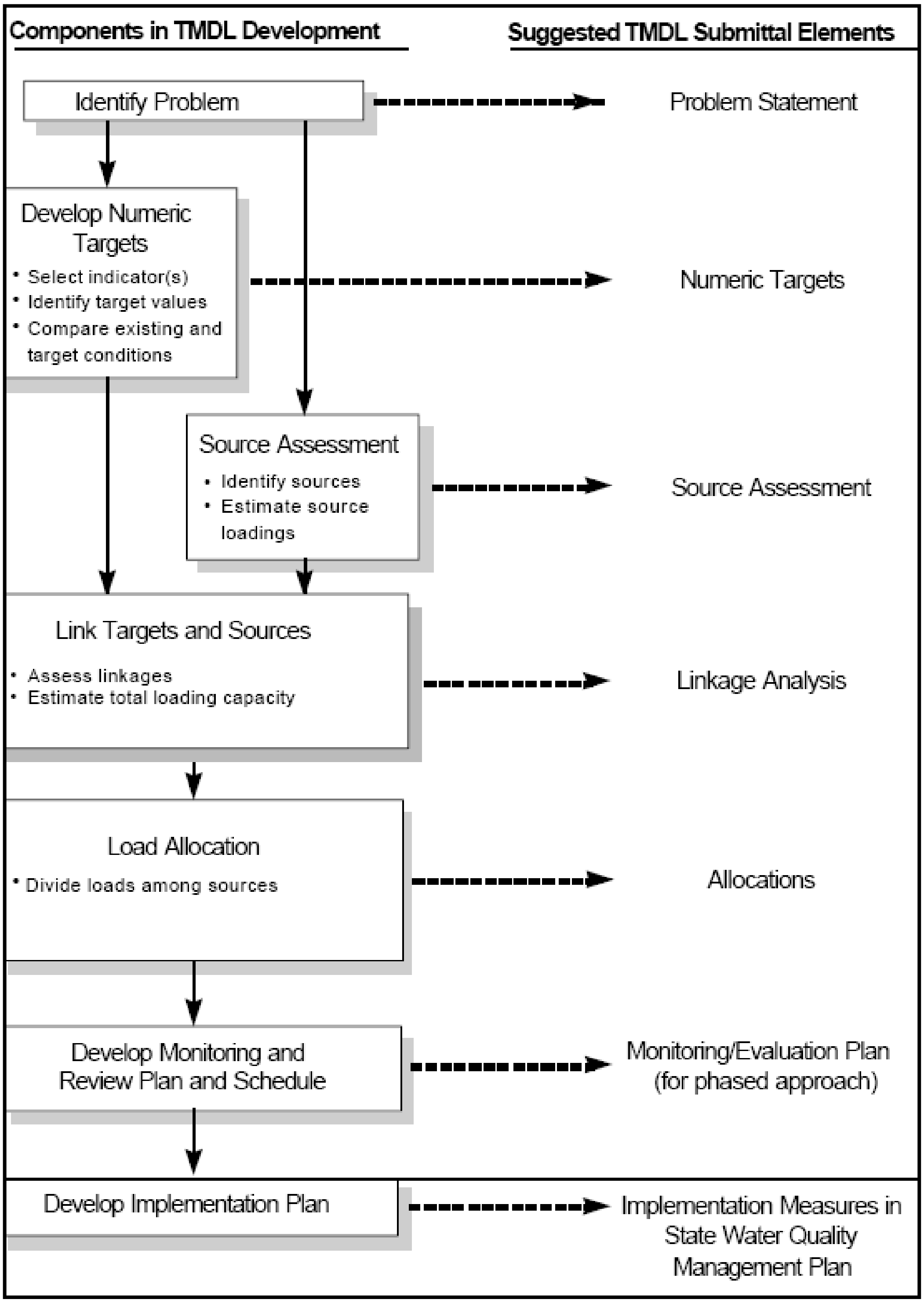


Figure 2: Components of TMDL developments (U.S. Environmental Protection Agency, 1999. Protocol for Developing Nutrient TMDLs).

Problem identification

Problem identification is a key factor in the development of a TMDL. The identification of the key cause and the knowledge of background situation that describe the nature of the impairment is the objective of this first step in the implementation process.

Target analysis

Identified the problem the next step in the process of establishes a TMDL is to define the relationship between the designated uses of waters and pollutant loading. The process of target analysis permits to identify the pollutant and evaluate its allowable load according to numeric or narrative water quality criteria; when no numeric water quality criterion is available, a site-specific quantified target that results in the attainment or maintenance of water quality standards must be developed as part of the TMDL.

The amount or degree by which the current pollutant load deviates from the target determines how much the pollutant load must be reduced to meet the maximum allowable pollutant load and therefore sets the stage for allocation of the pollutant among its sources.

Sources assessment

During the process of identification and assessment of sources some key factors have to be individuated: the type of source (point, non point and background), location of each source, magnitude of its loads, mechanism of transports, duration and frequency of pollutant transports.

The evaluation of pollutant loading is typically performed using a variety of tools, including existing monitoring information, air photography analysis, simple calculations, spreadsheet analysis using empirical methods, and a range of computer models from simple to sophisticate.

Linkage of source and target

To estimate the degree of pollution reduction needed to attain water quality standards occurs to establish the relationship between the in-stream water quality target and pollutant loads.

In addition, the linkage analysis facilitates the evaluation of management options that will achieve the desired load reductions. The link can be established through a range of techniques from the use of qualitative assumptions backed by sound scientific justification to the use of sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that associate certain waterbody responses to flow and loading conditions.

When long-term monitoring data are unavailable, it might be necessary to use a combination of methods, including monitoring data, analytical tools (including simulation models), and qualitative information. The monitoring data help to define characteristics such as baseline water quality conditions, pollutant source loading rates, and waterbody system dynamics. The available monitoring data will be supplemented by analytical tools. The linkage consists of evaluating the relationship between source loadings and the waterbody's response to those loads over time if long-term data is available.

Allocation

The allocation of pollutant loads permits to create a technically feasible and reasonably fair division of the allowable load among sources.

The concept of allocation is central to the TMDL process because it reinforces the importance of identifying what sources need to be addressed to eliminate the impairment. The type of pollutant sources drives the way to establish the TMDL.

EPA has developed numerous technical guidance manuals to assist States, Territories, and authorized Tribes in calculating waste load and load allocations for point sources that are identified as contributing to the impairment of a waterbody. Waste load allocations should be expressed as: numeric maximum allowable loads, required numeric reductions in pollutant loads, and/or narrative effluent requirements.

Another required elements that have to be included in a TMDL is the seasonal variation that can contribute to variations in the waterbody's assimilative capacity caused by seasonal changes in temperature and flow, or sensitive periods for aquatic biota (e.g., algae growth, fish spawning, larval emergence), and other factors. TMDLs should also consider seasonal fluctuations in pollutant loads to the waterbody. Some nonpoint sources contribute pollutant loads only during precipitation events, a distinct rainy season, or snowmelt. Similarly, some point sources operate only during certain times of year.

In some cases it's important to incorporate also the future population's impacts on water quality.

Implementation and monitoring plan

The implementation plan in the establishment of a TMDL is similar to the Programmes of Measures and the Monitoring Program required by the WFD.

The implementation plan permits to identify the measures, such as specific best management practices, that must be implemented to help identified sources meet their allocations.

The implementation plan should describe what actions will be implemented by source category, source subcategory, or individual sources. The description of the actions should include an analysis of the anticipated or past effectiveness of the control actions and/or management measures expected to meet the allocations. The implementation plan should also describe where the control actions and/or management measures will be implemented.

To achieve the specified load allocation, the implementation plan should include a time line for installation of identified management actions. Especially in the case of nonpoint source controls, the specific management actions will be distributed in various locations in the watershed.

3.2 METHODOLOGIES FOR TMDLs CALCULATION

TMDLs are developed for a variety of pollutants, environmental settings, pollutant source types, and waterbody types. They may be calculated using an assortment of analytical approaches and commonly use time steps, ranging from daily to annual, to express the loading capacity and associated allocations. EPA encourages TMDL developers to select the most appropriate method and time step, according to the available data, watershed and waterbody characteristics, pollutant loading considerations, applicable standards.

Two types of daily load expressions are available for presentation of daily loads:

1. **Static expression**, a single daily load number or set of numbers applicable to all conditions in the waterbody. It is most suitable when source inputs are relatively constant and show little variability.
2. **Variable expression**, used when the applicable daily load value is determined as a function of a particular characteristic that affects loading or waterbody response, such as flow or season. Of these, the most common options will be targets that vary by flow (flow variable) and those that vary by month or by season (temporally variable).

For many TMDL pollutants, such as nutrients and sediment, primary threats to achieving water quality standards (WQS) can depend on cumulative load, and accuracy of pollutant loading estimates increases as the length of the calculation period increases. Therefore, establishing longer-term allocations is appropriate given the chronic nature of the pollutant loading and resulting impairments.

Traditionally the approach used in the TMDL development tends to focus on targeting a single value, which typically depends on a water quality criterion and some design flow. The single number concept does not work well when dealing with impairments caused by NPS pollutant inputs (Stiles, 2001). One of the more important concerns regarding nonpoint sources is variability in stream flows, which cause different loading mechanisms to dominate under different flow regimes (Cleland, 2002).

EPA recommends that all the TMDLs and associated load allocations (LAs) and waste load allocations (WLAs) also be expressed in terms of a daily time increment. While TMDL analytical approaches that result in longer (non-daily) averaging periods may continue to be used to demonstrate consistency with applicable water quality criteria, all final TMDL submissions should include an adequate expression of daily loads in addition to any longer-term loading expression. Loading capacity of most waterbodies is not constant in time. Depending on the constituent of concern, it can vary with stream flow, temperature, and many other variables.

The TMDLs that include time-variable loading limits are often generated by using a dynamic modeling technique, which can include both continuous simulation models and statistical approaches.

While TMDLs should contain an expression of daily load, this daily load may be either a constant daily maximum load or a time-varying daily maximum load. Expressing long-term LAs as daily loads can also be used to inform post-TMDL monitoring and tracking.

Monitoring data collected during a given sampling event can then be compared to the identified daily load values to evaluate whether the TMDL is being attained.

Process for Deriving Daily Load Expressions from Typical Non-daily TMDL Analysis

Whether TMDLs are expressed as daily allocations or non-daily allocations depends on such considerations as expressions of applicable WQS, pollutant type and behavior, source characteristics, critical conditions, and TMDL development methodology. If it is deemed appropriate to express a TMDL on a non-daily time frame, that non-daily TMDL should also include a daily expression.

The first step in the process to identify the daily load expression, an evaluation of the technical approach to developing the non-daily load, provides the analyst with an understanding of what information is available for the process.

The second step requires the creation of the daily load dataset from which the daily expression will be created.

The third step involves working with the dataset to identify the most appropriate daily load expression on the basis of the practitioner’s knowledge of the system.

Allocations based on monthly, seasonal, or annual timeframes are valuable components to guide management measures and implementation plans because they are related to the overall loading capacity of the waterbody, while the daily expressions represent day to day snapshots of the total loading capacity based on ambient conditions. The daily expression can provide a useful tool for tracking the progress toward meeting the longer-term allocations and goals. Follow-up monitoring data can be compared with daily maximum loads to gather insight into how the waterbody is responding to implementation efforts and whether short-term loads and conditions are within the range of conditions represented by the longer term TMDL allocations. The daily expression of the TMDL supports and informs monitoring efforts and other implementation activities such as implementing best management practices (BMPs) and establishing permit limits.

The daily expressions are based upon a daily average long term flow condition. The calculation is very simple; in this way the TMDL is not able to reflect adequate water quality status across flow conditions.

Developing a Daily Dataset from a Non-daily Analysis

Develop a daily dataset is important to create a dataset that represents the variation and magnitude of allowable daily loads that result in attainment of long-term loading goals, a dataset from which the daily expression for the TMDL will be established.

There are five commonly used approaches for developing TMDLs:

1. **Dynamic Model**. The use of dynamic, time-variable watershed and receiving water models on a daily or smaller time steps to establish the link between source loading and water quality response and to evaluate load reduction and management scenarios.
2. **Load Duration.** The load duration methodology relies on using observed flows and water quality criteria to establish loading capacities for various flow conditions. This builds on using flow duration curves, which use hydrologic data from stream gages to evaluate the cumulative frequency of historic flow data over a specified period. A duration curve relates flow values to the percent of time those values have been met or exceeded. A criterion concentration can then be converted into a distribution of allowable loads as a function of daily flow. Duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (e.g., wet versus dry and to what degree).
3. **General Watershed Model.** For general watershed models are assumed to be those that provide simulation capabilities and output on a non-daily basis, typically monthly or event-based. The models simulate basic watershed processes related to weather, erosion, and runoff and pollutant wash off, and they typically do not involve waterbody response or in-stream fate and transport.
4. **Export Coefficients/Pollutant Budgets.** All the approaches that use empirical or literature values of typical watershed loading rates.

5. **Steady-State or Mass-Balance Analysis.** The approach relies on identifying the necessary loads entering a waterbody that will meet the desired waterbody target after the consideration of all inputs and losses.

Considerations for Selecting the Appropriate Daily Load Expression

The selection of appropriate type of daily load expression (static or variable) and the associated target value is driven by the characteristics of the waterbody for which the TMDL was calculated as well as characteristics of the analysis used for developing the non-daily TMDL allocations. Considerations such as critical conditions and pollutant source types will be more indicative of the approach to use.

One of the main factors that drive the selection is the type of pollutant source involved in the TMDL. For example, in a point source-dominated, impaired river, critical conditions generally occur during low flows when less stream flow is available to dilute the discharge. Target selection will generally focus on ensuring that WQS are attained during critical low flows, in this case the static daily load expressions could be reasonable. Meanwhile, nonpoint source-dominated watershed tends to experience impaired conditions as a result of rainfall events and associated runoff. As a result, a flow-variable daily load expression is good option to use in crafting the daily target. Also the typical behavior of both type of source, constant and variable, is a factor that influence the selection of analysis approach.

Finally, in waterbodies with a mix of both point and nonpoint sources, there could be multiple critical conditions or none apparent at all. A variable daily load expression is the most appropriate for mixed source watersheds.

3.3 TMDL CALCULATION

Three methods can be used to calculate daily load as described below:

1. 365-average. This method involves dividing the annual TMDL by 365 to arrive at a mean daily load. In practice, this approach would rely on the annual load generated for a particular area. For example, if the model predicts a load of X tons of phosphorus is needed at a certain location to meet relevant water quality criteria, the daily expression would be X/365. This method is simple but not provides insight into the day-to-day variability of loads;

2. Multiplier. The Multiplier Method is a statistical approach to identifying a maximum daily load. It is consistent with the approach presented in EPA's *Technical Support Document for Water Quality-based Toxics Control*. This method is often used when long periods of continuous simulation data are not available or when the daily load dataset covers only a limited period of time.

In practice, a long term total load (e.g., an annual load) is converted into a daily load. For example, annual load X is divided by 365 days to arrive at a daily load of X/365. This mean daily load is then multiplied by a number, Y, which is based on the coefficient of variance (e.g., 0.6) and a selected % of the standard normal distribution of the data (e.g., 95^{th} %'ile). The resulting load (XY/365) represents a maximum acceptable value consistent with achieving the annual cumulative load target (X) and daily average (X/365). It is essentially the maximum daily load. This method can be readily calculated based on annual model data but does not provide insight into the full variability of day-to-day loads; selection of the multiplier to use must be justified (e.g., which %'ile),

3. Variable Daily Load. This method involves presenting the TMDLs in terms of seasonality or flow. It is frequently used when a dynamic watershed model is available.

To present the loads based on seasonality, modeled loads at a location are grouped by season (or another relevant period, such as by month). Then, the minimum, maximum, mean, and other statistical measures are presented for each of these seasons. The resulting plot presents the range of loads for each season.

To present the loads based on flow, modeled loads and corresponding flows (e.g., the flow corresponding to each daily load from the model output) are ranked by flow. Then, the minimum, maximum, mean, and other statistical measures are presented for user-specified flow percentiles (e.g., every 10^{th} percentile of flow). This paints a picture of the range of loads contributed under various flow conditions. The method takes full advantage of information available in the models; provides insight into the day-to-day (from a flow or seasonality standpoint) variability of loads; can inform implementation efforts (if loads are presented at an appropriate scale).

CHAPTER 4 - CASE STUDY CANDELARO RIVER BASIN

4.1 GENERAL DESCRIPTION

The selected study area is the Candelaro watershed located in South Italy. It is one of the main watersheds located inside the boundary of Apulia Region territory. It is under the jurisdiction of the “Southern Apennines District”.
The watershed presents a well defined hydrographic network; it shows an intermittent behavior as the typical Mediterranean rivers. The streamflow regimes follow the precipitation patterns, period of drought follow wet and flashfloods. This hydrologic characteristic is one of the factors that forced to investigate the use and evaluate the effectiveness of adopting a mathematical approach to define the “Measures” required by WFD to achieve its objectives.

The drainage area of the Candelaro watershed (Fig. 3) is approximately 2300 km^2. The length of the Candelaro River is about 67 km; it flows to the edge of the Gargano Mountain in direction NW-SE, in correspondence of a fault formed during the rising of the promontory. The right slope of the basin is rather small while the left one is very wide and ploughed by a large number of tributaries that flow in the large plain area. The most important affluent are the torrent Celone, Salsola and Triolo. These streams originate from the Subappennino Dauno, receive water from several sub-tributaries, flow through the plain of the “Tavoliere” and go into the Candelaro River in correspondence of its middle course. The superficial density of the hydrographic network is rather elevated; the final water body is the Adriatic Sea. Before to reach the sea the Candelaro River flows closely to a lowland area that is flooded during the rainy period; this area called “Palude Frattarolo” is a wetland area protected under national and regional regulation due to significant natural importance.
It is an agricultural watershed, about 90 percent of the area is agricultural land and only 2 percent is a residential area.

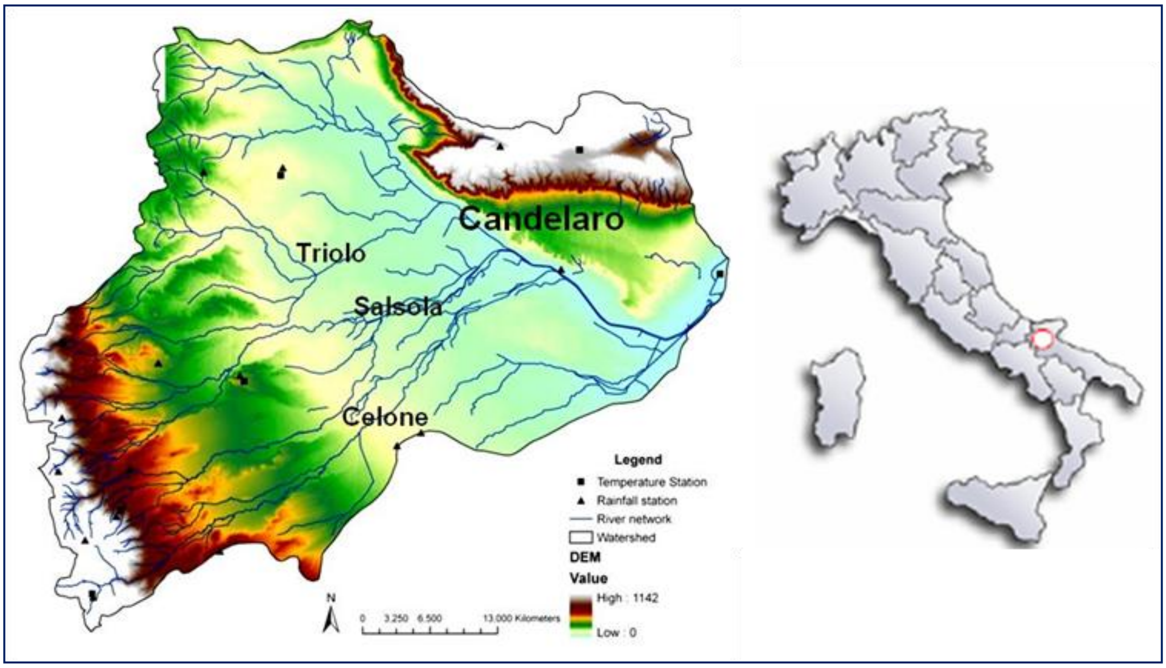


Figure 3: Candelaro watershed location, hydrographic network and main tributaries.

Climate

The watershed is characterized by the typical Mediterranean climate, with warm to hot, dry summers and mild, wet winters.

On the base of the values of temperature (minimum and maximum), rainfall and evapotranspiration it is possible to characterize two homogenous climatic areas in the Candelaro watershed. One homogenous climatic area coincides with the western border of Gargano Promontory and with the eastern Daunia Mounts. These areas reach the maximum altitudes of the whole watershed; the elevation range is 800-1142 m. a.s.l.

The continental climate, with cold winter and warm summers, is strongly influenced by holography. The rainfall, concentrated in autumn-winter season, is greater than regional averages with the maximum peaks of 800-1000 mm of rainfall per year. A particular climatic characteristic of the area is the high value of wind intensity in every period of the year. The precipitations in these areas are caused by the rising air motion of a large-scale flow of moist air across the mountain ridge, resulting in adiabatic cooling and condensation. Often the precipitation events are characterized by heavy rain, high rate in short time. From December to March of coldest years snow precipitations were recorded in this mountain part of the watershed.

The other one homogenous climatic area coincides with the “Tavoliere plain”. This zone is the largest flat area in the South Italy. It is among the warmer and main drought zones in Italy with the maximum values of temperature that often exceed 45 °C, moreover in the last years, during the summer period.

Rainfall is unevenly distributed and often occurs as convective thunderstorms. These thunderstorms

promote runoff and erosion that may carry soluble and sorbed phases of applied nutrients and pesticides to lower landscape positions or into surface waters. These events often cause flash flooding in short time.

The average annual precipitation at watershed scale, from 1990 to 2004, is 650 MM. The figure 5 shows the location of 9 rainfall stations located in the watershed and the average annual precipitation for each one (1990-2004). Each rainfall station shows a relevant annual variability of precipitation amount.The average monthly precipitation (Fig. 4) ranges from 26 MM in August to 82 MM in December, the driest period is the summer period, also if in February and March the recorded values are lowest compared to the precipitation of April.

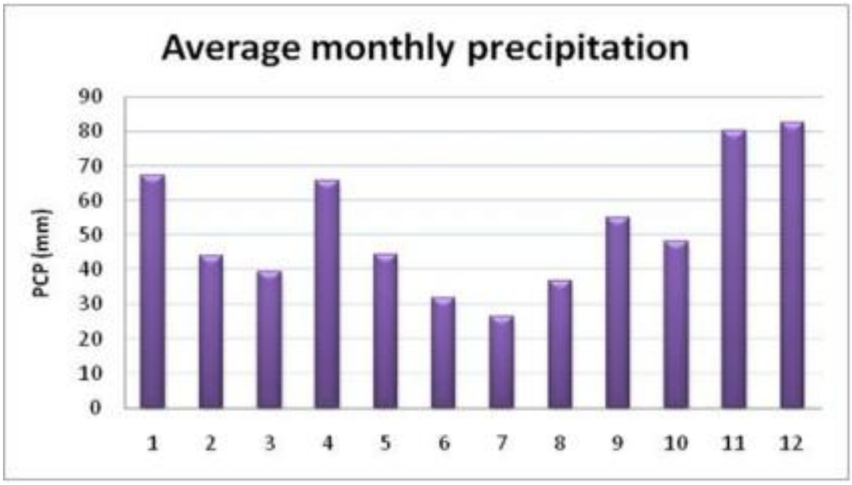


Figure 4: Average monthly precipitation at watershed scale.

