Doctoral Degree

Bellaterra
January, 2009

University: Universitat Autònoma de Barcelona

Institute: Institut de Ciència i Tecnologia Ambientals, Facultat de Ciències

PhD program: Environmental Sciences, option in Analysis of the Natural Environment

Title:

Integrated Environmental Assessment of Nutrient Emissions in a Mediterranean catchment: A case study in La Tordera, Catalonia

Research conducted by:

Frédérique Caille

Directors of research:

Dr. Joan Lluís Riera Rey
Department of Ecology
Universitat de Barcelona

Dr. Antoni Rosell Melé
ICREA Research Professor
Institut de Ciència i Tecnologia Ambientals
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Funding for this project was provided by the Institute of Environmental Sciences and Technology (ICTA, UAB) and the European Project Eurolimpacs (FP6-SUSTDEV, project reference 505540). Frédérique Caille benefited from an IQUC, Marie Curie and ICTA short-time scholarship, respectively from the Catalan government, the European Community for the Sense research school programme, and the ICTA for PhD completion.

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Summary

Rivers, particularly in developed regions, are under significant ecological stress as a consequence of the increasing development of human activities in their catchments. This is especially reflected in excess nitrogen (N) and phosphorus (P) emissions, which are the product of complex dynamic systems influenced by demographic, socioeconomic and technological factors among others. This situation has been addressed in Europe through specific legislation such as the European Water Framework Directive (WFD). Its application requires conducting an Integrated Environmental Assessment (IEA) for the management of nutrients in river basins. In Mediterranean regions, where the aquatic ecosystems are particularly vulnerable, an IEA is essential for the sustainable management of hydrological resources and to maintain the ecological quality of the ecosystem.

In this thesis, using a Catalan river catchment as a case study (La Tordera, North-East of Spain), an integrated and interdisciplinary environmental assessment of nutrient flows was undertaken for the period from early 1990s to early 2000s, and the future, i.e., the 2030 horizon. This assessment involved not only the estimation of N and P fluxes, and the analysis of the socioeconomic system that interact with theses fluxes, but also the participatory development of future scenarios, their quantification and the evaluation of the potential changes in nutrient flows under each of these quantitative scenarios.

By analysing the social system and point and diffuse sources of nutrients (N and P), the respective roles of socio-economic driving forces that affect N and P loads and hence water quality were recognised. Interviews were conducted to identify and understand the interactions and feedbacks between the natural and social system over the past and present time, and the analysis of the social actors that contribute to water contamination. The application of a nutrient emission model, MONERIS (Modelling Nutrient Emissions into River Systems), designed for river basin scale, enabled the identification of nutrient sources and quantification of their emissions during the period 1995-2002. This assessment was then followed by the development of narrative socioeconomic scenarios through a participatory process and their quantification.

The study conducted can be viewed as an example of the process required for the sustainable management of the anthropogenic sources of nutrients in a river basin. By integrating findings of natural sciences and socioeconomic analysis, it is then possible to obtain information that can assist catchment managers and planners in evaluating optimal management strategies for the anthropogenic sources of N and P as required by the European Water Framework Directive for river basin management plans.

Acronyms

ACA	Catalan Water Agency (Agència Catalana de l'Aigua)
ANFFE	National Association of Fertilisers Producers
BAU	Business As Usual
DARP	Department of the Agriculture and Fisheries (Departament d'Agricultura, Ramaderia i Pesca)
DEM	Digital elevation model
DIN	Dissolved Inorganic Nitrogen
DMAH	Department of the Environment and Housing (Departament de Medi Ambient i Habitatge)
DTI	Industrial Work Department (Departament de Treball i Indústria)
EEA	European Environmental Agency
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
GIS	Geographic Information System
ICC	Catalan Cartographic Institute (Institut Cartografic de Catalunya)
IDESCAT	Catalan Statistical Institute (Institut d'Estadistica de Catalunya)
IEA	Integrated Environmental Assessment
IPCC	Intergovernmental Panel on Climate Change
IRTA	Farm-Produce Technological Research Institute (Institut de Recerca i Tecnologia Agroalimentàries)
JARC	Young farmers of Catalonia (Joves Agricultors i Ramaders de Catalunya)
MONERIS	MOdelling Nutrient Emissions in RIver Systems

N	Nitrogen
NCW	New Culture of Water
NH_3	Ammonia
NH_4^+	Ammonium
KN	Kjeldahl N
NO_x	Mono-nitrogen oxides
NO_2^-	Nitrite
NO_3^-	Nitrate
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
PESERA	Pan-European Soil Erosion Risk Assessment
PO_4^{3-}	Phosphate
PSARI	Industrial Waste Water Treatment Program (Programa de Sanejament d'Aigües Residuals Industrials)
PSARU	Urban Waste Water Treatment Program (Pla de Sanejament d'aigües residuals)
PTOT	Department of Territorial Policy and Public Works (Departament de Política Territorial i Obres Públiques)
Q	Mean annual discharge
SRP	Soluble Reactive Phosphorus
TN	Total Nitrogen
TP	Total Phosphorus
WFD	Water Framework Directive
WWTP	Waste Water Treatment Plant

Chapter 1

Introduction

The interactions between social agents and the environment are ultimately responsible for the evolution and enrichment of nutrient loads, which cause rivers, particularly in developed regions, to be under significant ecological stress. An integrated and interdisciplinary environmental assessment of nutrient loads involves not only the study of the biogeochemical cycles based on the estimation of fluxes of major elements, i.e., nitrogen (N) and phosphorus (P), but also the analysis and understanding of the main social and natural factors interacting with and controlling these fluxes. Integrating the estimation of N and P emissions and the assessment of the socioeconomic system with the development of future scenarios generated through a participatory process may help policy-makers to develop a set of measures to mitigate current impacts or prevent the probable negative consequences of future anthropogenic pressures. An integrated analysis of nutrient cycles is, in that sense, critical for the sustainable management of the anthropogenic sources of nutrients at the catchment scale.

1.1. Conceptual background for the research project

In modern times, the sustainable relationship between human beings and their environment has been disturbed by the increasing development of human activities. Even if human beings are able to adapt successfully to their surroundings, the process tends to have a negative impact on the environment (Stanners and Bourdeau, 1995; De Wit, 2001). Rural and urban landscapes change due to human influence, often as a result of human purpose (De Aranzabal et al., 2008; Wagner and Gobster, 2007). This influence seldom depends on the local development of one main sector of activity, such as agriculture, but on a wider and more complex socioeconomic structure (Schmitz et al., 2003). By modifying the socioeconomic system, human beings change not only the cultural landscape, but also land uses that characterise and determine the structure, function and dynamics of the landscape. Thus, any modifications or adjustments in the territorial and socioeconomic “co-evolving systems” lead to changes in the environment (Turner et al., 1998; Lorenzoni et al., 2000; Lacitignola et al., 2007).To reach socioenvironmental sustainability, which is one of the main challenges facing modern society, changes in our scale of values and our habits are required (Arrojo, 2006). However, in order to identify these necessary changes, and to develop and integrate new values into our daily lifes, it is essential that society incorporates the pervading, strong, and often dominant influence of humanity into its understanding of the structure and functioning of the Earth’s ecosystems (Vitousek et al., 1997).

The Brundtland Commission, formally known as the World Commission on Environment and Development (WCED), and set up by the United Nations in 1983, defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Created to address the growing concern about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development, this Commission highlighted the need to develop a basis for sustainable development policy. That is to say, a policy that respects the limits of the environment, resources and biodiversity while ensuring a strong, healthy and just society meeting the diverse needs of all people.

As an essential and vital element for life on Earth, preserving and securing water resources are an increasing preoccupation for many people in different places of the planet. Nowadays, water condition reflects the nature of our society where human activity is intensifying (EEA, 2003; or EEA, 2007). Even though the water quality of European rivers has significantly improved over the last 35 years thanks to a range of EU environmental directives, nutrient emissions, especially those from diffuse sources, are still a key environmental concern (Withers and Haygarth, 2007). Nutrients are naturally present and essential to sustain life, but they can have strong negative impacts on the ecosystems if they are in excess (Goudie, 2005). These impacts include the eutrophication of surface waters, which may result in changes in ecosystem productivity, oxygen depletion, biodiversity loss and the buildup of substances (e.g., episodes of high ammonia concentration) that are toxic for aquatic ecosystems (OECD, 1982; Kalff, 2001; Wetzel, 2001).

The interactions among social agents and the environment are ultimately responsible for the evolution of nutrient emissions (Cole et al., 1993; Vitousek et al., 1997; Bennet et al., 2001). Nowadays, stream nutrient loads in the rivers have been affected and disturbed by many natural and human factors, including urbanisation, population growth, agricultural intensification, land-use change, water diversions, groundwater pumping, coastal modifications, wetland conversions and industrial activity (Novotny, 2003). This is why in order to understand the N and P cycles and the elements that affect sustainability, nutrient management in river basins requires not only the identification and quantification of nutrient sources, but also an understanding of all relevant natural and social processes and their interactions (EEA, 2003). In short, in the context of sustainable development, nutrient management calls for integrated environmental assessments (IEA) (Bailey et al., 1996).

The message of interdisciplinarity and policy relevance conveyed by IEA implies a broad and strategic look at the issue that contrasts sharply with the more traditional top-down view of policy making (Bailey et al., 1996; Hisschemöller et al., 2001; Rotmans and Dowlatabadi, 1997; Toth and Hizsnyik, 1998). By allowing a synoptic perspective on the causes and effects involved (Rotmans et al., 1996), IEA facilitates an understanding of the interactions and feedbacks between the natural and the social systems involved in, for instance, the dynamics of river nutrient loads. As a powerful and useful process to assess innovative options for managing local, regional and global environmental problems, IEA has never stopped to be redefined and adapted depending on the issues at stake. To be considered for an IEA, environmental issues have to be pertinent for future policy and offer scientific challenges. First applied to understand and control acid rain deposition in Europe and North America during the seventies (Toth and Hizsnyik, 1998), the application of this interdisciplinary process has been then extended to many other problems related to climate change, local air pollution, waste, water, health, among other issues.

However, to address these issues in a fast, flexible and consistent way, IA modelling (IAM) emerged during the eighties. This approach aims at using computer simulation models, integrating knowledge from different disciplines in an analytical computational framework. One of the best-known applications of IAM was the regional acidification information and simulation project (RAINS) (Alcamo et al., 1990). But IAM has been applied also to other purposes, including scenario analysis, evaluation of the environmental, economic and social consequences of different policy strategies, or optimisation of key policy variables such as assessing rates of greenhouse gas emission reduction or levels of carbon taxes, among others.

These studies, together with various conferences on climate change (Villach Conference in 1985 and Toronto Conference in 1998) led towards the creation of the IPCC (Intergovernmental Panel on Climate Change), and to the policy development for the climate change problems (e.g., the Kyoto protocol with the goal of long-term reductions of greenhouse gas emissions). Moreover, with the aim to improve IEA, integrate it better in the context of the current issues at stake and strengthen the interaction between environmental science and policy (or scientists and policy makers), forums have been organised, such as the European Forum on Integrated Environmental Assessment (EFIEA) launched in 1997. In 2000, one of their objectives was to contribute to the development of a framework for IEA of water scarcity and water quality, which are great challenges facing Europe nowadays. In the context of the European Union Water Framework Directive[1] (WFD), an IEA process for surface waters and land management was applied to many European river basins, e.g., the Rhine, Danube, Odra and Elbe rivers (ICPDR, 2004; Salomons, 2004). In place since 2000, the WFD embodies key principles of modern water and land management through river basin planning and presents a framework for the protection of all European natural water bodies (including inland surface waters,

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[1] WFD, or the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

transitional waters, coastal waters and groundwater), with the objective of achieving good ecological water status for all water bodies by 2015.

Traditionally, river basin management has been reactive, focussing on the reduction of point nutrient sources, i.e., from urban and industrial sectors, mostly through the construction of waste water treatment plants. However, it is increasingly being recognised that one also should attempt to foresee problems and take a proactive approach. Proactive management is also better suited to accommodate societal action in environmental policy development and governance (Berry and Rondinelli, 1998). This can be accomplished through a variety of approaches, including participation and policy evaluation as part of an IAM. Catchment models are widely used to analyse the evolution of specific state variables (e.g., nutrient concentrations and loads) in relation to driving forces of interest (e.g., land use or climate change) (Hofmann et al., 2005; Brown Gaddis et al., 2007) and to explore options for catchment management. This modelling effort is also recommended by the WFD. However, to assess whether the Directive objectives concerning nutrient emissions and water quality can be achieved, the estimation of nutrient fluxes through the use of a reliable conceptual model under different management scenarios is necessary.

Models are not only instruments to generate representations of the natural environmental system, but also useful assessment tools for the quantification of pollution pressures by nutrients (De Wit, 2001, Behrendt et al., 2002). Indeed, when applied over long time scales, models allow the estimation of the point and diffuse sources of nitrogen and phosphorus from households, industry and agriculture in a river catchment. As a first step of an IEA, modelling can facilitate an understanding of the influence of the various pressures and multi-cause/multi-effect relationships involved in the evolution of nutrient emissions. However, if we are to explore management options for the future, it is judicious and helpful to combine this modelling effort with the development of alternative socioeconomic scenarios. Indeed, scenarios are useful instruments to think about the future and to build storylines about how the future might develop (Nakicenovic et al., 2000). Thus, scenarios at the catchment scale are recognised as essential tools for planning and communication (Raskin et al., 1998), for gathering information from expert judgement, and for effectively representing environmental changes caused by a specific socioeconomic context. When used together with a catchment model, scenarios can help evaluate potential changes in nutrient flows and assess the impact of relevant socioeconomic indicators on the environment. This, in turn, provides a sound basis for future decisions. This is an area that can greatly benefit from the involvement of stakeholders, as the WFD recognises (WFD, 2002b).

In sum, results from this type of analysis will help water managers devise paths to the sustainable management of catchments. But, perhaps more importantly, it may also help stakeholders and citizens to envision alternatives to current trends and understand the interconnectedness between decisions on land uses and the ecological quality of our rivers.

1.2. Nutrient emissions and catchment management: the Catalan context

Economic development has led, especially since the mid 20th century, to the enrichment of surface and coastal waters with nutrients (N and P) derived from anthropogenic sources. In Mediterranean rivers, this phenomenon has often contributed to eutrophication because of naturally low and variable flows compounded with high water demand (Sabater et al., 1992; Alvarez Cobelas et al., 2005). Nevertheless, despite the fact that it has become a major environmental issue in recent decades, rivers in Mediterranean Europe have been less intensively monitored and less studied than rivers in Central Europe. In Catalonia, many rivers bear witness to the negative consequences of economic development on the environment (Prat and Munné, 2000; Céspedes et al., 2006; Binimelis et al., 2007). Nonetheless, the water quality of Catalan rivers has improved over the last 20 years thanks to partial control of point emissions, as part of the traditional top-down and reactive management of the internal basins of Catalonia (i.e., river catchments that lie entirely within Catalan borders) (Prat et al., 2002).

In the context of the current efforts to develop programmes of measures for river basins as required by the WFD and the European Statement for a New Culture of Water (NCW), adopted in Madrid in 2005 by a group of European scientists, the traditional management of the internal basins has changed to a more proactive management including the implementation of an integrated assessment process guided by the principles and objectives of the WFD (ACA, 2005; Munné et al., 2002). This represents an event at the catchment level with regards to water management and planning.

IEA plays a crucial role in the implementation of the WFD in the internal catchments of Catalonia as a tool to analyse the future evolution of the natural/socioeconomic system based on a long-term approach. However, although catchment nutrient emissions are currently being studied, the description of the social system and the participatory development of scenarios applied to nutrient emissions problems at the catchment scale in the Mediterranean region is quite novel; we are not aware of any precedent published in the scientific literature. Moreover, in Catalonia, due to poor databases, we encounter many uncertainties notably related to diffuse sources, which are still largely unaddressed. Nonetheless, the Catalan Water Agency (ACA) recently implemented a participatory process at the catchment scale following WFD guidelines for the participatory development of catchment management programmes. Participation at the local level and for a long-term approach serves better to adapt measures to local conditions, to include people concerned in the design process and eventually to raise public acceptance. A participatory process like this will, therefore, be useful to assist policy makers collaborating with the ACA to improve water quality and sustainable management of the anthropogenic sources of nutrients at the catchment scale.

Among the Catalan river basins that lie entirely within the Catalan borders, La Tordera basin has been selected to perform an IEA in the context of the WFD for this thesis research project. La Tordera basin is a medium-sized catchment that presents a contrasting topography between mountains and valleys, a close proximity to the city of Barcelona, and heterogeneous territorial division including natural parks and important economic activity (see section 1.3). Many of these changes in the territory were due to the spatial relocation of industries from Barcelona and its surroundings and the improvement of leisure and residential areas. Although many social factors have interacted with the environment of La Tordera catchment and disturbed nutrient loads, the water quality status presented a moderate contamination with some fluctuations during the nineties (see Study Site below). However, a better understanding and management of point and diffuse nutrient emissions, e.g., agricultural diffuse nitrogen emissions, is required to reach a sustainable management of the anthropogenic sources of nutrients at the catchment scale. Moreover, many other issues may present a risk of failing the WFD objectives. These problems are related to industrial and urban waste water discharges, urban areas not connected to sewers, and agricultural practices, among others (ACA, 2008).

Because of these characteristics and the fact that no integrated and interdisciplinary environmental assessment applied to nutrient emissions issues in Catalonia has been published yet, La Tordera basin is an interesting and suitable study area to introduce and perform an IEA.

1.3. Study area

1.3.1. Location

The Tordera basin (877 km^2) is located in Catalonia (NE Spain), about 60 km north-east of Barcelona. La Tordera stream originates in the Montseny massif (maximum altitude, 1712 m a.s.l.), and runs for about 60 km along the valley formed by this massif and the littoral mountain range of Montnegre before ending in a delta between two important coastal tourist towns, Malgrat de Mar and Blanes (Fig. 1.1).

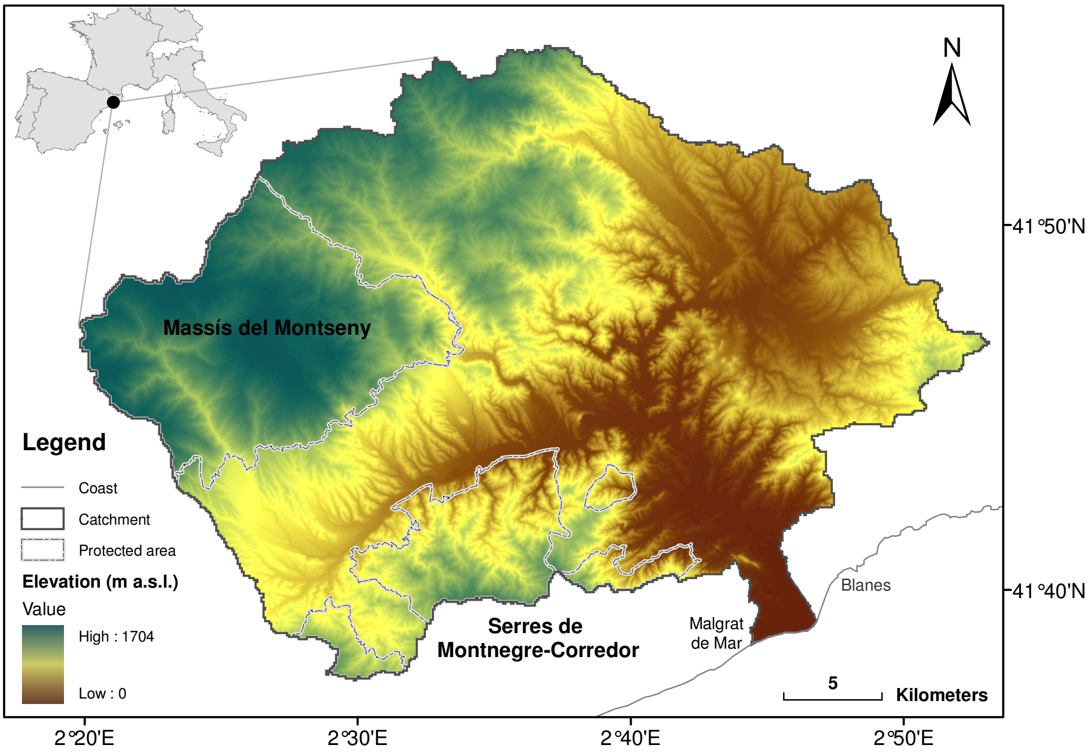

Figure 1.1 *Location of La Tordera catchment in Southern Europe, showing the topography and the limits of two protected areas: Massís del Montseny (Biosphere Reserve) and Serres del Montnegre - El Corredor (Natural Park). Source: Catalan Cartographic Institute (ICC, Institut Cartogràfic de Catalunya).*

1.3.2. Hydrogeology and climate

The catchment geology is composed mainly of solid, poor porosity plutonic and metamorphic rocks overlaid by sandy, unconsolidated quaternary deposits forming wide terraces and a significant fluvial aquifer in the mid and lower sections of the river.

The climate is sub-humid Mediterranean. Based on two subcatchments, 14001 and 14026 (Fig. 1.5), with contrasting climate within the catchment, the mean temperature ranges from 5 to 10°C in winter (November-March) and from 20 to 25°C in summer (July-September); the mean annual precipitation was 780 mm/yr over the 1995-2002 period, with large variation both temporally and spatially (Fig. 1.2). The hydrologic regime of the streams follows the climatological patterns, with low or intermittent flows during summer and higher and permanent flows for the late autumn to early spring. River flow was highly variable both seasonally and inter-annually. For example, median discharge at the Fogars village, 10 km upstream the mouth of La Tordera, was 0.95 m^3/s from 1994 to 2003, with a range from 0 to 170 m^3/s.

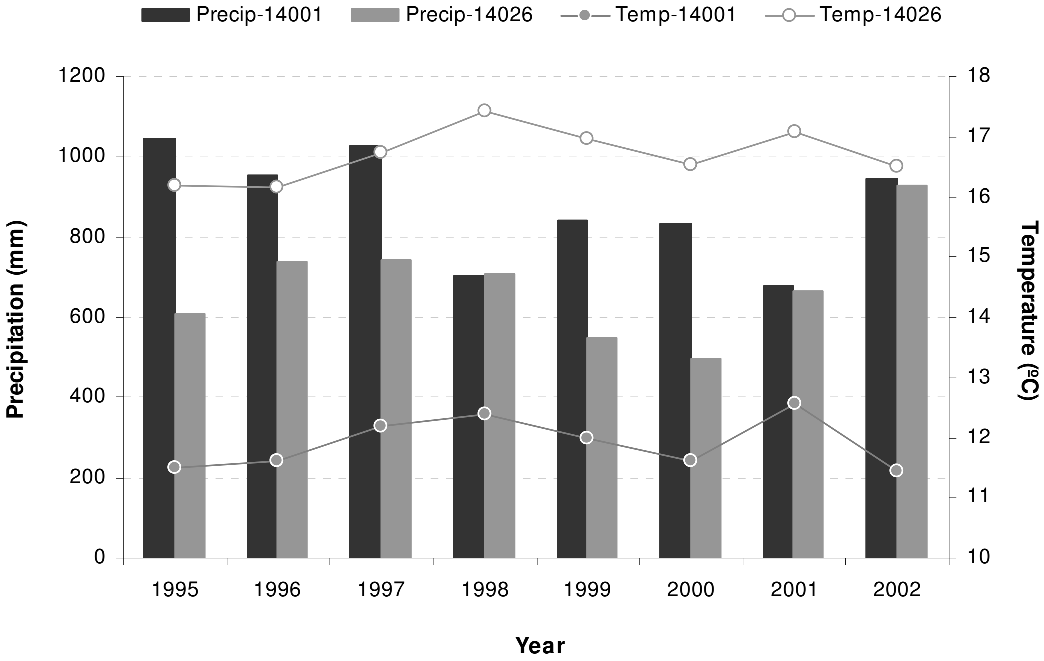

Figure 1.2 *Mean temperature and mean annual precipitation from 1995 through 2002 for two subcatchments (14001 and 14026, see Fig. 1.5) with contrasting climate. Source: Catalan Water Agency, (ACA, Agencia Catalana de l'Aigua).*

1.3.3. Territorial divisions and land uses

The catchment spreads over 25 municipalities in three counties (La Selva, El Vallès Oriental and El Maresme), and includes sections of two Natural Parks: Montseny and Montnegre-Corredor. These are managed by two provincial delegations of the central Spanish government (Diputació de Barcelona and Diputació de Girona). Approximately 90% of the Montseny park area is privately owned and managed by the Diputació de Barcelona and Diputació de Girona, based on the 1977 Special Plan of the natural park of the Montseny Massís, which includes regulations aimed at protecting the ecological integrity of the ecosystems with the collaboration of local organisations. The Park of El Montnegre-Corredor is legally safeguarded by a Special Physical Environment and Landscape Protection Plan approved on 20 July 1989. The Natural Spaces Area of the Diputació de Barcelona administers this protected area in co-operation with the local councils within the park, and with the participation of the various sectors involved.

In the catchment the main land uses are forests and grassland (77%), covering most of the mountainous terrain, agricultural lands (16%), mostly on the low elevation north-eastern part of the catchment, and urban and industrial land (7%), mostly along the main valley (Fig. 1.3; see also Chapter 3).