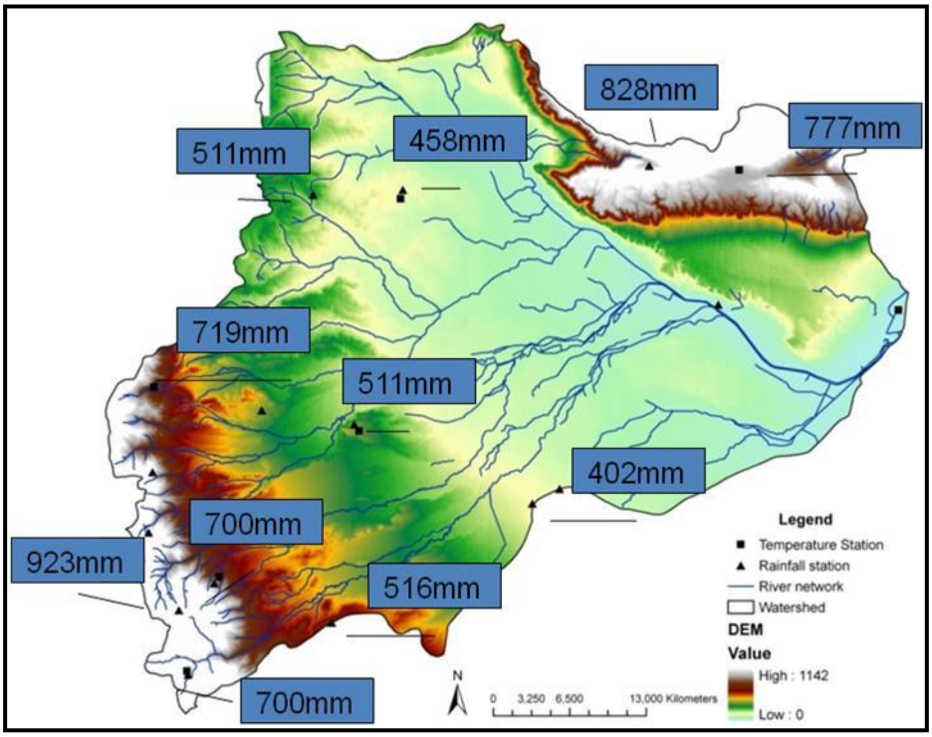


Figure 5: Rainfall stations and average annual precipitation (1990-2004).

The average daily temperature ranges from 12 C° to 15 C°.
The mean annual potential evapotranspiration is more than 1100 mm.

Geology

The plain zone of the watershed is characterized by a calcareous and calcareous-dolomitic framework. The Plio - Pleistocene basin-filling sediments (Bradanic cycle), essentially consist of clays (indicated with the generic term of “grey-blue clays”), interbedded with thin sandy and silty-sandy lenses, which evolve to sand, sandy gravel and gravel in the upper part of sequence. The regressive sequence is overlaid by quaternary deposits referring to different marine sedimentary cycles and continental alluvial phases (Maggiore et. al 2005).
The quaternary alluvial and marine deposits (shallow porous aquifer), the deepest thin sandy lenses interbedded with grey-blue clays (deep porous aquifer) and the carbonate framework (deep karts-fractured aquifer) provide the conditions for the groundwater circulation.
The shallow porous aquifer consists of soils having different relative permeability: sand and gravel (aquifer) with interbedded clay silts and subordinately sandy silts. Generally, the more permeable layers prevail in the upper part of the plain (recharge zones), where groundwater

occurs under phreatic conditions, while the less permeable layers prevail in the lower part of plain towards the sea. Here the aquifer becomes locally confined and groundwater occurs under pressure conditions. The aquifer is recharged principally by rain, though a secondary source is represented by the streams crossing the plain of the "Tavoliere" (Maggiore et al. 2005; Barca et al., 2006).

Watershed hydrology

Candelaro River is strongly influenced by the rainfall characteristics of the area. The general pattern of seasonal flows includes a dry season, which runs from May through November when the zero flow condition was frequently recorded, and a wetter period, from December to April. The Candelaro River is classified as "intermittent" river.

Across a period of recorded data, natural variations in climatic conditions in the region, especially the timing and amounts of rainfall, had a substantial impact on the river's flow regime. The mean daily flow of Candelaro River at "Bonifica 24" (1788 Km^2) gauge is 8.66 cms (1965-1974) while the minimum flow is 0 cms. The maximum flow value recorded occurred on January 1969 with a magnitude of 145 cms. The average flow measured during the 7 consecutive days of lowest flow during 10 years (Q 7,10) is 0 cms.

On the 1974 the above mentioned flow gauge was destroyed during a flood event until today there are any recorded flow data.

Variations of discharge volumes, distributions of floods during the year, frequency of floods and magnitude are evident among the years (Fig. 6).

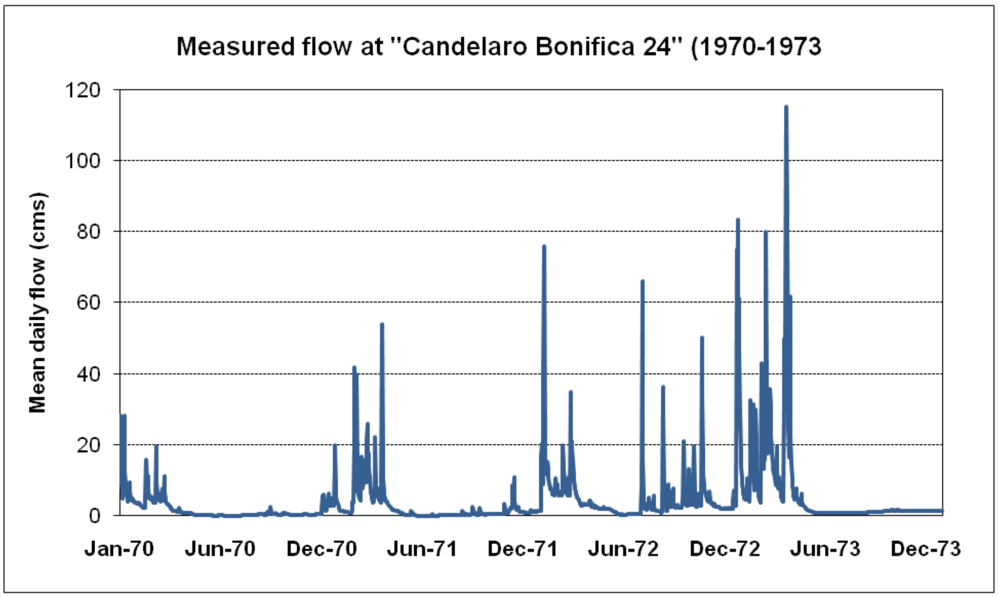


Figure 6: Measured daily flow of Candelaro River at gauge "Bonifica 24" (1970-1973).

In the table 1 are reported some hydrologic parameters calculated for the years with recorded data available; the mean daily maximum flow (Q max); the mean daily low flow (Q min); average daily flow (Q average); runoff coefficient; total number of days with no flow; the minimum and maximum consecutive days with no flow in one year; the total water yield and the average annual discharge (m^3) are reported. The recorded data used of Candelaro River covers the years 1970-1973; for the Celone tributary (at San Vincenzo station, 92 Km^2) the years: 1970-80, 1982-84, 1987-88, 1990-96; for Salsola tributary (at Ponte Foggia – San Severo station, 455 Km^2) the years 1970-1995 and for Triolo (at Ponte Lucera, 56 Km^2) the years: 1970-77, 1981, 1989-1990, (Ministero dei Lavori Pubblici - Servizio Idrografico-Sezione di Puglia).

	CANDELARO (1778 Km^2)	**SALSOLA (455 Km^2)**	**CELONE (92 Km^2)**	**TRIOLO (56 Km^2)**
Q max	**115 m^3/s**	**104 m^3/s**	**20.8 m^3/s**	**25.9 m^3/s**
Q min	**0 m^3/s**	**0 m^3/s**	**0 m^3/s**	**0 m^3/s**
Q average	**4.14 m^3/s**	**1.26 m^3/s**	**0.45 m^3/s**	**0.20 m^3/s**
Days no flow	**46 (5 years)**	**847 (26 years)**	**2789 (18 years)**	**1224 (11 years)**
Min days no flow	**0**	**0 (1996)**	**3**	**56 (1981)**
Max days no flow	**26**	**164 (1978)**	**225**	**197 (1990)**
Total water yield	**84.24 MM**	**88 MM**	**163 MM**	**123 MM**
Runoff coeff.	**0.09**	**0.14**	**0.25**	**0.18**
Average annual discharge	**150 Mm^3**	**40 Mm^3**	**15 Mm^3**	**7 Mm^3**

Table 1: Hydrologic parameters of Candealro River and main tributaries.

The Celone River shows the higher water yield and runoff coefficient but it is the tributary with longer day of no flow (Table 1). This tributary shows also a higher value of Flashiness Index (FI) (De Girolamo et al., 2009, Baker et al., 2004), indicating that the river, often, during the years changes rapidly the flow magnitude in response to the rainfall events. This behavior is typical for basins characterized by steeper or rolling topography, often with a low degree of soil permeability, or with a significant impervious area. Also the other tributaries show a high value of FI but lower compared to the Celone River. During the summer period, when often thunderstorms are recorded, the FI assumes highest values.

The streamflow characteristics influence all the processes that characterize a watershed as: sediment regime, channel formation, floodplain and flood processes, groundwater and surface water interactions, nutrient delivery, and water quality.

The area was often characterized by landslides, soil erosions and floods, during the winter period; where recorded damages to urban infrastructures and also to the crops cultivated close to the rivers. About 35 percent of the watershed is classified under landslides risk and about 8 percent under high hydraulic risk (PTA, 2009).

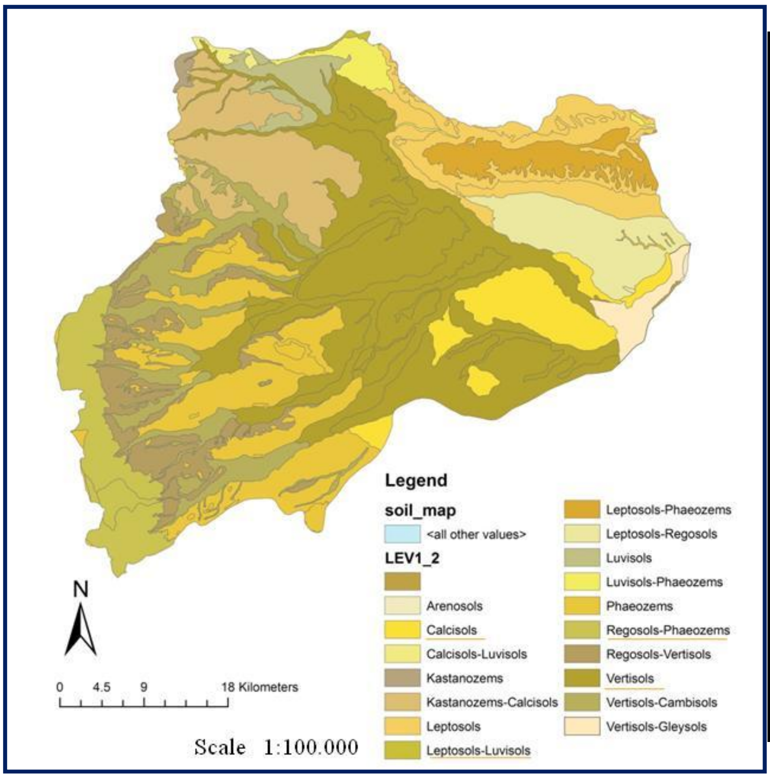
In the past, in order to reduce floods and sediment loads, at the confluences of the three main tributaries, the reaches were modified building levees and sinking the river bed; also reclamations lagoons were created as reservoir for floods close to the mouth of the Candelaro River.

Soils

The soils are related to the lithology and generally show a texture varying from sandy-clay-loam to clay-loam or clay. The plain area of the watershed consists of vertisols and calcisols that are the deepest soils (1.5 - 2 m), the mountain western part is characterized by regosols, eroding lands reach of humus; while on the eastern mountain part, the Gargano promontory, there are leptosols over calcareous hard rocks. About 60% of the watershed is clay soil and about 20% is sandy clay (Fig. 7). The mountain part, particularly in areas where the slop is very steep, is often characterized by landslides during the wet period.

Regarding the permeability of the soils, in general they have a moderate or slow infiltration and in some cases they are characterised by very slow infiltration. In according with the U.S.

Natural Resource Conservation Service (NRCS) classification of soils, almost all profiles are grouped in the class C and in the class D.



Soil type	Area (ha)	(%)
Vertisols	**123,956**	**53.17**
Calcisols	**4102**	**1.76**
Calcisols-Luvisols	**817**	**0.35**
Phaeozems	**175**	**0.07**
Vertisols-Gleysols	**2,887**	**1.24**
Luvisols	**18,597**	**7.98**
Leptosols-Luvisols	**53,832**	**23.09**
Leptosols	**28736**	**12.3**
Arenosols	**5**	**0**

Figure 7: Soil types map and table of type soil, area and percentage of area of the watershed.

Land use and cover condition

The intensive agriculture characterizes the Candelaro watershed. This area is the main Italian zone for the production of durum wheat.

The urban area covers less than 2% of the whole area. Deciduous and mixed forests are present at the highest elevations where also some pasture lands can be found. The industrial activity is not relevant in this area; it covers only 0.5 percent of the whole watershed.

The Apulia region is characterized by water scarcity, the water for the irrigated crop in the Candelaro watershed, derives from the Occhito dam, located in one of the surrounding Region, and from the Celone reservoir. The irrigation in the plain part of the watershed is managed by a local authority “Consorzio per la Bonifica della Capitanata” of Foggia, that gives irrigation water on demand through a pipeline network. In the areas equipped with the irrigation systems the durum wheat is cultivated in rotation with tomatoes or sugarbeat.

In the winter time the watershed is covered almost completely by the cereal durum wheat, it is about the 90 percent of the agricultural area of the watershed. The figures 8, 9 show two maps reporting the land cover status during winter and summer period (CASI 3 – SIGRIA – INEA, 1999).

Others important cultivations, in this area, are represented by irrigated vineyards and olive orchards, respectively covering about 5% and 10% of the watershed.

The long term average yield of durum wheat is about 3 t/ha; the sowing date is generally executed in November and the harvesting in summer, according also to the weather situations; generally three conventional tillage operations were executed and two fertilizations.

The sowing date for the tomatoes is generally in late April or after the harvesting of durum wheat in the rotation cultivations; the harvest operation generally is after 120 days of cultivation. The irrigations system mostly diffuse in the area is the drip irrigations method, seasonal irrigation volumes range between 300 – 500 mm. Also for tomatoes cultivation were executed generally three conventional tillage operations and two fertilizations.

The sugarbeet can be cultivated in winter or summer period. The irrigation volume applied for the summer cultivation ranges between 400 – 550 mm; while for the winter cultivation the volume applied is maximum 450 mm according also to the weather conditions. The diffuse cultivation is the winter type; the sowing date is in October and the harvest date in late summer. Generally were executed three fertilizer application and three conventional tillage operations.

The vineyard is mostly irrigated, the volumes range between 200 – 300 mm; generally were executed two fertilization operation and two conventional tillage operations before the harvesting period in late autumn.

The olive orchards are mostly not irrigated; where there is the water supply the volumes applied per year during the summer period range between 200 – 300 mm. The fertilizer operations are generally two per year but there are some areas where are diffuse organic farming, mostly located in the area of Gargano promontory.

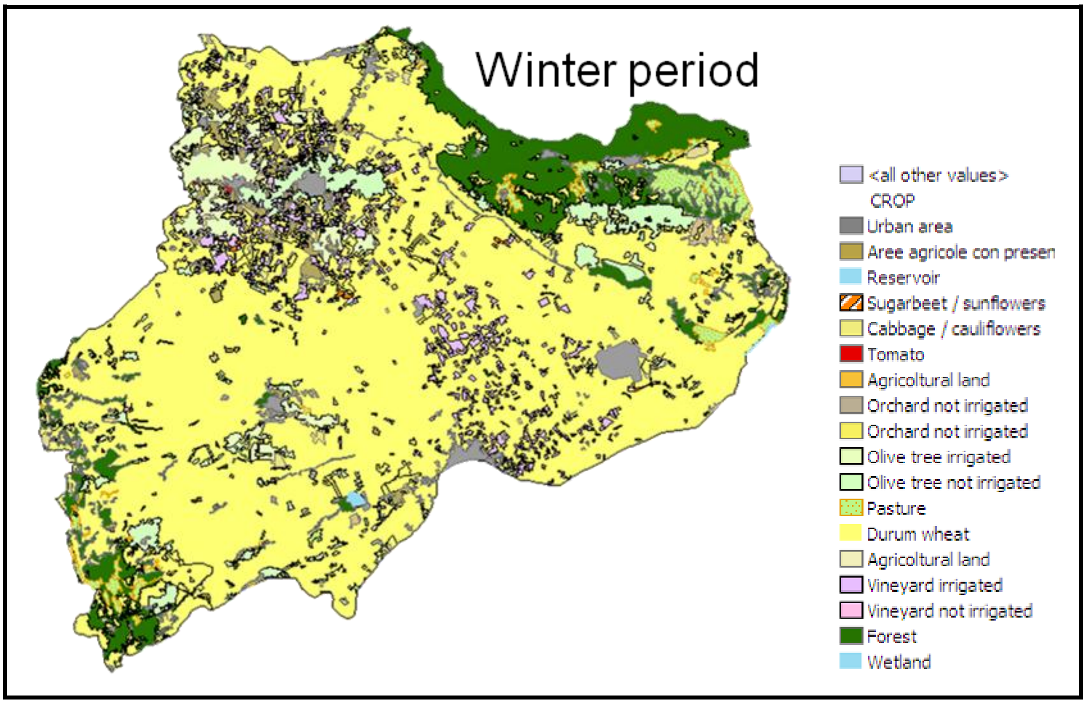


Figure 8: Land use map during the winter period.

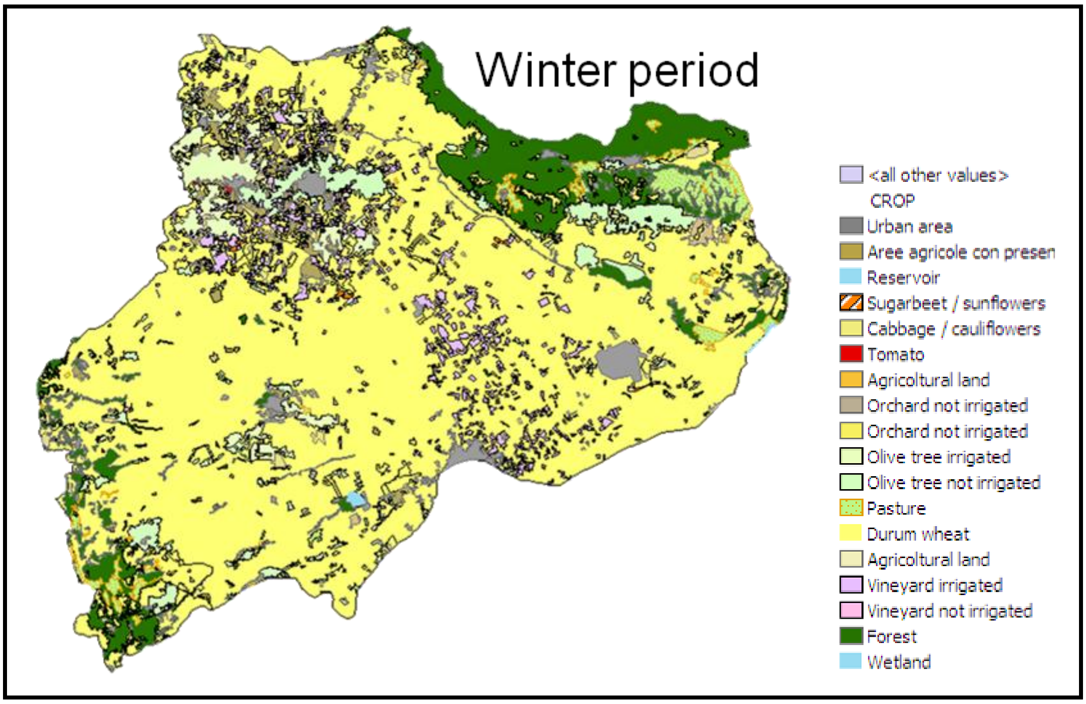


Figure 9: Land use map during the summer period.

Twenty-four municipalities are located in the Candelaro watershed. The total number of inhabitants is about 347,000; the population density ranges from 10 to 365/Km^2. The map reported in figure 10 shows the main municipalities and the range of population density for each municipality.

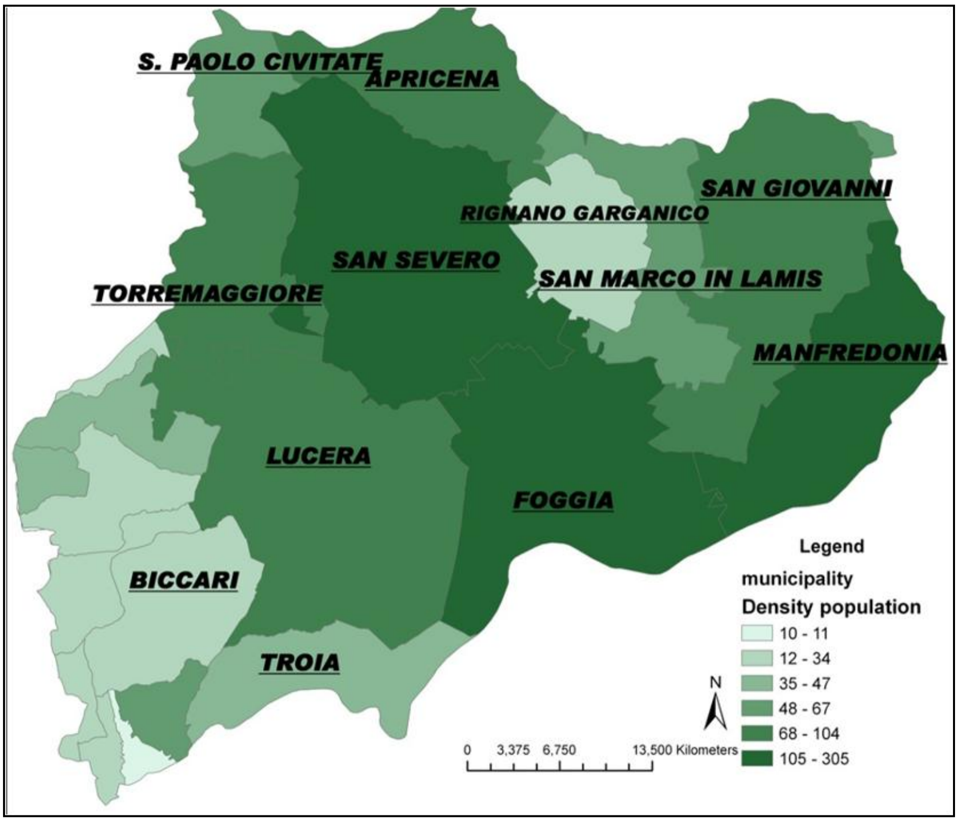


Figure 10: Municipalities and related population density.

Pressures on water quality

Diffuse sources

Diffuse sources derive from the agricultural activities. The intensive agriculture represents a considerable diffuse soil and water contamination sources due to the huge use of chemicals employed as fertilizer, herbicide and pesticide. The conventional tillage is a diffuse practice in the area, that associated with the described climatic characteristics and the soil types, cause significant sediments loads.

The average annual amount of mineral nitrogen applied with fertilizer is about 102 Kg/ha, while the mineral phosphorus is about 35 Kg/ha. Table 2 Summarizes the type, the rate (Kg/ha) and the period of fertilizer application generally applied in the area also if there are some areas where the management operations can be different. The information reported on management operation were collected from some farmer's interviews and from the assistance services of "Consorzio di Bonifica della Capitanata" who manages the distribution of water for the irrigation.

Crop	Fertilizer	Period	Amount
Durum weath	18-46-00 Urea	November January /March	150-200 Kg/ha
Tomato	18-46-00 Ammonium nitrate	March May	200-250 Kg/ha 300-400 kg/ha
Olive	15-15-15 Ammonium nitrate	Genuary/February	500 kg/ha
Vineyard	15-15-15	January or February	500 kg/ha
Sugarbeet	18-46-00 Urea	January October	200 kg/ha

Table 2: Fertilizer operation: type, rate and period of application.

The estimation and evaluation of impacts on water quality from chemicals as pesticides and herbicides is very complicated at watershed scale. Obtain information about the period and the rate of pesticides and herbicides applications is difficult because these types of operations are related to the presence and type of weeds and pests affecting the crops.

Point sources

The pressure from industrial activities was evaluated negligible. Great or heavy industries are completely absent meanwhile the few industries operating in the Candelaro watershed are small or medium at least. These industries are mainly tied up to the agry – food industry for the transformation or conservation of agricultural products (e.g. sugar refinery, olive oil mills, wineries, dairies and grain mills).

The main contributions from point sources derive from the waste water treatment plants discharges, 17 facilities discharge urban waters (Fig.11) into the Candelaro River and its tributaries. The mean annual average discharge is about 23.2 Mm^3/year. The process type of these WWTPs is the secondary treatment, except for two treatment facilities (San Severo – Torremaggiore and San Paolo Civitate) where there is the tertiary treatment; this is the situation on 2008 (Piano Tutela Acque- Regione Puglia, 2009).

The point source loads evaluated for biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (N) and total phosphorus (P) are reassumed in table 3 (Piano Tutela Acque Puglia, 2009).

BOD (ton/year)	**COD (ton/year)**	**N tot (ton/year)**	**P tot (ton/year)**
1,379	**4,148**	**617**	**108**

Table 3: Point source loads.

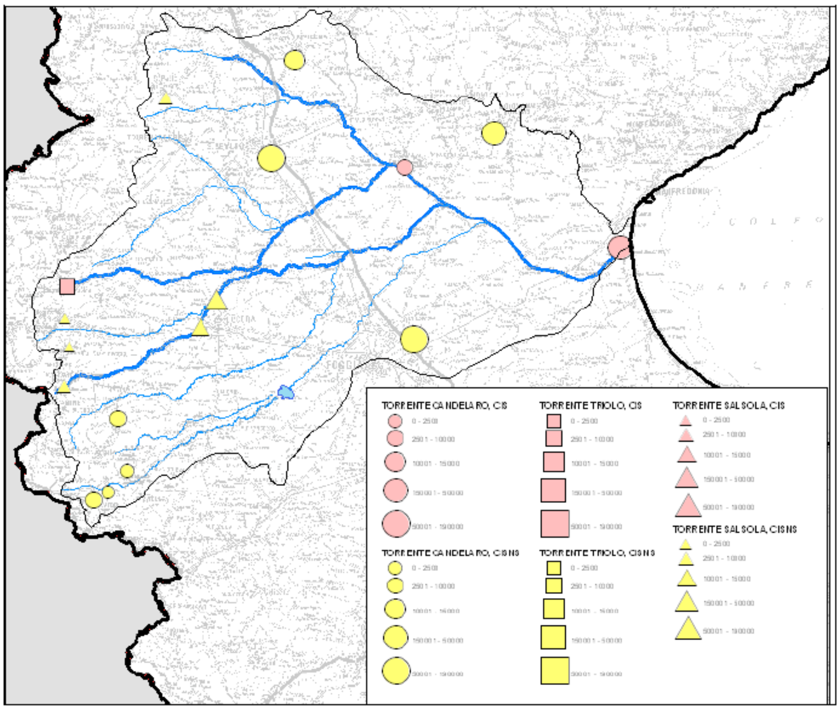


Figure 11: Location of waste waster treatment plants (Piano Tutela Acque-Puglia, 2009).

4.2 IMPLEMENTATION OF THE WATER FRAMEWORK DIRECTIVE

The implementation of Water Framework Directive in the Candelaro River follows the evolution of the transposition process of the Directive into Italian law that is still now in progress with the emanation of new decrees on water policies as described in the chapter 2.

The Candelaro river basin is under the authorities of the Southern Apennines District. For the development of the Draft Water Management Plan were used mostly the information collected and evaluated with the "Water Protection Plan" (PTA) provided by the Apulian Region.

The following informations contained in the PTA for the Candelaro watershed, together with all the Apulia Regional watersheds, were used in the development of the Draft Water Management Plan on the following points:

- *General description of the characteristics of the river basin district:*
    - location and boundaries of water bodies;
    - geological and hydrogeological characterization;
    - hydrological characterization;
    - land use;
    - socioeconomic characteristics;
    - characterization of water bodies;
    - identification of significant surface water bodies;
    - identification of significant groundwater bodies
    - vulnerability of aquifers

- *Identification of pressures on water quality:*
    - Estimation and identification of significant point source pollution;
    - Estimation and identification of significant diffuse source pollution;
    - Estimation and identification of significant water abstraction for human activities;
    - Analysis of the infrastructure system (distribution system and sewage–treatment;
    - Estimation and identification of other significant pressures on the status of surface water.

- *Identification and mapping of protected area:*
    - Areas designated for the abstraction of water intended for human consumption;
    - Areas designated for the protection of economically significant aquatic species;
    - Bodies of water designated as recreational waters included bathing water;
    - Nutrient-sensitive areas, including areas designated as vulnerable zone under Directive 91/676/EEC;
    - Areas designated for the protection of habitats or species where the maintenance or improvement of the status of water is an important factor in their protection.

- *Monitoring network:*
    - Surface water (ecological and chemical)
    - Groundwater (chemical and quantitative);
    - Protected areas;
    - Monitoring programmes.

- *Evaluation of impacts on water quality status.*

- *List of environmental objectives*
    - Surface water;
    - Groundwater;
    - Heavily modified surface water bodies.

- *Economic analysis of water use:*
    - Estimation of the volume, prices and costs associated with water services;
    - Estimation of relevant investment including forecasts of such investments

- *Programme of measures*
    - Structural and non structural measures

Focusing on the assessment of water surface status of Candelaro River and its tributaries a brief description of the instruments adopted in the PTA for the individuation and assessment of pressures on surface water bodies is reported.

Assessment of current water surface quality status

Diffuse sources

The assessment of pressures from diffuse sources on water quality status of surface waters, adopted in the development of the PTA document, was carried out with a simple calculation of surplus of nitrogen and phosphorus transported with runoff processes.

In details the following steps were adopted:

- Land use information derived from a land use map (Corine Land Cover, 1999; SIGRIA- INEA and ISTAT - Censimento Agricoltura, 2000);
- Management operations information (fertilizer application) extracted from the Italian National Statistical Institute (ISTAT) about agricultural activities.
- Calculation of total loads applied at geographic level;
- Use of literature values of nutrient uptake by plants;
- Calculation of N surplus;
- Estimation of surface runoff and infiltration amount;
- Estimation of surface nitrogen loads transported with surface runoff process.

The loads from animal farming where accounted in the calculation of diffuse sources loads.

The number of livestock present in each municipality was collected from the census of ISTAT. Using specific coefficient was calculated also the nutrient loads from manure;
The loads were reported as annual value (Kg/animals/year).

Point sources

The annual loads (tons/year) deriving from urban waste water were estimated for each municipality accounting the literature values of nutrients (TP and TN) per total number of population equivalent (PE). The 17 urban water treatment plants identified in the Candelaro watershed (all together have a potential depurating capacity corresponding to about 453.661 AE) produce a load corresponding to 547.659 urban AE (equivalent inhabitants). According to the data provided by the Apulian Aqueduct Authority for 2003, the total amount of sludge produced by the above mentioned waste water urban treatment plants is 25803 t/year and is all reused for agricultural activities.
The calculation of annual loads from civil activities accounted also the loads produced from industrial activities.

The annual loads estimated in the Candelaro River for BOD, COD, TN and TP, accounting the diffuse and point sources, are summarized in the table 4 published in the PTA of Apulia Region.

	BOD (ton/year)	**COD (ton/year)**	**N tot (ton/year)**	**P tot (ton/year)**
Point source	1,379	4,148	617	108
Diffuse source	4,538		3,751	102
Total loads	**5,917**	**4,148**	**4,369**	**210**

Table 4: Total annual loads (point and non point sources) in the Candelaro River

Apart from the loads shown in table 4 the SACA (water course environmental state) index has been estimated for the Candelaro River as established by L.D. 152/1999. The index indicates the environmental quality of a water body, taking into account chemical, biological and ecological parameters. According to this index, calculated integrating monitoring data with data coming from other sources, the Candelaro River has a “very bad” environmental status. This bad environmental status is to a certain extent the result of the 16 of the above mentioned waste water treatment plants whose discharge has been estimated to represent the prevailing amount of the flowing water during some periods of the year and who not always respect the law limits. Meanwhile the huge contribution to total nitrogen loads derive from agricultural activities (Tab. 4) (Piano di Tutela delle Acque- Regione Puglia, 2009).

Monitoring network

The monitoring activities of surface water status, required by Art. 8 of the WFD, have to follows the criteria, methods and standards established into the Italian L.D. 152/2006 and following decree: L.D. 30/2009 and the Decree 56/2009).

These monitoring programmes enable the collection of the physical, chemical and biological data that are necessary for the assessment of the status of the surface and groundwater bodies in each river basin district and constitute (in many cases) extensions or modifications of existing programmes (Legislative Decree 152/99). The Art. 8 of the WFD requires also the measurement of the volume and level or rate of flow to the extent relevant for ecological and chemical status and ecological potential. The hydrographical network of Candelaro watershed consists, on 2009, of nine automatic water level and stream-flow gauge. Daily data from these stations are already available for the period 1965-1996 (Fig. 12). For the last decade, there are only data for the water levels because the wetted cross sections used for the calculation of the daily water discharge changed and the new cross sections were not detected.

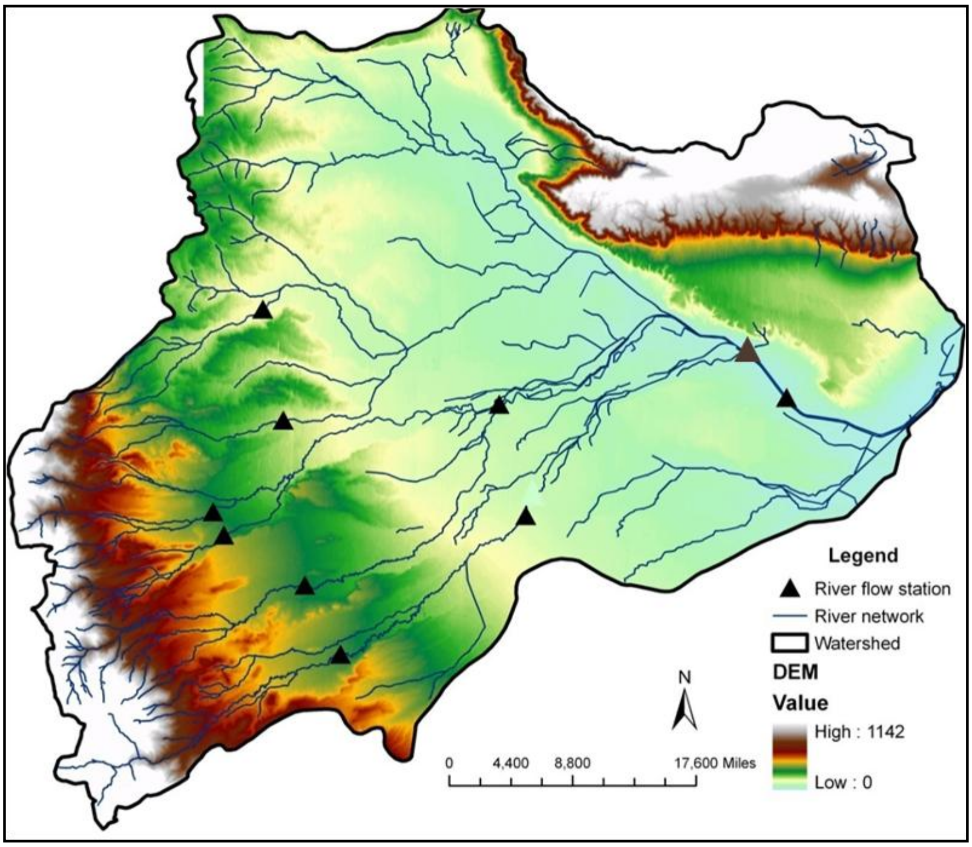


Figure 12: Monitoring network of river flow.

The monitoring programme for surface waters, established by the Apulia Region Authority according to the Italian decrees, is direct by the Regional Environmental Agency (Agenzia Regionale per la Protezione Ambientale - ARPA).

According to the L.D. 152/1999 and following decree 152/2006, the Candelaro River and its tributaries were classified as waters "suitable for fish life" (cyprinids), due to the presence of the National Park of Gargano and Protected Areas designated for protection of habitats or species as required by the Directive 79/409/EEC (OJ L 103, 25.4.1979, p. 1.).

The monitoring network for collection of the physical, chemical and biological data consists of 5 sampling points along the Candelaro River and Salsola and Celone affluent; where selected also 4 monitoring points for the assessment of the ecological condition of the water bodies. The sampling points were selected immediately after the confluence of the major tributaries (Fig. 13).

The water samples are collected manually and on monthly frequency, when the rivers present a "normal" flow. The parameters analyzed and the procedures adopted to collect them follow the criteria required by the L.D. 152/1999 and 152/2006. To asses if a water body status results suitable for fish life the Law require that some important parameters respect the maximum concentration limit, those parameters are: BOD5, COD, ammonia, nitrate, total phosphorus and also the limit for the Escherichia coli and oxygen dissolved.

The results of the investigations performed indicate that in the upstream part of the water body the water is suitable for fish life; however this suitability is soon lost as the downstream segments close to the sea.

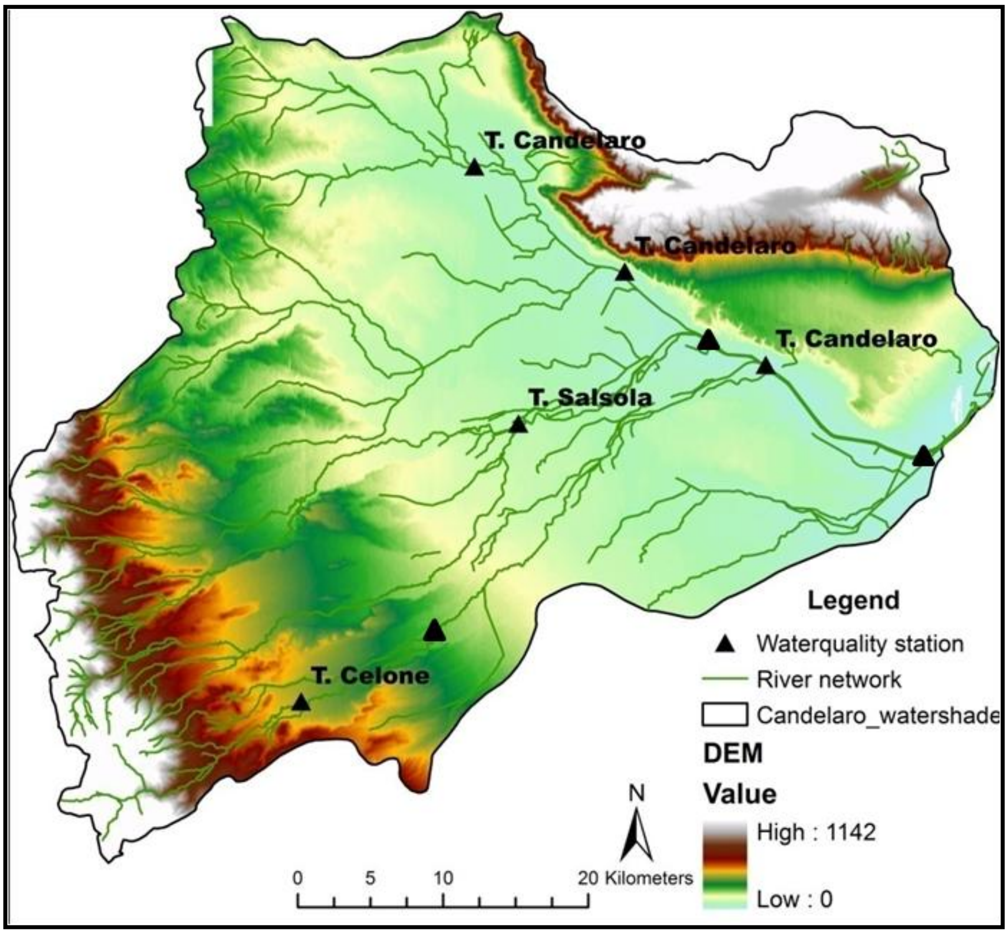


Figure 13: Surface water quality monitoring network.

The monitoring activities include also the assessment of the coastal water environmental status. Close to the Candelaro River outlet there is a monitoring point located in the Manfredonia Gulf (very close to the town of Manfredonia). From the analysis of the monitoring data, it has been established that the Manfredonia gulf waters are continuously characterized by low transparency. The gulf bottom waters, besides, present a considerable hypoxia. The monitoring data prove that the current status of the sea waters, close to the Candelaro River mouth, is not suitable for swimming.

The environmental status of water bodies, in Italy defined as "SACA" was conducted integrating the monitoring data with data arising from other sources, previously studies in possession of the Regional or other entities that have interests and influence on the waters.

The process for identifying the classification of the water body was determined following the Italian (L.D. 152/2006) and European Directive (WFD), defined in terms of certain parameters related to the natural status of water body or to the human impacts.

The SACA results obtained for the years 2005-2007, related to the three points monitored along the Candelaro main course, permits to define the environmental status between the range "low-very low", decreasing on 2007 (Piano di Tutela delle Acque - Regione Puglia, 2009).

Environmental Quality Objectives

The Candelaro River is expected to achieve by 2015 the objective of "good environmental quality" established by L.D. 152/2006 for all significant water bodies. However, due to the negative results of actual status, resulted from extensive human pressures, it is more realistic to expect that the Candelaro River achieve the intermediate objective of "sufficient quality", which would, in itself indicate the efficiency of the PTA proposed measures. This deviation is allowed by L.D. 152/2006.

Programme of Measures

Having identified, thanks to the preliminary knowledge acquisition phase, the pressures on the Candelaro river basin and the environmental quality objectives to be achieved, the PTA also describes a number of interventions and measures to be implemented to reach these objectives. The PTA also makes provisions for the undertaking of monitoring campaigns to

check the occurrence of significant impacts caused by its implementation and also for the checking of the achievement of the foreseen environmental sustainability objectives.
With reference, in particular, to the surface water the forecasted measures are:

1) *Minimum vital flow*: Measures to respect the minimum vital flow (DMV) downstream to the flow control works. These measures are based, among others, on the withdrawals control. The value of DMV of Candelaro River and its tributaries is estimated in the PTA equal to 0 l/s.
2) *Waste water treatment plants*: Measures are based on the check of the quality and quantity of the sewages sludge that enters the plants and on the quality of the products that exit from them. Another measure consists of the adaptation of the treatment technologies in order to decrease at least 75% the total nitrogen and the total phosphorus that exit from 11 treatment plants. This decrease has as final objective the reduction of the pollution load on the significant water bodies with particular reference to BOD5, COD, TN and TP.
3) The measures individuated for the reduction of point source loads from the WWTPs discharge permits to reduce the TN of about 40% and TP about 60%.
4) *Waste water collection and transport***:** Actions aimed at improving sewer working to collect waters to be directed towards the treatment plants of the basin are foreseen.
5) *Reuse:* The measure has the objective to reduce the load disposed on the basin area together with the replacement of the withdrawals from surface waters so to allow, among others, the maintenance of the DMV.
6) *Protection from agricultural nitrates*: The reduction of agricultural loads in the areas polluted by nitrates is foreseen thanks to the application of the Code of Good Agricultural Practices (CBPA) approved by the Ministerial Decree April the 19th 1999 and also thanks to the respect of the Regional action programs, mandatory for the water protection and the reclamation from nitrate pollution, according to the implementation of the Ministerial Decree of April the 7th 2006.
7) *Discharges:* The plan makes provision for the fulfillment of a registry of the discharges existing in the territory, for their control and the elimination of the not licensed ones.

Monitoring program

Environmental status: Monitoring activities also for the Triolo tributary; increase the monitoring water quality activities on Candelaro River and its tributaries; requirement of monitoring activities on water quantity.

Waters suitable for fish life: assessment of presence of fish species in the rivers and only after this investigation redefinition of rivers of segment that could be suitable for fish life.

Effectiveness of implementation: monitoring activities to assess the success of implementation of measures and the objective achieved.

CHAPTER 5 - WATER QUALITY MODELLING WITH THE SOIL AND WATER ASSESSMENT TOOL FOR TMDL

5.1 MODELS AS DECISION SUPPORT TOOLS FOR TMDL AND WFD

Models are often used to support development of TMDLs, typically to estimate source loading and evaluate loading capacities that will meet water quality standards. Hydrologic models are used o understand better and describe the physical system of a watershed.
The technical requirements of a TMDL stipulate that analysis should demonstrate that the allocation of point and nonpoint source loads would result in meeting water quality standards. The wording of the TMDL requirements also stipulates that WLA and LA must be separately defined. For modeling purposes, this requirements means that point and nonpoint sources must be evaluated as separate sources so that they can be simulated under various loading scenarios.
Once a pollutant enters the water body, then the entire system may undergo various changes and transformation depending upon the quantity and nature of the pollutant. This whole process of transformation and changes is very complex as it may involve various sub processes, reactions, mass transfer kinetics, degradation and resuspension etc. All these factors render water quality as non static both in temporal and spatial terms. Thus, to describe all these factors and link them together various water quality models are necessary for the development of TMDLs.

The WFD, setting the Environmental Objectives, requires relevant changes on watershed's management in Europe. The challenges introduced are very close to the TMDL programs and the use of mathematical models also for the implementation of the WFD can help to meet the objectives.
The assessment of current status is a preliminary step before to develop a River Basin Management Plan (RBMP), the evaluation of gaps with the objective of Directive permit to specify the measures to be implemented.
The data scarcity is a diffuse problem in the European States where a monitoring program was absent before the Directive. Few years of quality samples permit to define the status of a water bodies but are not enough to analyze the gaps with the environmental objective and

setting up a *Program of Measures* to restore waters, controlling the pollution at sources. The Directive requires not only good scientific practice to measure quality and quantitative status of waters but also the understanding of the effect of changing pressures, including seasonal, on that status.

Many studies prove that models are useful tool to assist in the understanding of hydrological and chemical transport and processes that occur in catchments, to understand the response to anthropogenic alterations that affect them and also to evaluate the effect of scenarios. Irvine et al. (2005) investigate the need to apply mathematical model to assist policy and implement the WFD and confirm that the use of model is indisputable.

In this study the watershed loading/water quality model, Soil and Water assessment Tool (SWAT) (Arnold et al., 1998) was used to investigate the hydrologic processes, to assess the actual water quality status of Candelaro River and finally to quantify the efficiency of some measures individuate in the Program of Measures developed by the River Basin Authority of Apulia Region, defined without any evaluation of their effectiveness to reach the objectives.

The SWAT model was also applied to evaluate nutrient TMDLs for Candelaro River; it operates on a basin-scale and on a daily time step; it is designated to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods (Gassman et al., 2007).

5.2 THE SOIL AND WATER ASSESSMENT TOOL (SWAT)

SWAT is a distributed hydrologic model. Distributed hydrologic models allow a basin to be broken into many smaller subbasins to incorporate spatial detail. Water yield and loading are calculated for each subbasin, and then routed through a stream network to the basin outlet.

In the U.S., SWAT is increasingly being used to support Total Maximum Daily Load (TMDL) analyses; it is also indicated in the guidelines to model selection for the development of a TMDL .

It is a continuation of nearly 30 years of modeling development conducted by the USDA Agricultural Research Service (ARS) (Gassman et al., 2007). A large number of applications across the globe prove the efficiency of SWAT model to predict the hydrologic and nutrients processes in many different watershed, ranging from small to large scale, dominated by agricultural areas. SWAT is continuing reviewed, the latest version is the SWAT2005, a theoretical documentation and a user's manual help to understand all the modification and improvements (Neitsch et al, 2005). This version is supported by the interface tools of ArcGIS 9.3 (ArcSWAT) that helps to input the geographic information (digital elevation model, land use, soil type, etc.) and uses a geodatabase approach. The SWAT2005 includes also an automated calibration, sensitivity and uncertainty analysis component that use a Latin hypercube (LH) OAT sampling method (van Griensven et al. 2006).