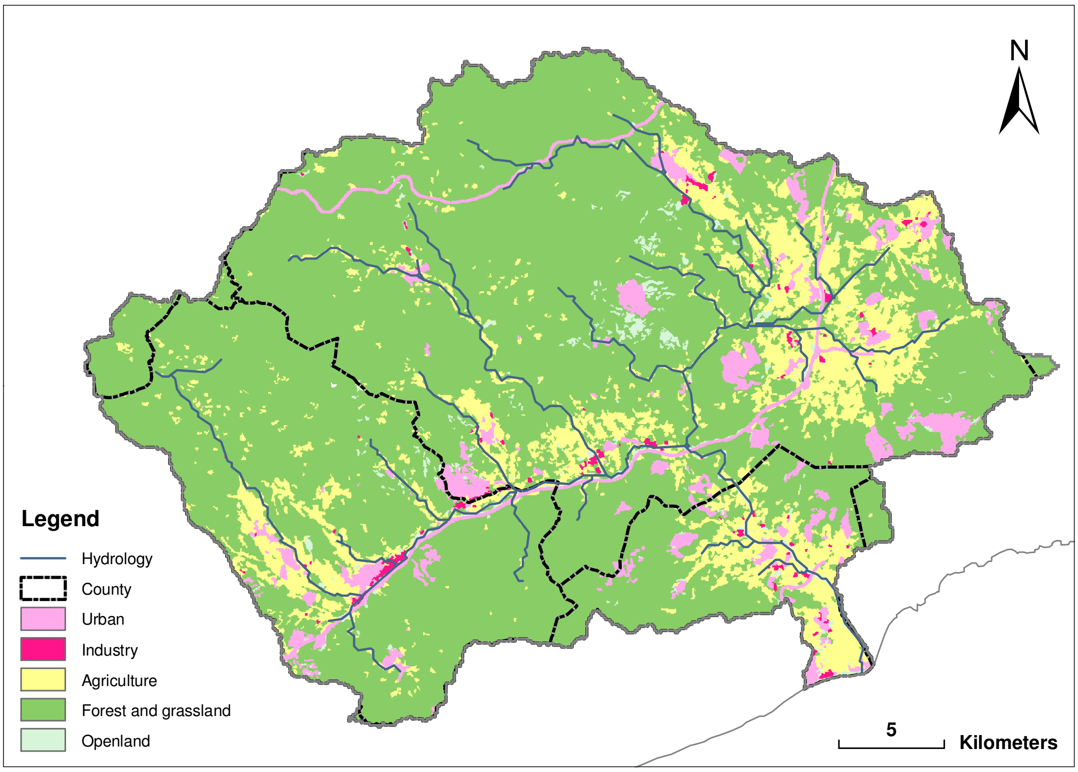

Figure 1.3 *Main land uses, borders of the catchment and counties, and the river network in La Tordera catchment in Catalonia for the year 1997. Source: ICC.*

1.3.4. Population and nutrient management

Over the last thirty years, the population of La Tordera catchment has increased from 59,000 inhabitants in 1975 to 65,000 in 1985, 76,000 in 1995 and 103,000 in 2005 (census data from IDESCAT; see Fig. 1.4). This trend reflects changes in human activities in the catchment, which have increased during the 1990s (see Chapter 2). Fluxes of N and P have been affected and disturbed by many factors associated with anthropogenic activities (see Chapter 3). Today, the agency in charge of managing La Tordera is the Catalan Water Agency (Agència Catalana de l'Aigua, ACA). This public organisation, attached to the Department of the Environment and Housing (DMAH), is the only water administration of the Catalan Government with full authority on the internal catchments of Catalonia.

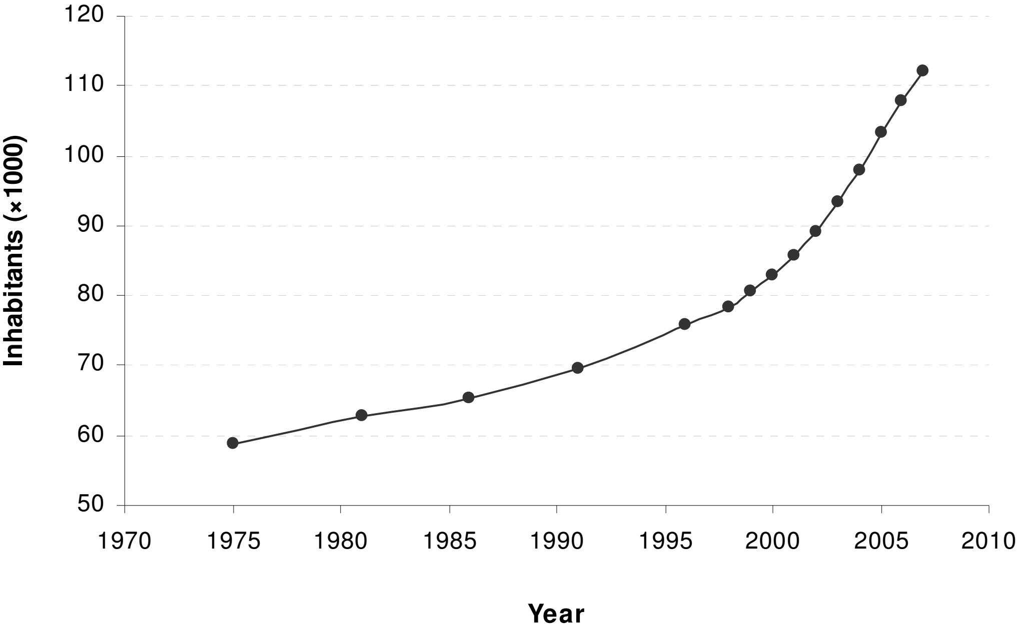

Figure 1.4 *Population growth from 1975 to 2007 in La Tordera basin. Source: IDESCAT.*

From the end of the 1990s, the departments of the Catalan government in charge of agricultural and industrial activities, and of demographic growth (DARP, DTI, and DMAH[2]) gradually reinforced the control and management of human activities. In accordance with the Urban Waste Treatment Directive (UWWTD, 91/271/EEC), the Catalan government developed and implemented strategic plans for the treatment of all urban and industrial waste waters (in 1995 and 2002 for urban waste waters, and in 1994 for industrial waste waters) (ACA, 2002a, 2003). The number of waste water treatment plants (WWTPs) as shown in Figure 1.5 is only valid for the period of study, and similarly for the monitoring stations and gauging stations. Indeed, with the WFD, the number of WWTPs and stations has increased, and particularly, the number of monitoring stations.

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[2] DARP, Catalan Department of Agriculture and Fisheries (Departament d'Agricultura, Ramaderia i Pesca); DTI, Industrial Work Department (Departament de Treball i Indústria); DMAH, Catalan Department of the Environment (Departament de Medi Ambient i Habitatge).

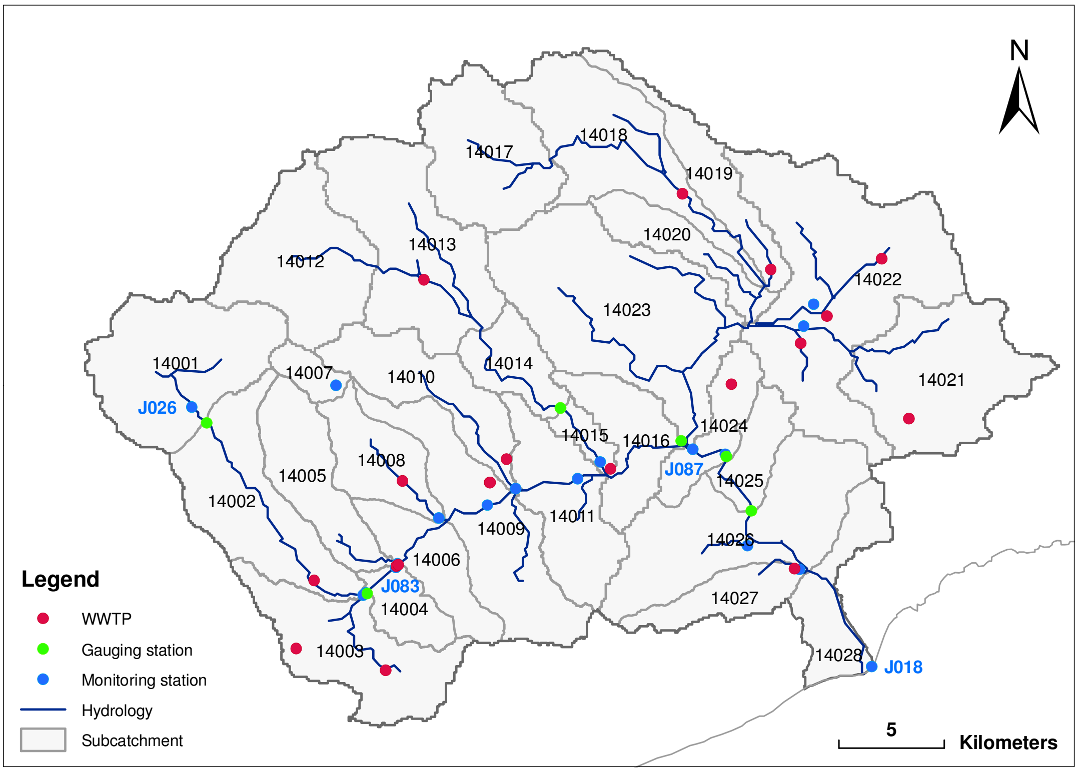

Figure 1.5 *Representation of the borders of the subcatchments with their label and location of waste water treatment plants (WWTPs), monitoring and gauging stations in La Tordera catchment. The monitoring stations selected along the river to show the evolution of water quality status are indicated by their labels in blue. Source: ICC and ACA.*

Nowadays, waste waters from towns with more than 2,000 inhabitants are treated, and point sources of nutrients have decreased substantially since the first plans for urban and industrial waste water were initiated (ACA, 2002a, 2003, 2005; Prat et al., 2005; Jubany, 2008). However, agricultural diffuse nitrogen emissions remain largely unaddressed. For example, at Forgars monitoring station, 14 km upstream of the river mouth, the mean concentration of soluble reactive P has decreased from 0.22 mg P/l in 1990-1995 to 0.07 mg P/l in 2000-2004, whereas the mean concentration of nitrate has decreased only from 1.81 to 1.32 mg N/l between the same two periods.

The evolution and changes of water quality status of La Tordera river are represented by N and P concentrations at selected monitoring sites for the period 1994-2003 (Figs. 1.6, 1.7 and 1.8). Both elements are measured in several forms, namely NO_3^-, NH_4^+ and dissolved inorganic phosphorus which is expressed as PO_4^{3-}. The level of concentration is based on the N, P standards of water quality defined by "very good, good, moderate, bad and very bad" quality according to the guidance document, Impress (ACA, 2005) (Table 1.1).

Table 1.1 *Classification of grades of river water quality for different concentrations of nutrients as used by the ACA (abbreviations stand for VB: very good, B: good, M: moderate, B: bad, VB: very bad). Source: ACA (2005).*

Parameter	**Unit**	**Grade description**				
		Very good (VB)	**Good (G)**	**Moderate (M)**	**Bad (B)**	**Very bad (VB)**
Ammonium	mg N-NH_4^+ / L	0.16	0.39	0.78	3.89	> 3.90
Nitrate	mg N-NO_3^- / L	0.45	2.26	5.65	11.29	> 11.30
Phosphate	mg P-PO_4^{3-} / L	0.03	0.16	0.33	0.65	> 0.65

The monitoring sites along the river are selected to be representative of a pristine area and those affected by the most common anthropogenic activities, i.e., urbanisation and tourism, agriculture and industry (Table 1.2 and Fig. 1.5).

Table 1.2 *Selected monitoring stations used to represent the evolution of water quality in La Tordera river for the period 1994-2003 (Fig. 1.5). Source: ACA.*

Land use	**Monitoring station**	**ACA ID**
Pristine	Montseny	J026
Urbanisation/Industry	Sant Celoni (before WWTP)	J083
Agriculture	Riera de Santa Coloma	J087
Urbanisation/Tourism	Malgrat de Mar	J018

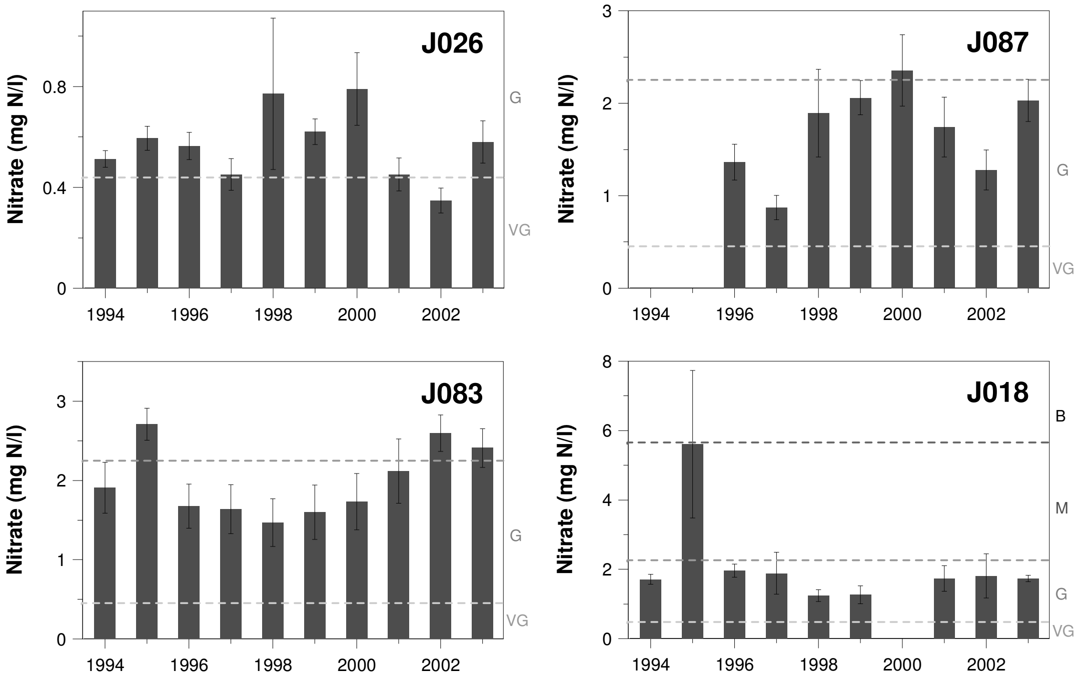

Figure 1.6 *Evolution of the nitrate concentration at selected monitoring sites (Table 1.2) for the study period. The threshold grades of river water quality are indicated by a dotted line (Table 1.1).*

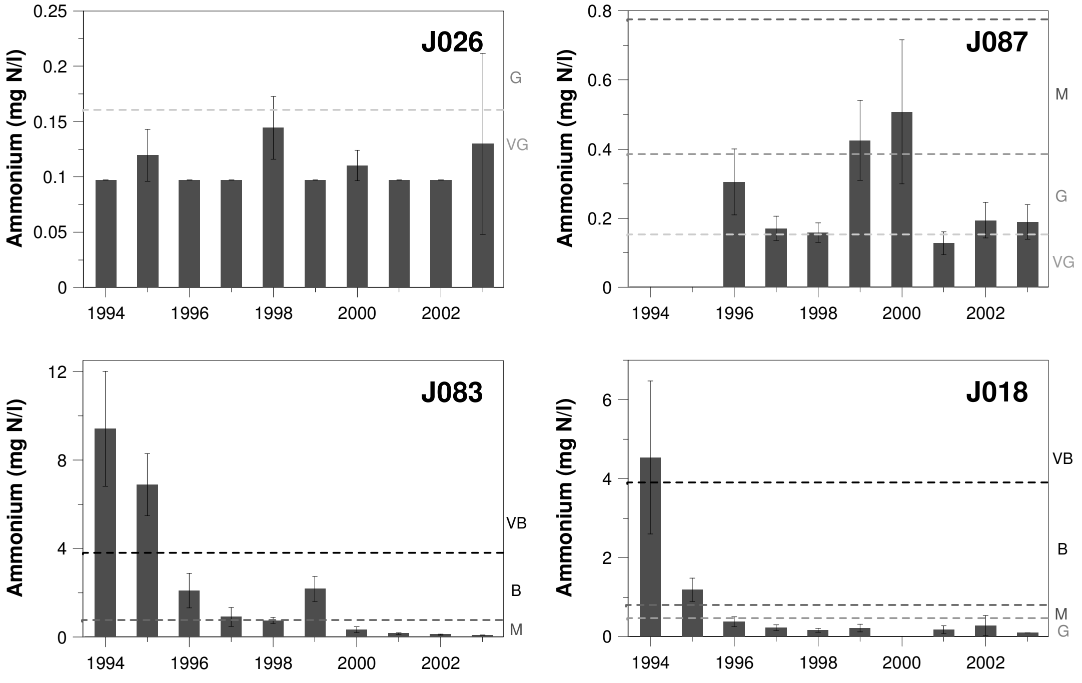

Figure 1.7 *Evolution of the ammonium concentration at selected monitoring sites (Table 1.2) for the study period. The threshold grades of river water quality are indicated by a dotted line (Table 1.1).*

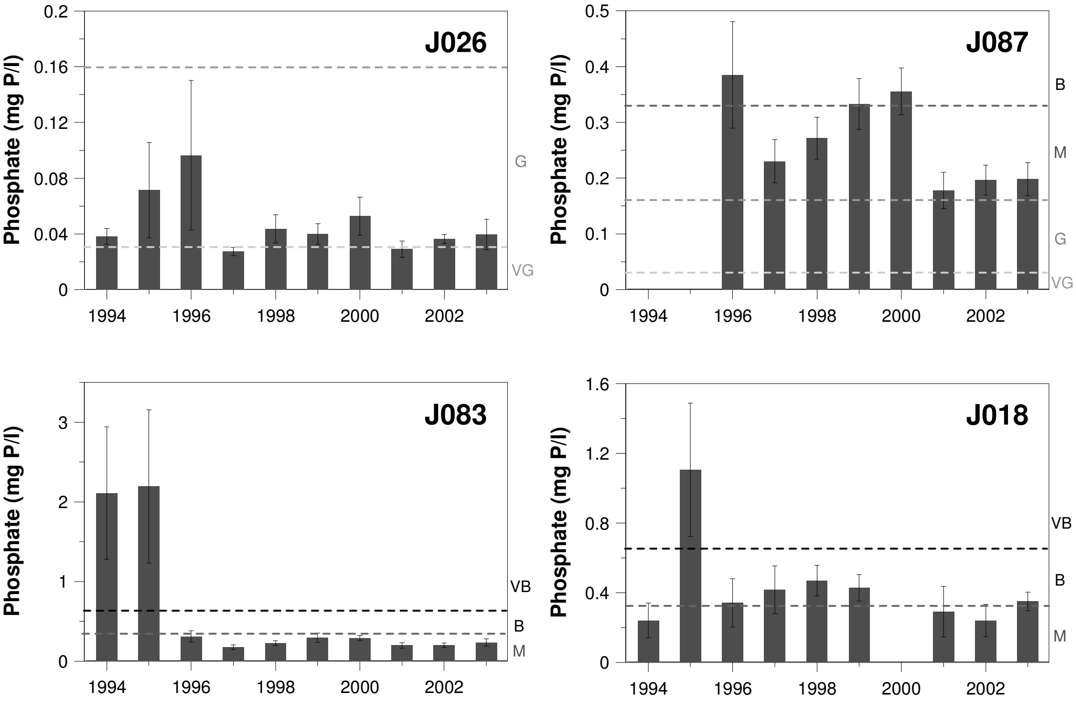

Figure 1.8 *Evolution of the phosphorus concentration at selected monitoring sites (Table 1.2) for the study period. The threshold grades of river water quality are indicated by a dotted line (Table 1.1).*

1.4. Objectives and structure of the thesis

The aim of this study is to undertake an integrated and interdisciplinary environmental assessment of nutrient flows for the past, i.e., early 1990s to early 2000s, and future, i.e., the 2030 horizon using the Catalan river catchment of La Tordera (NE Spain) as a case study. The four following main objectives will be addressed (each corresponding to one of the four core chapters of the thesis):

1) What are the main socioeconomic components that drive the environmental changes associated with N and P loads?

   This is addressed by interviewing representatives of the main social actors of the catchment, and analysing the pressures and impacts related to nutrient emissions from the river basin. This analysis of the social system is addressed in Chapter 2;

2) What are the main sources of N and P across the catchment, and how have nutrient emissions changed over the last decade?

   This is addressed by collecting statistical and monitoring data for catchment land uses and stream flow and nutrient concentrations, and then fitting a mass-balance N and P catchment model of annual loads. The estimation of N and P emissions for the 1995-2002 period is presented in Chapter 3;

3) What are the alternative views of the future for La Tordera catchment for the 2030 horizon?

   This is addressed by developing local alternative socioeconomic scenarios through a participatory process with local stakeholders, which is discussed in Chapter 4; and,

4) How will nutrient emissions change for each of the socioeconomic scenarios developed above?

   This is addressed by evaluating potential changes in nutrient flows using the catchment nutrient emission model. The aim is to help to develop programmes of measures for the sustainable management of the sources of nutrients for river basins as required by the WFD. The nutrient emissions for each of these scenarios are estimated in Chapter 5.

The dissertation ends with a synthesis of this study that summarises the main conclusions.

Chapter 2

Social system analysis for the integrated assessment of nutrient flows

2.1. Introduction

In this chapter it is presented a description of the social system relevant for the management of stream nutrients in La Tordera catchment. It is portrayed as a case study, and as part of the process, to undertake an integrated and interdisciplinary environmental assessment (IEA) of the nitrogen and phosphorus fluxes in a Mediterranean catchment. By allowing a synoptic perspective of the causes and effects involved (Rotmans et al., 1996), IEA facilitates the understanding of the interactions and feedbacks between the natural and the social system involved in the dynamics of river nutrient loads. The social system analysis of La Tordera will serve as a support tool for the design of qualitative future socioeconomic scenarios (Kok et al., 2006; Caille et al., 2007). This is also viewed as an important step for the elaboration and evaluation of policy and management options by policy makers and academics for a long term period, i.e., one relevant to the evolution of nutrient flows.

Thus, the development of river basin management plans the Water Framework Directive (WFD) requires undertaking the analysis of the social context within which human pressures and impacts on river systems develop and evolve (WFD, 2002a; Pirrone et al., 2005). The WFD is the piece of European legislation for the effective protection, amelioration and management of all European natural water bodies. The first and essential task is to establish an inventory of the main socioeconomic components, i.e., the social agents, their activities and their linkages, which together drive human pressures and impacts on the river, including those associated with enhanced N and P loads, the two principal nutrients responsible for the eutrophication of surface and coastal waters. Exploring and characterising the social conditions surrounding the nutrient cycles and fluxes in a river catchment allows us to define the links between social agents, socioeconomic activities, landscape transformation and nutrient loads, and thus helps us to understand, model and manage better the complexity of the causes of water quality problems (Ledoux et al., 2005; Schmitz et al., 2003).

An approach that has proven effective in the description of socioecological systems is stakeholder mapping (Jacquemin and Wright, 1994; Newcombe, 2003), a method for classifying stakeholders and positioning them in a picture that helps to clarify and communicate their role in the studied system. The identification of stakeholders is performed through the analyses of printed and internet materials, statistical reports and expert consultation. In contrast, stakeholder mapping is obtained from in-depth, one-on-one, confidential interviews (Schostak, 2006). Interviews enable data to be collected through direct verbal interactions with stakeholders. They constitute, then, a powerful support tool to access stakeholders' perspectives (Gubrium and Holstein, 2001; Van den

Hove, 2000) on the social and environmental conditions surrounding a specific issue and to describe socioecological systems.

For in-depth analysis of socioecological systems, the DPSIR (driver, pressure, state, impact, response) framework has proven useful in providing and communicating knowledge on the state and causal factors regarding environmental issues (Turner et al., 2001; Bowen and Riley, 2003). The DPSIR model was originally developed by the European Environmental Agency, the European Commission and the United Nations, among others (EEA, 1999), from an earlier framework, the "Pressure-State-Response" model, put forward in 1993 by the Organisation for Economic Cooperation and Development (OECD, 1993) as a means for environmental evaluation. By including the causes of environmental change and their impacts, the DPSIR approach allows to represent the complex social/environmental interaction and highlight the dynamic characteristics of the socioeconomic and ecosystems changes. The social system analysis using the DPSIR framework and its application to integrated assessment of nutrient flows in a catchment has been adopted for the implementation strategy of the Water Framework Directive (WFD, Directive 2000/60/EC). The European research project, EuroCat, used a similar perspective and analytical framework to understand and analyse catchment changes and their impacts on the coast. It proved to be useful for understanding the social system in a general context, and relevant for the development of European directives and strategies (Salomons, 2004).

Our goals are first to identify the main social actors affecting or affected by nutrient emissions to the river, and then to describe how they interact among themselves and with La Tordera river ecosystem. Finally, we will present the changes in nutrient loads and in the main sectors of activity around La Tordera catchment over the last decade, from 1993 through 2003, and analyse the perspectives of stakeholders on the catchment environmental problems and water quality.