A key strength of SWAT is a flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer/manure application rate and timing, cover crops (perennial grasses), filter strips, grassed waterways, and wetlands. However, there are limitations in how these practices are represented in the model, and some practices such as riparian buffer zones cannot be directly simulated at the present time. SWAT has been incorporated into the AgriBMPWater modeling system to evaluate different agricultural BMPs in eight watersheds in five European countries (Turpin et al., 2005).

In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the subwatershed area and are not identified spatially within a SWAT simulation. Alternatively, a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management.

Hydrology of the SWAT model

To simulate hydrological processes, SWAT is using a water balance. The simulation of the water balance, as well as the pollutant balances can be separated into two major items. The first item is the land phase of the hydrologic cycle which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel of each subbasin. The second item is the routing phase of the hydrologic cycle. This phase can be defined as the movement of the water, sediment, etc. through the channel network of the watershed to the outlet of the watershed (Neitsch et al., 2005).

Land phase of the hydrological cycle

The land phase of the hydrological cycle is based upon the water balance (see equation 1, Neitch et al., 2005). Processes simulated include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation.

SWAT divides groundwater into two aquifer systems, a shallow unconfined aquifer which contributes to the return flow and a deep and confined aquifer that, besides pumping is disconnected from the system.

A distributed Soil Conservation Services (SCS, 1972; now Natural Resources Conservation Service) curve number is generated for the computation of overland flow runoff volume, given by the standard SCS runoff equation (USDA, 1986). The curve number method is empirically based and relates runoff potential to land use and soil characteristics. The curve number method combines infiltration losses, depression storage, and interception into a potential maximum storage parameter called *S*.

The curve number indicates the runoff potential of an area for the combination of land-use characteristics and soil type. Curve numbers are a function of hydrologic soil group, vegetation, land use, cultivation practice, and antecedent moisture conditions. The SCS has classified more than 4,000 soils into 4 hydrologic soil groups according to their minimum infiltration rate for bare soil after prolonged wetting. The amount of moisture present in the soil is known to affect the volume and the rate of runoff. Consequently, the SCS developed three antecedent soil moisture conditions: Condition I, Condition II, and Condition III. Dryer antecedent conditions (C I) reflect soils that are dry but not to the wilting point. Wetter conditions (Condition III) characterize soils that have experienced heavy rainfall, light rainfall and low temperatures within the last 5 days, or saturated soils. Condition II is known as the average condition.

Curve numbers are updated daily as a function of initial soil moisture storage. A soil database is used to obtain information on soil type, texture, depth, and hydrologic classification.

Infiltration is defined in SWAT as precipitation minus runoff. Infiltration moves into the soil profile where it is routed through the soil layers. A storage routing flow coefficient is used to predict flow through each soil layer, with flow occurring when a layer exceeds field capacity. When water percolates past the bottom layer, it enters the shallow aquifer zone (Arnold et al., 1993). Channel transmission losses and pond or reservoir seepage replenishes the shallow aquifer while the shallow aquifer interacts directly with the stream. Flow to the deep aquifer system is effectively lost and cannot return to the stream (Arnold et al., 1993).

Based on surface runoff calculated using the SCS runoff equation, excess surface runoff not lost to other functions makes its way to the channels where it is routed downstream.

Routing phase of the hydrological cycle

Once SWAT determines the loadings of water, sediments, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed. As water flows downstream, a part may be lost due to evaporation and transmission through the bed of the channel. Another potential loss of water is through utilization for agricultural or human purposes. Flow may be supplemented by rainfall directly on the channel and addition of water from point source discharges. The rate and velocity of flow is calculated with the Manning's coefficient equation.

Flow is routed through the channel using the variable storage routing method or the Muskingum method, both methods are variation of kinematic wave model.

The variable routing storage method was developed by Williams (1969) that consider the variation of volume of storage during the time step, derived from the variation of inflow rate and outflow rate.

The Muskingum method is a hydrologic routing method that is based upon a variable discharge-storage relationship. This method models the storage volume of flooding in a river channel by a combination of wedge and prism storage.

When a flood wave advances into a reach segment, inflow exceeds outflow, producing a wedge of storage. During the recession, outflow exceeds inflow in the reach segment, resulting in a negative wedge. In addition to wedge storage, there is a prism of storage that is formed by a volume of constant cross-section along the length of the prismatic channel (Neitsch et al., 2005).

The volume of outflow of a reach is calculated accounting also the total losses, which are represented mainly by: transmission losses through the bed for intermittent and ephemeral stream and by evaporation.

Water quality modelling with SWAT

The ability to simulate in-stream water quality dynamics is a definite strength of SWAT (Gassman et al, 2005).

As in the part about the hydrology, the water quality module of SWAT can be separated into two major items. The catchment or land phase model calculates the mass flows as they travel along the land phase to the receiving water body. Pollutants, originating from the land phase are generally called non-point or diffuse sources.

The in-stream water quality model is responsible for the in-stream transformations and the determination of the water quality status of the stream as well as for the integration of all contributors of the catchment or land phase model to the river and the contribution of the point sources.

Land phase water quality modelling

The catchment or land phase model simulates the runoff of water and entrained pollutants from the land area to the receiving water body. Rainfall-runoff processes are the main processes of the land phase water quality model.

Processes affecting oxygen household

a) Carbonaceous Biochemical Oxygen Demand (CBOD)

Carbonaceous biochemical oxygen demand (CBOD) defines the amount of oxygen required to decompose the organic matter transported in surface runoff. Thus, oxygen demand for oxidation of ammonia does not contribute to CBOD.

b) Dissolved oxygen (DO)

To determine the dissolved oxygen concentration of the surface runoff, the oxygen uptake by the oxygen demanding substances in runoff is subtracted from the saturated oxygen concentration (Neitsch et al., 2005). Rainfall is assumed to be saturated with oxygen.

In SWAT no ammonia nitrogen originates from overland flow. Ammonia binds tightly to soil particles and does not leach into groundwater unless it is first oxidized to nitrate which is highly soluble and does not bind to the soil.

Nutrients

The transport of nutrients in the watershed depends on the transformations the compounds undergo in the soil environment. SWAT models the nutrient cycles for nitrogen and phosphorus. In large subbasins with a retention time larger than one day, only a portion of the surface runoff and lateral flow will reach the main channel on the day it is generated. SWAT incorporates a storage function to lag a portion of the surface runoff, lateral flow and the nutrients they transport (Neitsch et al., 2005).

a) Nitrogen

The three major forms of nitrogen in mineral soils are organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids and mineral forms of nitrogen in solution. Nitrogen may be added to the soil by fertilizer, manure or residue application, fixation by bacteria and rain. Nitrogen is removed from the soil by plant uptake, leaching, volatilization, denitrification and erosion (Neitsch et al., 2005).

SWAT monitors 5 different pools of nitrogen in the soil. Two pools are inorganic forms of nitrogen: NH4+ and NO3-. The other 3 pools are organic nitrogen forms. Fresh organic nitrogen is associated with crop residue and microbial biomass while the active and stable organic N pools are associated with the soil humus. The organic nitrogen associated with the soil humus is partitioned into 2 pools to account for the variation in availability of humic substances to mineralization (Neitsch et al., 2005).

Plant use of nitrogen is estimated using the supply and demand approach where the daily plant nitrogen demands are calculated as the difference between the actual concentration of the element in the plant and the optimal concentration. In addition to plant use, nitrate and organic N may be removed from the soil via the water fluxes. Amounts of nitrate contained in runoff, lateral flow and percolation are estimated as products of the volume of water and the average concentration of nitrate in the layer. Organic N transport with sediment is calculated with a loading function, estimating daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil (van Griensven, 2002).

b) Phosphorus

The 3 major forms of phosphorus in mineral soils are organic phosphorus associated with humus, insoluble forms of mineral phosphorus and plant-available phosphorus in soil solution. In SWAT, phosphorus can be added to the soil by fertilizer, manure or residue application. Phosphorus which is present in the soil through sorption processes is removed from the soil by plant uptake and erosion. Figure 8 shows the major components of the phosphorus cycle in SWAT. Unlike nitrogen which is highly mobile, phosphorus solubility is limited in most environments.

SWAT monitors 6 different pools of phosphorus in the soil. Three pools are inorganic forms of phosphorus while the other three pools are organic forms of phosphorus. Fresh organic P is associated with crop residue and microbial biomass while the active and stable organic P pools are associated with the soil humus. The organic phosphorus associated with humus is partitioned into two pools to account for the variation in availability of humic substances to mineralization. Soil inorganic P is divided into solution, active and stable pools. The solution pool is in rapid equilibrium (several days or weeks) with the active pool. The active pool is in slow equilibrium with the stable pool (Neitsch et al., 2005).

Plant use of phosphorus is estimated using the supply and demand approach where the daily plant phosphorus demands are calculated as the difference between the actual concentration of the element in the plant and the optimal concentration. In addition to plant use, soluble phosphorus and organic phosphorus may be removed from the soil via the water fluxes. Because phosphorus is not very soluble, the loss of phosphorus dissolved in surface water is based on the concept of partitioning phosphorus into a solution and a sediment phase. The amount of soluble phosphorus removed in runoff is predicted using labile concentrations in the top 10 mm of the soil, the runoff volume and the partitioning factor. Sediment transport of phosphorus is simulated with a loading function similar to organic N transport (van Griensven, 2002).

In-stream water quality modeling

The most widely known and used software model for river quality modelling is the QUAL2E model developed by the U.S. Environmental Protection Agency. The in-stream water quality algorithms of the SWAT model incorporate constituent interactions and relationships used in the QUAL2E model (Neitsch et al., 2005).

The QUAL2E model includes the major interactions of the nutrient cycles, algal production, benthic and carbonaceous oxygen demand, atmospheric reaeration and their effect on the dissolved oxygen balance. In addition, the model includes a heat balance for the computation of temperature and mass balances for conservative minerals, coliform bacteria and non-conservative constituents. Chlorophyll a is modelled as the indicator of planktonic algae biomass in QUAL2E.

The nitrogen cycle is composed of four compartments: organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. The phosphorus cycle is simpler, having only two compartments. Carbonaceous biochemical oxygen demand is modelled as a first order degradation process in QUAL2E, which also takes into account removal by settling.

The major source of dissolved oxygen, in addition to that supplied from algal photosynthesis, is atmospheric reaeration (Puttemans, 2005).

More detailed information on the in-stream water quality algorithms of the SWAT model can be found in Neitsch et al. p 387-412 (2005).

Data Inputs

Spatial dataset

Since SWAT is categorized as a distributed model, it needs spatially distributed properties and processes within the boundaries of the watershed. This model's characteristic determines the use of geospatial data as the main source of its input. Most of the parameters that populate the text files have a spatial component. Therefore, the use of Geographic Information Systems (GIS) proves to be a valid tool for analysis and calculation of the required input parameters. Thus, the elements that constitute the three levels of parameterization can be defined spatially using GIS technology and spatially distributed data. Watershed and subbasins can be delineated spatially performing an analysis over a Digital Elevation Model (DEM). A DEM is based on an array of square cells that models the topography of the system. Each cell has the value of the elevation of the terrain at its center. Data that follows a distributed pattern of square cells containing numeric or coded information is called raster data.

Digital soil and land use are required to create the Hydrologic Response Units or HRUs representing unique land use/soil/slope combinations for each subbasin. The ArcSWAT interface permits to choose a single or multiple slope class.

Climatic Inputs and HRU Hydrologic Balance

Climatic inputs used in SWAT include daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity, and wind speed data, which can be input from measured records and/or generated. Relative humidity is required if the Penman-Monteith (Monteith, 1965) or Priestly- Taylor (Priestly and Taylor, 1972) evapotranspiration (ET) routines are used; wind speed is only from deep-rooted plants (termed "revap") can occur from the shallow aquifer. Water that recharges the deep aquifer is assumed lost from the system.

Cropping, Management Inputs, and HRU-Level Pollutant Losses

Crop yields and/or biomass output can be estimated for a wide range of crop rotations, grassland/pasture systems, and trees with the crop growth submodel. New routines in SWAT2005 allow for simulation of forest growth from seedling to mature stand. Planting, harvesting, tillage passes, nutrient applications, and pesticide applications can be simulated for each cropping system with specific dates or with a heat unit scheduling approach. Residue and biological mixing are simulated in response to each tillage operation. Nitrogen and phosphorus applications can be simulated in the form of inorganic fertilizer and/or manure inputs. An alternative auto fertilizer routine can be used to simulate nitrogen applications, as a function of nitrogen stress. Biomass removal and manure deposition can be simulated for grazing operations. SWAT2005 also features a new continuous manure application option to reflect conditions representative of confined animal feeding operations, which automatically simulates a specific frequency and quantity of manure to be applied to a given HRU. The type, rate, timing, application efficiency, and percentage application to foliage versus soil can be accounted for simulations of pesticide applications.

Selected conservation and water management practices can also be simulated in SWAT. Conservation practices that can be accounted for include terraces, strip cropping, contouring, grassed waterways, filter strips, and conservation tillage. Arabi et al. (2007) present standardized methods for simulating these and other practices (see additional discussion in the SWAT Strengths, Weaknesses, and Future Research Directions section). Simulation of irrigation water on cropland can be accomplished based on five alternative sources: stream reach, reservoir, shallow aquifer, deep aquifer, or a waterbody source external to the watershed. The irrigation applications can be simulated for specific dates or with an auto-irrigation routine, which triggers irrigation events according to a water stress threshold.

The preprocessing phase

The new interface and geodatabase ArcGIS SWAT (2005) was used to input the spatial data and soil, crop personal database for creating the SWAT input text files. The creation of the input files for the SWAT model follows the next processes: watershed delineation, HRU distribution, weather definition, and writing and editing SWAT input.

The postprocessor phase consists of viewing graphical and tabular results. The export of data from GIS to the SWAT model and the return of results for display are accomplished by Avenue routines addressed directly by the interactive tools of GIS and the exchange of data is fully automatic.

Watershed delineation

Subbasins*:* The main input data required for the watershed delineation are: Digital Elevation Model (DEM); digitized stream network (used for burning operation) and subbasins outlet location tables (recommended to compare measured and simulated data).

The DEM was created from 87 ASCII files converted into raster format. The data was provided by the Apulian river Basin Authority. The tiles have a size of 40 m cell.

The Land Use data used for this case study is a part of the National Italian Project finalized to realize a Geographic Information System for Water Resources Management in Agriculture (SIGRIA). The National Institute of Agricultural Economics (INEA) has collected data on irrigation infrastructure and on crop water requirements in all the Southern Italy Regions, Land Reclamation and irrigation Consortium (Italian administrative structure for irrigation water management). The land use map has an accuracy of 1:50.000 scale. The classification system relies on the 4th level of CORINE Land Cover 2000. The discretization of this map permitted to identify the area covered with irrigated crops.

The land use map and soil database derive from a European Project (P.O.P. – Misura 4.3.6), the ACLA 2 Project which aimed at agro-ecological characterization of the Apulia Region (Southern Italy) through the assessment of potential agricultural productivity. The ACLA 2 project was coordinated by the Mediterranean Agronomic Institute of Bari (CIHEAM/MAI-Bari) and the Agricultural University of Bari (Institute of Agronomy) and it was financed by the European Union funds and the Apulia region.

The ACLA 2 project uses a number of soil information (maps) realized within the frame of ACLA 1 project (the previously project) and other investigations on soil characteristics of the region. The spatial data and the primary soil attributes of these maps are stored in coverages created and maintained by ArcInfo. Actually, soil database includes already created data sets: preliminary polygonal soil coverage of the ACLA 1 (PEDA1), point soil samplings sites of the ACLA 1 project (PEDA1P), point reference soil sites (PEDREF), and point soil sampling sites of the ACLA 2. Development of the regional soil map is being supported through the 5000 soil samplings including about 4000 drilling samplings, 500 soil profiles and 500 observations. Soil physical and chemical properties of each series of data are analyzed in laboratory and stored in two MS Access dbf files pertaining to site and horizons information. The locations of sampling sites are digitized as a point features in ArcInfo where site's soil physical and chemical characteristics are associated to geographic information. Soil data set provides identification of the soil taxonomy classes in the Apulia region including detailed information about soil characteristics according to Soil taxonomy (1994). The final product of soil database was the regional soil map in the scale 1:100,000 (Todorovic et al., 1998). The soil map for the Candelaro watershed was clipped from the Regional map; the characteristics of 33 soil samples collected in the watershed area were used to create the personal soil database of SWAT. The soil profiles were analyzed in order to define the physical and hydrological characteristics of each soil layer. A special software tool (Saxton 2007), based on soil texture, organic matter, and gravel content, was used to estimate soil properties such as hydraulic conductivity and water holding capability. The soil map in figure 14 shows the location of soil samples collected in the study area during the Projects ACLA 1-2.

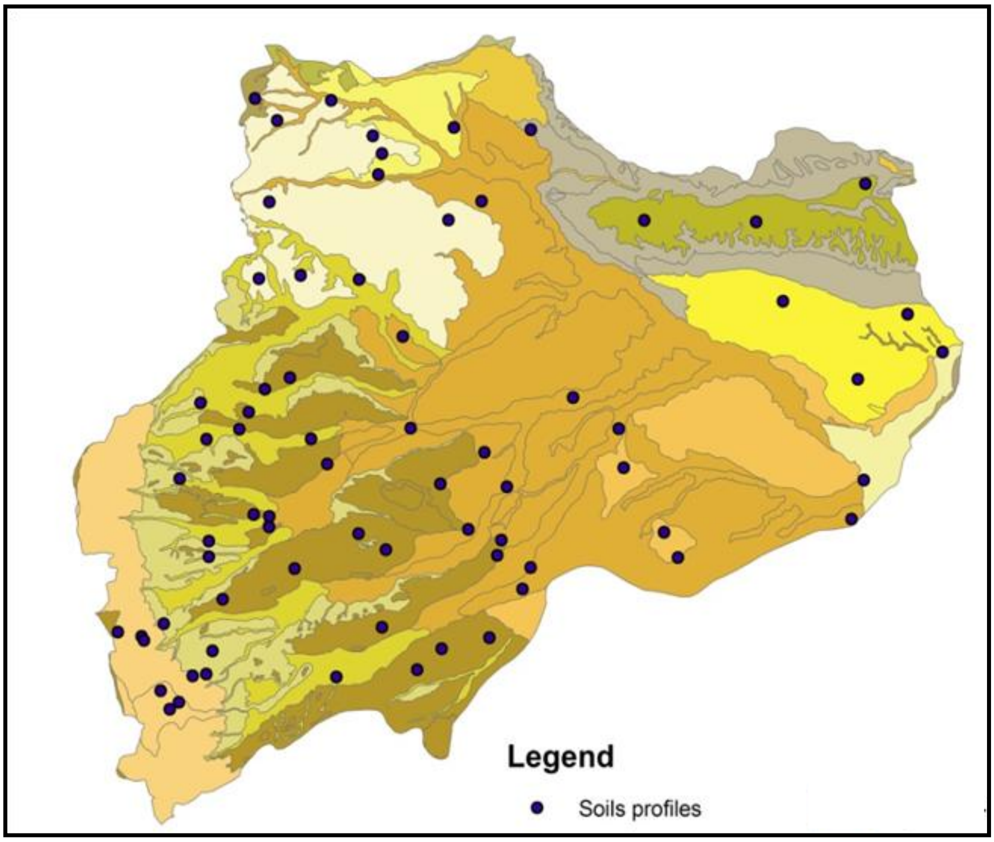


Figure 14: Soil maps and soil samples coordinate (Project ACLA2).

Watershed delineation results

The study area was divided using SWAT into 55 sub-basins (Fig. 15), corresponding to a critical source area of 39 km^2, the minimum drainage area required to form the origin of a stream. This type of spatial subdivision process was chosen in order to consider the most complete climatic, soil and land use data available. In order to exclude minor types of land use and soil, a threshold level was selected for each sub-basin of 5 percent and 10percent, respectively and 50 percent of slop class. Given these thresholds, 390 HRUs were created.

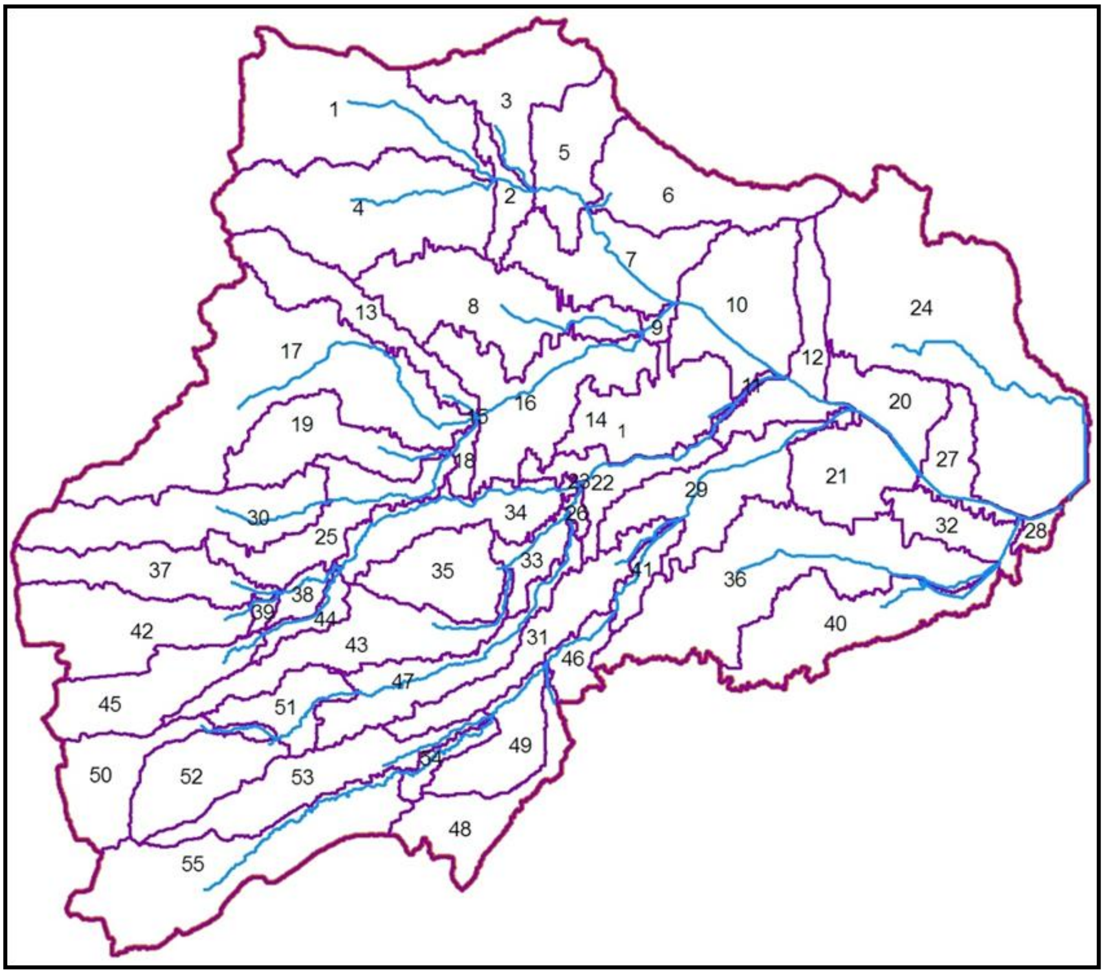
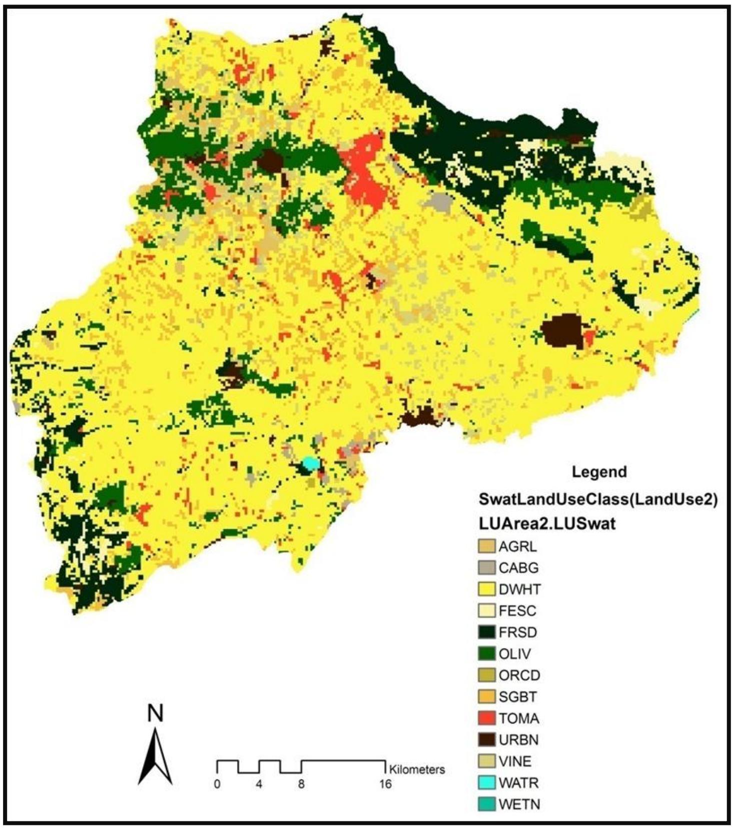


Figure 15: Subbasin delineation of Candelaro watershed.