2.2. Methodology

To answer the main questions in our analysis of the socioeconomic system relevant to nutrient emissions in La Tordera catchment, we used: social actors analysis to identify the stakeholders at the catchment and regional levels (section 2.2.1), interviews with selected representatives of stakeholders, statistical data and published documents to describe their interactions, understand the changes in nutrient loads and collect information on stakeholders' perspectives on water and environmental issues (section 2.2.2). For the organisation and analysis of interview data, we applied the framework of the pressures and impacts analysis (section 2.2.3).

2.2.1. Identification of stakeholders

We used social actors' analysis to identify the main stakeholders involved in generating, regulating or managing nutrient emissions in La Tordera catchment. We organised stakeholders by sector of activity because of the relevant impact of these activities on nutrient emissions to the river.

To identify the main social groups and select the key stakeholders, we followed a methodology inspired by the "Shaping actors - shaping factors" method, used for the first time in "The European Challenges post-1992" (Jacquemin and Wright, 1994). We based this process on a previous analysis of the nutrient emissions, on recommendations and former project reports from academic experts and local informants (Tàbara et al., 2004a; http://www.observatoririutordera.org/), and on internet research. Stakeholders were selected to include both public and private sectors, groups with a direct effect on water quality (nutrient emitters, i.e., farmers, industrialists, inhabitants and tourists), local and regional administrative departments with a stake in the development and implementation of policy relevant to nutrient emissions, and locally represented organisations involved in environmental conservation.

The identification of stakeholders groups was followed by a selection of stakeholder representatives. This is a crucial phase if we are to conduct interviews and subsequently develop a participatory process with the joint effort of the main stakeholders (Caille et al., 2007). Stakeholder representatives were selected to represent a diversity of beliefs, interests, experiences and values. Selection was also guided by the following criteria: having knowledge about processes acting on specific zones of the catchment (e.g., landscape transformation and its impact on water quality), an open attitude, and a strong interest in the issues.

2.2.2. Interviews

In the social sciences, interviewing is one of the primary methods of data collection and research. Interviews are an efficient tool to collect stakeholders' perceptions (Gubrium, 2001; Kvale, 1996), to analyse the system status and to characterise the social conditions surrounding an environmental issue. We followed the targeted and functional method of qualitative interviewing developed by Patton (2002) to conduct interviews on La Tordera catchment with the selected stakeholder representatives. The objectives were to find out the stakeholders' perception of the social and environmental conditions surrounding nutrient emissions in La Tordera catchment between 1993 and 2003. For this, we applied the semi-structured interview or interview guide approach (Patton, 2002) that may be the most widely used format among the three basic types of qualitative interviewing for evaluation (i.e., the unstructured interview, also called informal conversation interview or in-depth interview, the semi-structured interview or interview guide approach, and the structured interview with the same series of pre-determined questions). Using the information collected during these interviews, supplemented with reports, statistics and maps from, among others, the Catalan Water Agency (ACA), the Catalan Statistical Institute (IDESCAT), the Catalan Department of the Environment (DMAH) and the Catalan Cartographic Institute (ICC), we analysed the past and present states of the system, and looked for indicators of factors that may have changed these states (the pressures and impacts analysis). The goal was first to obtain a representation of the social system, i.e. a representation of the main groups of stakeholders involved in nitrogen and phosphorus emissions at the public and private level, with an indication of how these groups interacted. Then, for each sector of activity, we pursued a detailed explanation of the interplay between the main social actors centered on the main nutrient emitters and based on the way they influenced nutrient loads. Because of the implementation of new legislation after 2000 in the water management of the catchment (i.e., the WFD), we separated the information into two periods: (1) 1993-2000, and (2) 2000-2003.

All interviews were conducted at the interviewees' business premises or at their homes. Occasionally, interviewees preferred a public meeting room for convenience. Usually, meetings were conducted with one person, but a few times they involved two or more individuals. The interviews included 31 to 34 questions (depending on the sector of activity) and lasted between 45 minutes and 1 hour. They were conducted in Spanish and tape-recorded. Because a broad range of topics and issues had to be covered with each interviewee in a short period of time, a visual support was used to introduce the project and explain the context of the study. This visual aid included a simple representation of a model to estimate N and P emissions into a river system, and an illustration of a catchment including the main social actors and their inputs via their activities. Presented at the beginning of the interview, this visual support proved to be an effective way to trigger discussion by focusing the subject's attention on the catchment situation and the main issues linked to nutrient fluxes. Moreover, this straightforward approach helped to elicit responses and information useful for the social analysis assessment of the catchment. While this type of interviews is quite systematic and comprehensive, it may prove difficult, distracting and time-consuming to log during the meeting all the important points discussed. This is why, notes were taken to summarise the most relevant information obtained after meeting with the interviewees. In exchange for their time, interviewees participated in and were involved in the understanding of the social system dynamics of the catchment.

Questionnaires[1] were specific to each sector, but shared a common structure, which included the following topics: land, water, polluting practices, policies and economic factors, and personal opinion. More specifically, questions were designed to reach an understanding of the stakeholders' perception of land use and land use changes, water quality and management, polluting practices in their sector, implementation of policy and changes in legislation. We also tried to obtain the stakeholders' viewpoints on the main sector(s) responsible for impacting the N and P cycles.

The specific issues discussed with representatives of each sector of activity were as follows.

Agriculture

Interviewees were asked how they believed farming activities interacted with N and P cycles, and about changes during the previous decade in the amount of farm land, the type of farming operations, and the management and protection of land uses.

Urbanisation

Questions pursued information about demographic changes as drivers of landscape transformation in this catchment; about the extensive and increasing urbanisation, which potentially augmented N and P emissions; and about the increase in impervious surface cover within urban watersheds, which can alter both catchment hydrology and stream geomorphology. Interviewees were also questioned about nutrient loads (e.g., is the loading of nutrients increasing? How is runoff from urbanised surfaces, and municipal and industrial discharges controlled and managed?)

Tourism

Tourism was viewed as a factor complementary to urbanisation. Stakeholders were asked about the reasons and causes for the expansion of infrastructures and services along the coastal zone for tourism and the increase in secondary residences, which are relevant in the Catalan culture. They were also asked about the means provided to access these residences, such as road and rail networks coming from both provinces, Barcelona and Girona.

Industry

Questions focused on the particularly significant expansion of industrial activities in the nineties in relation with nutrient loads' changes, e.g., „Is the loading increasing?“. We also

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[1] See Appendix 1

sought the stakeholders' viewpoints regarding the management of industrial activities and wastewater treatment, and the changes that had occurred throughout the study period.

2.2.3. Analysis of interview data

Interviews were analysed with the help of the DPSIR framework using the following key terms: Social Actors, Role, Pressure, Impact and Response (EEA, 1999; WFD, 2002a). Because these terms are widely used but often misused, we present below their definitions, which are based on the glossary included in the Water Framework Directive of the European Commission:

Sector of activity: In this study, a set of economic activities which share socioeconomic drivers and environmental effects on the N and P emissions to La Tordera river, i.e., agriculture, urbanisation, tourism and industry.

Social actors: A social group whose activity interacts with the environment, either because they have a direct effect on water quality through the emission of nutrients or because they have a stake in the development and implementation of policy relevant to nutrient emissions.

Role: Function of the actors in relation to nutrient emissions, either as direct emitters or as modifiers of emissions through their interaction with other social actors.

Pressure: Direct effect of a social actor on water quality and biogeochemical cycles (e.g., a change in flow or a change in water chemistry), and on the social system (i.e., the effect of the social actors surrounding the nutrient emitters on the other actors, thus reflecting the interplay among them).

Impact: The ecosystem and social effect of the pressure, e.g., eutrophication or changes in nutrient retention in the stream, protestation and refusal to the implementation of directives and guidelines.

Response: The measures taken to improve the state of the water body and social system, e.g., by limiting point source discharges, or developing best practice guidance for agriculture.

2.3. Results and discussion

We start by presenting the stakeholder selection, then we describe, analyse and discuss the structure and functioning of the socio-ecological system of La Tordera catchment with respect to the emissions of nutrients to the river. We then relate and comment on the changes occurred in this system during the decade 1993-2003 based on the implementation of different policies that refer to agricultural practices, urban and industrial waste water planning strategies, and basin management at the local, national and European level. This part of the analysis is relevant if we are to improve or develop measures for a better management of the basin. We analyse changes in each of the main sectors of activity and in the perspectives on water quality environmental issues as reflected in the interviews with stakeholders.

2.3.1. Selection of stakeholders

Stakeholder representatives are presented in Table 2.1 according to the identified social groups within the main sectors of activity in the catchment, i.e., agriculture, industry, urbanisation and tourism, including both public and private sectors.

***Table 2.1** Stakeholders identified as having an economic activity in interaction with the environment of La Tordera or with a stake in the management of the catchment.*

	Public Organisations/Institutions	Private Organisations/Institutions
Agriculture	- Catalan Department of Agriculture and Fisheries (DARP): technical offices at Barcelona and La Selva county)	- Farmers cooperative of Blanes
	- Catalan Water Agency (ACA)	- Experts: agricultural engineer of the Farm-Produce Technological Research Institute (IRTA) and a veterinary - Catalan farmers' union: Unió de Pagesos and Young farmers of Catalonia (JARC) - Environmental/Social institution: Observatori de la Tordera
Urbanisation Tourism	- Department of Territorial Policy and Public Works (PTOT)	- Environmental consulting group (EGAM)
	- City halls: Sant Celoni, Tordera, Blanes and Malgrat (territorial sector)	- Expert: Professor at the Social Psychology Department
	- ACA: water use planification department	- Observatori de la Tordera
	- Catalan Department of the Environment (DMAH)	
Industry	- DMAH	- EGAM
	- ACA	- Observatori de la Tordera
	- Industrial Work Department (DTI)	

The representatives from the industrial sector were under-represented. Indeed, this observation was underlined by the refusal of the selected industries to be interviewed. Nonetheless, all the stakeholders who took part in the research were active, participative and communicative bringing to light the information needed and helping us to hear their perspectives on the problem at stake. Among all social groups, the most powerful ones in terms of their influence on decision-making are the Catalan Governmental Departments, including the Catalan Water Agency (ACA), and the city halls (Fig. 2.1).

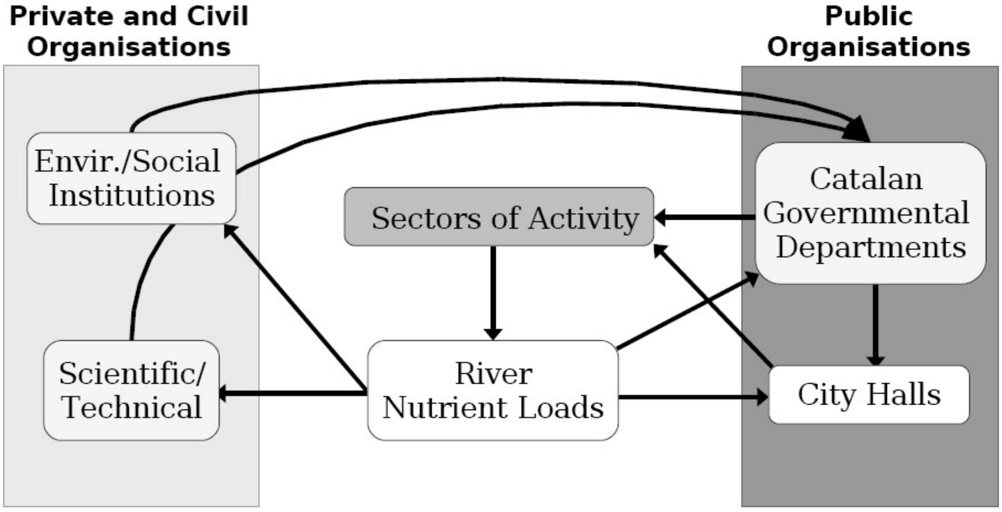

Figure 2.1 *Schematic representation on the main stakeholders identified for La Tordera catchment relative to nitrogen and phosphorus emissions. Arrows indicate the main directions of influence between stakeholder groups. Sectors of activity (agriculture, industry, and urbanisation plus tourism) affect nutrient emissions directly.*

2.3.2. Description of the social system

For each of the three sectors of activity, we will present the main social actors and their interconnections and role within the sector, with the market as an external factor and the nutrient loads as a result of the activities of the sector (Figs. 2.2, 2.4 and 2.5). Then we will discuss the pressures and impacts exerted by the central actors (i.e., the emitters) in each sector. In the discussion, we will emphasize how each actor affects the nutrient loads and is in turn controlled by other factors, in particular the market, the demography and the legislation. However, to simplify the representation of the social system for each sector, we will only include the market in the figures. A summary of the pressures and impacts exerted by the other social actors surrounding the main agents of the three sectors of activity is presented in Table 2.4, where the main changes occurred after 2000 are underlined.

Agriculture

The private and civil organisations, as well as the public organisations, that are presented in Figure 2.2, have a common objective: improving the agricultural sector, e.g., services required by and offered to farmers to protect their interests, and preserving the agricultural market. This goal is pursued through collaboration and negotiation between the DARP and farmers' unions (i.e., Unió de Pagesos and JARC). Acting in concert, they help farmers to improve practices and water quality while enhancing agricultural work efficiency and productivity (Boixadera et al., 2000) and ensure the viability of the sector for future generations of farmers in Catalonia, e.g., through ecological agriculture (Maynou et al., 2006). Farmers' unions and experts collaborate with farmers, providing information, support, defence and help for the implementation of guidelines and directives. In contrast, the DARP (the department in charge of agriculture) develops and enforces legislation and controls its implementation by doing some follow-up. The water agency, ACA, exerts an indirect pressure on farmers through negotiation with the DARP for the implementation of the water planning, and a limited direct effect through the water rate.

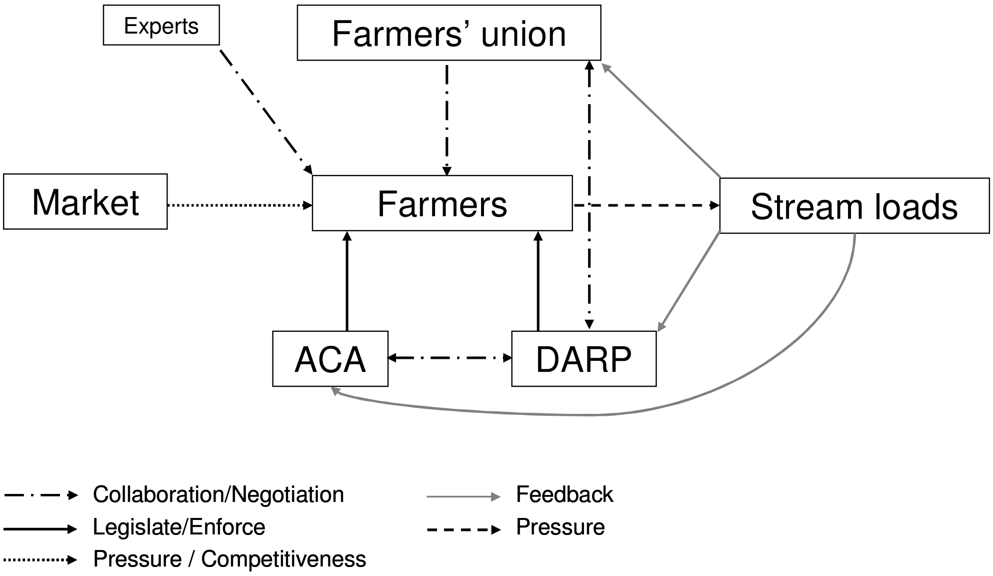

Figure 2.2 *Representation of the interplay of the social actors in the agricultural sector of La Tordera catchment.*

Based on statistical data from the Catalan statistical agency (IDESCAT; http://www.idescat.net), the agricultural population decreased significantly, i.e., 14.7%, during the 1991-2001 period (Fig. 2.3). Non-livestock farmers were more numerous than livestock farmers in this study area, i.e., 66% vs. 34%. Land use maps compiled five-yearly by the Catalan Cartographic Institute (ICC) based on LANDSAT imagery show that, although the agricultural area decreased during the 1992-2002 period, agriculture remains the sector of activity that occupies the most important part of the land (Table 2.2). Although the agricultural area represents only 16% of the catchment (see Fig. 1.3 in Chapter 1), the pressure of farmers' practices (e.g., organic and inorganic fertiliser application) on the stream is significant (See § 4 of the section 2.3.2 and Chapter 3).

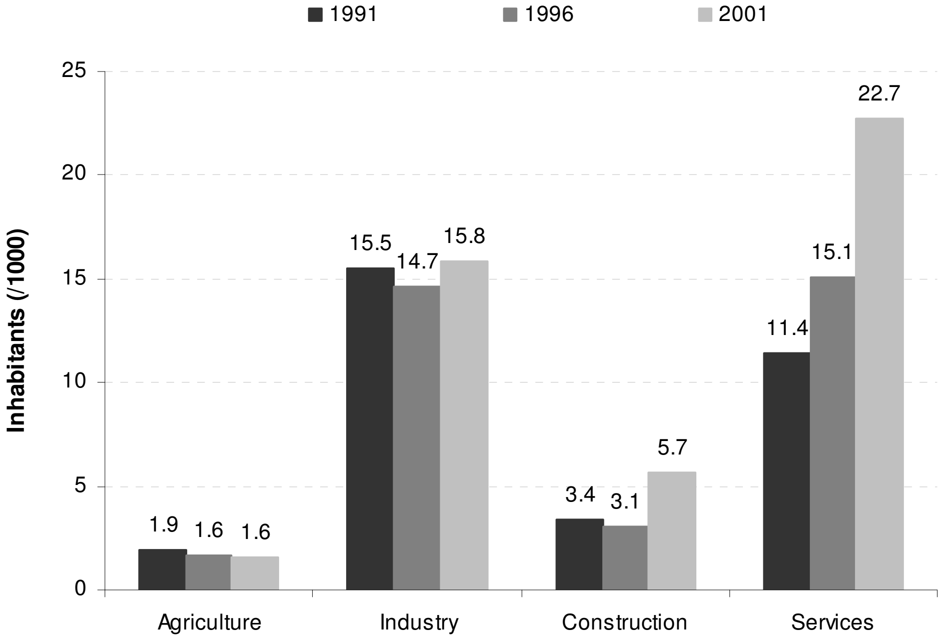

Figure 2.3 *Distribution of the population per sector of activity for the years 1991, 1996 and 2001. Source: IDESCAT.*

Based on the interviewees' information about this sector, and on the evaluation of data on farmers' practices, on crops and forage, and on stockbreeding, we may characterise farmers in this catchment as independent and liberal producers. With the help of the Catalan farmers' union and experts, farmers have attempted to improve their standards of living, their knowledge to produce safely and more, and their competitiveness in the economic market. They have also counted with the support of governmental departments, although they have been more focused on the control of water quality and the economic and legislative aspects, i.e., implementation of guidelines and directives on best practices in 2000. This has translated into an effort to improve productivity and to control the distribution of produce to markets, among others.

In response to this, agricultural practices have been more strictly regulated thanks to the implementation of environmental legislation, including the European Nitrates Directive (Council Directive 91/676/EEC), adopted on December, 12, 1991, through the supervision of the DARP and ACA. This Directive addresses the protection of waters against pollution caused by nitrates from agricultural sources and requires from the member states a report to the European Commission every four years including information pertaining to codes of good farm practice. As a reinforcement of this directive, new best practices guidelines were implemented in 1998 (DOGC num. 2761 de 09.11.1998). Moreover, new farming methods in relation to fertilisers' management and watering management (Boixadera et al., 2000), among others, were implemented based on the interaction with and the impact of the economic market on agricultural practices. As a result of all of this, the use of inorganic fertilisers per unit area decreased. Based on the best data available for Catalonia provided by the national association of fertilisers producers (ANFFE, Asociación Nacional Fabricantes de Fertilizantes), nitrogen inorganic fertiliser application rates decreased from 73.7 kg N/ha in 1992 to 63.1 kg N/ha in 1997 and 49.2 kg N/ha in 2002. As for phosphorus, the use of fertilisers decreased from 36.5 kg P_20_5/ha in 1992 to 30.75 kg P_20_5/ha in 1997 and 26.6 kg P_20_5/ha in 2002. For a future adaptation, this could include crop changes and resource substitutions, but this requires considerable transitional costs and other residual costs.

Table 2.2 *Land uses in La Tordera catchment in 1992 and changes in the area occupied by each land use from 1992 to 1997, and from 1997 to 2002. Changes are given as percentages and areas in km^2. Source: ICC.*

	1992	**1992-1997**		**1997-2002**	
	km^2	**%**	**km^2**	**%**	**km^2**
Agriculture	152.01	-14.58	-22.16	-5.48	-7.11
Urbanisation	43.00	23.73	10.20	6.56	3.49
Industry	4.90	1.68	0.08	27.18	1.35
Forest and grassland	669.48	0.80	5.34	0.11	0.74
Others[a]	7.12	91.84	6.53	11.18	1.53

[a] Beaches, barren lands and areas with low vegetation cover.

Urbanisation and tourism

As Figure 2.4 shows, the three local and regional administrative departments, i.e., ACA, DMAH and city halls, work together in close collaboration to maintain a good balance in the management of the environment and therefore of the streams undergoing the pressures from the urban and tourism sector. In charge of land settlement and urban management, the city halls authorise population to build and take residence, and to connect to any decontamination system.

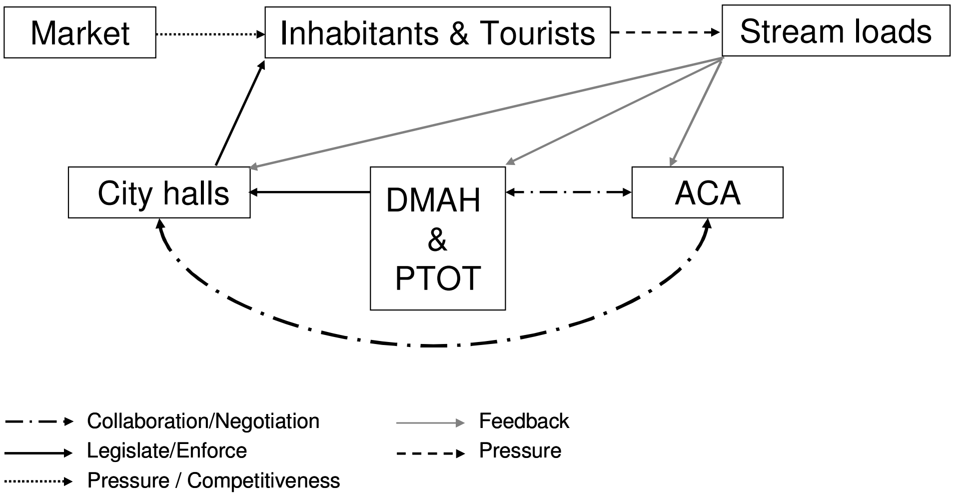

Figure 2.4 *Representation of the interplay of the social actors in the urban and tourism sectors of La Tordera catchment.*

Even though the total area covered by urban land is minimal in comparison to agricultural areas (Table 2.2), urbanisation and tourism are globally a pervasive and rapidly growing form of land use change and one of the major causes of stream impairment, as important as agriculture (Paul and Meyer, 2001). This statement also applies to La Tordera catchment. Based on ACA data about water consumption for the year 1999 (Table 2.3), urban water consumption is as important as that of agricultural irrigated land.

Table 2.3 *Sectoral distribution of water consumption in hm^3 and as a percentage of the total consumption in 1999. For the agricultural sector, the two water uses, i.e., livestock and irrigated crops, are highlighted. Source: Plana, 2004.*

	Urbanisation	**Industry**	**Agriculture**		**Total**
			Livestock	**Irrigated crops**	
Consumption (hm^3)	19.9	31.1	0.6	18.3	69.9
Consumption (%)	28.4	44.6	1	26	

According to a project report by the Observatori de la Tordera[2], total urban water consumption is mainly concentrated in the southern and coastal area of the catchment, where it represents 48% of total consumption against 21% in the northern area and 22% in the central area. In terms of water consumption, we differentiate between two urban uses: domestic use and consumption to support economic activities, e.g., businesses, hotels,

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[2] L'Observatori de la Conca de la Tordera, Memoria 2003-2005, Informe de Seguiment de l'Estat Socioecològic, Martí Boada i Juncà, Xavier Cazorla-Clariso i Marta Miralles. Available on-line at: http://www.observatoririutordera.org/, Juny de 2006.

offices, and others. These two uses account for approximately 70% and 30% of the total annual Catalan urban water consumption respectively (ACA, 2005).

With the increasing population of the basin, from 65,000 inhabitants in 1985 to 76,000 in 1995 and 103,000 in 2005 (census data from IDESCAT), waste waters management and urban planning development are essential for the welfare and safety of the environment. New residents must register with the local administration, and be connected to either a septic tank or to a waste water treatment plant (WWTP). The measures taken to deal with the pressure exerted on the stream through the generation of waste water were the construction of WWTPs. This was part of the urban and waste planning strategies, PSARU[3], implemented by the ACA (ACA, 2002a) and based on a European directive approved in 1991 for the treatment of urban waste waters (Directive 91/271/CEE). The first plan for urban waste water treatment was implemented in 1995. Thus, 10 WWTPs started operating in La Tordera between 1991 and 2002. This first plan was followed by improvements in waste water management, and in the N and P removal efficiency of WWTPs, with an extension of the first plan in 2002 based on a better connection to sewers and WWTPs. This allowed the reduction of water contamination during the period of study, together with the transposition in 2000 of another European directive (Directive 2000/60/CE), which was related to the WFD, i.e., with the objective to achieve good water status for all waters by 2015 based on measures for the protection, improvement and regeneration of these waters. Nontheless, urban development has often followed a recommended but not really coercive building planning without strong controls or fines for non-compliance applied by the local administration, i.e. the territorial department of the city halls.