Land use

The ArcSWAT interface executes the clip operation in which the land use dataset is cut using the basin boundary. A reclassification was made over this dataset in order to assign the SWAT land use codes. Figure 16 shows the SWAT land use map with the SWAT class codes; the table (Fig. 16) reports the land use reclassification and the coverage percentage of each crop class in the whole area of Candelaro watershed.



LANDUSE	% Area
Agricultural Land-Generic --> AGRL	1.75
Cabbage --> CABG	0.72
Durum Wheat --> DWHT	61.99
Tall Fescue --> FESC	1.62
Forest-Deciduous --> FRSD	8.91
OLIVO --> OLIV	8.14
Orchard --> ORCD	0.36
Sugarbeet --> SGBT	6.88
Tomato --> TOMA	3.49
Residential --> URBN	1.99
VITE --> VINE	4.02
Water --> WATR	0.08

Figure 16: Land use map for Candelaro watershed with SWAT class legend and table of SWAT land use classification with coverage percentage of each crop class.

Soils definition

The soil map was reclassified using the soil type (ACLA2) edited in SWAT database (Fig 17). According to the U.S. Natural Resources Conservation Service (NRCS) classification of soils, the major soil series in the basin fall within hydrological groups C and D with moderate to low drainage properties.

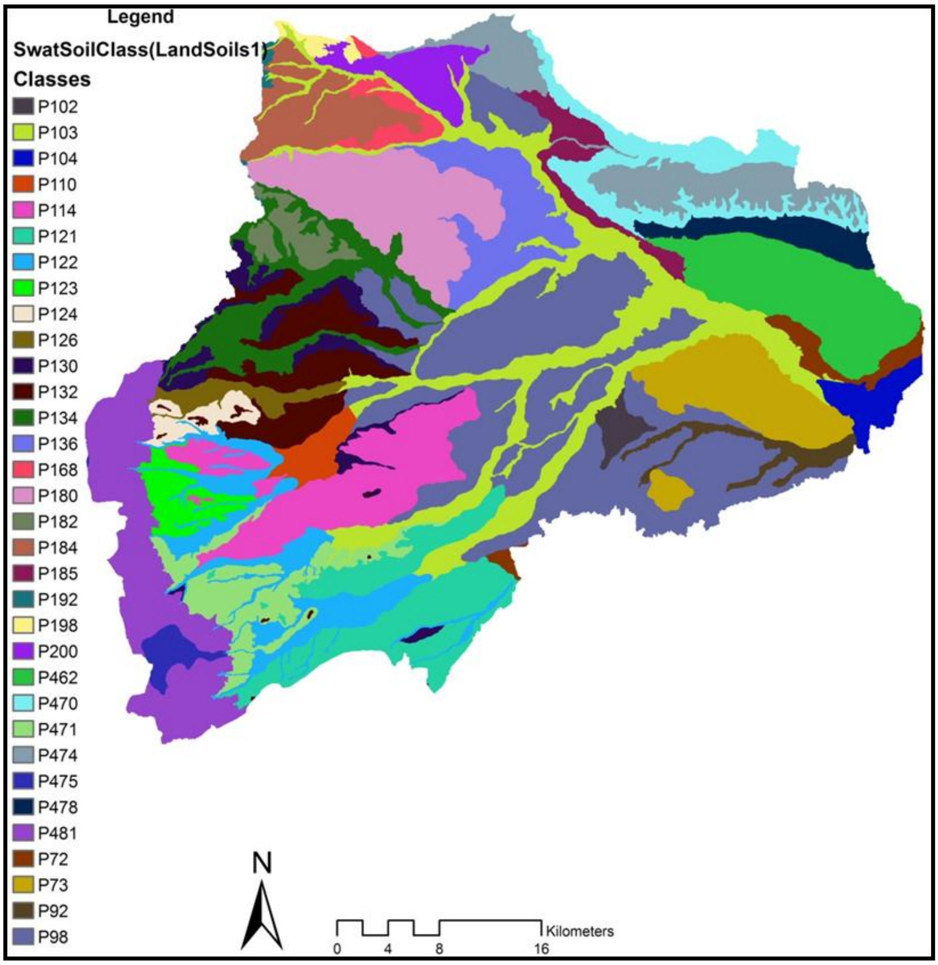


Figure 17: SWAT soil map reclassified with the personal soil database.

Climatic data

For this case study, daily precipitation data were obtained from 10 rainfall stations; while the minimum and maximum daily temperature are recorded data of 7 weather stations, provided by the Hydrographic Regional Office of Apulia region. Precipitation and temperature data was provided in the specific format required by SWAT. The rest of the meteorological information was chosen to be simulated by the SWAT weather generator based on a weather station database that has more than 20 years of record.

Emission data

Point sources

Files containing the point sources loads are created by the user. These files are free format files and have the extension ".dat". Flow and pollutant loads are routed through the channel network by use of the watershed configuration file (fig.fig) (Neitch et al., 2004).

In SWAT only one point source can be added in each subbasin, point sources are added at the end of the subbasins reach. Hence, the routing and associated processes of the imported pollutants only start in the subbasin downstream.

Four options/commands are available to read in point sources in SWAT: RECDAY, RECMON, RECYEAR, RECCNST. For all options, the same units are used. In RECDAY, daily measurements are read-in; RECMON and RECYEAR reads in average daily load for the month, respectively the year. RECCNST requires average daily load for the year. When modelling a longer time period, RECCNST reads in average values over the whole period (so constant values all years), whereas in RECYEAR the yearly averages can be read in. For this case study average daily data of WWTPs discharges were used so the RECDAY input data were added from the SWAT interface.

The data input required by SWAT for point source input are: flow, sediment, organic N, organic P, NO2-, NO3-, NH4+, mineral P and BOD for each point source. Point sources need to be added in SWAT as loads in kg/d (except for sediment in ton/d) instead of concentrations. Concentrations were multiplied with flow to become daily loads.

Diffuse source

All management operations, such as fertilizer application, planting, sowing, harvesting and irrigation were imputed in the SWAT interface creating the management files ".mgt" for each crop. The information were collected from local farmers interview and from the assistance services of "Consorzio di Bonifica della Capitanata" the local institution in charge of Operation, Management & Maintenance activities.

The post processing phase

After the watershed configuration and the set up of the model, SWAT runs can be performed. Model simulation was run from 1987 to 2004, related to the availability of measured weather data; three years were skipped from the output results, in order to define the initial conditions for parameters such as soil moisture and aquifer depths within the model.

The SWAT setup phase, before to launch the run, permits to configure some important equation and method that the model permits to choose, the following list reports what was settled for this study:

- Rainfall/Runoff/Routing configuration shows that were chose a rainfall input on a daily basis; SCS Curve number as the method for calculating runoff and a daily routing of the water in the system.
- The daily Curve Number calculation method chose is the plant evapotranspiration method.
- Potential Evapotranspiration was calculated using the Hargreaves method.
- The variable travel-time method was used for routing the water along the stream channels.

Results

Before to start the calibration processes was investigated if the average yield simulated of each crop present in the area was similar to the real production. The results were compared with the data published by the Italian National Statistic Institute (ISTAT).

Another important result that was investigated, before to proceed with the calibration, was the Potential Evapotranspiration (ETp). The annual and monthly values obtained with the SWAT model were compared with the values published by Food and Agriculture Organization of the United Nations (FAO) for the study area.

Although the SWAT model is physically based, there are some model parameters/variables that are either not well defined physically. These parameters (e.g. curve number) can be adjusted within the practical range to fit the model predicted and measured values at specific locations. Before to adjust the parameters was launched the “Sensitivity analysis” for the hydrologic parameters from the SWAT (2005) interface. The Latin-Hypercube-One-factor-At-a-Time (LH OAT) design (van Griensven et al., 2006) has been incorporated as part of the automatic sensitivity/calibration package included in SWAT2005. This method provides a ranking list for the importance of the parameters on model outputs. Table 5 provides a list of parameters that were considered in the analysis, their definitions and rank. The suggested range of model parameters were obtained from the SWAT users’ manual (Neitsch *et al.*, 2005).

Parameter	rank
Curve Number (CN)	**1**
Soil available water (AWC)	**2**
Soil depth	**3**
Soil evaporation compensation factor (ESCO)	**4**
Satured hydraulic conductivity	**5**
Maximum canopy storage	**6**
Average slope steepness	**7**
Snow fall temperature	**8**
Snow melt base temperature	**9**
Maximum melt factor for snow	**10**

Table 5: Sensitivity analysis result for hydrologic parameters.

The hydraulic parameters that show significant effect on daily stream flow of this simulation are the Curve Number, the soil available water soil depth, soil evaporation compensation factor and satured hydraulic conductivity.

The parameter sensitivity analysis provides insights on which parameters contribute most to the output variance due to input variability. Based on this information, a calibration can be performed for a limited number of influential parameters. A manual calibration procedure was followed by the run of the calibrated project with the autocalibration tool incorporated in ArcSWAT2005.

Calibration

In the calibration process, simulated values are compared with observed values to become simulations witch match better to the actual situation. Calibrations must be performed for flow as well as for water quality. To achieve a better fit, the model needs to be conditioned by optimising its internal parameters. Calibration can be performed manually or can be automated. As manual calibration is carried out by a human person, success of calibration depends on the knowledge, experience and patience of the performer. Automated calibration is conducted by computer programs which make multiple model simulations using different parameter values in the different simulations.

Model simulation was run from 1987 to 2004, related to the availability of measured weather data; three years were skipped from the output results, in order to define the initial conditions for parameters such as soil moisture and aquifer depths within the model.

SWAT was calibrated for daily discharge using the stream flow records from 2 gauging station of two tributaries of Candelaro River, for the period 1990-1991 for Celone flow station and for the years 1990 -1992 for Salsola station. The model was then validated for the period 1994 -1996 for Celone station and 1995-1996 for Salsola station. The 1996 is the last year of recorded data actually available in the entire watershed. The drainage area at Celone station is 84 Km^2, at Salsola station is 433 Km^2 (Fig. 18). The recorded flow data (1971) at Candelaro station were used to investigate the annual hydrologic balance and calculate the baseflow contribution.

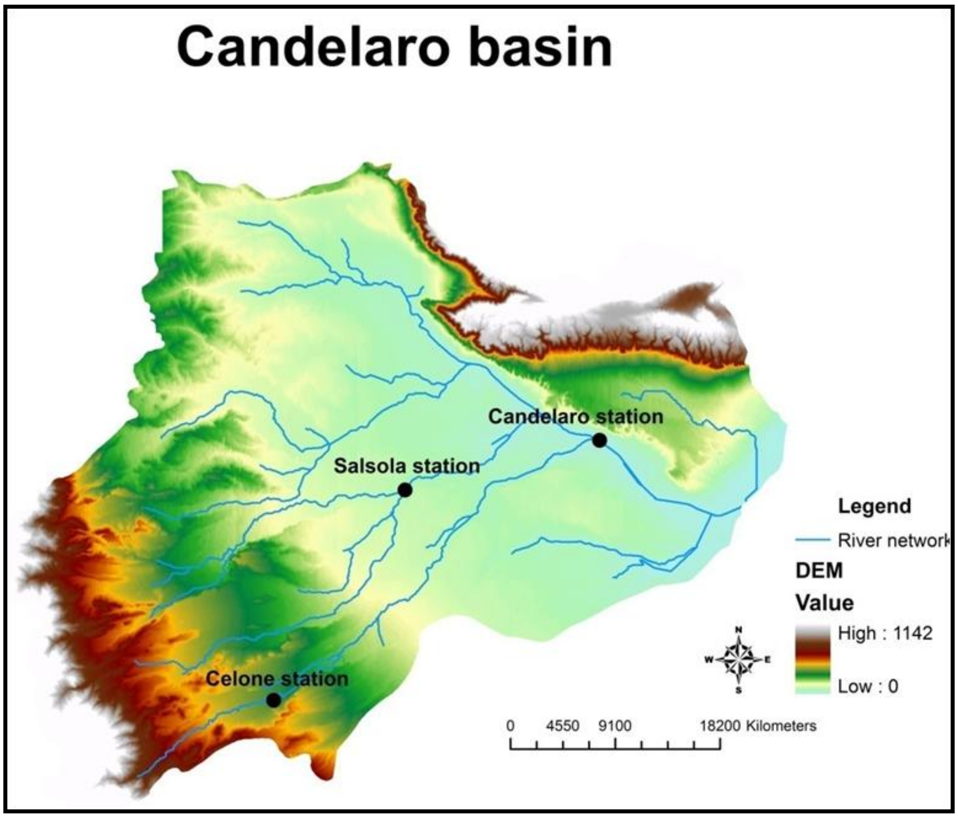


Figure 18: Flow gauge stations used for the calibration and validation period.

An automated digital filter technique (Arnold et al., 1995) was used separately for the observed and simulated daily flow at Candelaro, Celone and Salsola stations, for base flow separation and estimating the proportion of the base flow.

The 18 years of simulation permitted to simulate and evaluate the model under a wide range of climatic conditions.

In the manual calibration, parameters influencing baseflow and surface flow were optimized. Mainly the curve number and the groundwater parameters were adjusted until the annual total water yield simulated was similar to the measured. To reduce the number of parameters that will be calibrated, the above-mentioned ranking of influential parameters was used.

After the manual calibration done for water balance and streamflow on yearly basis at Celone and Salsola station, including a realistic fraction of baseflow contribution; the automated calibration was runned in order to obtain acceptable daily results.

The accuracy of SWAT model to predict the discharge during the calibration and validation period was evaluated according to the recommended hydrologic model evaluation, graphically and statistically; in particular Nash and Sutcliffe Efficiency (NSE) (Nash and Suttcliff, 1970) and coefficient of determination, R^2 (Moriasi et al., 2007) were computed.

The r^2 measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted dispersion equals the measured dispersion (Krause et al., 2005). The regression slope and intercept also equal 1 and 0, respectively, for a perfect fit; the slope and intercept are usually not reported for most studies.

The NSE ranges from $-\infty$ to 1 and measures how well the simulated versus observed data match the 1:1 line (regression line with slope equal to 1). An NSE value of 1 again reflects a perfect fit between the simulated and measured data. A value of 0 or less than 0 indicates that the mean of the observed data is a better predictor than the model output (Nash and Suttcliff, 1970).

Measured and simulated daily flow for the calibration and validation period at Celone and Salsola station matched well (Fig. 19 - 22). Visual inspection indicates that SWAT model is able to predict well the presence of flow, the peaks, the baseflow and the absence of flow. Some years the simulated flow misses out some peaks particularly at Celone station. Those results can be attributed to the missing data that affect the rainfall dataset or to the large variability in rainfall distribution and amount, strongly influenced by orographic aspects that are typical of this watershed (Lo Presti et al., 2008).

The NSE values obtained at both station, for calibration and validation period permit to accept the model performance as satisfactory. The correlation value (R^2) shows values higher than 0.5 (Fig. 19 - 22) that are considerate acceptable in others publications (Moriasi et al., 2007).

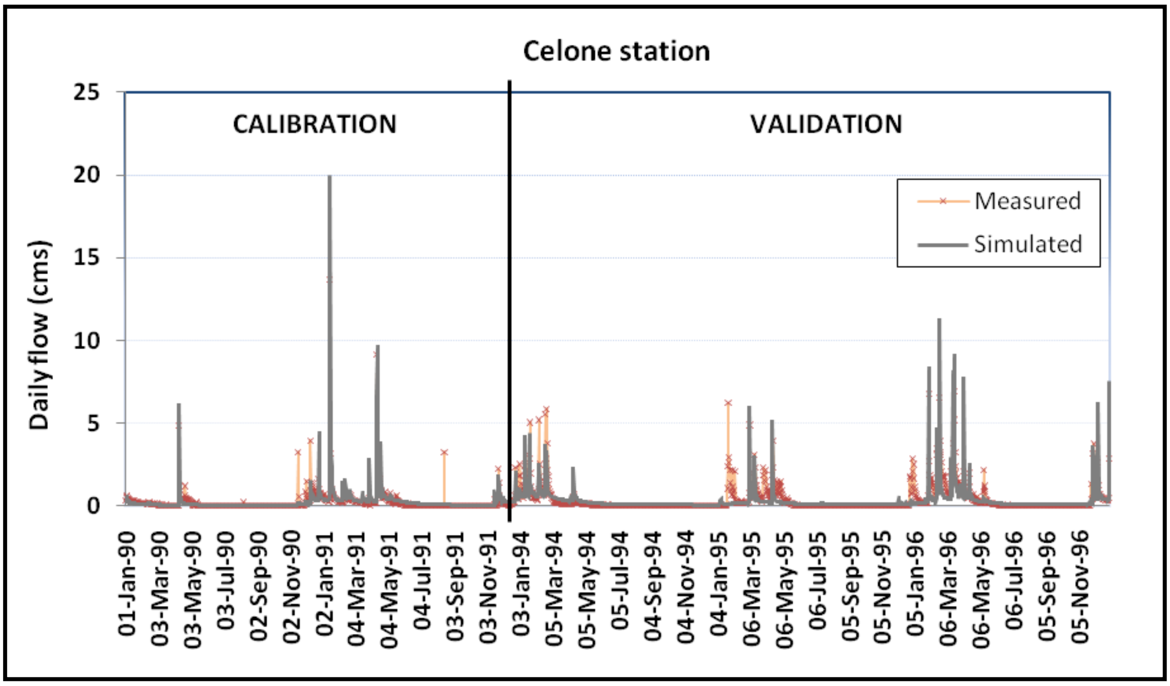
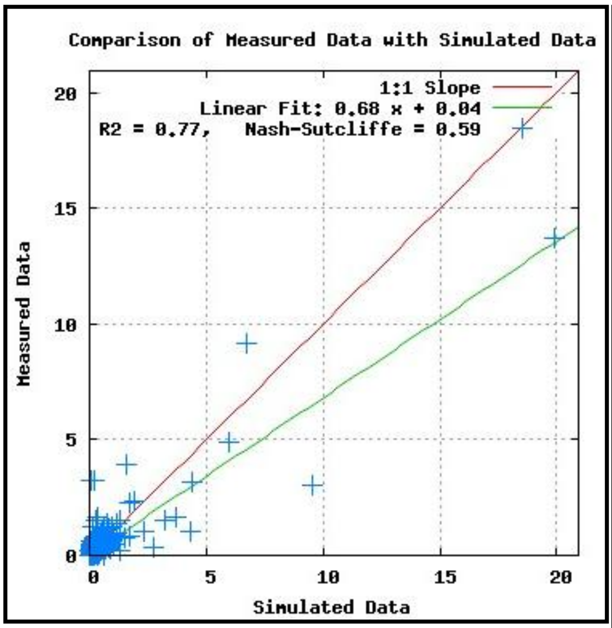


Figure 19: Simulated and measured daily flow (cms) at Celone station. Calibration (1990-1991): NSE=0.59; R2=0.77. Validation (1994-1996): NSE=0.48; R2=0.53.

Calibration at Celone station



Validation at Celone station

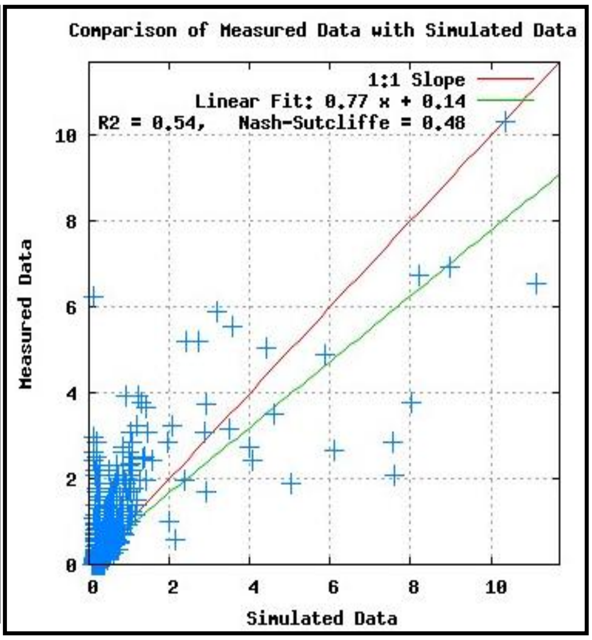


Figure 20: Monthly scatter plot with regression R^2 and 1:1 line at Celone station on daily basis.

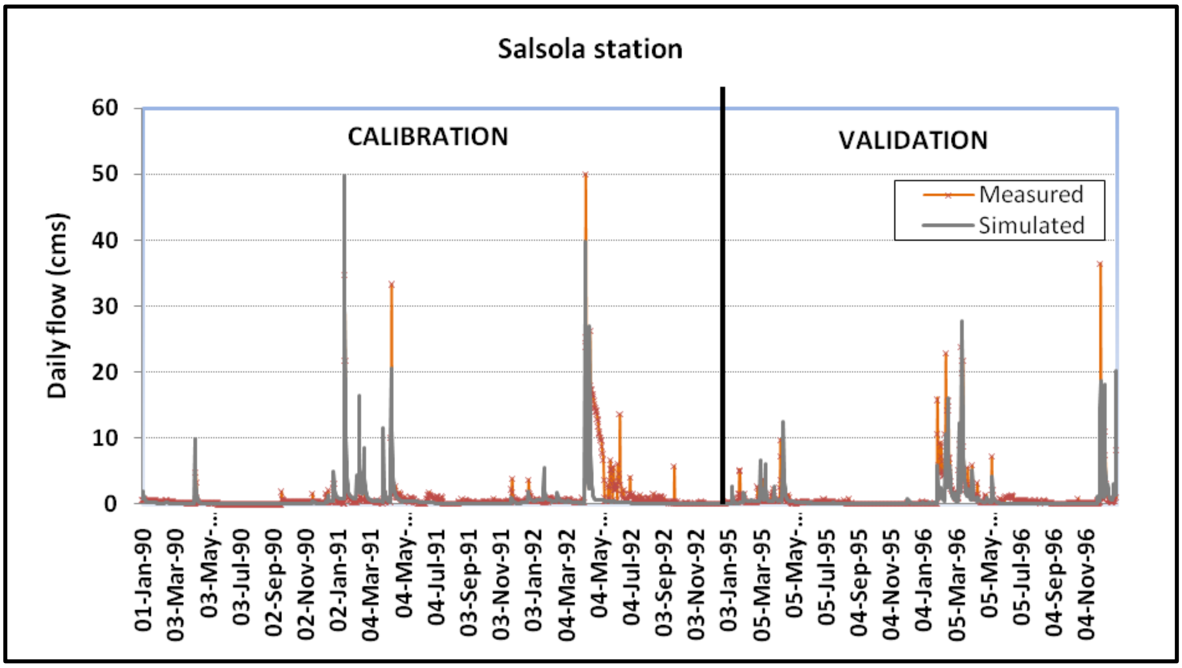
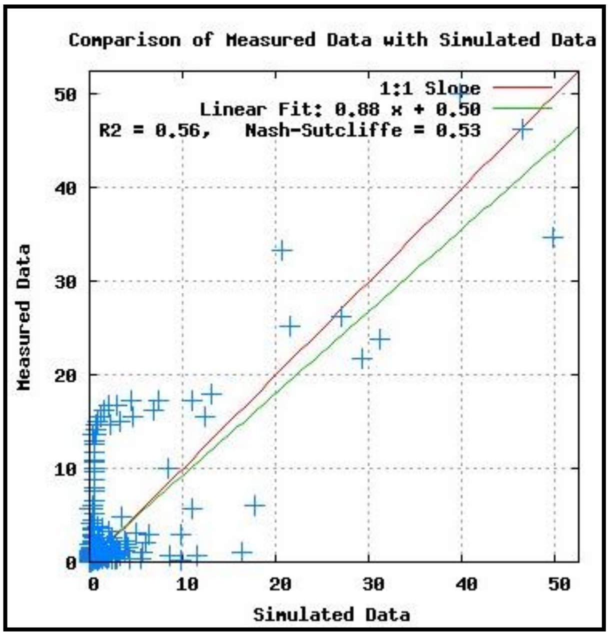


Figure 21: Simulated and measured daily flow (cms) at Salsola station. Calibration (1990-1992): NSE=0.53; R2=0.56. Validation (1995-1996): NSE=0.41; R2=0.46

Calibration at Salsola station



Validation at Salsola station

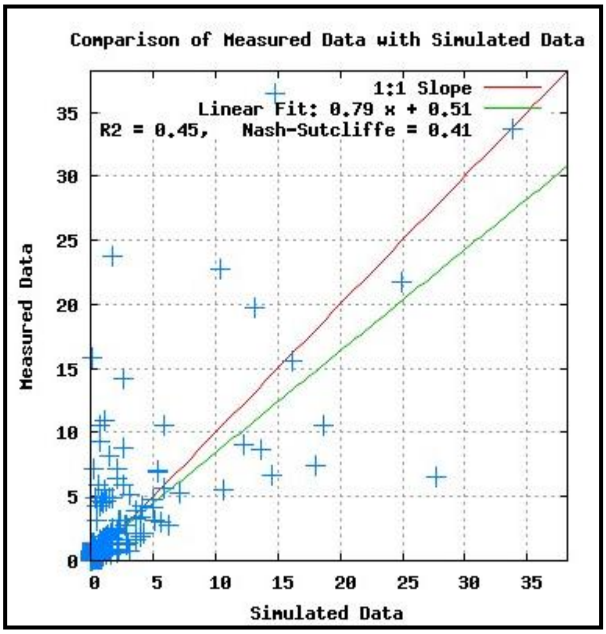


Figure 22: Monthly scatter plot with regression R^2 and 1:1 line at Salsola station on daily basis.