Tourism's role is mainly economic; but while its development can increase income, revenues, and employment, it also involves costs. Indeed, tourism development through infrastructure development is arguably the major driver of land use and land cover change in the catchment (Table 2.2). Another pressure stemming from these changes is a potential increase in urban runoff, i.e., a source of diffuse urban pollution, which includes nutrients and sediments. As a result of all of these pressures, impacts have been observed in stream geomorphology with potential decrease in stream nutrient retention capacity, and in the quality and services provided by riparian forests and floodplains. The response to these problems has been the promotion of river restoration projects and a better control of land use and infrastructure management in the coastal zone; for example, there have been efforts to revert a few touristy areas to a natural status through a collaboration strategy between ACA and municipalities.

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[3] The PSARU is the Pla de Sanejament d'Aigües Residuals Urbanes (Urban Waste Water Treatment Plan), Further informatin can be found at: http://mediambient.gencat.net/aca/es//planificacio/sanejament/psaru2005.jsp.

Industry

Figure 2.5 highlights the close collaboration between the ACA and city halls to control the establishment of the industries and their connection to any decontamination system. Their work is mainly based on land organisation, economic planning for the implementation of the network decontamination system, and authorisation to the industries to be connected to public WWTPs or build private WWTPs. ACA and DTI inform industries about new local policy measures concerning the decontamination system.

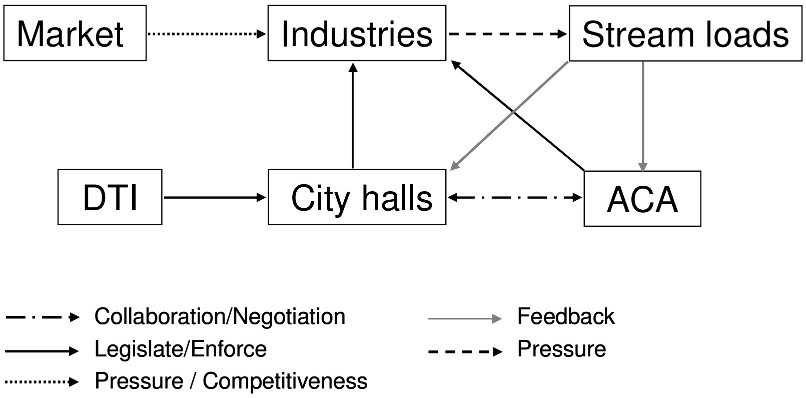

Figure 2.5 *Representation of the interplay of the social actors in the industrial sector of La Tordera catchment.*

The largest industrial companies in La Tordera catchment are in general set up in industrial parks in periurban areas along the river. They operate mainly in the following industries: metallurgy, textile, chemical, pharmaceutical, and furniture. Figure 2.6 shows the evolution of the number of industries by sector in the catchment from 1994 to 2002.

The main pressures applied by local industries on the river during the nineties, resulting in increased N and P emissions, were mainly the lack of connection to public or private WWTPs or, where they existed, their inefficiency (saturation and overflows), which translated into chemical and solid waste spills, as interviewed representatives of the ACA and of the environmental consulting group (EGAM) confirmed. The effects of wastes were aggravated on a stream with Mediterranean discharge regime, where base flow is often not sufficient to dilute WWTP effluents, resulting in elevated nutrient concentrations. Other pressures were changes in the landscape (Table 2.2), especially as industrial parks are in several cases located on La Tordera's floodplain, and water demand (Table 2.3).

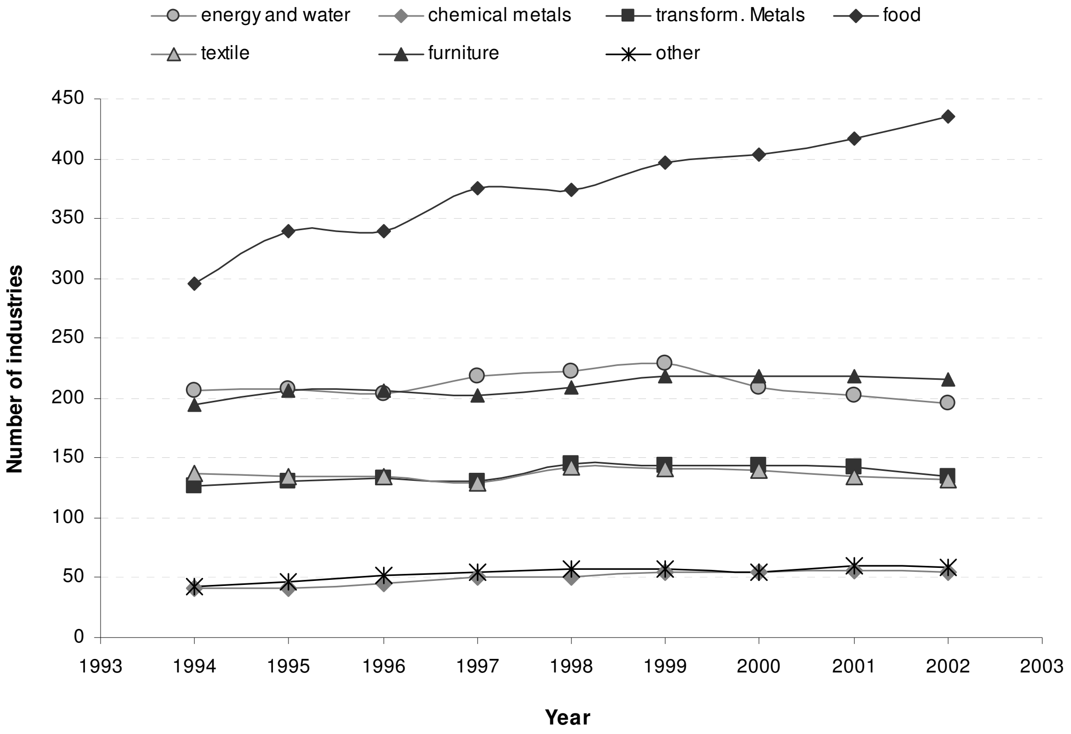

Figure 2.6 *Number of industries by sector of activity in La Tordera catchment from 1994 to 2002. Source: IDESCAT.*

The main responses to these types of problems have been the implementation of local policy measures by the DTI and industrial and waste planning strategies by the ACA with the implementation of the PSARI[4] in 1994 (ACA, 2003) and the support of the city halls concerned. Thus, the industrial sector faces now more restrictions and constraints that at the beginning of the nineties, and their impacts on the river, in terms of nutrient loads, are on the way to being reduced.

In sum, the description of the social system strengthened by the pressures and impacts analysis bring to light that all the social actors in the catchment are not only just responding to external forcing, i.e., European and Spanish directives/regulations or role of the economic market, but are also part of the dynamics occurring among them that drive changes in, for instance, waste water management, water supply/demand, protection of river landscape and riparian areas, and zoning laws among others.

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[4] The PSARI is the Pla de Sanejament d'Aigües Residuals Industrials (Industrial Waste Water Treatment Plant), Further informatin can be found at: http://mediambient.gencat.net/aca/es//planificacio/sanejament/psari2003.jsp.

Table 2.4 *Main pressures and impacts reflecting the interplay between the social actors for the past and present time (from 1993 to 2003). We bring together all the stakeholders surrounding each nutrient emitter for the three sectors of activity. The key changes that occurred after 2000 are underlined.*

SOCIAL ACTORS	ROLE	PRESSURE (socioeconomic and on the environment)	IMPACT	RESPONSE
ACA	– Responsible for water planning and management – Control and manage public water resources	– The water rate	– Protest against the ACA	– Attempt to adapt policies – Sanction if policies are not implemented
Departments: – DARP, – PTOT, – DMAH, – DTI	– Develop planning and regulatory framework (more indicative than mandatory) – Legislate – Manage natural resources – Attempt to provide services – Control market competitiveness, territorial policy, sustainability and renovation of building – Improve quality management system – Develop and encourage urban education	– New regulations and guidelines implementation – Enforcement of directives – Pressure to improve competitiveness: produce and export more	– Protest the implementation of EU/Catalan directives from nutrient emitters – Change policies regarding the market, practices, the use of chemical products, the control of and sanction against farmers' behaviour – Attempts to sanction	– Reach an agreement with Unió de Pagesos – Reinforce the policy framework to overcome problems and disapproval – Implement new policies – Improve N &P management and farming methods
City halls	– Preserve and plan the organisation of the territory – Provide land for industries, infrastructure and services to tourism development – Ensure and maintain the supply and quality of the lower part of water resources – Guaranty water treatment – Identify, control and regulate industrial waste waters loads – Inform the ACA about the water network	– Control of the overexploitation – Issue guidelines – Introduction and monitoring of EU/Catalan directives – Control of industrial waste waters loads – Control of the good implementation of waste water systems	– Refusal from residents and industries to apply guidelines and directives – Protest from residents against the local government	– Inform better and more frequently inhabitants, tourists, and industries – Get a deeper knowledge of urban, industrial and waste planning – Implement stronger urban, industrial and waste planning strategies

	management – Collect and transport municipal residues – Inform on good practices and water quality – Take a census of the annual industrial wastes			
Unió de Pagesos	– Support and inform farmers – Act as farmers' interlocutor – Continuously improve services – Disseminate, implement and follow up on the EU/Catalan directives and regulations	– Issue guidelines – Follow up on implementation of regulations – Ensure that farmers abide by the agreements	– Organise farmers' protest against the DARP – Directives introduced but not applied – Negotiate to reach an agreement between farmers and governmental directives	– To disseminate information on and build knowledge of new farming methods, and – To implement directives
JARC	– Protect the agricultural trade – Farmers' interlocutor for the agricultural trade – Inform farmers on policy actions	– No pressure on farmers	– No relevant social or environmental effect of any pressure	– No pressure or impact, so no measure to take
Experts: – Agronomist – Scientists and environmental institution (e.g., Observatori) – EGAM – Veterinary	– Analyse soil, water quality and manure for private and public institutions – Educate and inform farmers to increase productivity and competitiveness – Set up a farming planning – Build a strong relationship with farmers	– Enhance farmers' responsibility: to make farmers feel concerned and vested of a mission, with the duty to respect and implement it (regulations, guidelines…etc)	– No relevant and direct social or environmental effect of the pressure	– Inform and collaborate with all the social actors – Provide a report, i.e. analytical support for key issues with options to improve N/P cycles management

2.3.3. Changes during the 1993-2003 period

The analyses of the interviews and the collation of statistical data form the basis for understanding the changes that took place over the past decade in nutrient loads and in the three main sectors of activity around La Tordera catchment: agriculture, urbanisation and tourism, and industry.

From 1993 to 2003, results show that the environmental conditions improved, in particular with regard to the emission of nutrients into the river system. This improvement was mainly due to a reinforcement of the policy framework in the three sectors of activity (Table 2.5).

Table 2.5 *Selection of the main pieces of legislation, legal instruments, programmes or management measures implemented during the 1993-2003 period regarding agricultural practices, urban and industrial waste water planning strategies, and basin management at the local, national and European level, which were relevant for La Tordera basin.*

Year	Legislation, instrument, or measure
1991	- European Nitrates Directive (Council Directive 91/676/EEC)
	- European Directive for the treatment of urban waste waters (Directive 91/271/CEE)
1994	PSARI 1
1995	PSARU 1, based on the European Directive approved in 1991
1998	Guidelines on best practices with regards to nitrogen fertilisers
2000	- European Water Framework Directive (WFD, Directive 2000/60/EC)
	- New farming methods in relation to fertilisers' and watering management (Boixadera et al.)
2002	- PSARU 2002
	- Spanish statute law for the prevention and control of contamination
	- Coordinating commission of technological transfer (CCTT) to supervise the implementation of the annual plans based on technological innovations developed by IRTA and DARP
2003	- Catalan governmental decree about decontamination including limits for pollution parameters (Decret 130/2003 de 23 de maig)
	- PSARI 2003
	- Identification of river basin and transposition of the Directive (WFD) into national and regional legislation
2005	Impress report based on Article 5, 6 and 7 of the WFD for River Basin Management Plan (RBMP): review of the environmental impact of human activity and economic analysis of water use (OR characterisation of river basin districts in terms of pressures, impacts and economics of water uses, including a register of protected areas lying within the river basin district)
2007	Sessions of public participation for the development of a planning strategy for La Tordera basin (from September 2007 to February 2008)

Indeed, starting from no strict management and almost no control by the governmental departments on the agricultural and demographic growth (Table 2.1), and on the industrial development and practices, strategic plans were implemented for the treatment of all urban and industrial waste waters, i.e., PSARU in 1995 and 2002 for urban waste waters, and PSARI in 1994 for industrial waste waters (ACA, 2002a, 2003), as well as the Nitrates Directive and guidelines on best practices with regards to nitrogen fertilisers (Boixadera et al., 2000). This was reinforced by the implementation of the Spanish statute law established in 2002 (Ley 16/2002, de 1 de julio) for the prevention and control of contamination and the Catalan governmental decree in place in 2003 about decontamination including limits for pollution parameters (Decret 130/2003 de 23 de maig). The result has been a stronger agricultural (Unió de Pagesos, 2005), territorial, environmental, and industrial policy at the regional level. Therefore, based on the general context, the interplay between all the main actors of the key sectors of activity enabled the development and improvements of services and policy.

From 1992 to 2002, we noticed a reduction of the agricultural land use and an increase in urbanisation, especially in the 1992-1997 period, and industry, especially in the 1997-2002 period (Table 2.2). This was due to industrial changes partly due to an extension of their activities and partly to a progressive abandonment of the production of goods in favour of logistics, service production and intellectual services. Also, pressures from the urban and tourism sectors led to the transformation of agricultural lands into urban and tourist uses. These pressures included promoters’ investment in farmers’ lands, population migration from nearby urban centres, farmers’ financial conditions, and a lack of strict territorial management and control by the city halls and the Catalan government.

Furthermore, this reduction, supported by no strict controls on agricultural practices and poorly regulated agricultural water management, led to a significant decrease of the agrarian population (Fig. 2.3). However, according to the agricultural engineer that we interviewed, some of the farmers that remained could invest on technological development, which allowed them to change their activity and do less demanding work for a higher profit. According to the same source, this contributed to the development of important farming structures, mainly around Santa Coloma, the main agricultural area in the catchment, and to further increases in productivity.

According to interviewees of the agricultural sector, water consumption went down over the last decade. ACA’s data on water consumption reported in 2002 and based on the year 1999 (Table 2.3; Plana, 2004) cannot support the interviewees’ statement. Nevertheless, this decrease may be explained and supported not only by the decreasing evolution of agricultural irrigated land that follows the reduction of the agricultural land use (19.6% in 10 years, which corresponds to 7 km^2, i.e., a decrease from 4.05% in 1992 to 3.26% in 2002 as a percentage of the catchment area; see Fig. 2.7), but also by the better water management and new water irrigation methods, i.e. drip in coast land and „water pressure“ in inland.

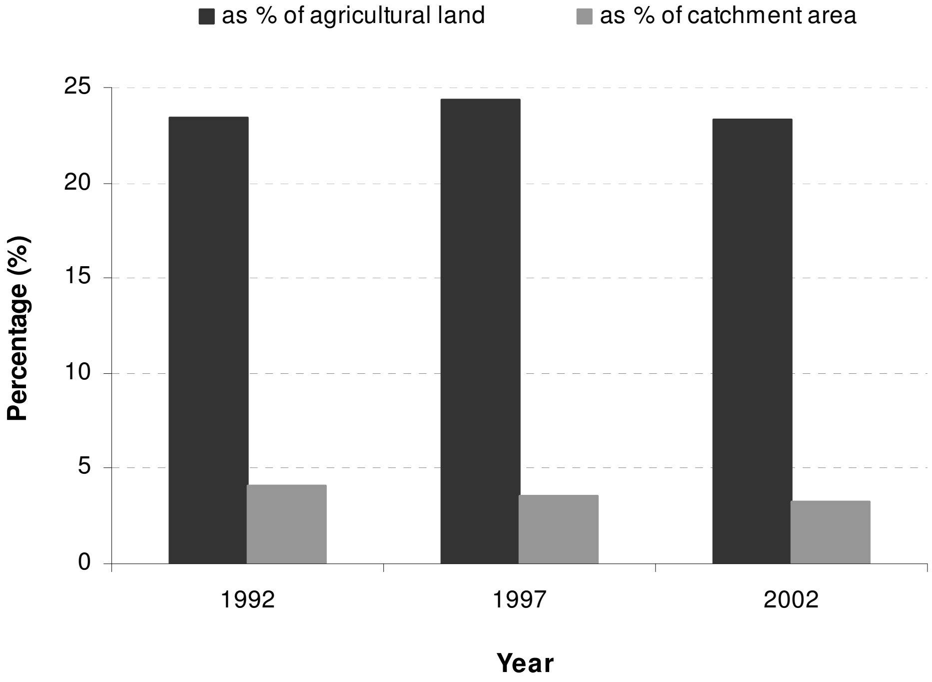

Figure 2.7 *Changes in irrigated land area as a percentage of total agricultural land and of catchment area during the last decade, i.e., for the 1992, 1997 and 2002 years. Source: ICC.*

Another important problem lies with groundwaters. As reported by the expert in agronomy interviewed, the large aquifer of La Tordera has been affected by water abstraction, and from infiltration of fertilisers in agricultural land. The excess of the nitrates in relation to water supply has been one of the most important pressures on surface waters in the internal basins of Catalonia, and presumably also in La Tordera catchment, especially on groundwaters' quality (Mas-Pla, 2005).

During the nineties farmers made liberal use of inorganic fertilisers. However, a few relevant changes in their attitude, practices, and also views on their responsibility started to happen in the late nineties and a decrease has been observed in the use of fertilisers (see section 2.3.2 above) such as the guidelines on best agricultural practices recommended. Nonetheless, according to the JARC and experts, even though the way of communicating and informing on the best farming practices remains a problem, farmers still avoid implementing some of the best practices guidelines stated in 1998 (Boixadera et al., 2000).

Since these guidelines are viewed only as recommendations, farmers follow a non-coercive production planning that does not impose strong constraints on their agricultural practices or on use of fertilisers, and that does not trigger fines for noncompliance of environmental regulations.

Furthermore, new farming methods started to be used following the interaction with and the impact of the economic market and the government. These specific methods were elaborated thanks to the contribution of analyses of soil, water quality and manure. Uncommon at the beginning of the 1990s, these analyses were conducted by private individuals, the main administrations and agents of the agricultural sector, i.e. DARP, IRTA and Unió de Pagesos. However, with a view to introducing, coordinating and promoting the technological innovations developed by IRTA and DARP, a coordinating commission of technological transfer (CCTT) has been created and incorporated following a DARP internal resolution of January 2002 to supervise the implementation of the annual plans.

In addition to this, during the last two decades, connections between agricultural raw material produce and its post-transformation or use have been weak at best in Catalonia (Albajes and Romagosa, 2002), or in La Tordera basin. In a study dedicated to the technological challenges in the Catalan agricultural production, Albajes and Romagosa (2002) represent the evolution of these processes and show that nowadays they are more integrated, taking into account environmental conservation. Therefore, based on the agronomist interviewed from IRTA, a change occurred from a "Productivity" model to a model based on "Quantity and Quality", i.e., from „how to make a profit“ to „how to increase benefits and protect the environment“.

Regarding the urban sector, the population has changed over the last thirty years. From 1975 to the end of the eighties, the local population increased moderately and constantly (1% per year), especially in the coastal areas. However, since 1991, the demographic trend has increased significantly, i.e., a mean annual rate of 1.7% for 1991-1998 and 3.5% for 1999-2003 (census data from IDESCAT). This trend was mainly due to the decentralisation/suburbanisation process of the residents of Barcelona (Ajuntament de Malgrat de Mar, 2002), the closest large metropolitan area to La Tordera catchment. This process has led to significant changes in the territory wherever towns and extra-metropolitan areas have grown faster than central and rural areas (Ajuntament de Malgrat de Mar, 2002). Urban sprawl is a territorial change phenomenon that is a general trend in developed countries (Soja, 2000; Luzón et al., 2003). In industrialised areas, such as Barcelona and its surroundings, including the Tordera catchment, this change is due to the spatial relocation of industrial companies and the improvement of leisure and residential areas. Because of the railway line and motorway in La Tordera basin, which both facilitate the movement of people, many have relocated further away from the city of Barcelona, or alternatively bought a secondary residence in the surrounding countryside, to enjoy a better environment and to improve their standards of living.

An additional parameter that has contributed to land use changes is tourism, which is an important sector of activity in the coastal zone of the Tordera catchment. Since the eighties, the development of tourism and the urban growth have continuously impacted and transformed the landscape in the coastal areas and near the railway line and motorway. Even though tourism is a seasonal phenomenon, the population more than doubles during the high season (from June to September) (ACA, 2002a); it thus represents a threat to the streams and the environment in general as significant as that of the agricultural sector. However, with the implementation of the PSARU in 1995 and 2002 (ACA, 2002a) and the control systems of WWTPs including nutrient monitoring that are managed by the ACA for the protection of waters against pollution, stream water quality has improved, leading to an incipient restoration of the environment. Although the increase in the number of treated inhabitants has not been able to catch up with population growth over the last ten years (Fig. 2.8), the WWTPs have contributed to the reduction of water contamination.

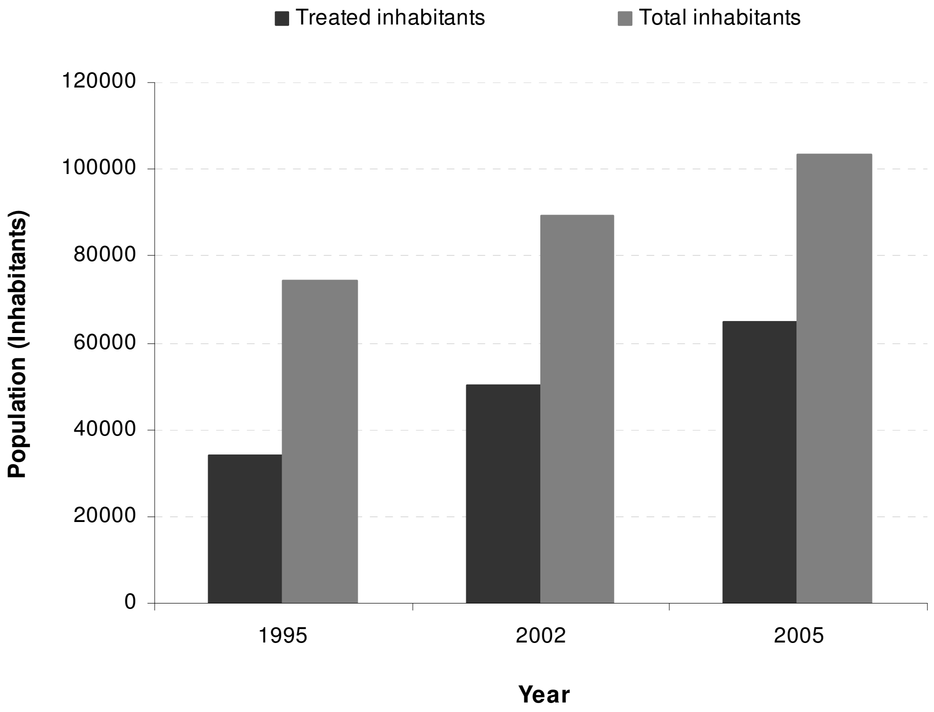

***Figure 2.8** Total inhabitants and inhabitants whose waste waters are treated in WWTPs (i.e., treated inhabitants) in La Tordera catchment in 1995, 2002 and 2005. Source: ACA and IDESCAT.*

The infrastructure related to tourism, hotels, flats and camping sites, has been strongly developed and extended since the eighties with a particular emphasis in the nineties. Taking advantage of this seasonal activity, the main coastal towns of Blanes, Malgrat de Mar, and Tordera (which is located in the lower part of the basin near the coast) have expanded their local economy, e.g., for the period 1991-1996, the Gross Domestic Product (GDP[5]) per inhabitant has increased from 10,000 to 15,330 euros in Malgrat de Mar (Ajuntament de Malgrat de Mar, 2002). However, this phenomenon is not without negative fallout on other sectors of human activity, in particular for the agricultural sector whose activities and land have been affected by the growth of tourism.

As for the industrial activity, collecting data and information about and from industries has proved challenging. The collection of statistics on industrial waste waters started officially in 2001 and was published in 2003 for the new PSARI 2003 (ACA, 2003). Thanks to the contribution of the private environmental consulting company EGAM and from the government agency ACA, the information gathered allowed to explain the changes over the last decade. During the nineties, the fast development of industries in La Tordera catchment (Fig. 2.9) contributed to surface stream water contamination (e.g. toxicity and important emissions of N and P into the river) (see Table 3.3 in Chapter 3).

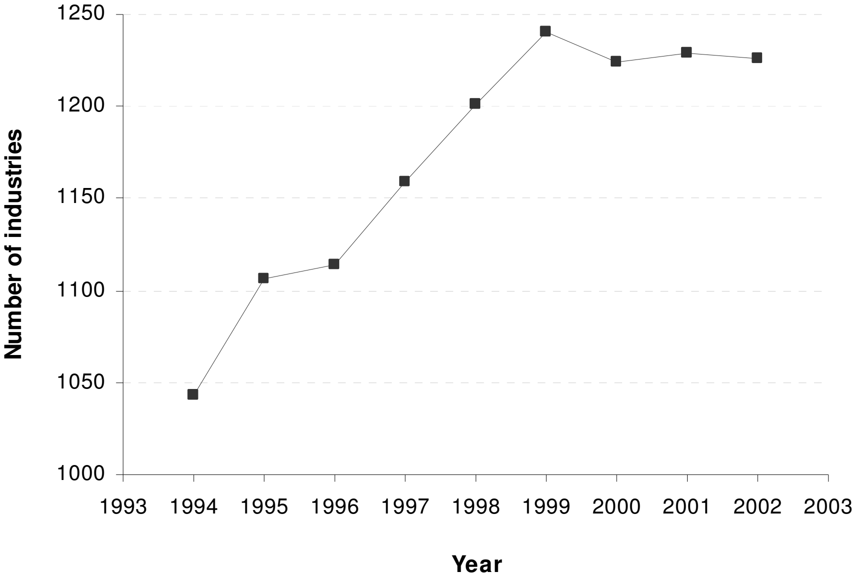

Figure 2.9 *Evolution of the total number of industries in La Tordera catchment between 1994 and 2002. Source: IDESCAT.*

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[5] Equivalent to PIB per habitant. Source: from a study realised by INNOVA SCCL, based on data from the Catalan Statistical Institute (IDESCAT).

This was probably due to industries without any connection to public or private septic systems that poured waste waters to streams without pre-treatment; and/or to those connected to WWTPs that were meeting both problems of saturation and overflow of contaminated loads into the river. Indeed, according to an interviewee from the Department of water use planning of the ACA, the capacity of the septic systems to treat waste waters was not always responding to the demand: connected industries represented around 60 % of the total wastewater treated at a public WWTP, i.e., more than the total of domestic sewage (connected inhabitants) and sewage from domestic septic tanks transported to and treated at WWTPs (non-connected inhabitants, which represented about 46% of the total population in 1995).

These problems and impacts of industrial practices on nutrient loads probably stemmed from the strong expansion of the economic activity and therefore the demand of economic benefits in the short term. Since the implementation of the PSARI in 1994 (ACA, 2003), industries treat their waste waters through municipal or regional WWTPs or through their own purge systems, presumably reducing their nutrient emissions (reliable statistics about industrial loads have only been collected since 2001). A closer collaboration among most of the agents of the ACA, city halls and representatives of the industries probably contributed to this improvement. Modernising and updating industrial process required ACA's support and approval to respond to the environmental legislation. Collaboration and/or negotiation between the representatives of the ACA, city halls and industries were presumably the keys to the successful application of the legislation. New regulations on good practices and analyses of census of the annual industrial wastes and stream water quality were also part of the changes. Based on information from the environmental consulting agency, EGAM, industries do not represent as an important of a threat to the water quality (with respect to N and P emissions) since the end of the nineties, although data to support this claim are missing (see Chapter 3).

To implement new changes addressing the demands of each sector while preserving the harmony between all social actors of the different sectors, is a very difficult and long process, and a challenging task which needs the contribution of all social actors. As mandated by the WFD in 2000, the ACA has started a participatory process with a view to the integrated management of the watershed and an improved communication and input from stakeholders (Costejà and Font, 2006). This process should allow managers to adapt better any measures to local conditions and to include people concerned in the design process (Tàbara et al., 2004b; WFD, 2002b). Thus, not-for-profit organisations or institutes, such as the Observatori, farmers' unions or the IRTA, have the opportunity to be involved in the development of management programmes, and therefore, contribute in the catchment development. Comparing with the management and its implementation during the nineties, current participatory catchment programmes highlight the endeavour to consider and integrate public perspectives. Sessions of public participation for the development of a planning strategy for La Tordera catchment took place recently, i.e., from September 2007 to February 2008 (http://www.acaparticipacio.cat/). Importantly, this participatory process reverts not only on a new water policy, but also on a new culture of water, i.e., it contributes to the defence of human and citizen rights in the context of democratic governance based on transparency, participation and citizen control to reach social and environmental sustainability (Arrojo, 2006).

2.3.4. Stakeholders' perspectives on the environment and water quality

The results of interviews represent stakeholders' viewpoint on the following topics: land, water (i.e. perception of water quality and management), policies and economic factors of the main sectors of human activity in the catchment over approximately the last decade. Both the first contact and interviews with the social actors revealed that interviewees were not resisting communication and the release of information about the environmental situation of the catchment.

Landscape transformation

All the private institutions and the Catalan agricultural department agreed that the landscape transformation that occurred during the last decade with the continuous and increasing migration of population into the catchment has had a negative impact on the agricultural activity. Increases in population were not only due to people looking for a better quality of life, i.e., better environmental quality, health and social welfare (Pol et al., 2002), but also to the development of tourism. As a result of this, the landscape changed with a decrease of farming land (Table 2.2) and especially of traditional farmers (Fig. 2.3). This landscape transformation was induced certainly by the rapid and unconstrained development of urban and tourism activities, among others, which favoured land speculation by business and real estate promoters. In spite of the continuous and strong support and help of mainly the farmers' unions, i.e., Unió de Pagesos and JARC, and experts, such as the agricultural engineer, all of them are pessimistic regarding the future of the agriculture in the catchment. In contrast, representatives from the city halls thought that, taking into account the measures implemented (i.e., the plans for urban and industrial waste waters [ACA, 2005; Prat et al., 2005], increases in water rate and controls over the territory), the demographic and landscape changes have had overall a positive impact.

Water quality and management

For the ACA, the territorial changes and the environmental problems related to water quality, and more specifically to N and P loads, have been viewed mainly as a question of management and planning of water uses. Attached to the DMAH, the ACA is the agency in charge of managing La Tordera. Its objective is to strike a balance between use and conservation of the ecosystem. The agency considered that the problems of contamination, principally influenced by the continuously increasing urbanisation and tourism, could be faced by updating and improving the plans for urban and industrial waste waters. Through the participatory process implemented recently by the ACA in the catchment (September 2007-February 2008), a planning strategy could be developed. This public participation seems to be also a good attempt to overcome the problems of communication between the ACA and stakeholders, who have complained about a lack of information concerning the measures adopted, i.e., PSARU and PSARI, and the water rate.

Regarding the perspective of the other social actors, they all considered that water quality has been recovering and is still improving. However, according to the expert in agronomy from IRTA, nowadays the main problem lies with agricultural diffuse sources and groundwaters. Also, the measures implemented to attempt to overcome the problems of contamination, such as water rate and fertilisers application rate control, have never been well accepted, let alone adopted, by farmers. Indeed, farmers do not understand why they should pay for the use of water that has always been a free good of nature for them. Also the pressure of the increased market competitiveness both locally and from imported produce, and the restriction of fertilisers use have been viewed by interviewees of the agricultural sector as a conflicting situation that has hindered the communication between farmers and the DARP.

Policies

While farmers understand and share the objectives of the policies, they see them as reflecting a lack of understanding of their labour and think that most of them are not well adapted to promote the sustainability of agriculture. According to farmers' perception, the policies implemented by the Catalan government have contributed to the decrease in agricultural lands, in the number of farmers, and in the short term to the decline of their activity despite the support of the farmers' union. With the objective of improving the agricultural activities (Maynou et al., 2006), farmers' unions, and experts, e.g., the engineer in agronomy, consider their contribution pertinent to the implementation of regulations that are more suitable way to the present situation of the agricultural sector. But they also insist on the condition that farmers' financial costs should not be increased. By establishing a close and confident relationship with farmers, these agents help them to take advantage of the legislation that regulates the use of water and fertilisers, and ultimately to increase profits while protecting the environment. For the city halls, the ACA and the Catalan governmental departments, the policies and legislation (and their enforcement) that are geared towards water management, soil protection and fertiliser use (which include prominently the WFD) are considered key elements for the improvement of the management of Catalan river basins.

Responsibility

When directly questioned about the responsibility for environmental problems related to N and P loads, all stakeholders felt concerned, but all rejected being the main polluter. Each sector of activity placed some responsibility on the other sectors, mainly with the agricultural and urban sectors. This is supported by the following two viewpoints. Firstly, according to the expert in agronomy, nowadays farmers feel concerned about both the preservation of their sector and environmental problems, and consider acting responsibly. Thus, this expert attributes the responsibility to the urban and tourism sector, and considers that, although the welfare and equilibrium of the environment are key elements for “tourism”, its development is the main threat for the preservation of the environment. Secondly, agents of the city halls reject this opinion, considering that they have always acted for the welfare of people and for a good balance between development and environmental conservation.

Based on the analysis of the system status, we showed that sensitive issues, e.g., water use and good practices of the soil and fertilisers, brought to light problems of communication between, on the one side, nutrient emitters and, on the other side, the local and regional administrative departments. As regards to farmers, the free and short-sighted use of fertilisers put on the market for immediate cost-benefit evidenced their refusal to see one’s responsibilities regarding the methods used to produce more. But it also evidences a lack of comprehension between nutrient emitters and administrative departments. In summary, in the author’s opinion there is tendency “to bury one’s head in the sand” and to avoid facing reality by polluters and regulated agencies.

These problems have aggravated with the implementation of new legislation, especially the WFD, and new taxation devices, such as new water rates, that in the past have been difficult to implement, not well received and criticised by the nutrient emitters. Therefore, there is a strong need to set in place more effective mechanisms of communication among stakeholders, what the ACA has just realised by implementing public information and participation with the objective of achieving the implementation of effective water management, as recommended by the WFD (http://www.acaparticipacio.cat/).

In sum, whatever the sector of activity, there is still a need to inform better the population on good practices on a regular basis for effective sustainable development while improving humans quality of life.

2.4. Conclusions

The results from interviews organised and analysed within the framework of the pressures and impacts analysis has allowed a description and understanding of the interactions and feedbacks between the natural and social system, and the impacts of human activities on surface waters, over the past and into present time.

The description underlined that the central actors (i.e., the nutrient emitters) in each sector of activity were not only responding to external forcing, e.g., directives, regulations or the economic market. It also showed that they were part, along with all the social actors, of the interaction mechanisms that drive catchment management, e.g. through changes in waste water management or zoning laws, among others.

In spite of problems of interaction and communication between nutrient emitters and administrative departments, considerable progress has been made over the last decade regarding urban and industrial nutrient emissions, surface water quality, and, to some measure, the restoration of the environment. This improvement of the environmental conditions has been mainly due to a stronger policy in each sector of activity, as exemplified by the implementation and improvement of urban and industrial waste water planning strategies (PSARU and PSARI), changes in water rates, and the development and improvement of monitoring and services. However, the impact of agricultural practices on nutrient flows still remains a problem and devising economically and socially acceptable ways of further reducing diffuse nutrient emissions remains a challenge, especially for agricultural diffuse sources.

The key findings concerning the past and present complex interaction between the natural and socioeconomic systems will be considered in Chapter 4 for the elaboration of future socioeconomic scenarios relevant to the evolution of nutrient flows in the catchment through a participatory process, as the WFD recommends. Public involvement will have an additional benefit in helping develop a sense of ownership over the river basin management plans and will increase the effectiveness of measures taken to meet the Water Framework Directive‘s objectives.

Chapter 3

Modelling nitrogen and phosphorus loads in La Tordera, 1995-2002

3.1. Introduction

The water quality of rivers in developed countries, and in particular in Europe, has improved significantly over the last few decades thanks to current EU and national legislation, their enforcement, and changes in social attitudes towards the environment (EEA, 1999; or EEA, 2003). However, nutrient emissions are still a key environmental issue in continental and coastal waters. In developed regions, economic growth has led to significant increases in potential nutrient emissions and, consequently, to increased pressures on rivers, often with impacts on their ecological status (Vitousek et al., 1997). In this context, the European Water Framework Directive (WFD, Directive 2000/60/EC) was designed to achieve good ecological and chemical status for all European water bodies by 2015 (WFD, 2002a), promoting a new approach to water and land management through river basin planning. One of its aims is to reduce the impacts of eutrophication caused by excess nutrient inputs through point and diffuse pollution from urban and rural areas. To assess whether this objective of the WFD can be achieved, modelling of nutrient fluxes under different scenarios of the future is necessary. This requires an understanding and analysis of past and present nutrient sources, magnitudes of inputs and distribution of loads within subcatchments.

Models are not only instruments to generate representations of a natural environmental system, but also useful assessment tools for the quantification of pollution pressures by nutrients (De Wit, 2000). Over the last decade, many different models of nutrient transport, retention and loss in river basins have been developed within European countries (Kronvang et al., 1995; Arheimer and Brandt, 1998; Behrendt et al., 2000). Conceptual and physically based process models have been developed to describe pollutant mobilisation, transport and retention in soils, groundwater and surface waters (Conan et al., 2003; Billen and Garnier, 2000; Arnold et al., 1998; Whitehead et al., 1998). Other simpler, empirical catchment models have been based on the export-coefficient approach (Hetling et al., 1999), GIS-based mass balance method (Pieterse et al., 2003) and statistical regressions (Seitzinger et al., 2002; Behrendt and Optiz, 2000). Each model was initially developed for a different region and goal, and differed from other models in its complexity, spatial and temporal resolution, and data requirements. The selection of an appropriate model for a particular application must be made attending to these characteristics, and will always be limited by data availability. In general terms, a model needs to be functional with respect to scale (Addiscott, 1993), and has a degree of complexity that will depend on the area of the catchment to be modelled, with simpler models generally applied to larger catchments (Addiscott and Mirza, 1998; Whitmore et al., 1992).

Among the large number of models available for assessing nutrient loads, MONERIS (MOdelling Nutrient Emissions in RIver Systems) is a static, conceptual, lumped-parameter model that has been widely used in Europe to estimate annual nitrogen and phosphorus loads (Behrendt and Opitz, 2000; Behrendt et al., 2000; Behrendt et al., 2007). MONERIS also provides estimates of emissions through different point and diffuse pathways, and estimates of retention in the stream network. MONERIS is appropriate to estimate the point and diffuse sources of nutrients in data-sparse catchments where high temporal resolution, dynamic models would be difficult or impossible to apply, and whenever a relatively rapid assessment of the main nutrient emission pathways is needed. These conditions are typical of many real-life management situations in Mediterranean countries. To make the application of the model reliable and effective, a model calibration followed by an analysis of uncertainties and sensitivity is essential. Appraisal of the sources of uncertainty is necessary to evaluate the reliability of the model, while an assessment of model sensitivity is required to determine the model response to changes in driving factors, in particular land use change and management scenarios.

In this chapter, we present a modelling exercise of nitrogen and phosphorus emissions to the Catalan river La Tordera (NE Spain) for the 1995-2002 period using the model MONERIS. La Tordera exemplifies the consequences of increasing population, urbanisation, tourism, agriculture and industrial activity on nitrogen (N) and phosphorus (P) loads on the catchment waterways. The chief objective was to validate the application of MONERIS to La Tordera catchment in order to explore future scenarios in the context of river basin management plans as required by the European WFD. For this purpose we undertook: (1) a compilation of data on direct and diffuse nutrient emissions for the period 1995-2002, and used these (2) to calibrate and verify the estimated nutrient loads using MONERIS, over time and across subcatchments, and (3) to assess sources of uncertainty in the model, and (4) model sensitivity.

3.2. Methodology

We first present the model MONERIS, and describe in detail the required input data. We then introduce the model calibration and verification process, and the uncertainty and sensitivity analysis.

3.2.1. The MONERIS model

MONERIS is a steady-state model that was originally developed to estimate point and diffuse annual nutrient emissions in German river catchments larger than 50 km^2 (Behrendt et al. 2000). It has subsequently been applied throughout Europe, e.g., to the Axios, Elbe, Danube, Daugava, Po, Rhine, Vistula and Odra rivers (De Wit and Behrendt, 1999; De Wit, 2000; Behrendt et al., 2003; Behrendt and Dannowski, 2005; Schreiber et al., 2005; Kronvang et al., 2007). Although MONERIS is not a dynamic model, it was deemed an appropriate tool to analyse the river basin, La Tordera, because limited data availability advised resorting to a simple conceptual and empirical model that would still allow us to assess the major emission pathways, evaluate temporal and spatial changes in nutrient emissions, and ascertain the main factors that affected nutrient mobilisation and transport to surface waters during the study period. While temporal resolution was inevitably limited, MONERIS should be capable of discerning spatial patterns through the subdivision of the catchment into subcatchments.

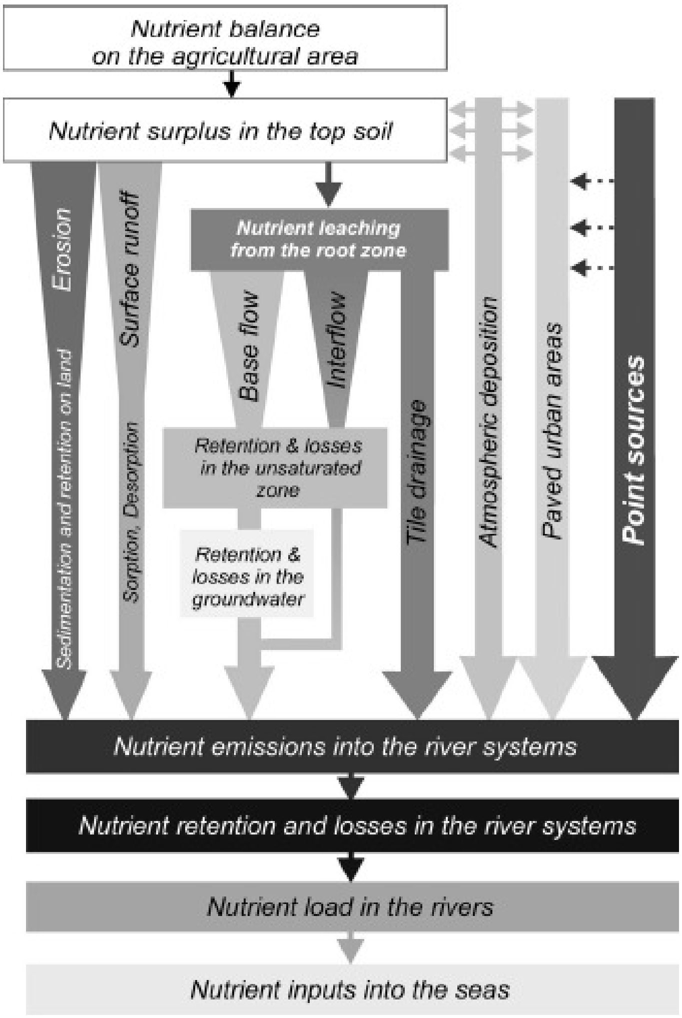

Figure 3.1 *Scheme describing the nutrient emissions pathways and processes modelled by MONERIS. Source: Behrendt et al., 2000.*

Based on data on precipitation and river flow, geographical data on catchment land uses and physical characteristics, and statistical data on nutrient inputs, MONERIS estimates annual emissions of nitrogen and phosphorus (N and P) from point sources, i.e., direct industrial discharges and municipal waste water treatment plants, and through a series of diffuse pathways that includes atmospheric deposition, erosion, surface runoff, groundwater, tile drainage and runoff from paved urban areas (Fig. 3.1). Nutrient loads are estimated as nutrient emissions from the catchment minus in-stream nutrient retention. Results are expressed as tonnes of P or N per year for total load, retention, total emissions, and emissions through each of the pathways. Further details on MONERIS, including the equations used to model each of the emission pathways, can be found elsewhere (Behrendt et al. 2007).

MONERIS is a spreadsheet model that consists in empirical equations sought to be of general application throughout Europe. In order to facilitate model calibration, verification and sensitivity analysis, we developed and used a version of the model, Rmoneris, that was completely rewritten in the R statistical programming language (http://www.r-project.org/). Besides the model itself, Rmoneris includes utilities for calibration, verification, plotting, mapping, and statistical analysis of input and output data (J. Riera, pers. comm.). Rmoneris reads and outputs data in comma delimited text files that can be easily read and edited with standard spreadsheet software. Rmoneris differs from MONERIS only slightly in how in-stream nutrient retention is estimated, as discussed in the calibration section below. All other equations are as described in Behrendt et al. (2007).

3.2.2. Model setup

In MONERIS, nutrient emissions and in-stream retention are estimated for each of a number of subcatchments, and are then accumulated down the stream network. In the present study, La Tordera was divided into 28 subcatchments following a study of ecological flows carried out by the Catalan Water Agency (ACA, 2004, 2005; Mas-Pla, 2006). The subdivision was based on the location of gauging stations and homogeneity in the hydrological response of the subcatchments. This division was adopted in our application of MONERIS in order to take advantage of modelled discharge for all 28 subcatchments (Fig. 3.2).

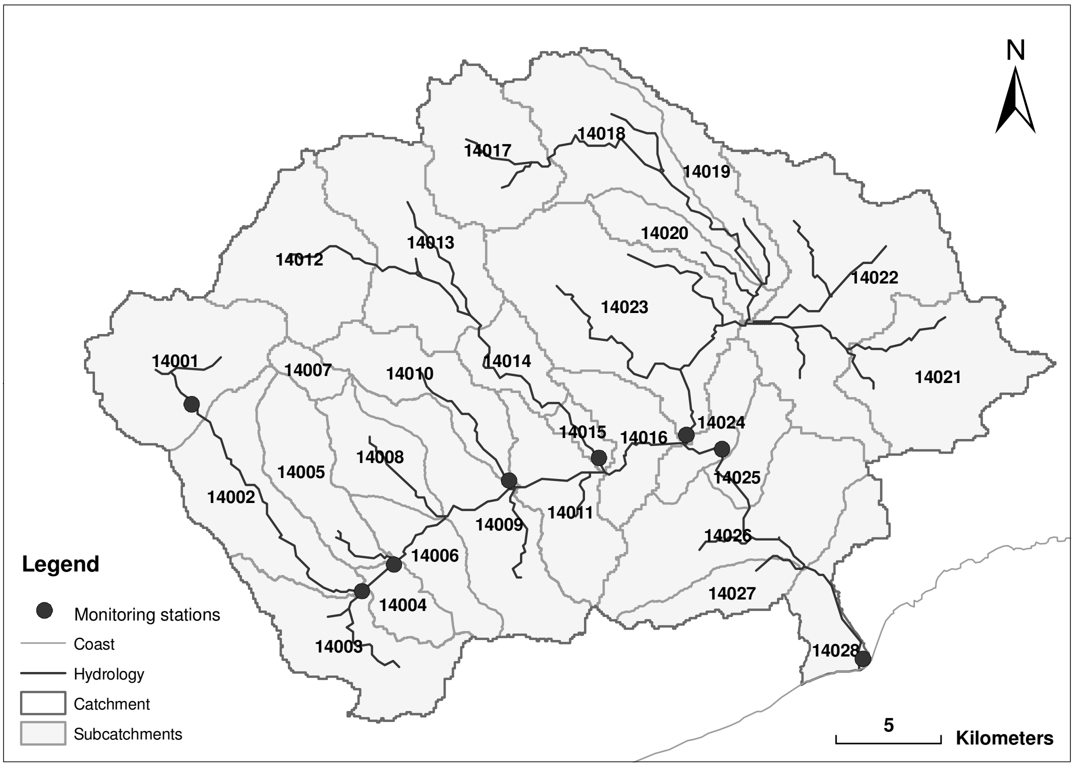

Figure 3.2 *Representation of the catchment and subcatchment borders, and river network with the locations of the monitoring stations used for the calibration (see also Fig. 1.5 in Chapter 1). Source: ICC and ACA.*

Nutrient emissions and loads were estimated yearly from 1995 to 2002. The selection of this modelling period was based on data availability. Discharge data was not available after 2002, while monitoring data were highly variable before 1995, probably reflecting episodic point discharges of untreated urban and industrial sewage.

To carry out the modelling exercise, MONERIS requires a variety of input data for each subcatchment, as summarized in Table 3.1, where the emission pathways in which they are involved is noted. Whenever available, data were compiled yearly.