The variable and ranges used to calibrate the two sub watershed (Celone and Salsola) were applied in similar HRU in the entire watershed.

In order to obtain reasonable daily discharge value of Candelaro River, the attention was focused on annual water balance and mean daily flow and base flow. The year 1995 simulated was compared with measured data on 1971 at Candelaro Bonifica 24, the station covers 1788 Km^2 due to the similar average annual precipitation (Tab. 6). The calibration permitted to obtain similar value of mean daily flow, base flow proportion and annual total water yield; the values obtained are reported in table 6.

YEAR	1971	1995
AVERAGE ANNUAL PCP (MM)	627	612
MEAN DAILY FLOW (m^3/s)	2.8	2.25
BASE FLOW FRACTION (%)	0.4	0.35
TOTAL WATER YIELD (MM)	49.4	40.7

Table 6: Annual average value measured (1971) and simulated (1995) at Candelaro River station.

Water budget estimation

The annual averages simulations performed are summarized in the following table.

ANNUAL BASIN VALUES	
PRECIPITATION (mm)	620.3 MM
SURFACE FLOW (mm)	52.27 MM
LATERAL FLOW (mm)	4.45 MM
GROUNDWATER (mm)	21.79 MM
EVAPOTRANSPIRATION (mm)	490.4 MM
POTENTIAL ET (mm)	1035.4 MM
WATER YIELD (mm)	75.39 MM

The results show a hydrologic balance dominated by ET. The ET and the transmission losses and aquifer recharge volumes represent remarkable losses for the total water yield.

It must be noted that this water balance includes also the contribution of WWTPs discharges contributing to the total water yield with about 23.2 Mm^3/year.

Relative weight of the various component of the water budget is summarized in the graph.

The monthly distribution of each components of water balance shows a surface runoff contribution moreover during the winter and spring period, in agreement with the rainfall distribution during the year in this area.

The contribution of each subbasin for the annual average amount of surface runoff is represented in the map of Fig. 23.

The higher value of annual surface runoff can be found in the subbasin characterized by higher altitude and high slope.

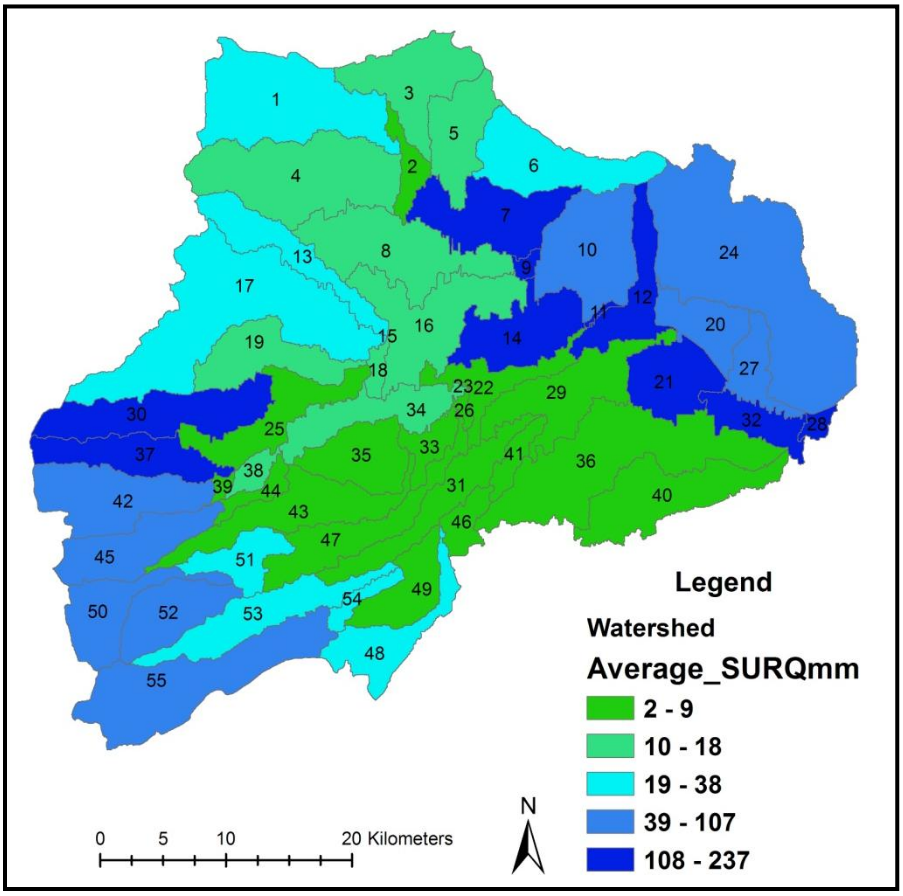


Figure 23: Surface runoff contributions from subbasins.

Nutrients results

Model calibration requires a significant amount of data. SWAT does not require calibration or validation to evaluate scenarios or BMPs, however the lack of calibration does limit the predictive accuracy of the model due to high uncertainty.

Direct comparisons of water quality sample values to SWAT model predictions require daily model output. Daily model output should only be generated when input data are of sufficient quality, which is seldom the case. To circumvent this limitation water quality data are combined with stream flow to generate pollutant loads, which can be compared directly to the SWAT predictions.

The measured data available are concentration of nutrients (total nitrogen, total phosphorus and ammonia) collected one time per month during years without flow measurements.

The comparison of simulated and observed data was done estimating pollutant loads from the concentration value measured.

The simulated TN and TP in the Candelaro River were compared at two sampling stations.

TN and TP loadings simulated generally are underestimated, except during the wet period, winter and early spring, when the model simulates higher loadings. It should be noted that the monitoring activities is carried out only during normal and low flow days, the data arise from grab samples and the estimation of uncertainty associated to this data is very difficult.

The predicted loadings at the sampling station 2, located upstream Candelaro River, were plotted with loading derived from the measured concentrations using the simulated flow; Fig. 24 shows the graph where are reported the simulated and measured N tot loadings for the period 2002 – 2004.

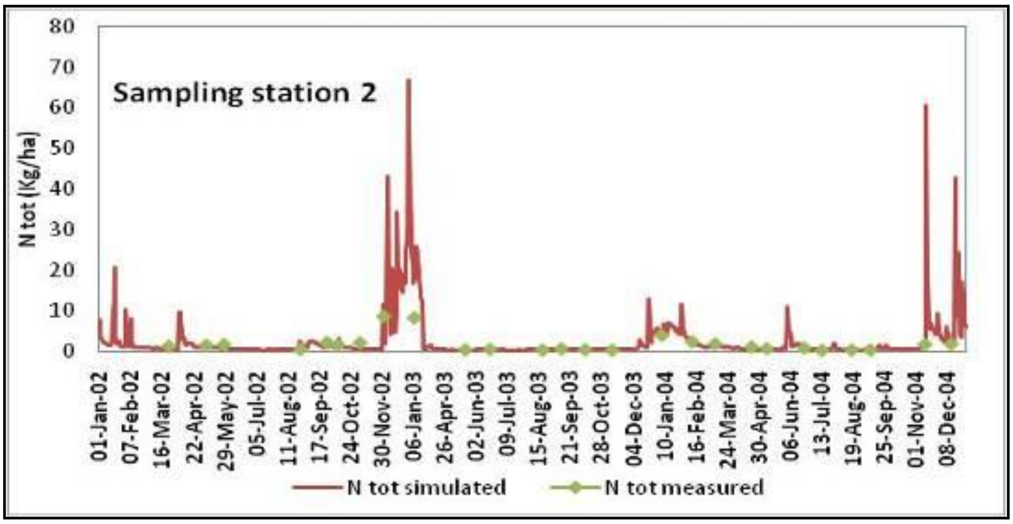


Figure 24: Simulated and measured TN (Kg/ha) at the sampling station 2 (2002-2004).

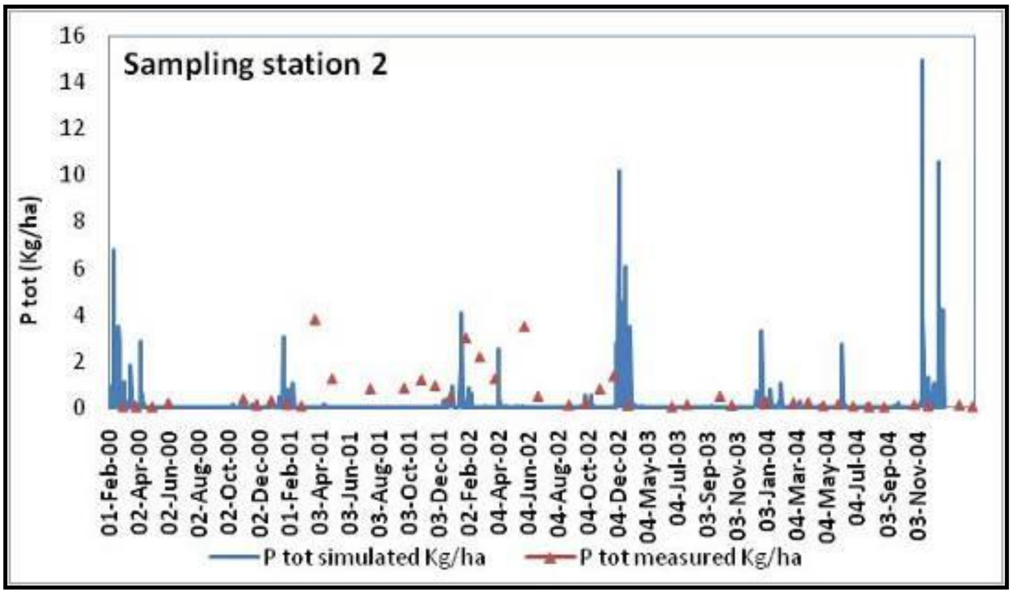
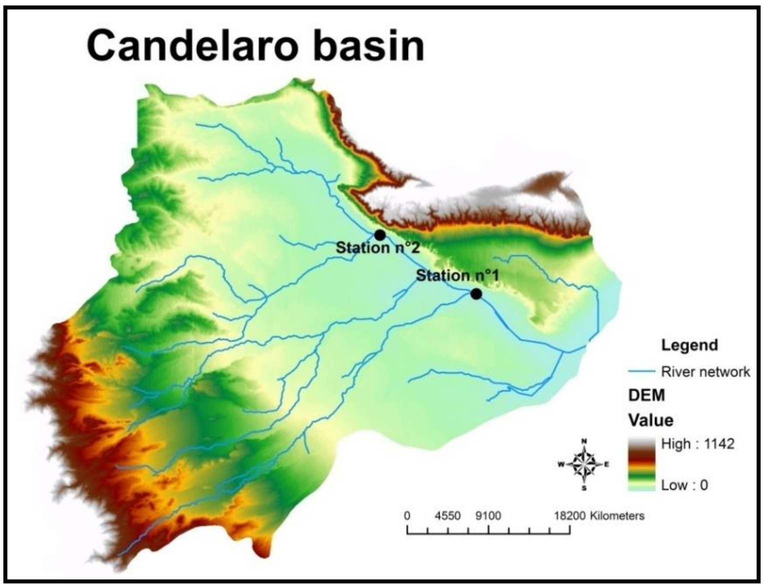


Figure 25: Simulated and measured P tot (Kg/ha) at the sampling station 2 (2000-2004).



The comparison of simulated and measured TP load, at the sampling station 2 from 2000 to 2004, are plotted on the graph in Fig. 25. The measured TP loads show a different behavior along the years, on 2001 was recorded higher value than the other year; this could be explained by the contribution arising from the point sources, in this case study the WWTPs.

The comparison results of ammonia concentration gives the same results of TN and TP, the simulated values are lower than the measured. The simulated concentration shows a constant behavior; the range of simulated value is 0.04- 5 mg/l meanwhile the measured concentration shows a large variability that can be related to the point source discharges. The measured data on 2004 shows a different behavior compared to the 2002, until the summer of 2003. A significant reduction is recorded, and a more constant value can be found (Fig. 26).

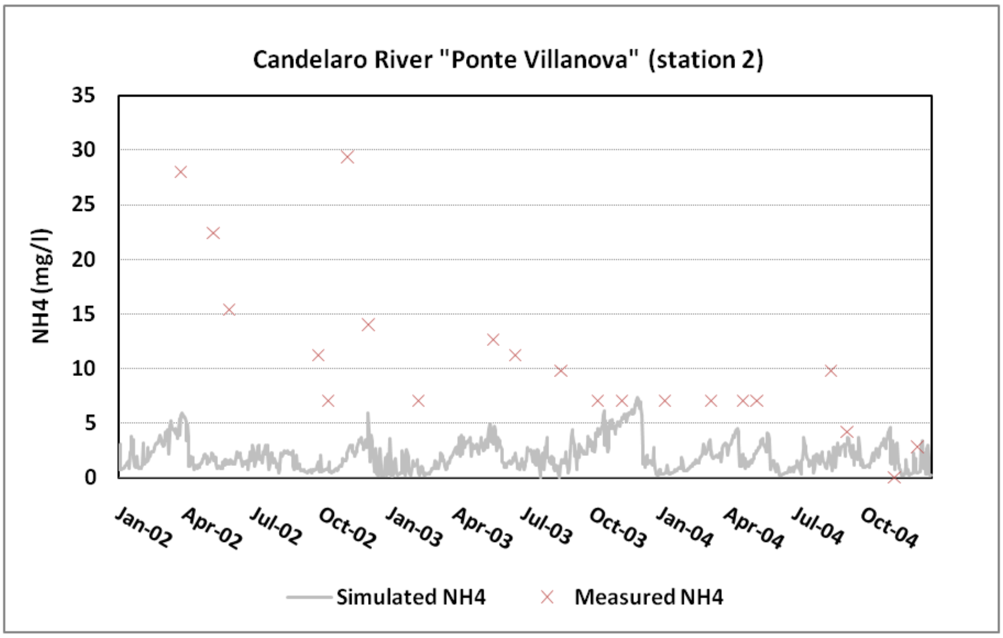


Figure 26 :Calibrated result of NH4 concentration at Candelaro River station 2 (2002-2004).

The measured data investigation affirms that the ammonia concentrations is the main form of N that contribute to the TN loads. The SWAT results predict well the reality. Given the facts that there were only monthly data collected during normal flow, to calibrate the model and match the daily simulated data was almost difficult.

In this simulation is possible to affirm that SWAT model match the measured nutrients value during normal flow, it's difficult to assess the model capability to simulate the nutrients load during high flows event due to the absence of measured data. Nevertheless, continued collection of monitoring data, also during high flow, are necessary to improve the validation of the model.

The investigation of Organic Nitrogen, organic Phosphorus and sediments yield resulted from the calibrated model were investigated also at basin level using the GIS support and the related maps were produced (fig. 27-28). The results of the nutrients reflect the sediment yield product for each subbasin. The area where there is the higher surface runoff contribution is the same that contribute to the higher values of sediment yield containing the nutrients that reach the river.

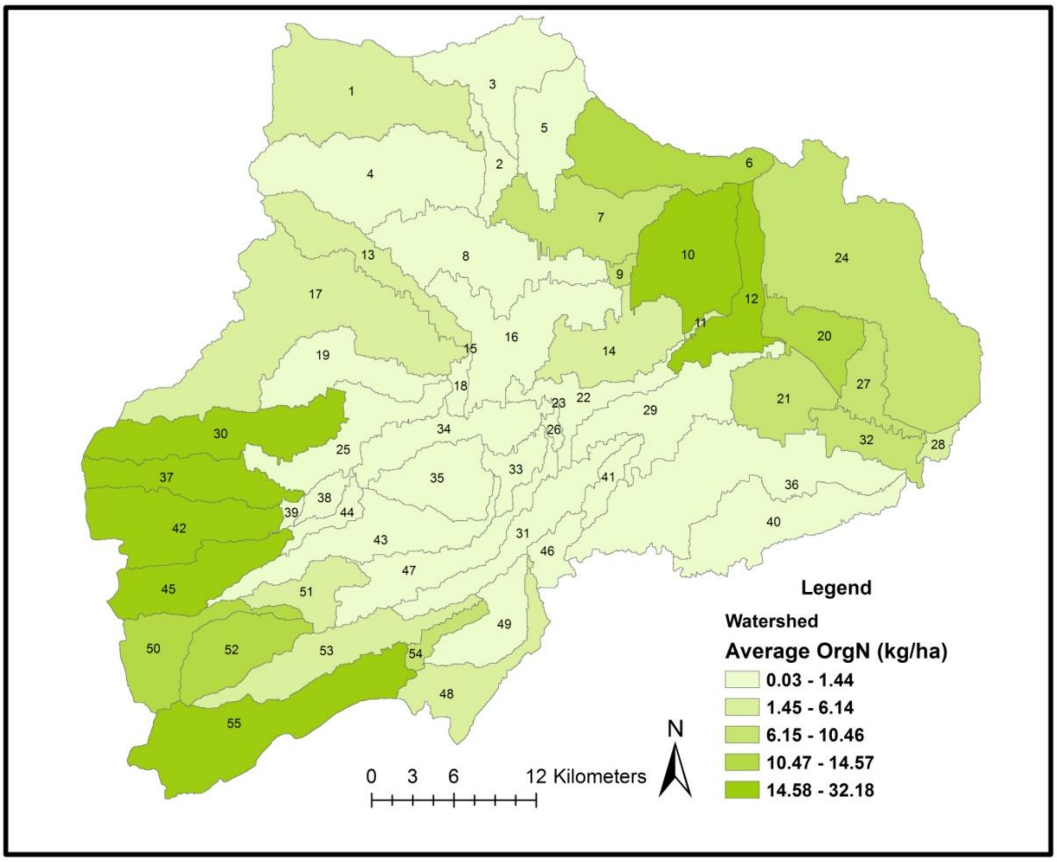
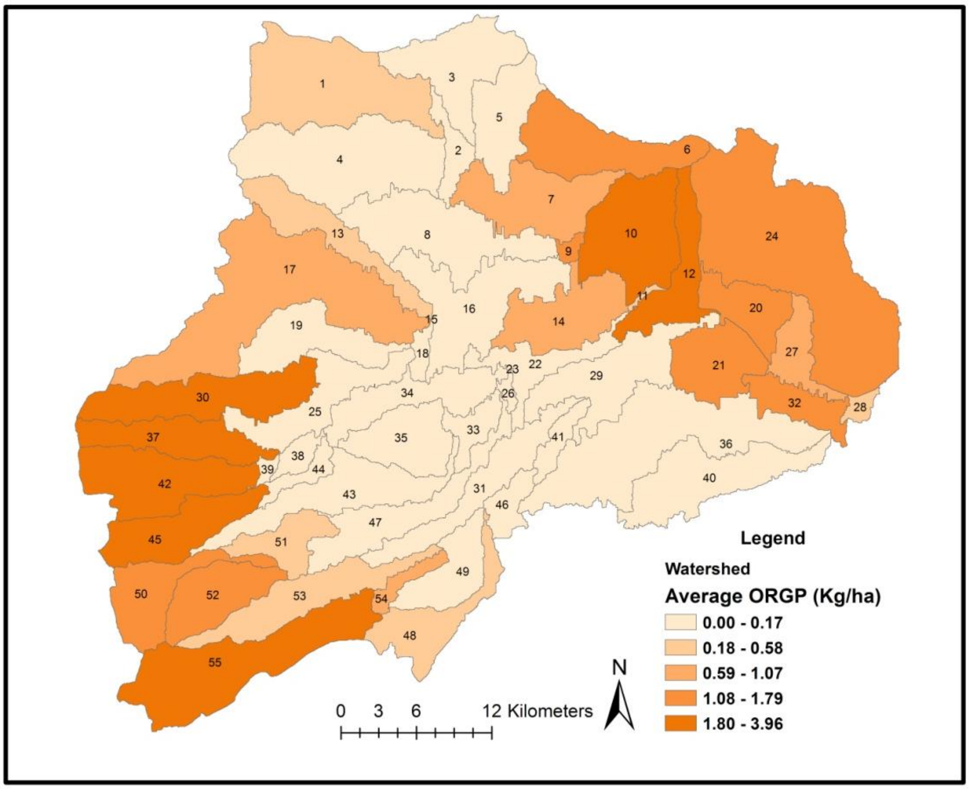


Figure 27: GIS map of organic nitrogen (kg/ha) SWAT output at subbasin level.



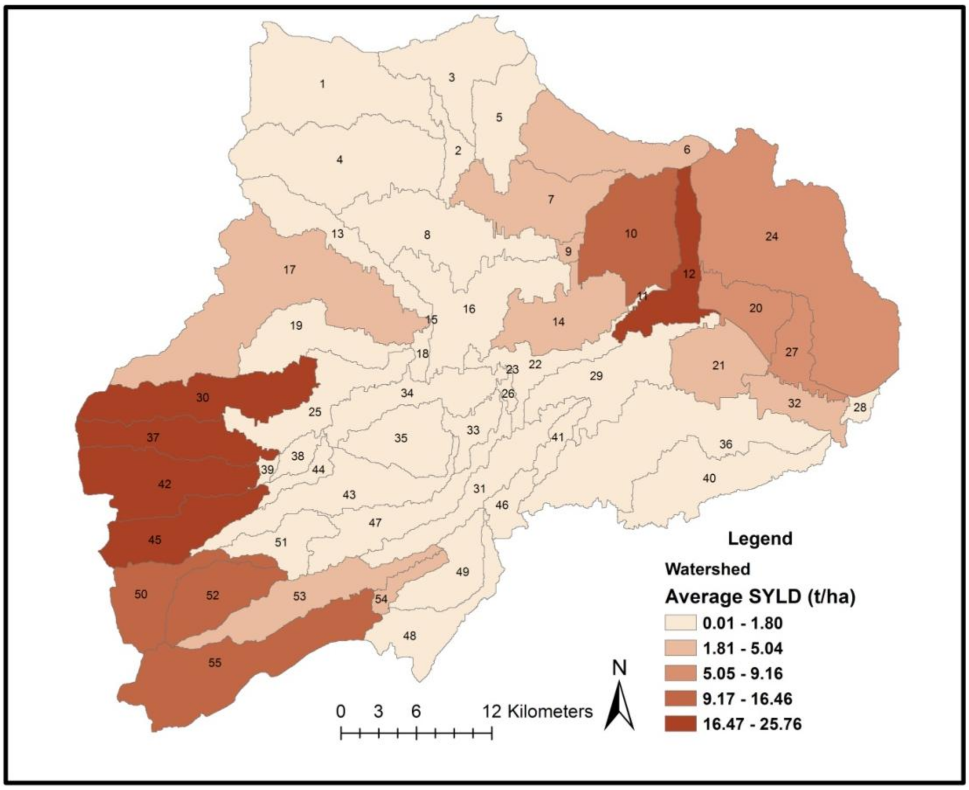


Figure 28: GIS map of organic phosphorus (kg/ha) and sediment yield (t/ha) SWAT output at basin scale.