***Table 3.1** Input data required by MONERIS. The pathways where each input data item is used in the model are numbered as: (0) basic input, (1) point sources (WWTPs and direct industrial discharges), (2) direct atmospheric deposition on the surface waters, (3) erosion, (4) surface runoff, (5) groundwater, (6) tile drainage, and (7) paved urban areas.*

Input Data	**Source**	**PATHWAY**
	Spatial data	
Borders of the subbasins and administrative areas	ICC	0
River network	ICC	0
Monitoring and gauging stations, and WWTPs	ICC	0, 1
Stream length	ICC	0, 2
Slope	ICC	3
Land use data	ICC	3, 4, 5, 6, 7
Hydrogeology	SGC/ICC	5
Soil texture	Literature, European Soil Database	5, 6
On-site soil loss	PESERA	3
Atmospheric deposition	EMEP	2, 5, 7
	Point source data	
Nutrient loads from urban and industrial WWTPs	ACA	1
Discharge from WWTPs	ACA	1
	Monitoring data	
Nutrient concentrations	ACA	0
Discharge	ACA	0, 4, 5
Precipitation	ACA	3, 4, 5, 6, 7
	Statistical data	
Population, sewage, WWTP, paved areas, etc.	ACA, IDESCAT	7
N and P content in topsoil	DARP, IRTA	3
Agricultural crops and harvests	DARP	5, 6
Livestock	IDESCAT	5, 6
Organic fertiliser	DARP, ANFFE	5, 6
Inorganic fertiliser	DARP, ANFFE	5, 6
Sewage sludge	ACA	5, 6

Spatial input data

The model needed first not only an inventory of the limits of the catchment, subcatchments and administrative areas, i.e., municipalities and counties, and the river network, but also an inventory of the monitoring and gauging stations, waste water treatment plants (WWTPs) and major industries. These data were made available by the Catalan

Cartographic Institute[1] (ICC) and the ACA[2] (Figs. 3.2 and 3.3, and Table 3.2). From the river network map and GIS calculations, the total stream length and the total area of surface waters in each basin were estimated (Table 3.2).

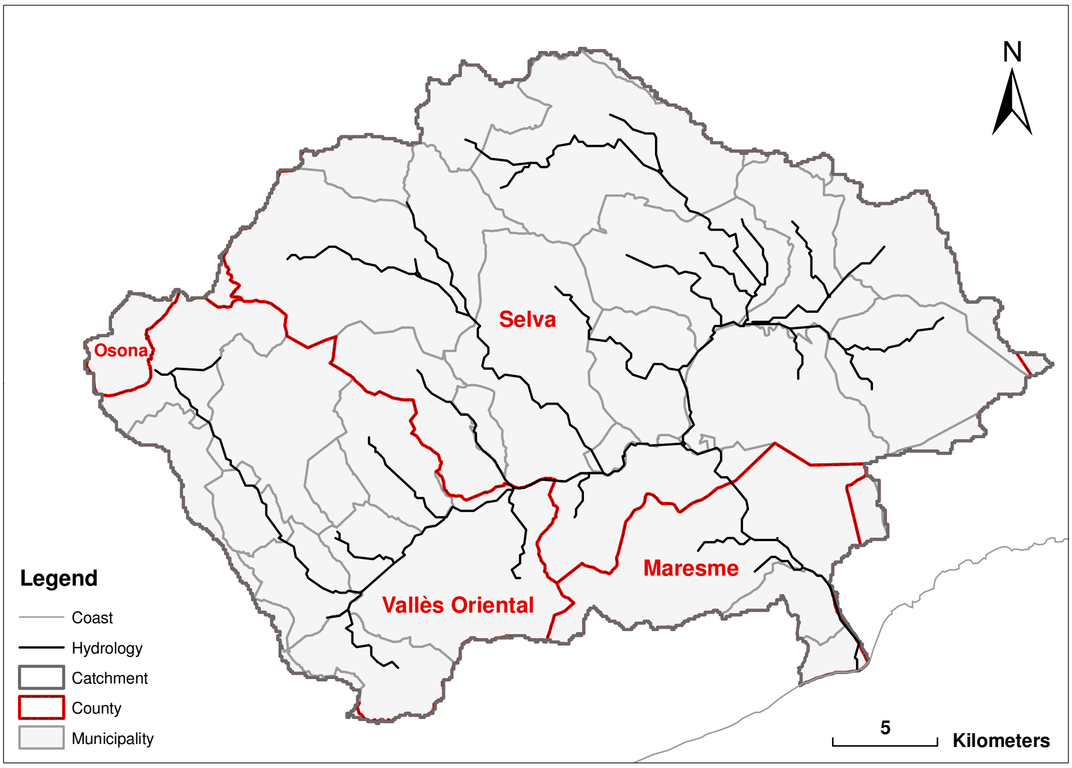

Figure 3.3 *Administrative areas and borders of municipalities and counties. Source: ICC.*

Land use data were obtained from the ICC, which compiles five-yearly land use maps of Catalonia based on Landsat imagery (30 m cell size). We considered that the land use maps for the years 1992, 1997 and 2002 corresponded respectively to the following hydrological years[3]: 1995-1997, 1998-2000 and 2001-2002. Figure 3.4 shows the distribution of land uses in the catchment in 1997. From these maps, we obtained the area (km^2) of each land use for the 28 subcatchments and for the three different periods (see Tables 3.a, 3.b, and 3.c in Appendix 2). Agricultural tile drained areas (see Table 3.d in

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[1] Available online at: http://www.icc.es

[2] Available online at: http://mediambient.gencat.net/cat/ el_departament/cartografia/inici.jsp

[3] A hydrological year is defined from 1st October to 30th September.

Appendix 2) for the 28 subcatchments were calculated from land use data provided by the ICC and assumed to be equal to irrigated lands.

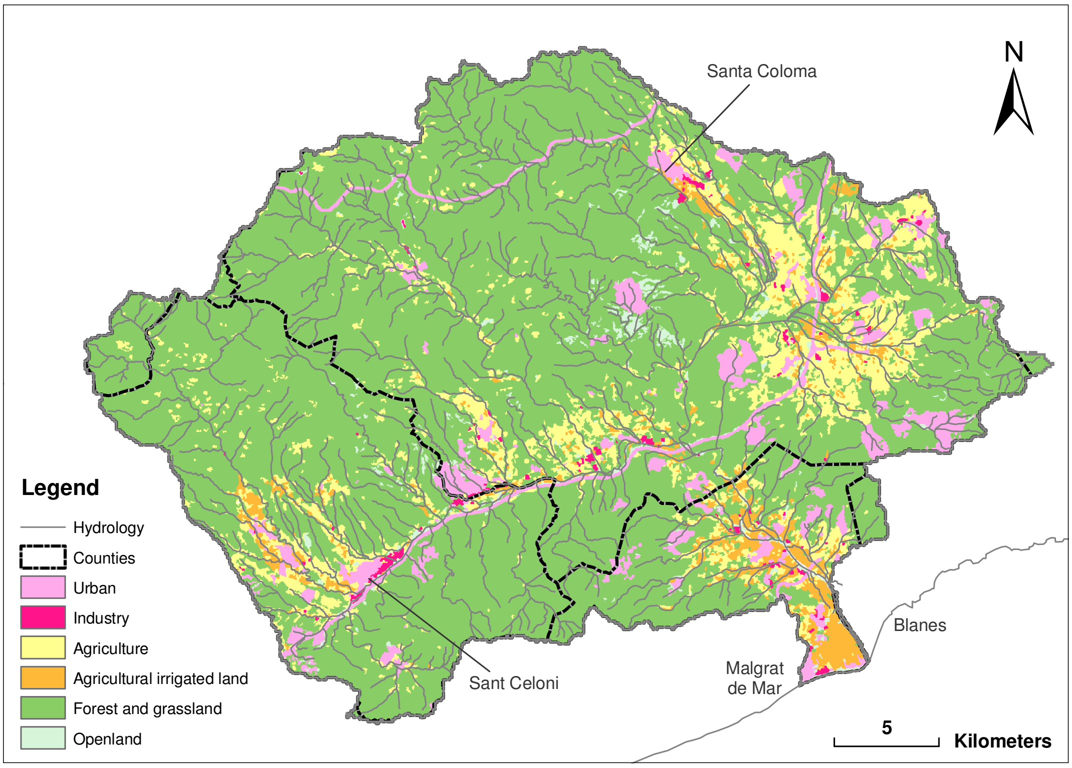

Figure 3.4 *Land uses in La Tordera catchment for the year 1997. Source: ICC.*

To estimate nutrient inputs into surface waters by erosion, the model required the mean slope, which was mapped for the 28 subcatchments from a 30 m cell size digital elevation model (DEM) obtained from ICC (Fig. 3.5 and Table 3.2). Data on in-situ soil loss (t/yr) were obtained from the PESERA (Pan-European Soil Erosion Risk Assessment) map[4] of soil erosion by water (Kirkby et al., 2004) (Table 3.2). This map is based on the European Soil Database, CORINE land cover, climate data from the MARS project and a DEM (Kirkby et al., 2004).

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[4] Available online at: http://eusoils.jrc.ec.europa.eu/ESDB_Archive/pesera/pesera_data.html

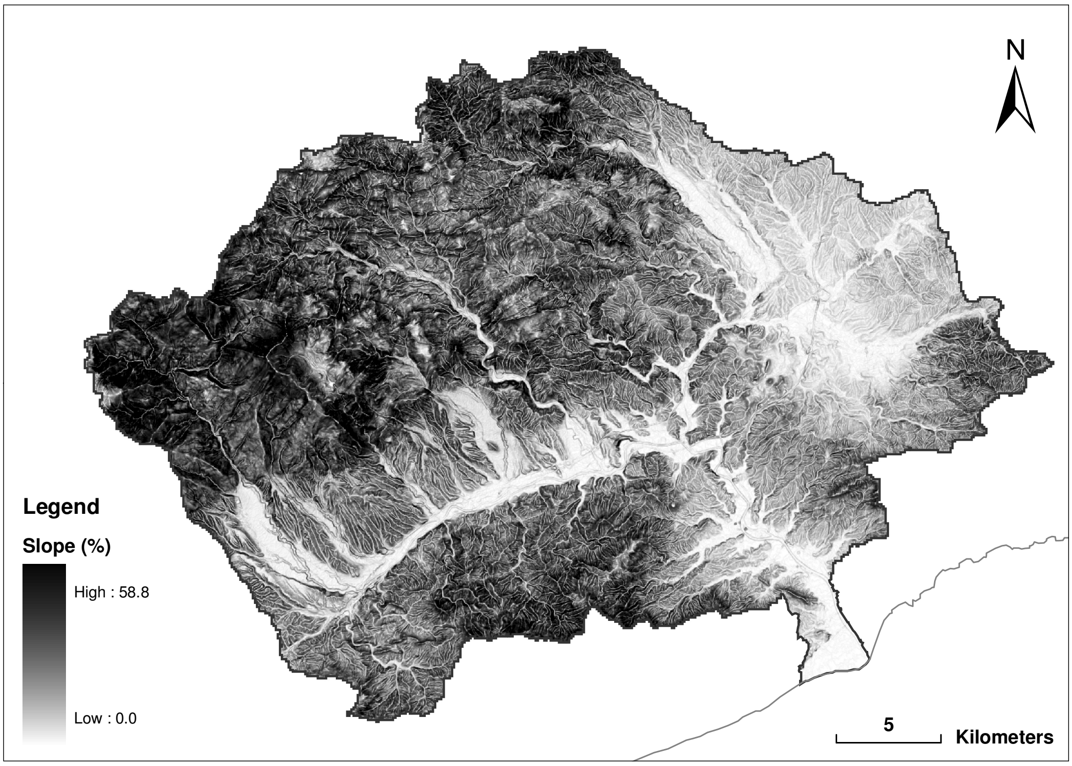

Figure 3.5 *Slope mapped for the 28 subcatchments of La Tordera catchment from a digital elevation model (DEM). Source: ICC.*

The hydrogeology of the subcatchments is represented in MONERIS as four classes resulting from a combination of good or poor porosity and shallow or deep groundwater; these were obtained by digitising the hydrogeological map of Catalonia for the Tordera catchment (SGC, 1992) (Fig. 3.6).

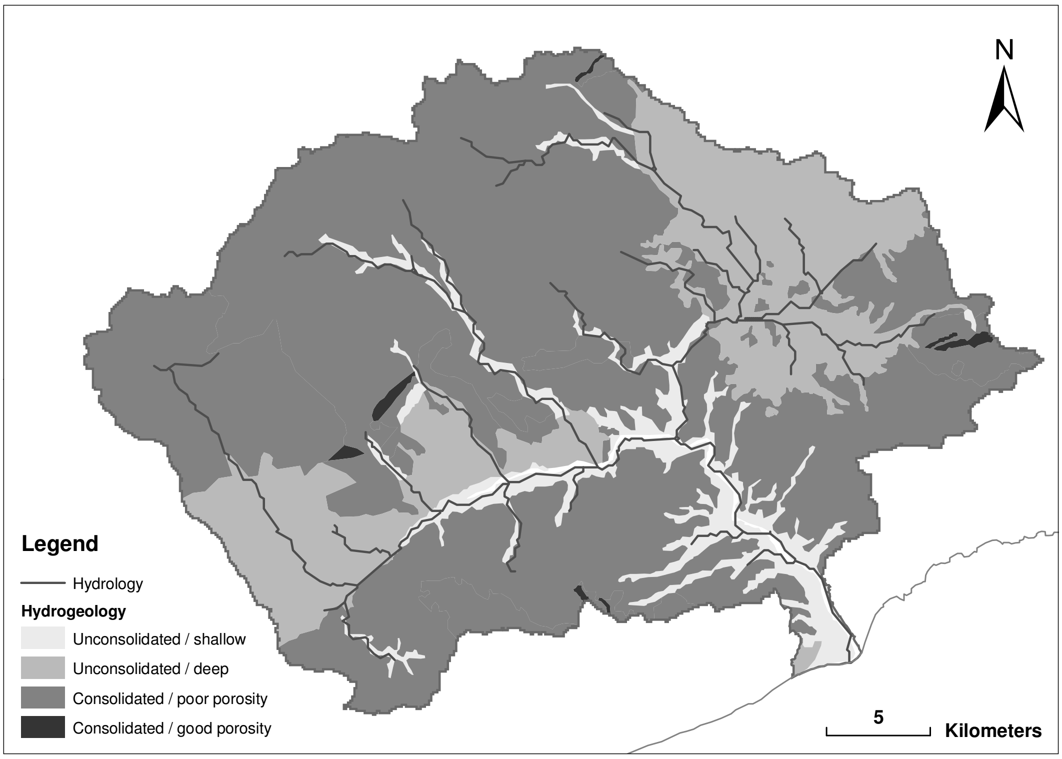

Figure 3.6 *Hydrogeological map of La Tordera catchment. Source: SGC, 1992.*

Because of a lack of good resolution maps of soil texture (percent sand, clay, loam, and silt) of the study area, our estimates were based on various studies[5] conducted on an area adjacent to and partially including La Tordera catchment (Danés, 1984) and on the European Soil Database[6]. Data on the nitrogen and phosphorus content in topsoil (%) was not available for the study area either; therefore, an estimation was made based on the best judgment of experts from the Catalan Department of Agriculture (DARP) and the Institute for Food and Agricultural Research and Technology (IRTA).

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[5] *Mapa del suelos forestales de la comarca La Selva* [Map of Forest Soils of La Selva County] (unpublished, bachelor's degree final project of F. Xavier Castro Doria).
[6] Available online at: http://eusoils.jrc.it/ESDB%5FArchive/ESDB/

Table 3.2 *Area, estimated water surface area, stream length, mean slope and on-site soil loss rate for the 28 subcatchments of La Tordera basin. Mean slope and soil loss rate were used to estimate nutrient inputs by erosion. Sources: ACA, ICC and PESERA.*

ID	Name of subactchment	Area	Total water surface area	Total stream length	Mean slope	Soil loss rate
		km^2		km	%	t/yr
14001	Tordera A E.A. A0026 (La Llavina)	47.4	0.10	50.0	22.1	0.00
14003	Vallgorguina Completa	37.0	0.10	50.3	8.8	1.98
14002	Tordera A E.A. A0015 (St. Celoni)	40.3	0.12	61.3	11.4	15.77
14004	Tordera Aigua Amunt de la Pertegàs	11.1	0.03	12.9	9.6	0.00
14005	Pertegàs Completa	25.3	0.09	43.2	13.3	5.44
14006	Tordera Aigua Amunt de la Gualba	19.2	0.06	27.5	11.3	8.79
14007	Gualba a l'Embassament	6.1	0.07	6.7	17.1	0.00
14008	Gualba Completa	19.5	0.05	25.8	14.0	8.15
14009	Tordera Aigua Amunt de la Riera de Breda	42.5	0.13	63.5	11.7	0.50
14010	Breda Completa	27.0	0.06	31.3	12.1	14.75
14011	Tordera Aigua Amunt de la Riera d'Arbúcies	30.1	0.08	39.2	9.2	2.67
14012	Arbúcies a Capçalera	40.8	0.10	51.4	17.0	0.08
14013	Arbúcies a Bosc de les Gavarres	51.6	0.13	66.0	13.3	0.14
14014	Arbúcies A E.A. A0056 (Hostalric)	15.2	0.03	15.6	13.5	0.02
14015	Arbúcies Completa	5.2	0.01	4.0	4.0	6.41
14017	Sta. Coloma a Capçalera	37.1	0.12	58.6	13.7	1.78
14018	Sta. Coloma Aigua Amunt de l'Esplet	43.3	0.13	63.8	11.1	0.14
14019	Esplet Complet	20.0	0.08	41.9	4.2	0.33
14020	Sta. Coloma Aigua Amunt de la Sils	15.9	0.04	22.1	8.0	0.24
14021	Sils a Capçalera	47.2	0.13	67.3	6.0	0.86
14022	Sils Completa	84.1	0.21	105.1	3.0	1.15
14023	Sta. Coloma A E.A. A0081 (Fogars)	74.8	0.20	101.3	10.2	0.08
14016	Tordera a la Confluència amb la Sta. Coloma	21.4	0.07	34.3	7.3	1.97
14024	Tordera A E.A. A0089 (Fogars)	15.0	0.02	10.5	6.2	1.24
14025	Tordera A E.A. A0062 (Fogars)	12.1	0.03	13.2	5.1	0.65
14026	Tordera Aigua Amunt de la Vallmanya	52.9	0.15	73.6	7.2	0.95
14027	Vallmanya Completa	14.2	0.04	21.8	8.3	1.30
14028	Tordera Completa	20.1	0.04	19.4	5.5	2.35

Point source data

All data required by the model to estimate nutrient emissions from the urban and industrial waste water treatment plants (WWTP), such as year of implementation or changes in operation, outflow discharge, annual loads of N and P, and nutrient removal efficiency, were provided by the ACA (see Table 3.e in Appendix 2). Whenever data on discharge and nutrient concentration in a WWTP outflow was deemed insufficient, low quality or simply was unavailable, WWTP loads were estimated from data on inhabitant equivalents, mean domestic and industrial N and P per capita emissions, and WWTP efficiency.

The collection of statistics on industrial waste waters not connected to municipal WWTPs by the ACA started officially in 2001 and was first published in 2003 as part of the new PSARI 2003 (ACA, 2003). No data were available before 2001.

Monitoring data

Model performance was calibrated against observed nutrient loads. These were estimated from monthly measurements[7] conducted by ACA at selected monitoring stations (Fig. 3.2). These data included the following nutrient concentrations: nitrate (NO_3^-), nitrite (NO_2), ammonia (NH_4^+), Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), and total phosphorus (TP). Data for TP was unavailable or scattered before 2002, and TKN measurements were too scarce to be used for load estimation. Therefore, the model was calibrated against dissolved inorganic nitrogen (DIN, the molar sum of nitrogen as nitrate, nitrite and ammonia), and SRP. Out of the 22 monitoring stations in La Tordera, some were out of service, others provided data only from the end of the nineties, and for all of them, data collection was somewhat irregular, especially during the nineties. Eight stations had sufficient data for calibration (see “Calibration process” below).

Data on discharge and precipitation per subcatchment were needed to run the model. Discharge is used in the model to estimate groundwater and lateral discharge from the subcatchment water balance, and for the estimation of observed loads. Precipitation is used in the estimation of surface runoff, erosion and urban diffuse sources. Mean annual discharge (Q, m^3/s) for each subcatchment were obtained from ACA's analysis of ecological flows for the internal catchments of Catalonia, where the hydrological Sacramento model was calibrated in each catchment against monthly discharge from existing gauging stations, and then used to estimate discharge for each of the 28 subcatchments defined for La Tordera (ACA, 2002b).

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[7] Available online at: http://mediambient.gencat.net/aca/ca/xarxes_de_control.jsp

Data on mean annual precipitation (mm) for each subcatchment were also obtained from ACA (2002b), which provided mean precipitation spatially interpolated for each subcatchment from the 6 meteorological stations within or around the catchment (Figs. 3.7 and 3.8).

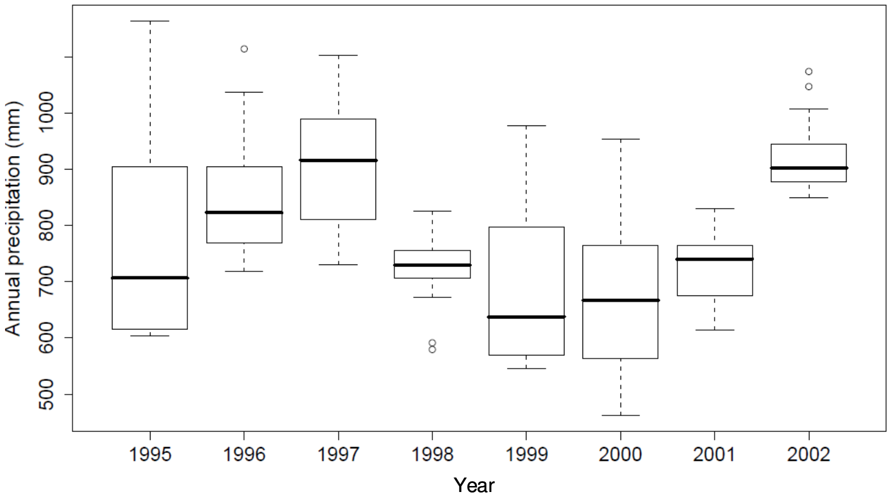

Figure 3.7 *Annual precipitation between 1995 and 2002 in La Tordera basin. Source: ACA.*

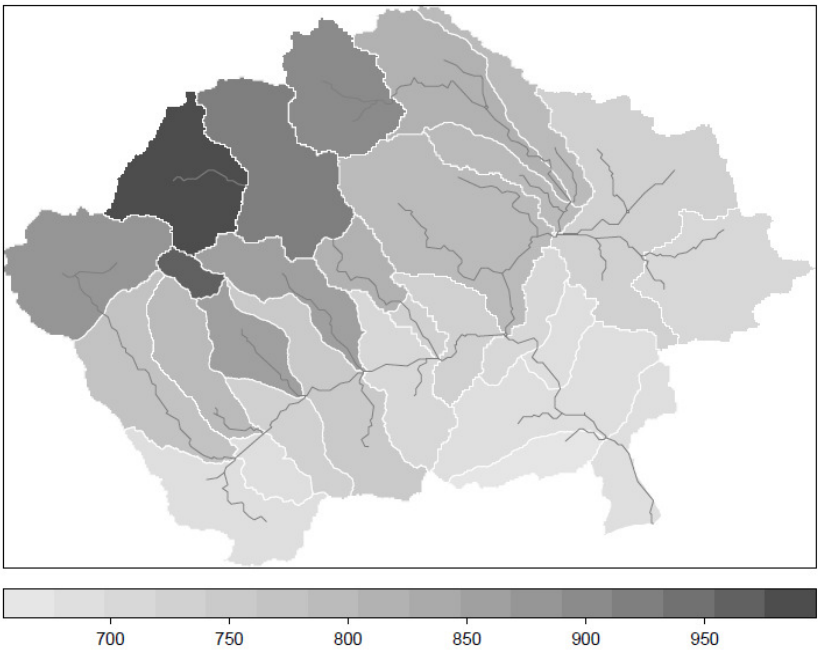

Figure 3.8 *Long term mean annual precipitation (mm) in La Tordera basin. Source: ACA.*

Statistical data at the administrative level

Statistical data at the municipality and regional levels that were required by the model, including data on population, crops, and livestock, were provided by the city halls and the Catalan Statistical Institute (IDESCAT).

The number of inhabitants in urban areas connected to sewage systems was estimated from information provided by the strategic plan for the treatment of all urban waste waters, i.e., PSARU (ACA, 2002a), and the concerned city halls (see Table 3.f in Appendix 2). The following classification was used: connected to combined sewers; connected to sewers but not to WWTPs; and connected to neither WWTP nor sewer. These data were only available for the year 2001 (PSARU 2002) (ACA, 2002a). Therefore, we used 2001 as a baseline against which we corrected for changes in connected inhabitants in previous years based on the year of implementation of WWTPs and the number of inhabitants per subcatchment.

Nitrogen balance, i.e., the balance between nitrogen inputs, mainly through atmospheric deposition, N fixation and fertiliser application, and outputs, mainly through harvest and ammonia volatilisation, is a key predictor of the nitrogen load that is potentially mobilised and transported to surface waters. It is also notoriously difficult to estimate with any accuracy. We used the OECD/Eurostat Soil Surface balance method (OECD, 2001). This method combines the use of statistics on crop harvests and the number of farm animals together with agronomic technical coefficients and CORINE Land Cover data to estimate nitrogen inputs to and outputs from each subcatchment. The DARP, the National Association of Fertiliser Producers (ANFFE) and waste managers were the main sources of data on fertilisers, manure farming production, and also on P and N content in topsoil. Statistics on livestock were provided by the IDESCAT. Data on sewage sludge were provided by the ACA.

Oxidised and reduced nitrogen atmospheric deposition rates (NOx, NHx, kg N/ha.yr) were obtained from the Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP8). From point measurements, the Unified EMEP model generates a 50x50 km2 resolution grid that is available at yearly resolution for the study period (Fig. 3.9).

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[8] Available online at: http://www.emep.int/

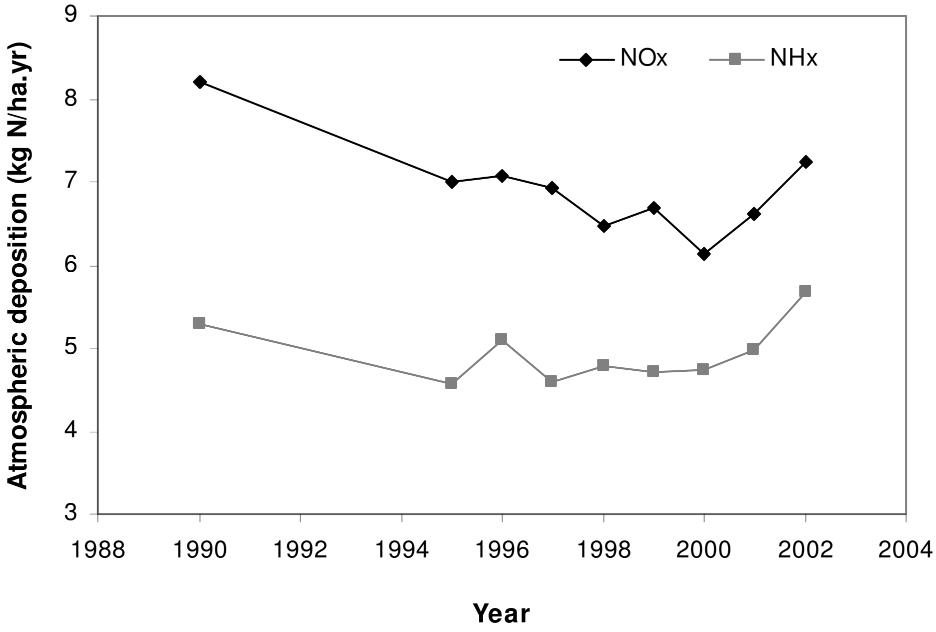


Figure 3.9 *Atmospheric deposition of oxidised nitrogen (NOx) and reduced nitrogen (NHx) estimated by the Unified EMEP model for the year 1990 and then every year from 1995 to 2002. Source: EMEP.*

3.2.3. Calibration and verification process

Among the twenty-two monitoring stations in the basin, we selected the eight stations that had both regular collection of SRP and DIN concentration data through the 1995-2002 period, as well as discharge data available (Fig. 3.2). Nutrient loads were estimated as the product of flow-weighted mean concentration and mean annual discharge:

$$L = \frac{\sum_{i=1}^{n} C_i Q_i}{\sum_{i=1}^{n} Q_i} \cdot \overline{Q}_N$$

where L is the annual load of phosphorus or nitrogen (tonnes/yr), C_i is the concentration of SRP or DIN (mg/l), Q_i is the daily flow, n is the number of days with concentration data, and $\overline{Q}_N$ is the mean daily flow in the hydrological year (i.e., N=365 or 366).

MONERIS is a calibrated model and, although one would ideally want to recalibrate all its empirical parameters, this is not possible in applications with scant observed data. In this application, the number of observed data points was 56 at best (8 stations times 7 years), so calibrating more than two or three parameters would quickly compromise statistical power. Therefore, the strategy followed here was to calibrate the minimum number of parameters that would yield an acceptable fit (i.e., $E > 0.8$, see below).

MONERIS estimates loads as the difference between catchment emissions and in-stream retention processes. Retention accounts for the fact that modelled emissions from the catchment generally overestimate observed nutrient loads due to temporary storage or permanent losses of nutrients occurring in the river network and riparian areas (Behrendt et al., 2002, Alexander et al., 2000; Howarth et al., 2002). Retention can be very high, especially in headwater catchments, where low flows allow contact between the nutrients in transport and the biologically active streambed (Martí et al., 2006). Because retention processes are important in small catchments such as La Tordera (von Schiller et al., 2008), in this application we calibrated MONERIS for nutrient retention parameters. Specifically, nutrient retention was modelled as a function of specific runoff (discharge divided by catchment area, $L{\cdot}s^{-1}{\cdot}km^{-2}$) (Behrendt and Opitz, 2000), and the parameters α and β were calibrated independently for P and N according to the following equation:

$$R = 1 - \frac{1}{1 + \beta \cdot (Q/A)^{\alpha}}$$

where R is the fraction of emissions that is retained in the stream network, Q is the discharge ($L{\cdot}s^{-1}$), and A is the area in km^2.

Calibration was performed by direct search in a limited parameter space after visual exploration of potential parameter values. The objective function for calibration was the Nash-Sutcliffe coefficient of efficiency, E (Nash and Sutcliffe, 1970):

$$E = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2}$$

where O_i is the observed data point, P_i is the modelled data point, O_{avg} is the mean of the observed data series, and n is the number of data points. E is preferred over correlation or linear regression's R^2 as a measure of goodness-of-fit because it penalises deviations from the 1:1 relationship between observed and modelled values (i.e., systematic biases in modelled values). In the calibration process, E was evaluated on log-transformed observed and modelled loads. The log transformation was required by the biased distribution of loads and the multiplicative nature of errors in catchment models (Grizzetti et al., 2005). After automatic calibration, the obtained parameter set was tweaked manually to improve the fit on loads vs. time graphs.

To verify the robustness of the model fit, automatic calibrations were run on all combinations of four years out of the seven years in the 1996-2002 period, i.e., 35 model combinations, and the model was run after each calibration on the three remaining years in the series.

3.2.4. Uncertainty and sensitivity analysis

Evaluating uncertainty is crucial to assess the reliability of the estimates produced by a model (Rode and Suhr, 2007). Our analysis was based on a qualitative assessment of the reliability of input data. Thus, each source of data was assigned a reliability rating from 1 to 5, where 1 means most reliable and 5 means least reliable.

Sensitivity analysis complements uncertainty analysis by providing information on the influence of model inputs or parameters on model outputs (Saltelli et al., 2000; Brown et al., 2001). By showing how the model behaviour responds to changes in parameter values, i.e., by providing information on the factors that most strongly contribute to the output variability, sensitivity analysis not only allows the relative influence of inputs to be assessed, but also provides a good basis for future scenario testing (Brown et al., 2001).

In this application we focused on the sensitivity of the model to variations in input data. For each input data item that was analysed, the original data were varied from -15% to +15% the current value, in steps of 5%, and the calibrated model was subsequently run. The set of input data included in the sensitivity analysis was: P deposition, NO_X deposition, NH_4 deposition, annual precipitation, winter precipitation, summer precipitation, evaporation rate, on site soil loss, mean slope, sediment area ratio, P and N content in topsoil, tile drained area, N surplus, and number of inhabitants.

3.3. Results

3.3.1. Model calibration and verification

Because of large uncertainties regarding the accuracy of the data observed during the hydrological year 1995, this year was excluded from the calibration, which was performed for the hydrological years 1996 to 2002.

The original version of MONERIS applied two different retention coefficients, one for diffuse sources in the stream network, and one for point sources and inputs from upstream catchments, that applied only to the main channel. After several calibration attempts, in this application a single retention factor was applied to all emissions. Main channel retention of inputs from upstream catchments was found to be almost negligible, and adjusted to a factor of 0.98 (i.e., 2% retention).

Also, inspection of observed and modelled data versus year revealed a significant underestimation of loads for the early years when the model was calibrated against later years. We attributed this to the fact that direct industrial inputs were available only for 2001 but could be expected to be greater as one moved back in time. To correct for this bias, which reflected an uncertainty in input data, the model was calibrated for a correction factor that increased industrial inputs yearly from 2001 backwards towards 1996. This substantially improved the model fit.

After calibration, the modelled annual P and N loads showed good agreement with the observed loads (Figs. 3.10 and 3.11), as measured by the Nash-Sutcliffe coefficients (E=0.85 for P, and E=0.86 for N). Furthermore, the deviation between modelled and observed values was lower than 30% on a log scale. The calibrated retention parameters were similar for both N and P and within the ranges reported by Behrendt et al. (2007) (P: α=-1, β=3.2; and N: α=-1.3, β=6), resulting in mean retention factors of 46% for P (90% of values between 25% and 62%) and 52% for N (90% of values between 24% and 72%).

Inspection of model fit to interannual variation and trends in the eight calibration subcatchments showed overall good agreement between model and observed loads, but also systematic biases for some subcatchments (Figs. 3.12 and 3.13). For example, modelled P load for subcatchments 14004, 14010 and 14024 tended to overestimate observed loads, especially for 1997, 1998 and 2001. In contrast, modelled P loads underestimated observed loads in subcatchments 14001 and 14002_3 (the combined loads of 14002 and 14003), especially in 1999 (Figs. 3.10 and 3.12). Modelled N loads overestimated observed loads for subcatchments 14010 and 14024, while the model underestimated loads for 14002_3 for several years (Figs. 3.11 and 3.13). In general, P loads were better modelled in the four stations closest to the river mouth along the main channel (Fig. 3.2). The greatest disagreement between modelled and observed loads corresponded to the evolution of P and N loads at 14024, where the model almost consistently overestimated observed values. Also modelled N loads at 14023 did not really followed the observed trend between 1996 and 2000 (Fig. 3.13). The general trend from 1996 to 2002 was a reduction of P and N loads with some fluctuations for the eight sub-basins.

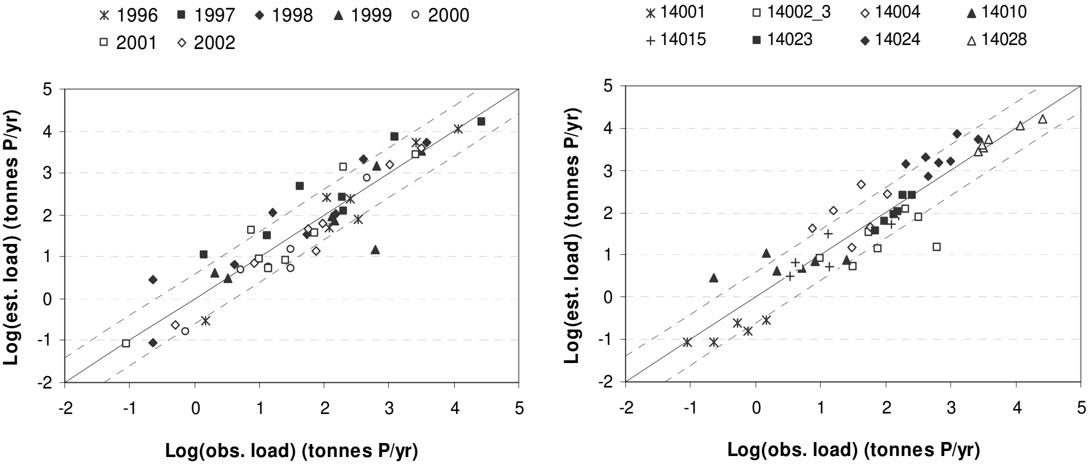


Figure 3.10 *Plots of modelled versus observed values of total phosphorus presented in logarithmic scales for the different years of the study period (graph on the left) and for the eight points along the river corresponding to the subcatchments 14001, 14002_3, 14004, 14010, 14015, 14023, 14024 and 14028 (graph on the right). The dashed lines represent a 30% deviation.*

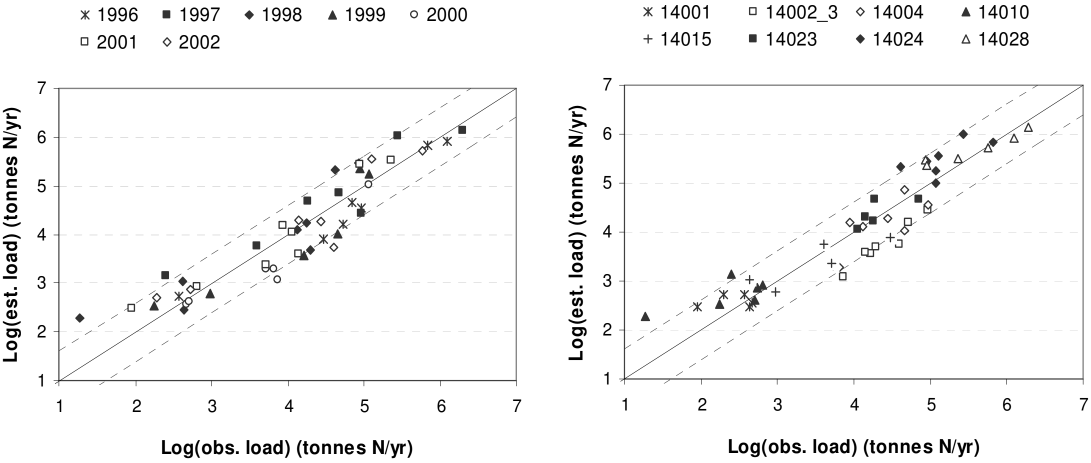


Figure 3.11 *Plots of modelled versus observed values of nitrogen presented in logarithmic scales for the different years of the study period (graph on the left) and for the eight points along the river corresponding to the subcatchments 14001, 14002_3, 14004, 14010, 14015, 14023, 14024 and 14028 (graph on the right). The dashed lines represent a 30% deviation.*

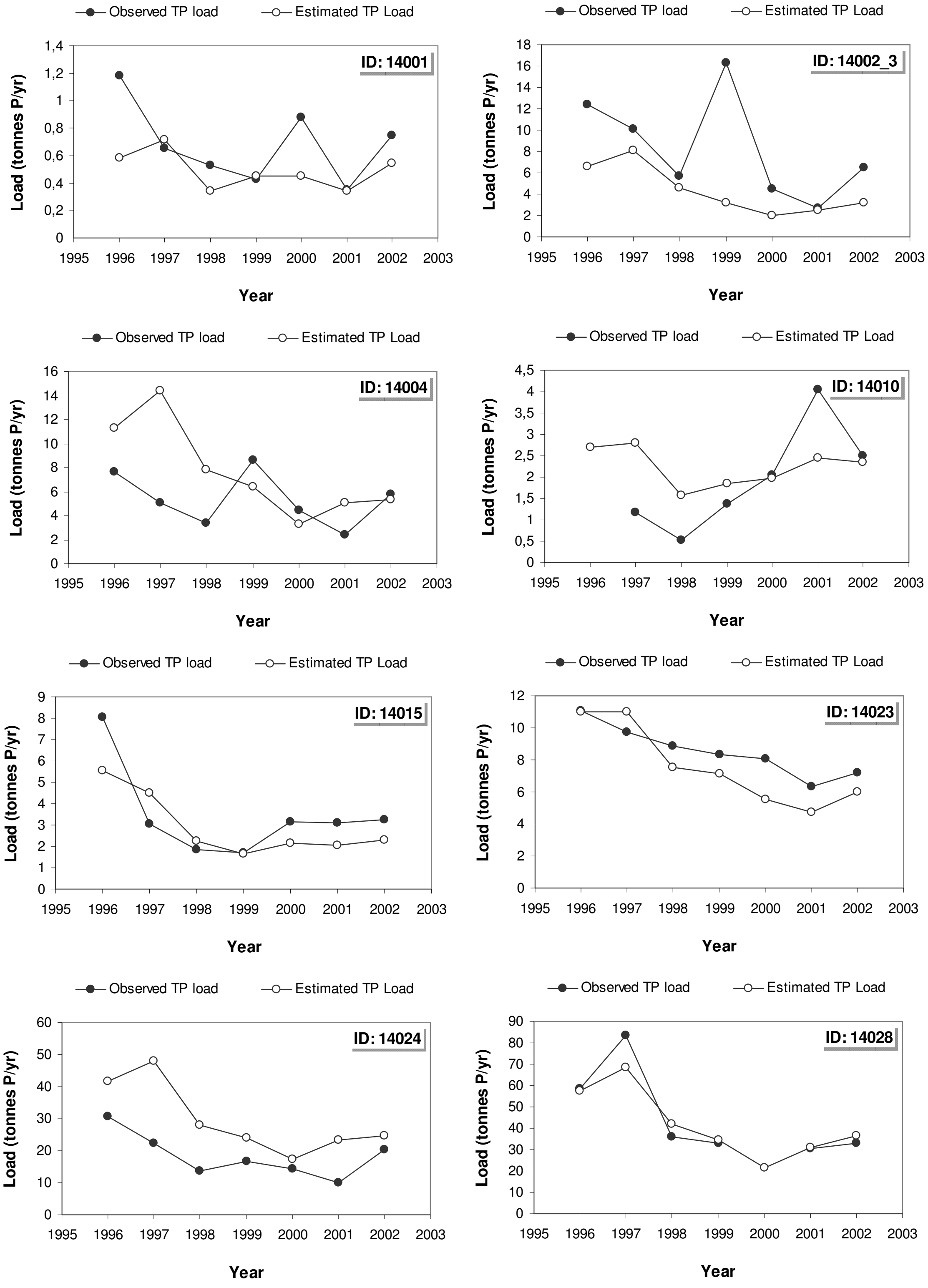


__Figure 3.12__ Temporal evolution of observed and modelled loads of phosphorus for the eight stations along the river, i.e., those corresponding to subcatchments 14015, 14023, 14024 and 14028 (Fig. 3.2).

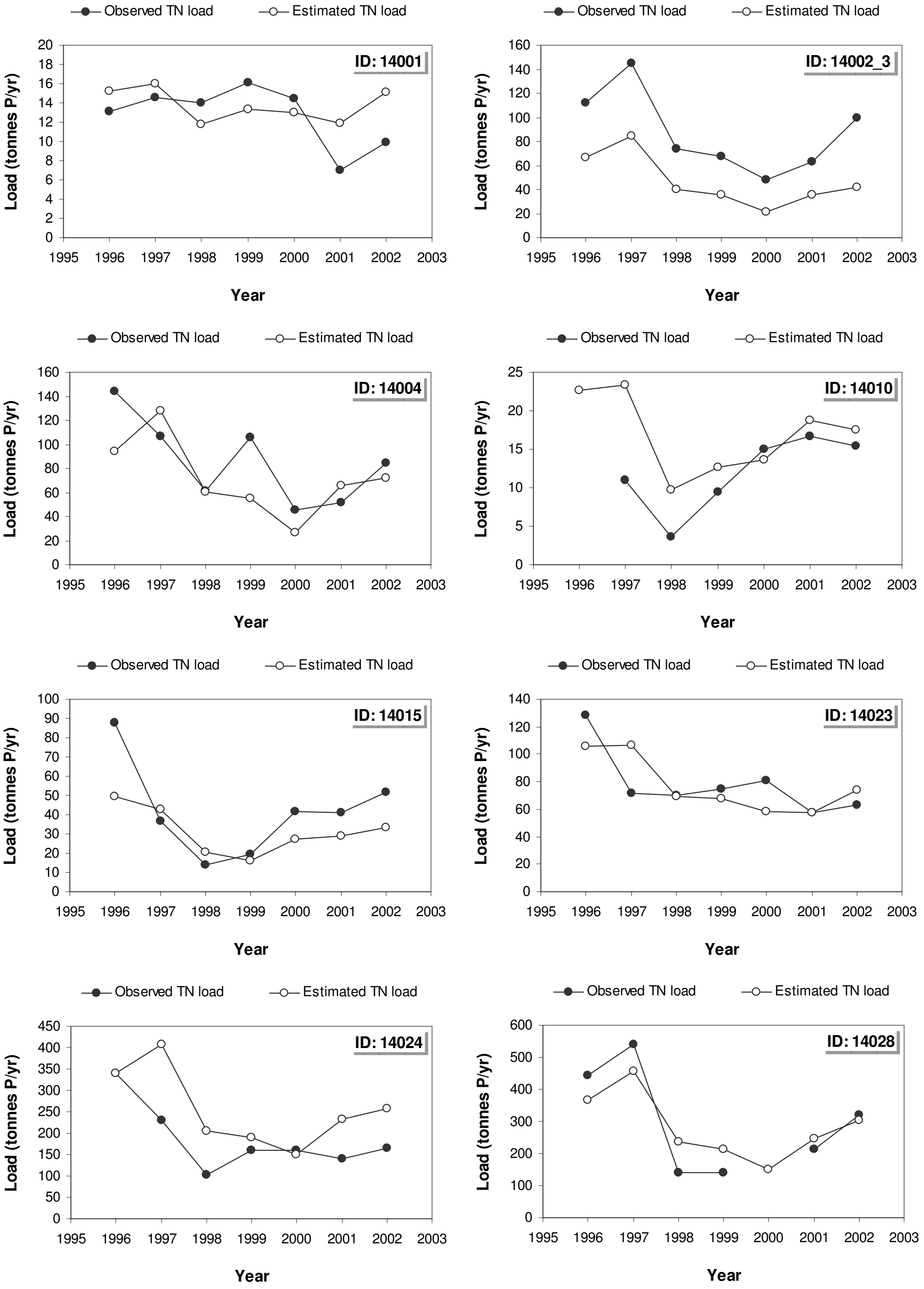


Figure 3.13 *Temporal evolution of observed and modelled loads of nitrogen for the eight stations along the river, i.e., those corresponding to subcatchments 14015, 14023, 14024 and 14028 (Fig. 3.2).*

The verification of the model showed that the calibration was not unduly sensitive to interannual variation, which was a concern because catchment hydrology varies greatly among years in Mediterranean catchments due to climatic interannual variation. Mean Nash-Sutcliffe efficiencies for verification sets were slightly lower than efficiencies for calibration sets for P, and were more variable for nitrogen than for phosphorus. In all cases, *E* values were above 0.75 (Fig. 3.14).

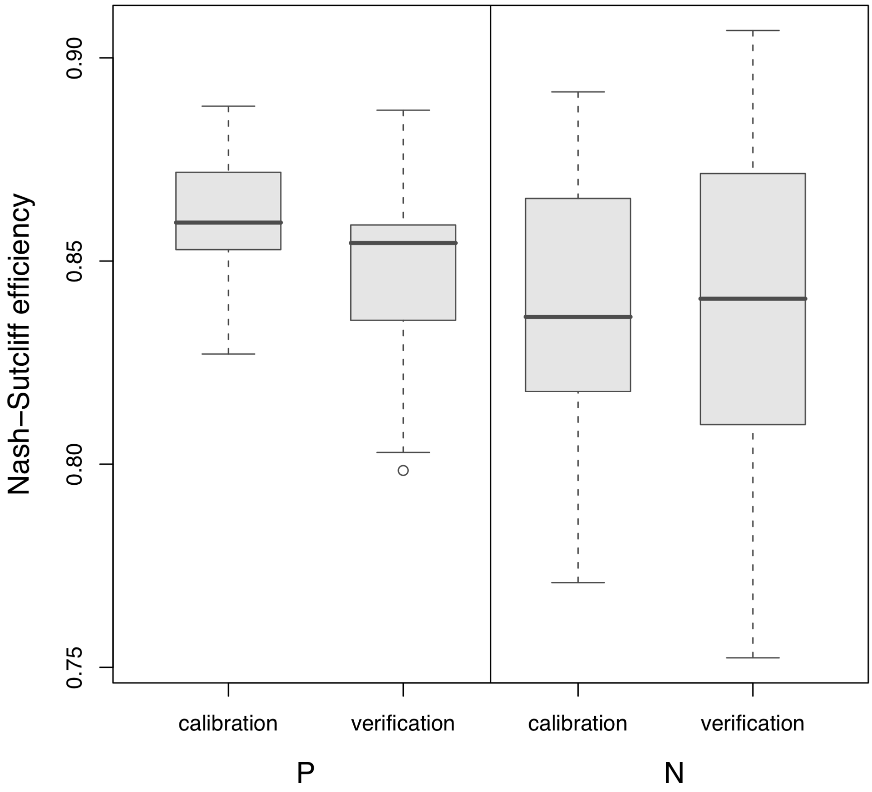


Figure 3.14 *Verification of Rmoneris for La Tordera. Calibration boxplots summarize Nash-Sutcliffe efficiencies for 35 automatic calibrations of the model (all combinations of four years in the period 1996-2002). Verification boxplots are for model runs with the parameter set from each calibration on the three years not used in the calibration for each of the 35 models runs.*

3.3.2. Partitioning of nutrient emissions

Phosphorus emissions were dominated by urban and industrial sources, which together contributed about 94% of total emissions in 1996-2002 (Table 3.3, and Fig. 3.15). Among the other sources of emissions, groundwater flow contributed about 2-3% of total P emissions, varying between 1.4 and 3.68 t/yr during the study period. Erosion, surface runoff, tile drainage and atmospheric deposition contributed together only around 3.5% of P emissions. The partitioning of the P emissions among subcatchments correlated with the land use distribution, with high P emissions along the main valley and lower Tordera (Figs. 3.4, 3.15).

According to the model, total P emissions into La Tordera river basin decreased by about 42% during the 1996-2002 study period (Table 3.3), corresponding to a decrease of about 10% per year between 1998 and 2001 and about 7 and 4% for 1997 and 2002 respectively. The decrease of P emissions during the study period was mainly the result of reductions in industrial and urban sources. Nonetheless, these sources remained the most important pathways of phosphorus emissions, with a contribution of 92% of the total P emissions in the catchment in 2002. Loads from WWTPs declined over the period despite an increase in connected inhabitants.