Determining the effectiveness of different mitigation measures using SWAT

In view of the Water Framework Directive implementation for each European watershed had to be individuated the measures that have to be implemented for improve the ecologic status of all European water bodies. Often the measures indicated in the “Plans” referrers to the literature knowledge on water protection. Also for the Candelaro watershed were indicated some measures that have to be adopted as showed in the chapter describing the study area.

An evaluation on effectiveness of those measures was not investigated.

By using watershed models, the impact of measures on hydrology, sediment transport, nutrients and pesticide loads can be assessed. Watershed models integrate landscape features, climatology and management, such that they are suitable for ranking mitigation measures according to their effectiveness.

The strength of SWAT model is just the flexible framework that allows the simulation of a wide variety of conservation practices and other BMPs, such as fertilizer/manure application rate and timing, cover crops (perennial grasses), filter strips, grassed waterways, and wetlands. Many studies show the capability of the motel to predict the effect of management plans (Gassman et al., 2007).

Measures simulated to reduce pollution

In this study the water quality impacts of the implementation of measures suggested by the River Basin Authority of Apulia Region in the “Regional Water Protection Plan” were evaluated at the outlet of the watershed. The measures simulated are: the reuse of treated urban wastewater for irrigation (orchard only) and application of the Best Management Practices, not specifically expressed in the Water Protection Plan. In this study was simulated the reduction of fertilizer rates application, according to the recommended rates for durum wheat, vineyard, olive and sunflowers; and also reduction of tillage operations and use of conservation tillage.

For developing the scenarios were modified the management file and the point sources file.

The reuse of wastewater was simulated selecting the HRU of the sub basin where are located the point sources of WWTPs and with olive trees and vineyards land cover. The amount of water discharge available from each WWTPs from April to October, the period of irrigation operations in the area, was divided by 3000 m^3/ha, corresponding to the water applied per irrigation season to olive trees and vineyard, and finally were selected the HRU with corresponding hectares irrigable. The irrigation source was also changed, from shallow aquifer source to outside of watershed source, and the fertilizer rates were reduced accounting to the nutrients available from the treated urban wastewater. The point source file was modified from a constant discharge to monthly discharge, and from April to October the discharge was imputed as 0 m^3.

The management files of durum wheat, sunflower, vineyard and olive were modified to reduce the fertilizer rates and the tillage operations and to simulate conservative tillage. In the baseline simulation N fertilizer applied was 102 Kg/ha and P was 35 Kg/ha, for the BMP scenario the N fertilizer was 57 Kg/ha and the P 26.5 Kg/ha.

The number of tillage operation was reduced from three to one per year and changed from chisel plow to generic conservative tillage prior to planting, leaving the residue on the ground after the harvest.

The results are presented as percentage reductions in average annual total nitrogen, ammonia and total phosphorus loadings at the watershed level. Loadings in the baseline simulation were compared to the loadings obtained with the BMP scenario to estimate the percentage load reductions.

Pollutant load reductions results

The percentage reductions of nutrients (Fig. 29) estimated from the model for the scenarios of BMPs and wastewater reuses were compared with baseline simulation results.

Relative comparisons are more robust than absolute predictions because they reduce the uncertainity related to simulated results.

The results are presented as percentage reductions in average annual total nitrogen, total phosphorus and ammonia loadings at watershed level.

The average reduction of nitrogen is 51% for the scenario that represent the application of BMPs, at watershed scale (scenario 1); the reduction of ammonia is 49%, almost the total amount of TN. These results can be explained investigating the amount of fertilizer rate reductions simulated and the type of fertilizer. The main nitrogen supply applied to the crops into the watershed area, with fertilizer, is the ammonia, applied with ammonium nitrate and urea. The amount of ammonia applied with fertilizer is actually 70 Kg/ha, reducing the fertilizer rates the amount become 19.5 Kg/ha. In the same way can be explained the lowest reduction of phosphorus, the amount of P applied with fertilizer is low compared to the nitrogen.

The reductions of phosphorus increase significantly with the second scenario, where is simulated the reduction of point source loadings. The percentage reduction reaches the 90% of the actual loads; also the reduction of ammonia loadings is almost the 50% than the scenario 1. According to the ammonia behavior also the total nitrogen is further reduced.
The phosphorus loads in the Candelaro River arise mainly from point sources, meanwhile the non point source contribute about the 50% at nitrogen loads, particularly in ammonia form.

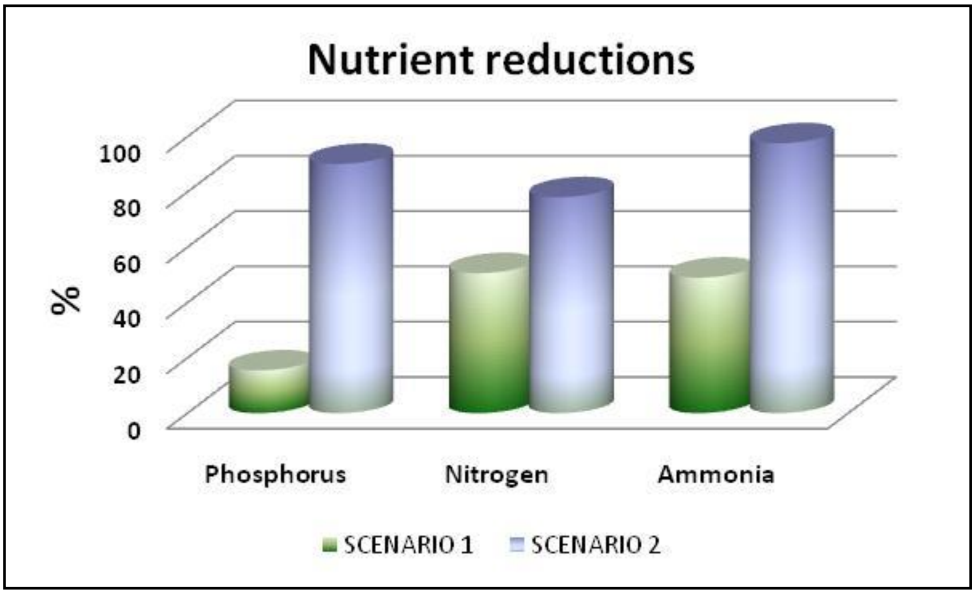


Figure 29: Reductions in nutrient loadings for the two scenarios at watershed scale.

CHAPTER 6 - TMDL CALCULATION FOR CANDELARO RIVER

6.1 DEVELOPMENT OF THE DAILY LOAD EXPRESSION

The Candelaro River was identified impaired mainly due to nutrients and bacteria. In this study three TMDLs were developed for the following nutrients: ammonia, total phosphorus and total nitrogen. Specifically the target analysis, the allocation process and finally the calculation of needed reduction were evaluated.

The observed impairments are primarily due to the agricultural activities and municipalities discharges, as resulted from the Apulian Region works on assessment status and from the analysis of pressures present in the watershed.

The reduction of the nutrients is required in order to obtain the numerical criteria established for aquatic life habitat, the use designated for the Candelaro River according to the Italian law (L.D. 152/2006).

The first step, to identify a daily load expression for long-term allocations, was to evaluate the TMDL approach and the available data and outputs.

The daily dataset available for the Candelaro River was calculated using SWAT model a continuous watershed model. The main model outputs are daily flow and nutrient concentrations and loads.

The criteria adopted in Italy are the water quality criteria, as required by the L.D. 152/2006.

In U.S.A. for this type of criteria the load duration curve method is widely used to develop the daily dataset.

The load duration approach can be used to calculate a series of allowable daily loads, which is then used as the daily load dataset for identifying the daily load expression.

The load duration approach involves calculating the allowable loadings over the range of flow conditions expected to occur in the river. The loading data are function of flow.

This approach permits to evaluate the TMDLs under conditions that reflect worst–case (critical) conditions for both point and nonpoint source loadings (e.g., low-flow drought and high flow conditions).

Determination of the TMDL under these two scenarios would identify the lower of the two loading capacities of the waterbody. This lower capacity is necessary to protect the waterbody in question.

Four steps have been followed to adopt the Load Duration Curve methodology for the calculation of TMDL for Candelaro River, as indicated into the technical document of EPA "Options for the Expression of Daily Loads in TMDLs" (EPA, 2007):

1. Development of a flow duration curve for the stream, generating a flow frequency table and plotting the data points. The data reflect a range of natural occurrences from extremely high flows to extremely low flows. A duration curve is a graph representing the percentage of time during which the value of a given parameter (e.g. flow, load) is equaled or exceeded. Such a graph is easily generated using a computer spreadsheet.
2. Conversion of flow duration curve into a Load Duration (or TMDL) Curve by multiplying each flow value by the WQS/target (maximum concentration allowable) for the particular contaminant, then multiplying by a conversion factor. The resulting points was plotted to create a load duration curve.
3. Each water quality sample was converted to a load by multiplying the water quality sample concentration by the average daily flow of the day that the sample was collected. Then, the individual loads were plotted as points on the TMDL graph so can be compared to the WQS/target, or load duration curve.
4. Points plotting above the curve represent deviations or exceedance from the WQS/target and the daily allowable load. Those plotting below the curve represent compliance with standards and the daily allowable load.

Steps in developing the load duration curve for Candelaro River and results

Step1. Development of Flow Duration Curve: using the available daily streamflow simulated by SWAT model, the flow duration curve was developed for the Candelaro River. Data for the curve was generated by:

1. Ranking the daily flow data from highest to lowest;
2. Calculating percent of days these flows were exceeded (= rank ÷ number of data points).

Figure 30 present a portion of the ranked data and resulting flow duration curve for the outlet of Candelaro River, for a 14 years period.

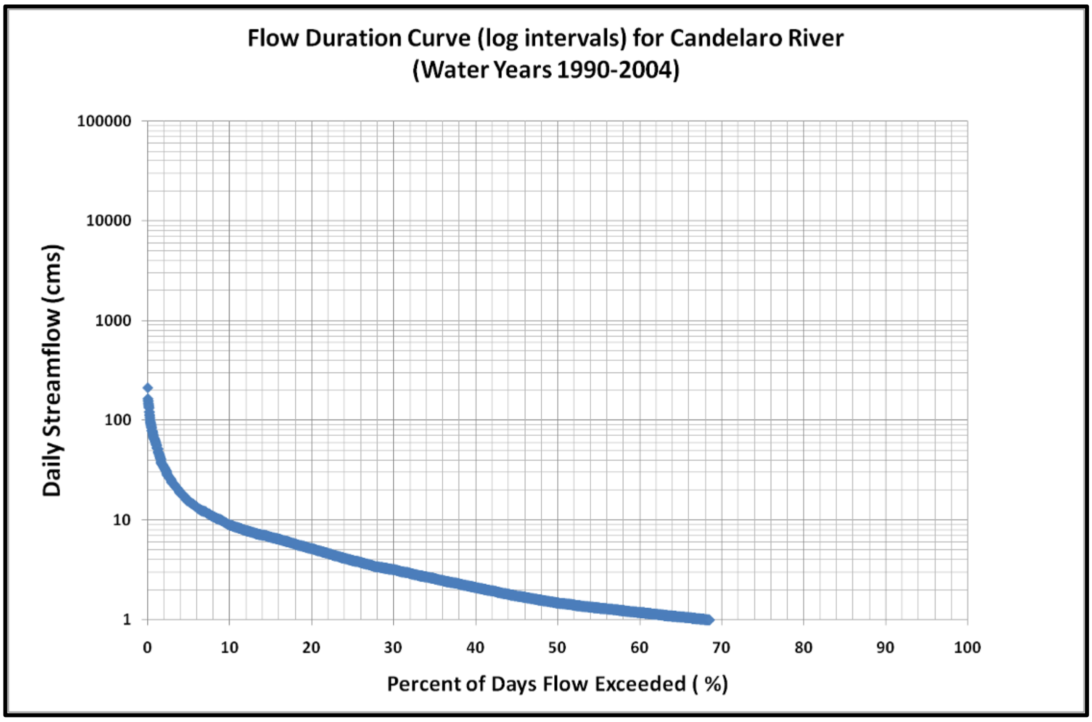


Figure 30: Flow Duration Curve for Candelaro River (years 1990-2004).

Step 2. Development of Load Duration Curve. Three load duration curves were developed for the nutrient parameters: total phosphorus, total nitrogen and ammonia.

The load duration curve was developed multiplying the individual daily flows values by the three parameters target and by a conversion factor (see Equation 1). The maximum allowable concentration of the three parameters investigated was used, the standard values are: 50 mg/l for total nitrogen, 0.14 mg/l for total phosphorus and 1mg/l for ammonia. To apply a 10% margin of safety (MOS), as is widely used in US, the results of Equation 1 was divided by 1.1.

$$\textit{Load (Kg/day) = streamflow (cms) x target (mg/l) x 86.4} \qquad \textit{[Eq.1]}$$

Step 3. Plot water quality sample data on load duration curves. Developed the load duration curve of the allowable daily loads then it represents the daily load expression. The curve represents a dynamic expression of the allowable daily load as a function of the measured flow for the respective day.

In order to compare water quality sample data to the load duration curve, the first task is to calculate daily loads for each sample using Equation 1 along with the pollutant concentration and streamflow for the particular day. Next, the load calculated for each day that the samples was taken and then plotted on the load duration curve (Figure 31, 32, 33).

Points above the curve represent exceedance of the water quality standards and the associated allowable loadings.

The examination of the pattern of impairment of the three parameters across all flow conditions permits to assess if it corresponds to high flow events, or conversely, only to low flows. Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left generally reflect potential nonpoint source contributions related to the runoff transport, that typically indicate the influence of non point sources.

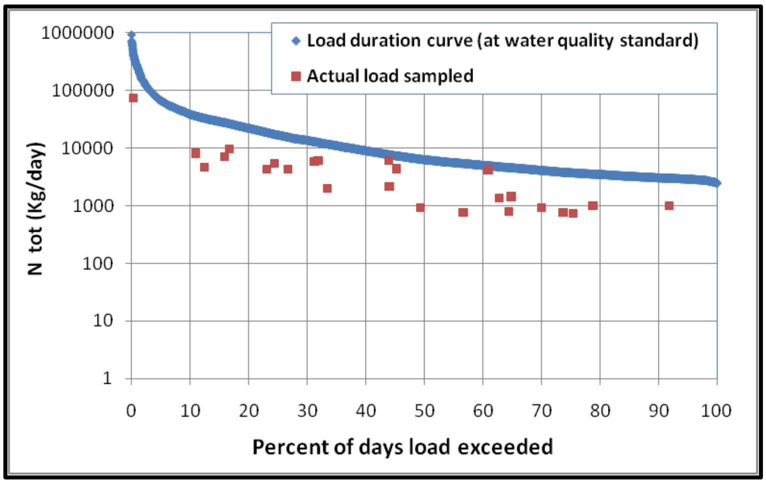


Figure 31: Total Nitrogen load duration curve at water quality criteria (50 mg/l) for Candelaro River simulated value (1990-2004) - sample data (2002-2004).

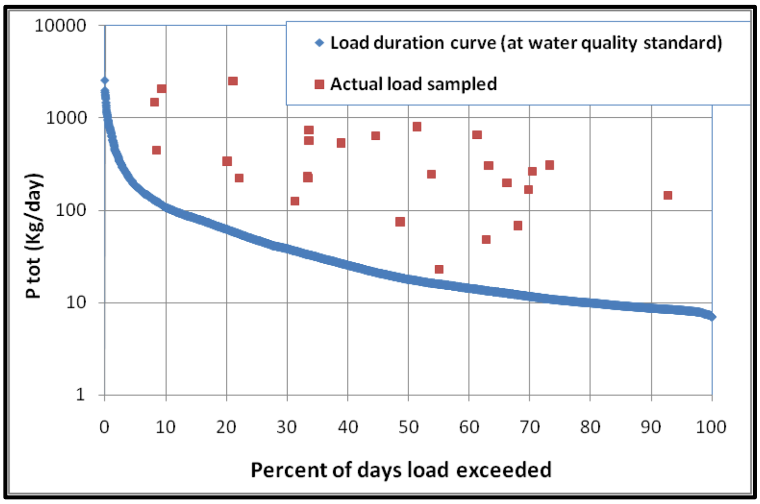


Figure 32: Total Phosphorus load duration curve at water quality criteria (0.14 mg/l) for Candelaro River simulated value (1990-2004) - sample data (2002-2004).

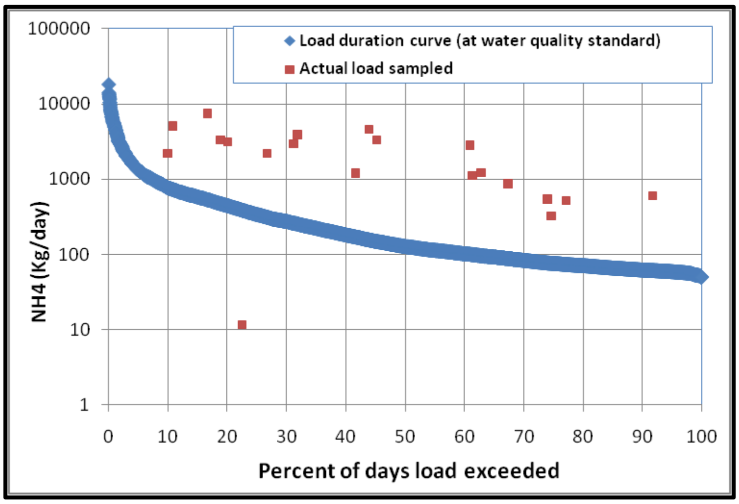


Figure 33: Ammonia load duration curve at water quality criteria (0.14 mg/l) for Candelaro River simulated value (1990-2004) - sample data (2002-2004).

Interpretation of Results

Important information can be derived from a load duration curve. First, the extent of the impairment can be visually assessed based on the number of loads that are above or below the allowable loading curve. The figure reported above (TN) indicates that all the calculated loads from the observed concentrations are below the curve representing compliance with the target and allowable daily loads. It has to be pointed out that the recorded values were collected during normal flow. The use of the TMDL methodologies in the assessment of current status of the Candelaro River confirms the compliance of total nitrogen concentration with the water quality criteria for the waters suitable fish life.

The figure 32, 33 reporting the data for ammonia and P tot loads, shows all points above the respective curves. Observing when the loads occur along the curves, it's possible to infer the nature of the impairments (Cleland, 2003).

Loads that plot above the curve during low flow conditions are likely indicative of constant discharge, for the Candelaro River can be assessed only to wastewater treatment plants discharges, the only point sources present in the watershed.

Those plotting above the curve between flow duration intervals of 10 to 30 reflect wet weather contributions associated with sheet and rill erosion, wash off processes, and, potentially, stream bank erosion.

Figure 32,33 illustrates that allowable total phosphorus and ammonia loads in the Candelaro River are exceeded during all flow ranges, indicating that multiple sources contribute to the impairment. These sources include agricultural activities and urban waste water discharges.

The area beneath the TMDL curve is interpreted as the loading capacity of the stream. The difference between this area and the area representing the current loading conditions is the load that must be reduced to meet water quality standards.

Advantages and Disadvantages

There are a number of advantages associated with using load duration curves in the TMDL development process. First, assuming that sufficient data are available, the method accurately identifies the allowable and existing loads in the stream where the data were collected. The calculated loads are the result of a straightforward mathematical exercise that does not require any assumptions regarding loading rates. The approach also allows one to use all of the available flow and water quality data and provides easy insight into the critical conditions. This is superior to very simplified TMDLs that are expressed as an average daily load based upon one average long-term flow and one average long-term concentration value. The last point is particularly significant for the rivers characterized by rapidly changes of flow.

Assuming that permitted point source loads are known, load duration curves also provide the information necessary to meet the basic minimum regulatory requirement of a TMDL (e.g., existing loads, loading capacity, load allocations, and wasteload allocations).

Load duration curves are also relatively easy to develop once one has an understanding of how they work. Most resource management personnel with a background in hydrology and water quality should be able to develop and interpret load duration curves with relatively little training. Similarly, explaining the results of a load duration curve to the public can be easier than explaining other technical approaches. This can promote effective communication between TMDL developers and those responsible for implementation (Cleland, 2002).

6.2 TMDL ALLOCATION EXPRESSION

The stream flows displayed on a load duration curve may be grouped into various flow regimes to aid with interpretation of the load duration curves.

The flow regimes are typically divided into 10 groups, which can be further categorized into five “hydrologic zones” corresponding to: high flow zone; moist zone; mid – range zone; dry zone and low flow zone (Cleland, 2005).

Taking into account the hydrologic behavior of the Candelaro river, as reported in the chapter of the study area, the usually percentile range adopted for each flow zone was changed.

Analyzing the flow duration curve and the corresponding flow value for each percentile the following ranges were used (Fig. 34):

- Extreme High flow zone: stream flows that plot in the 0 to 10-percentile range, related to extreme flood flows;
- High flow zone: flows in the 10 to 20-percentile range, related to flood flow;
- Moist zone: flows in the 20 to 30 percentile range, related to wet weather conditions;
- Mid-range zone: flows in the 30 to 70-percentile range, related to median stream flow;
- Low flow – dry zone: flows in the 80 to 90-percentile range, related to dry - drought conditions.

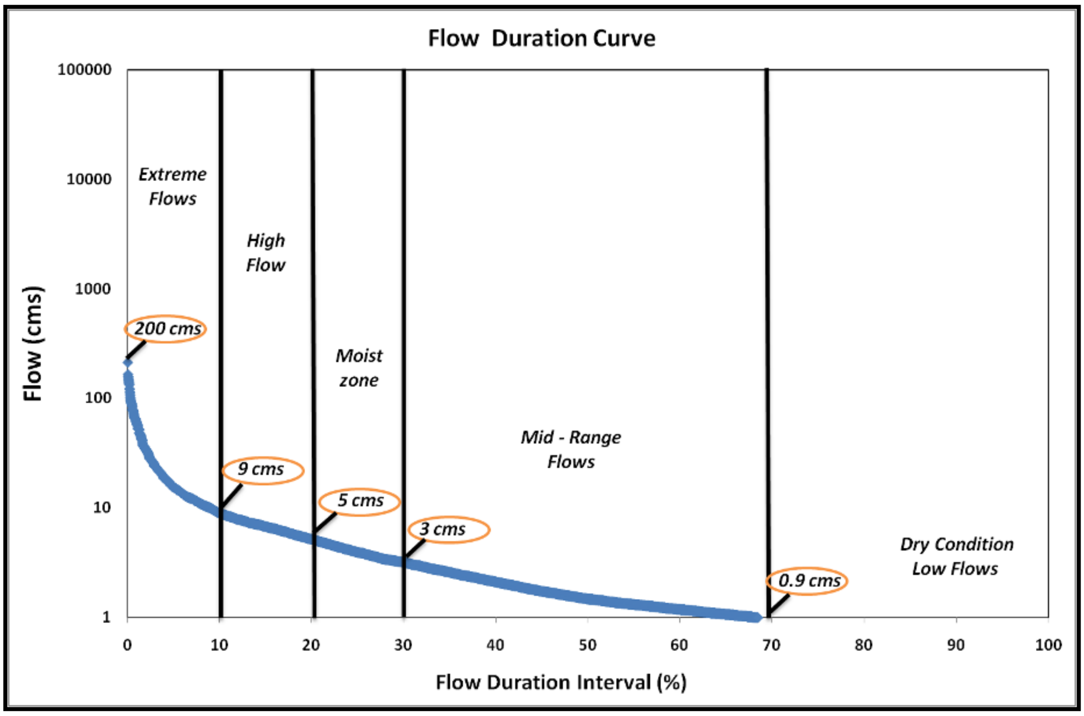


Figure 34: Flow Duration curve and flow range conditions for Candelaro River.

For each flow category, an allowable daily load was identified, using the maximum load for that range calculated by the SWAT model, according to the suggested indications gave by USEPA to identify a Maximum Daily Load.

The use of simulated nutrients in this case study was obligatory due to the flow data not available, but generally simulated data permit: to reduce the uncertainty related to the fewer measured value, to represent multiple years of data and a variety of environmental conditions, to estimate loads values during each flow zone, particularly important results the value obtained during high and extreme flows.

USEPA (2007) suggests to select, as the maximum daily load value, the high percentile of the load distribution (e. g., 95^{th} or 99^{th}), and not the maximum value of the distribution, in order to protect against the presence of uncertainty related to the dataset, moreover for extreme values. If the uncertainty is assumed to be higher the USEPA suggest to select the lower percentile. Meanwhile if the model calibration is well within the range of observed data and does not over – predict loads on individual days, a higher percentile can be used. The percentiles values was not used in this case study for the reason that lower loads simulated values, for all the studied nutrients, were obtained by SWAT simulation, as explained in the chapter reporting the SWAT results.

Calculation waste loads allocation

The calculation of waste load allocation was conducted not accounting the real or actual discharge value, due to the limited information available on historical flow and pollutant concentrations from each urban plant. In this case was considered that all the discharges into the Candelaro River respected the concentration law limit for each nutrient, as is established in the L.D. 152/2006 according to the European Directive (91/271/EEC, later amended by 98/15/EEC),concerning urban facilities.

The loads of ammonia, total nitrogen and total phosphorus were calculated multiplying the mean daily flow discharging from each treatment plants with the respective concentration limit permitted.

The mean daily flow discharge was estimated accounting literature value of waste water produced per person per day, for all the municipality discharging and connected to a waste water treatment plant in the Candelaro watershed. All WLA values were then summed to represent the total WLA for the watershed. In this way is not possible to evaluate the real flow and the corresponding nutrients loads during the storm event causing overflows.

Calculation Loads allocation

The outputs of SWAT summarize the non point and point sources loads without specify the respective load values. Calculated before the WLA, as described above, the Load allocation was calculated at any particular flow exceedance as shown in the equation below:

$$\mathbf{LA = TMDL - MOS - \Sigma WLA}$$

Load allocations are calculated as percent reductions from current estimated loading levels required to meet water quality criteria.

6.3 CURRENT DEVIATION FROM TARGET

The difference between actual in stream conditions, result of SWAT simulation, and the numeric targets established assists in determining the load reduction or other actions that are necessary to restore the designated uses of the watershed. The deviation from target translates to the percent reduction in load required to meet target conditions, which is then used in calculating the TMDL that will protect aquatic life.

Tables (7, 8, 9) present the existing ammonia, total nitrogen and total phosphorus loading in the Candelaro River based on SWAT model output, the target loading calculated using the load duration curve and the concentration limit established for water suitable for fish life, and the deviation from target, which equates to the percent reduction needed to improve water quality and restore aquatic life uses.

Total nitrogen

The total nitrogen (Kg/day) results were calculated and reported in the table 7. In order to assess if the targets are respected in all flow conditions, particularly during the high flows, condition were observed data are not available.

TMDL component	Extreme Flows 0 - 10	High Flows 10 -20	Moist conditions 20 - 30	Mid- range flows 30 - 70	Low flows 70- 100
Current Load N tot. (Kg/day)	**304608**	**50817**	**23387**	**19760**	**3419**
TMDL = LA + WLA +MOS (10%)	**1007424**	**42435**	**24663**	**15206**	**4595**
Load Allocation	1006206	41217	23445	13988	3377
Waste Load Allocation	1218	1218	1218	1218	1218
Load Reduction (%)	**0**	**16**	**0**	**23**	**0**

Table 7: Summary of total Nitrogen (TN) TMDL for Candelaro River and load reductions required.

The loading capacity of total nitrogen in the Candelaro River calculated using the maximum concentration value of 50mg/l was reported for each range flow in table 7. The load reduction calculated permits to individuate the critical flow range condition and to assess the type of source that contribute to the impairment. The critical range for total nitrogen loads are during the high and mid range flows. It is possible to assess that the impairment is delivered by runoff process that generates the high flows and also by baseflow transportation, during the wet period. This information can help to individuate the management implementation option that can better reduce the runoff and also the infiltration of nutrients than delivered with baseflow transportation. To better understand these results occur to investigate which one of the three forms of nitrogen measured in the water bodies, ammonia, nitrites and nitrates, is the main form that contributes to the total nitrogen.

In the Candelaro River, during the monitoring campaigns, the higher value measured was the ammonia. This result was confirmed also with the SWAT results and explained by the assessment of the main sources that contribute to this high concentration of ammonia.

Ammonia

In this study the behavior of ammonia, with the TMDL calculation, was investigated in order to understand the main source contributing, the mechanism of transport and the required reduction to achieve the water quality objective and finally was evaluated the effectiveness of "measures" indicated in the PTA of Apulia Region.

The table 8 shows the simulated loadings and the calculated target with load curve method, and the reduction required for each flow condition to achieve the objective.

TMDL component	Extreme Flows 0 - 10	High Flows 10 -20	Moist conditions 20 - 30	Mid- range flows 30 - 70	Low flows 70- 100
Current Load NH4(Kg/day)	**89752**	**6108**	**1813**	**1906**	**598**
TMDL = LA + WLA +MOS (10%)	**20148**	**849**	**493**	**304**	**92**
Load Allocation	88962	5318	1022	1115	0
Waste Load Allocation	790	790	790	790	790
Load Reduction (%)	**78**	**86**	**73**	**84**	**85**

Table 8: Summary of Ammonia (NH4) TMDL for Candelaro River and load reductions required.

As shown in the table 8. The current loads of ammonia exceed the target during all the flow ranges indicating that the contributions derive from both types of source. It's important, before to investigate the ammonia results, to underline the characteristics of ammonia related to the nitrogen cycle in aquatic environment.

The amount of ammonium in the stream may be increased by the mineralization of organic nitrogen and diffusion of ammonium from the streambed sediments. The ammonia concentration in the stream may be decreased by the conversion from $NH4+$ to $NO2$ - or the uptake of $NH4+$ by algae (Neitsch et al., 2005); the rate is controlled by temperature, oxygen concentration and pH values. Those factors can explain the lower value of current ammonia simulated in stream compared to the constant discharge loadings during the low flow conditions. The contribution to ammonia loads in the river deriving from the non point sources is related to the conversion of nitrogen into ammonia. The reduction is significant during the high and mid range flows, the same results obtained for the total nitrogen. These similarities could indicate that the exceeding loadings of total nitrogen could be related to the behavior of ammonia loadings. The reductions required during the each flow conditions are relevant (73% – 85%).

The abatement strategies have to be implemented to both types of sources in order to reduce the loadings during each flow range.

The allocation analysis assesses that the WLAs exceed always the allowable limits also if the effluent of all facilities, in this simulation, respects the limit value for ammonia concentrations in the effluent.

The figure 35 shows graphically this situation, an average daily value of 790 Kg/day is discharged from all the waste water treatment plants located in the Candelaro watershed. The contribution from the point sources is relevant for about the 70% of the period.

One of the strategies that can help to reduce the actual loads, as indicated also in the actual waste water discharge laws (L.D. 152/2006), is to reuse the waters for agricultural or industrial activities. In this way, moreover during the wet period and dry period, when the flow in the Candelaro River is represented mostly by the constant urban discharges, the point source can be completely removed from the River.

The contribution deriving from the non point sources is also relevant also if there is not a direct transport of ammonia into the river, due to the chemical characteristics and behavior of this form of nitrogen as explained above.

The reduction of fertilizer applied in all the watershed can reduce the nitrogen transported into the river with runoff, lateral flow and sediment; lower value of nitrogen into the river bed are present less could be the processes of transformation into ammonia form. In the same way all the other strategies applied in order to reduce the transport of nitrogen into the river, intercepting the flow of water from the source before it reaches a waterbody, an contribute to reduce the nitrogen into the river.

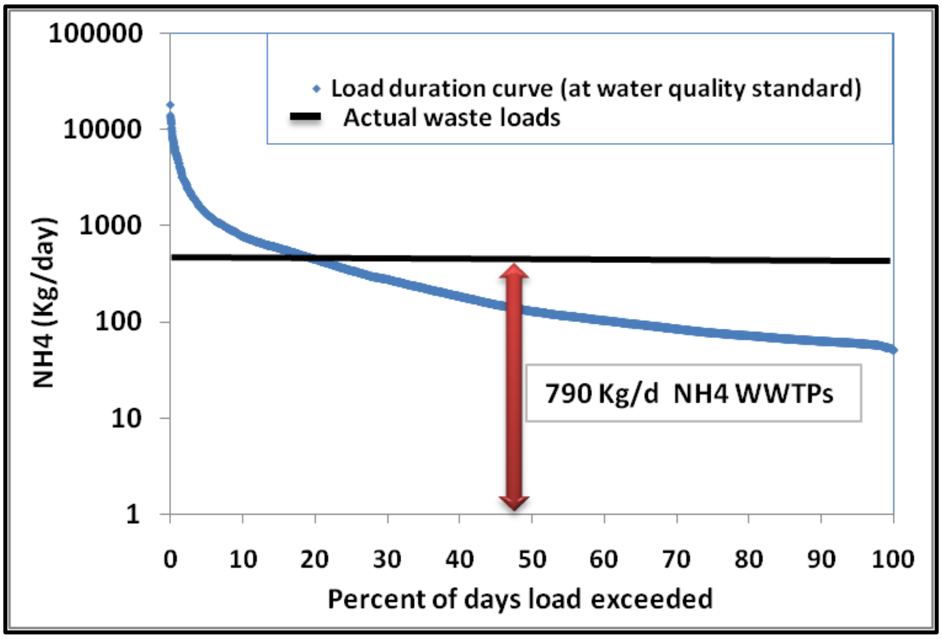


Figure 35: Waste loads (WLAs) contribution to the actual loads.

Total phosphorus

The results of total phosphorus loadings are reported in table 9. The conditions for TP resulted during each flow range very critical; more than 90 percent loading reduction is required to achieve the objective of 0.14 mg/l of total phosphorus.

TMDL component	Extreme Flows 0 – 10	High Flows 10 -20	Moist conditions 20 - 30	Mid-range flows 30 - 70	Low flows 70-100
Current Load P tot. (Kg/day)	**72498**	**4191**	**1297**	**1631**	**143**
TMDL = LA + WLA +MOS (10%)	**2564**	**108**	**63**	**37**	**12**
Load Allocation	72367	4060	1166	1500	12
Waste Load Allocation	130	130	130	130	130
Load Reduction (%)	**96**	**97**	**95**	**98**	**91**

Table 9: Summary of Total Phosphorus TMDL for Candelaro River and load reductions required.

The constant discharge from the wastewater facilities contributes with an average daily value of 130 Kg/day of total phosphorus (Fig. 36). According to the allowable TMDL the TP loads of WLAs exceed for the 90% of the period.

The contribution from the diffuse sources is also significant as showed in the table 7.

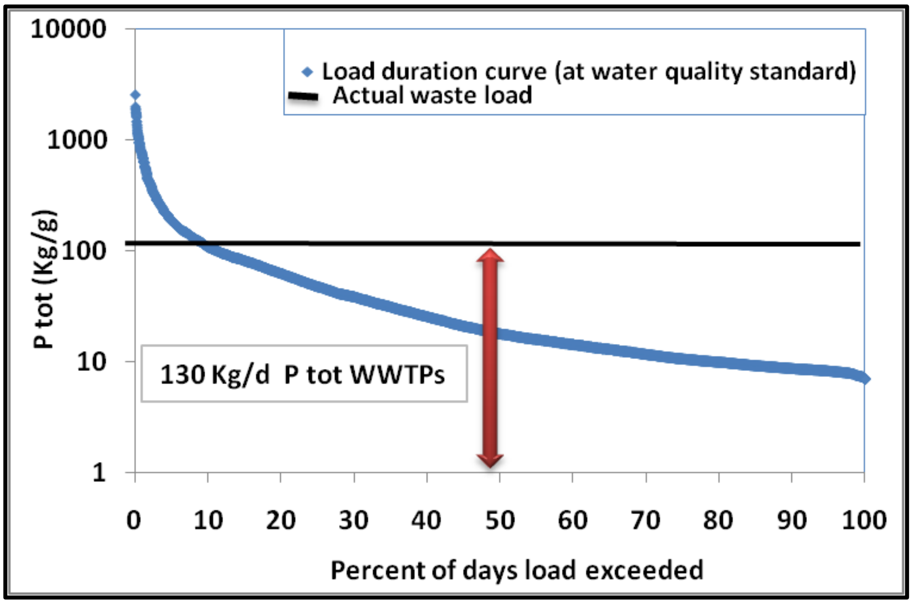


Figure 36: Waste loads of total Phosphorus.

The strategies to adopt have to be focused to reduce the point source loadings, particularly during the normal and dry flow conditions, the measures indicated for the ammonia reduction, as reported above, will take effect also for the reduction of TP loads.

The contribution of the non point sources loadings to the actual TP loads is also relevant, the load reduction resulted more than 90 percent during the mid range and high flow conditions. This result indicated that the transport of phosphorus with surface runoff from the cropland has to be reduced. The management objective that permits to reach the objective is to reduce the fertilizer application and implementation of Best Management Practices (BMPs) that reduce phosphorus loads from cropland runoff. For example, practices that reduces erosion and sediment delivery, like conservation tillage or riparian buffers, often reduce phosphorus losses because phosphorus is strongly adsorbed to silt and clay particles.

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6.4 IMPLEMENTATION STRATEGIES EFFECTS ON NUTRIENT TMDL

The SWAT results of scenarios were used to investigate if implementing the “measures” the TMDLs for nutrients, investigated in this study, will be met. The evaluation was done considering as a unique future scenario, the SWAT model was launched simulating the implementation of measures for the reduction of point and diffuse sources. Reduction of fertilizer rate, conservative tillage and reuse of waste water for irrigation were simulated at watershed scale. The method adopted to calculate the TMDL for the actual scenario was the same adopted for the calculation of TMDL after the implementation of measures.

The load duration curves were created for the scenario results and the TMDL for each flow condition were calculated and compared with the allowable TMDL. The annual loads reductions obtained were investigated in the discussion of SWAT analysis meanwhile using the TMDL method were investigated during which flow conditions were obtained.

TMDL TN (Kg/day)	**High Flows 0 - 10**	**Moist Conditions 10 - 20**	**Mid-Range Flows 20 - 30**	**Dry Conditions 30 -70**	**Low Flows 70 - 100**
CURRENT LOAD	**304608**	**50817**	**23387**	**19760**	**3419**
SCENARIO LOAD	**124915**	**21114**	**12015**	**12828**	**1075**
LOAD REDUCTION	**59%**	**58%**	**49%**	**35%**	**69%**

Table 10: TN load reductions for each flow condition implementing measures at watershed scale.

The total nitrogen loads were reduced more than 50 percent during the wet periods, 69 percent of reduction was founded during the low flow conditions (Tab. 10). During the dry conditions is predicted a lower reduction, this flow conditions are often recorded also during the spring or autumn period. The contribution during this flow condition derives from the point sources. The reduction obtained reusing the waste water for irrigation during the summer period do not permit to met the allowable TMDL for TN, TP and ammonia because this type of pressure is related to flow condition and not to the seasonality. The higher concentrations are simulated during the lower flow rate that often occurs also during months that the measures will not be implemented.

TMDL TP (Kg/day)	**High Flows 0 - 10**	**Moist Conditions 10 - 20**	**Mid-Range Flows 20 - 30**	**Dry Conditions 30 -70**	**Low Flows 70 - 100**
CURRENT LOAD	89752	4191	1297	1631	143
SCENARIO LOAD	26253	3490	1021	769	118
LOAD REDUCTION	**71%**	**17%**	**21%**	**53%**	**17%**

Table 11: TP load reductions for each flow condition implementing measures at watershed scale.

The measures could have higher effects on TP loads reduction from the diffuse sources. The higher percentage of reduction was found during the extreme floods, indicating that the runoff transport process is reduced and consequently the loads of TP in the river are lower.

TMDL NH4 (Kg/day)	**High Flows 0 - 10**	**Moist Conditions 10 - 20**	**Mid-Range Flows 20 - 30**	**Dry Conditions 30 -70**	**Low Flows 70 - 100**
CURRENT LOAD	**89752**	**6108**	**1813**	**1906**	**598**
SCENARIO LOAD	**29385**	**3557**	**1309**	**924**	**531**
LOAD REDUCTION	**67%**	**42%**	**28%**	**52%**	**11%**

Table 5: NH4 load reductions for each flow condition implementing measures at watershed scale.

The effects on nutrient TMDLs were evaluated calculating the reduction (%) required to meet the allowable loads. Tables 13 and 14 report the results obtained and the reduction still required also if will be implemented the measures simulated.

TMDL TP (Kg/day)	High Flows 0 - 10	Moist Conditions 10 - 20	Mid-Range Flows 20 - 30	Dry Conditions 30 -70	Low Flows 70 - 100
SCENARIO LOAD	26253	3490	1021	769	118
TMDL = LA + WLA + MOS	7858	331	192	119	36
LOAD REDUCTION	70%	91%	81%	85%	70%

Table 6 TP load reduction needed after the implementation of "measures" to meet the allowable TMDL.

TMDL NH4 (Kg/day)	High flows 0 - 10	Moist conditions 10 - 20	Mid-range flows 20 - 30	Dry conditions 30 -70	Low flows 70 - 100
SCENARIO LOAD	29385	3557	1309	924	531
TMDL = LA + WLA + MOS	20148	849	493	304	92
LOAD REDUCTION	31%	76%	62%	67%	83%

Table 7: NH4 load reduction needed after the implementation of "measures" to meet the allowable TMDL.

The reduction still necessary to meet the allowable loads is high during all flow conditions for the total phosphorus, meanwhile for the ammonia during the high flow the reduction is only the 30 percent but during the others flow condition resulted still high.

The phosphorus loadings during the dry condition can be allocate only to the point sources, the low flow condition often were recorded and simulated also during the spring and summer period of dry years. Simulating the reuse of waste water for the irrigation during the summer period will result anyway a high value of TP loads when the low flow condition happens in a different period. The same explanation could be given to the ammonia results also if in this case the processes that involve the presence of ammonia into the river are different.

The critical conditions during the low flow period, which in the Mediterranean area can be registered during all the season depending from the precipitation behavior, suggest to adopt specific measures.

In the U.S. many facilities are regulated according to the flow condition of the receiving water body; is not possible to discharge if the flow is lower than a fixed value.

For the management of non point sources, in this case only the agricultural activities, the reduction of fertilizer rate and the use of conservative tillage will not be enough to obtain the reduction necessary for reduce the loads during the high flow condition. The surface runoff and the sediment transport in some areas of the watershed are the main source of nutrient in the river, as the GIS map developed by the output of SWAT showed. Structural measures that are able to reduce the transport of sediments and nutrients could be more efficient.

CHAPTER 7 - CONCLUSION

The recent introduction of a new approach in the water management in Europe requires many challenges in the planning processes for many European States. Many similarities exist between the USEPA and the Water Framework Directive on water management, particularly related to the objective to protect waters from pollution. The guidelines defined in the Clean Water Act and WFD have some key elements equal but a different strategy is adopted in US to manage the polluted waterbodies.

The CWA require to establish the “Total Maximum Daily Load” for each type of pollutant to restore the waters impaired. It is a process analogous to the “Programmes of Measures” required by the WFD, the main difference is the analysis of the linkage between loads of different sources and the water quality of waterbodies. The water quality standards, defined in the CWA, allow to derive – by means of the TMDL calculation – effluent limits for the pollution sources in a river basin.

The TMDL calculation, taking into account the water quality standards, permit to establish a scientifically-based strategy to reach the common objective of CWA. This strategy could be adopted also for the European waterbodies polluted in the implementation of Programmes of Measures.

The WFD lacks to require the quantification of the objective and the efficiency of the measures; the results of this study demonstrate that those lacks will not permit to meet the objectives, in particular for the typical intermittent Mediterranean River. The application, for the first time in Italy and in Europe, of the concept of TMDL to assess the water quality status, to analyze the targets, to allocate the sources and finally to calculate the reduction needed to reach the allowable loads for the Candelaro river according to the water quality criteria established in the Water Protection Plan was described.

The application of the SWAT model, for the Candelaro River basin, has proven to be a very useful tool in predicting catchment behaviors to hydrologic and nutrient balances. The daily data set obtained from the SWAT outputs was necessary to calculate the TMDL on a daily basis and related to the different flow condition.

Calibration and validation of SWAT, using flow and water quality data available in the watershed, resulted in a modeled representation of the watershed that was well within acceptable standards. Based upon this acceptable correlation between modeled and observed

output, SWAT was able to effectively simulate the impacts of implementing various BMPs throughout the watershed in order to evaluate their efficacy in reducing nonpoint and point source pollution in the watershed.
The results permitted to evaluate the effectiveness of some measures individuated into the Regional Water Protection Plan of Apulia Region. With this study is possible to affirm that the measures directed to the point sources are really relevant but it’s important to associate also the implementation of BMPs, in order to reduce also the agricultural loadings.
The SWAT outputs permitted to develop a Load Duration Curve for total nitrogen, total phosphorus and ammonia, the main nutrients affecting the water quality of Candelaro River. Plotting the measured data on the Load Duration Curve of the allowable loads was possible to indentify, during each flow condition, the nutrient loads exceeding the water quality standards and the magnitude of exceeding. The sample points were distributed along the curve indicating that the contributions arise from point and from non point sources. Established the critical flow condition was possible to calculate the actual and allowable TMDL for each flow condition and calculate the reduction required for reach the target corresponding to the water quality criteria.
The percentage of reduction resulted very high for the total phosphorus and ammonia, more than 70 percent. Also the total nitrogen loads require reduction during the high and average flow condition.
Defining the allowable TMDL for each flow condition and calculated the constant loads deriving from the waste water discharge, which are the only punctual source in the watershed, is possible to visualize that the loads of ammonia and total phosphorus exceed, respectively, for the 70 and 90 percent of the period. This is the reason that also if the waste water will be used during the summer period the water quality standards will not be met because also during the normal or average flow the loads exceed the target. The critical conditions during the low flow period, which in the Mediterranean area can be registered during all the season, suggest to adopt specific measures. In the U.S. many facilities are regulated according to the flow condition of the receiving water body, the discharge is permitted only if the flow is lower than a fixed value.
For the management of non point sources, in this case only the agricultural activities, the reduction of fertilizer rate and the use of conservative tillage will not be enough to obtain the reduction necessary for reduce the loads during the high and moist flow conditions. The surface runoff and the sediment transport, in some areas of the watershed, are the main

sources of nutrients in the river, as the GIS maps developed by the output of SWAT showed. Structural measures that are able to reduce the transport of sediments and nutrients could be more efficient.

Many others scenarios can be simulated, with SWAT model, and evaluated with the methodologies applied in this study to assess the effectiveness of possible measures to adopt. The load duration curves developed can be used also during the monitoring program to evaluate in a rapidly way the type and the magnitude of source that have to be reduced if the waters are still impaired.

In the same way is possible to develop also the bacteria and the sediment TMDLs.

The TMDL in U.S. is also adopted for the water quality trading a system that is a program that permits to trade among the sources the loads; the source more polluting can purchase equivalent pollution reduction from another source at lower cost.

This dissertation proved that the application of mathematical model and scientifically-based analysis of the complex reality that characterize a watershed can help to get better results in the field of water management and planning.

Further study on hydrologic characteristics of the intermittent river could help to asses better the flow critical conditions to assess the TMDL. Also the availability of measured data will improve the results and a more realistic prevision of the future scenarios, also the knowledge of many others factor not considered in this study.

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