Table 3.3 *Contribution of the different sources to the emissions of phosphorus and nitrogen into the river basin in tonnes/yr and as a percentage of the total emissions in the basin. Two periods, 1997-1999 and 2000-2002, are used to show changes in the estimation of nutrient emissions based on the year 1996, the first reliable year of model application.*

	Phosphorus Emissions						**Nitrogen Emissions**					
Pathway	**1996**		**1997-1999**		**2000-2002**		**1996**		**1997-1999**		**2000-2002**	
	t/yr	%	**t/yr**	%	**t/yr**	%	**t/yr**	%	**t/yr**	%	**t/yr**	%
WWTP	14.6	12.7	14.5	14.9	10.5	14.7	91.2	12.1	108.3	16.0	117.7	19.7
Industry	64.4	56.0	52.4	53.7	34.5	48.4	171.7	22.8	139.8	20.7	91.9	15.4
Urban system	29.1	25.3	25.1	25.8	21.9	30.8	174.8	23.2	150.2	22.2	130.3	21.8
Atm. deposition	0.1	0.1	0.1	0.1	0.1	0.1	2.9	0.4	2.8	0.4	2.9	0.5
Surface runoff	1.6	1.4	1.1	1.1	0.7	1.0	14.1	1.9	9.4	1.4	7.0	1.2
Erosion	1.3	1.1	1.1	1.2	1.0	1.5	1.7	0.2	1.5	0.2	1.3	0.2
Tile drainage	0.9	0.8	0.9	0.9	0.7	1.0	62.3	8.3	57.7	8.5	51.8	8.7
GW	2.9	2.6	2.3	2.3	1.9	2.7	234.4	31.1	207.3	30.6	194.8	32.6
Total Emissions	114.9		97.6		71.3		753.3		676.9		597.7	
Retention	52.0	45.2	44.9	46.0	38.8	54.5	340.8	45.2	337.6	49.9	334.5	56.0
Load	**63.0**		**52.7**		**32.5**		**412.5**		**339.4**		**263.2**	

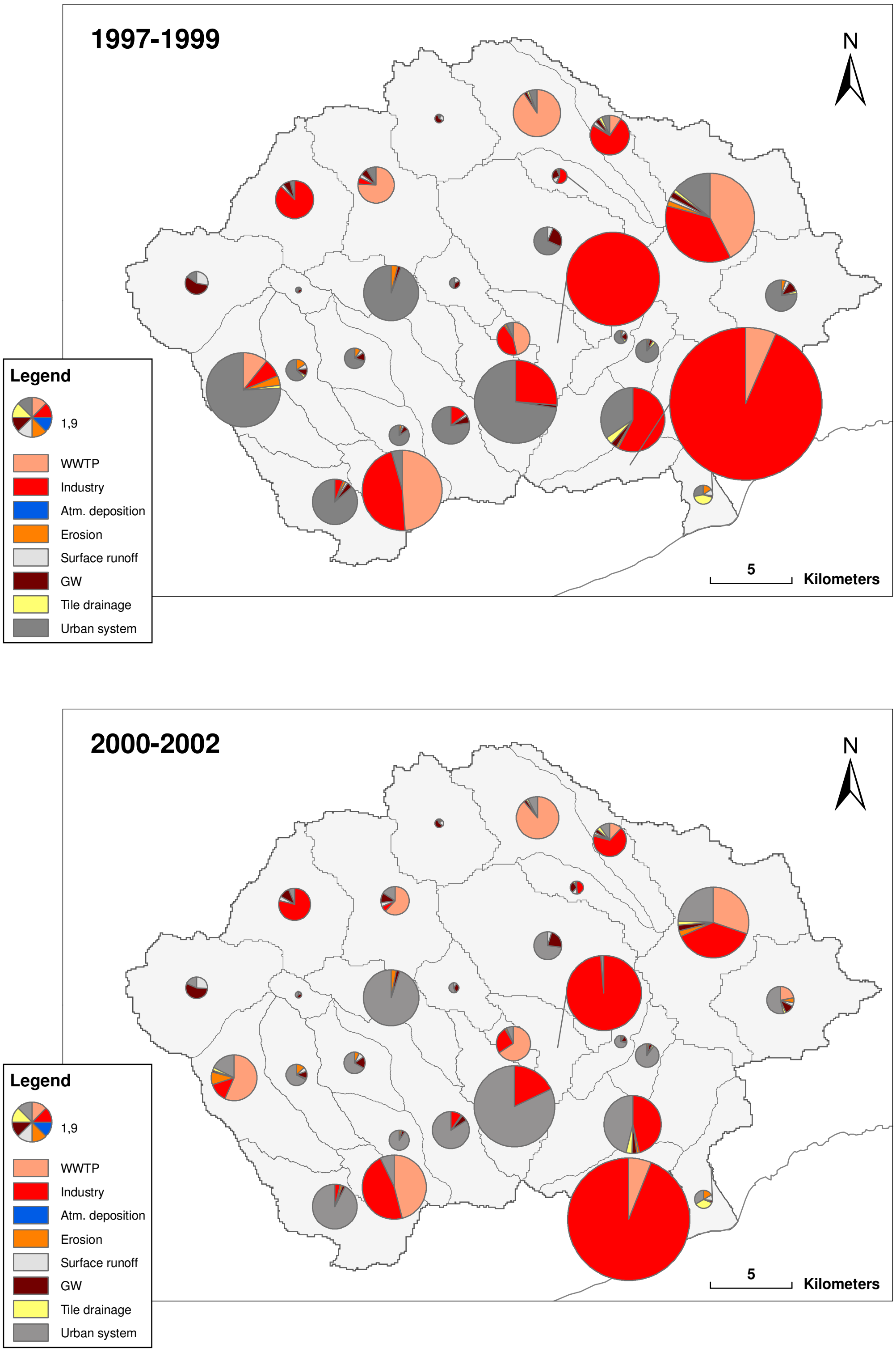


Figure 3.15 *Partitioning of the total P emissions (t/yr) by emission pathway in La Tordera basin for the 1997-1999 period (top) and the 2000-2002 period (bottom). Pie sizes are proportional to the magnitude of the total P emissions between subcatchments.*

In contrast to P emissions, N emissions were dominated by inputs via groundwater (31% of N emissions on average during the study period), followed by urban and industrial sources, which together contributed around 58% of total emissions in 1996-2002 (Table 3.3, and Fig. 3.16). Tile drainage was another source of consideration, with a contribution around 8.6%. The remaining sources of emissions (erosion, surface runoff, tile drainage and atmospheric deposition) contributed together only 2% of nitrogen emissions. The partitioning of the N emissions among subcatchments correlated with land use distribution (Figs. 3.4 and 3.16), with substantial urban sources along the main channel and lower Tordera and significant agricultural sources especially in the Santa Coloma basin (the northeastern part of the catchment) and lower Tordera. In headwater subcatchments, groundwater sources were important in relative terms, but low in magnitude.

Total N emissions into the river basin decreased by about 18% between 1996 and 2002, and were particularly low in 2000. The observed decrease in N emissions was mainly attributable to reductions in industrial and urban sources. N inputs from these two sources declined by about 56% and 22%, respectively, between 1996 and 2002. In most years, an increase of N emissions from WWTPs corresponded to a decrease of emissions from urban areas (i.e., from inhabitants not connected to WWTPs and diffuse urban emissions).

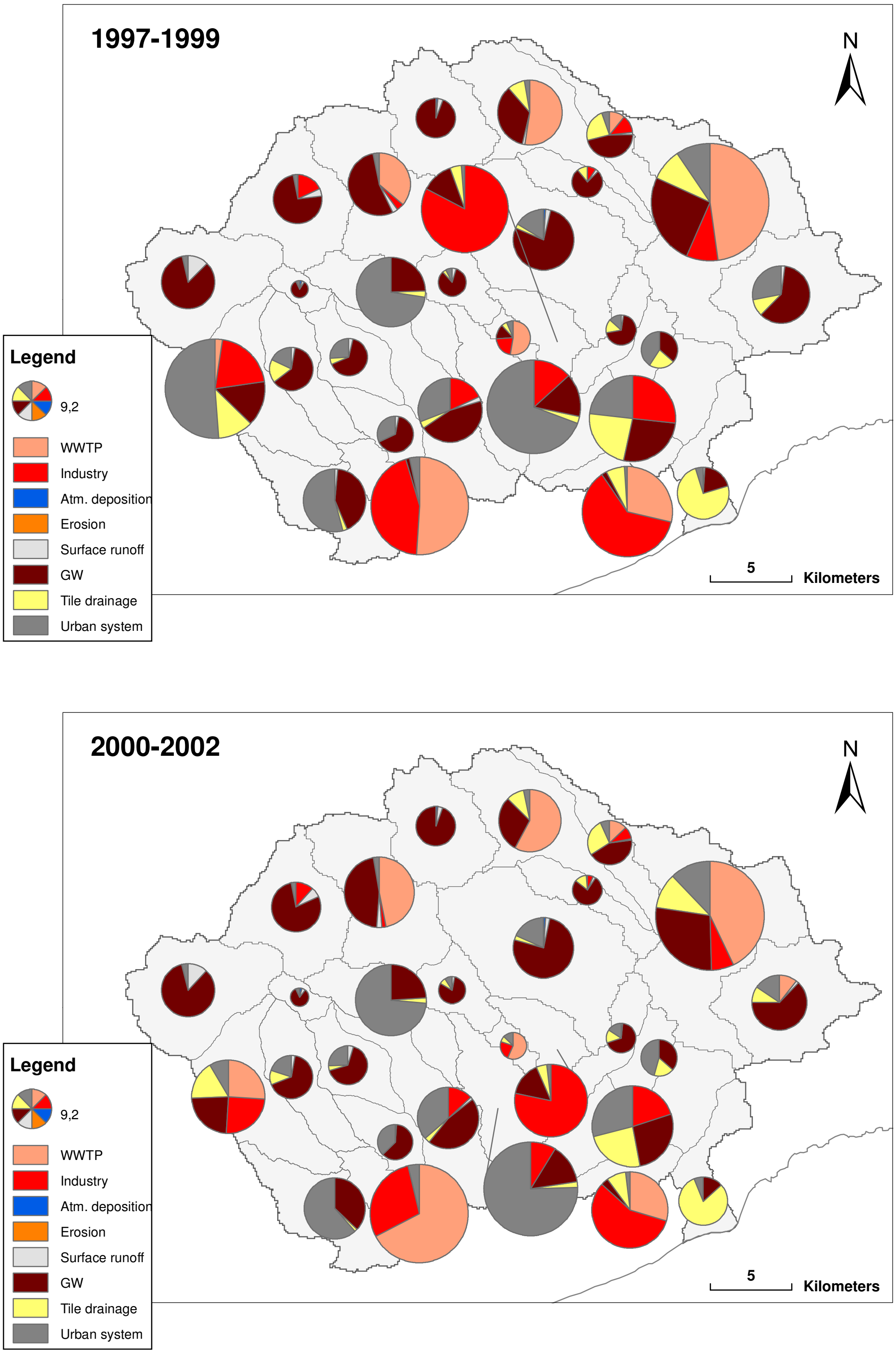


Figure 3.16 *Partitioning of the total N emissions (t/yr) by emission pathway in La Tordera basin for the 1997-1999 period (top) and the 2000-2002 period (bottom). Pie sizes are proportional to the magnitude of the total N emissions between subcathments.*

3.3.3. Model uncertainty and sensitivity to input data

Data sources related to inputs, stocks or annual surpluses of nutrients in agricultural areas received the worst reliability score in the assessment of input data uncertainty (Table 3.4) For instance, it was difficult to obtain data on the nitrogen and phosphorus content in arable topsoil or maps of the different soil classes that are needed to derive the average nutrient concentrations in tile drained water. This was mainly due to a lack of studies in the investigated basin. Also, limited data availability on nitrogen inputs and outputs made N surplus estimates notoriously uncertain. Data on point sources improved over the course of the study period, but were overall less reliable that one might have expected, especially for industrial sources.

Table 3.4 *Reliability rating of the sources of data. Scores range from 1 to 5, where 1 is most reliable and 5 is least reliable.*

Variable	**Reliability**
Climatic and hydrological characteristics	
Mean annual precipitation	2
Long term annual precipitation	2
Evaporation rate	2
Mean stream discharge	2
SRP concentration	2-3
DIN concentration	2-3
Land use, except urban areas	1
Urban and industrial areas	2
Industrial and urban point sources (WWTPs)	
Mean nutrient annual loads	2-3
Mean annual effluent discharge	2
Removal efficiency of N and P	3
Connected inhabitants	2-3
Equivalent inhabitants from industries	2-3
Diffuse sources	
NO_X deposition	2
NH_4^+ deposition	2
Area of surface water	2-3
On site soil loss	2-3
P and N content of arabe topsoil	5
Mean catchment slope	1-2
Drained agricultural area	2-3
N surplus	4-5
Inorganic fertilizers	2-3

Results of the sensitivity analysis of model estimates of P and N loads obtained by varying selected data items by -15% to +15% of their actual values were mostly linear. Therefore, we chose to plot model sensitivity to 5% increases in the input data items considered. For both phosphorus and nitrogen, annual precipitation was the data source to which the model was most sensitive, followed by the number of inhabitants (Fig. 3.17).

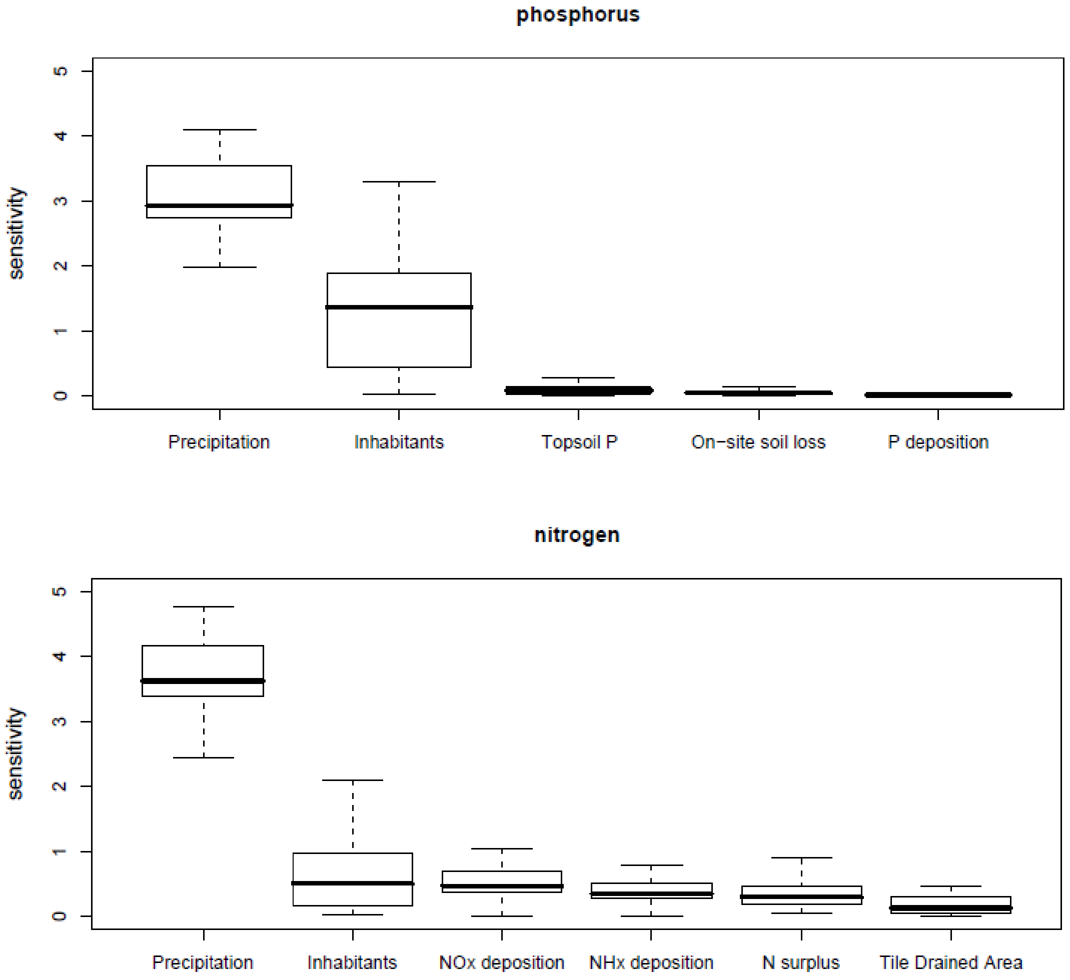
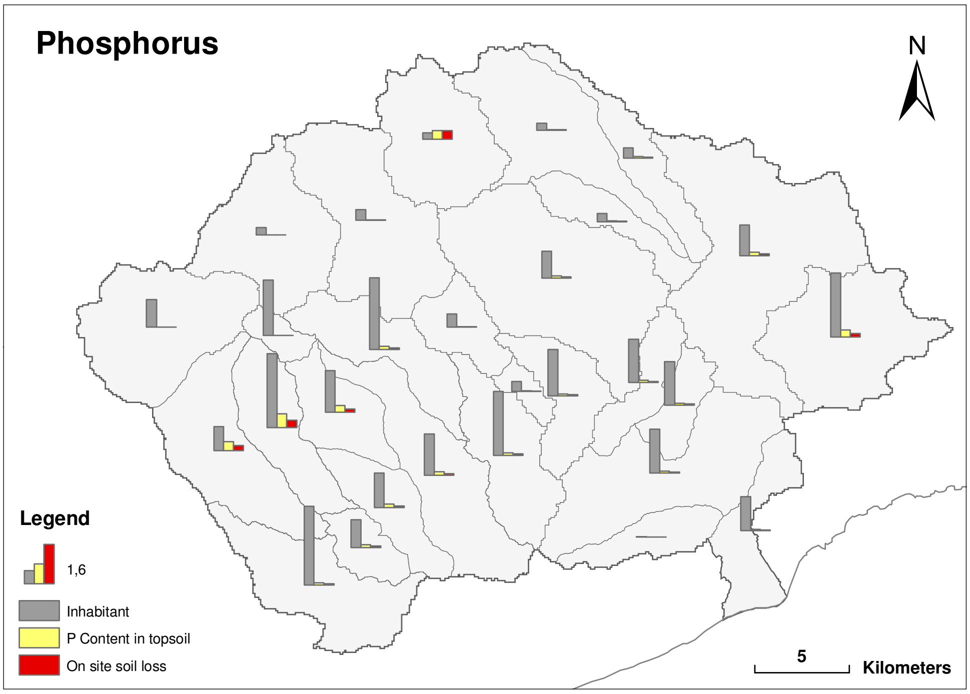


Figure 3.17 *Model sensitivity to input data for phosphorus and nitrogen. Input data items box plots across subcatchments summarise the sensitivity of the model.*

With a 5% increase in the annual precipitation on the 28 subcatchments, the outputs increased between 1.9% and 6.9% for phosphorus, and between 2.4% and 5.6% for nitrogen. Among the remaining data items, a 5% increase in population caused a 0.02% to 3.3% increase in the modelled P load, and a 0.02% to 2.3% increase in the modelled N load, depending on the subcatchment (Fig. 3.18). For the other parameters related to P, the changes in outputs were lower than 1%. With regards to nitrogen, N surplus caused a change from 0.04% to 1.8% in the output with 5% change in the input value. For tile drainage and atmospheric deposition, the changes in outputs were around 1%, and for the other parameters, the changes in outputs were lower than 0.1%.



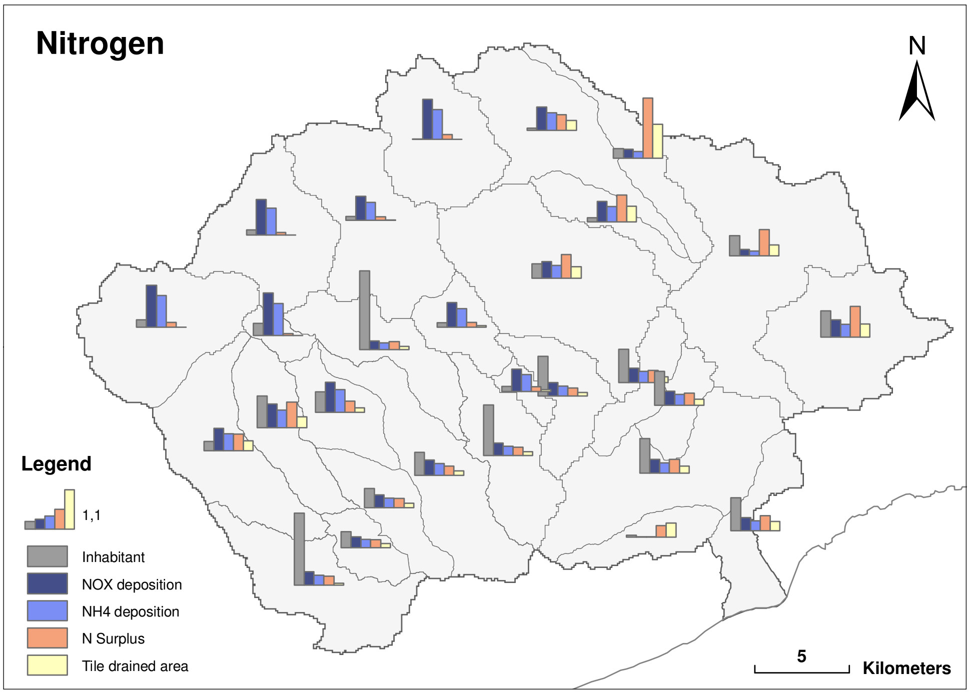


Figure 3.18 Model sensitivity to input parameters for phosphorus (top) and nitrogen (bottom) in La Tordera basin.

3.4. Discussion

3.4.1. Patterns of nutrient loads and emissions in time and space

Over the period 1995-2002, nutrient loads, as estimated from the model and from stream monitoring data, and nutrient emissions, as estimated from the model, showed a declining trend. These reductions in nutrient emissions over time and across subcatchments were mainly the result of the implementation and improvement of urban and industrial waste water planning strategies (PSARU and PSARI). Despite this, at the end of the study period, La Tordera was still dominated by urban and industrial effluents, whether treated or untreated, especially for phosphorus, with large emissions concentrating along the main valley and lower Tordera.

Agricultural sources follow urban and industrial emissions as the major source of phosphorus and, especially, nitrogen, but along different pathways, as it corresponds to the different chemical nature of phosphorus and nitrogen compounds. Phosphorus has low solubility but readily adsorbs to particles, while nitrate, the main form of inorganic nitrogen in oxic waters, is highly soluble and enters subsurface and groundwater compartments with the water that infiltrates in the soils (Novotny, 2003). Accordingly, the main pathways for phosphorus from agriculture were surface runoff and erosion, while subsurface and groundwater pathways were important for nitrogen. Nitrogen agricultural sources were high in both absolute and relative terms in some subcatchments, especially on the low-relief, northwestern part of the catchment. The model indicates a slight decline in diffuse emissions from 1995 to 2002, probably associated with reductions in fertiliser application (see Chapter 2), but also to loss of agricultural land and declines in atmospheric deposition. Despite this, the impact of agricultural diffuse sources on nutrient loads remains a problem.

Interannual variability around the declining trend from 1995 to 2002 was mainly associated with variability in precipitation, the input data item to which the model was most sensitive. This is to be expected since wet years increase the effective contributing area, enhance nutrient mobilisation and transport, wash out nutrients accumulated in impervious surface areas, and raise the probability of overflows in urban areas with combined sewers (Novotny, 2003; Grizzetti et al., 2005). In the calibrated model, variability in precipitation affected most strongly in-stream nutrient retention through changes in discharge, and therefore in specific runoff.

The retention term turned out to be crucial for model calibration not only because of its sensitivity to interannual climate variability, but also because of its magnitude. According to model results, on average about 50% of nutrient emissions are temporarily stored or permanently removed from the stream network on an annual basis. The importance of in-stream nutrient retention has been recognised both at reach (Peterson et al., 2001; Martí et al., 2004) and river network scales (Alexander et al., 2000; Behrendt and Opitz, 2000; Seitzinger et al., 2002), with retention efficiencies that are commensurate with those found in this study, especially for small basins, where low flows increase contact between nutrients in transport and the biologically active streambed. Yet the high retention estimated for La Tordera is probably related to other factors. Firstly, MONERIS estimates total phosphorus and total nitrogen, whereas calibration for La Tordera was performed against dissolved inorganic P and N. Therefore, calibrated retention coefficients must include also a correction for total to dissolved inorganic forms. Secondly, MONERIS does not take into account riparian areas, which are hot spots for nutrient retention (Lowrance et al., 1984; Osborne and Kovacic, 1993), and perhaps other forms of retention during nutrient transport across the landscape (Haag and Kaupenjohann, 2001); and the calibrated coefficients must also account for these forms of retention. And thirdly, La Tordera is a Mediterranean stream with low flow in the summer, which may even dry up on some sections during dry years, and with a large fluvial aquifer in the middle and lower sections. As a losing stream, a fraction of transported nutrients must flow into the hyporheos, where they might be lost through denitrification, or laterally to the riparian vegetation and wetlands. This could partially explain why, contrary to expectations (Peterson et al., 2001), calibrated retention efficiencies were higher in the lower Tordera than in headwaters (Fig. 3.19).

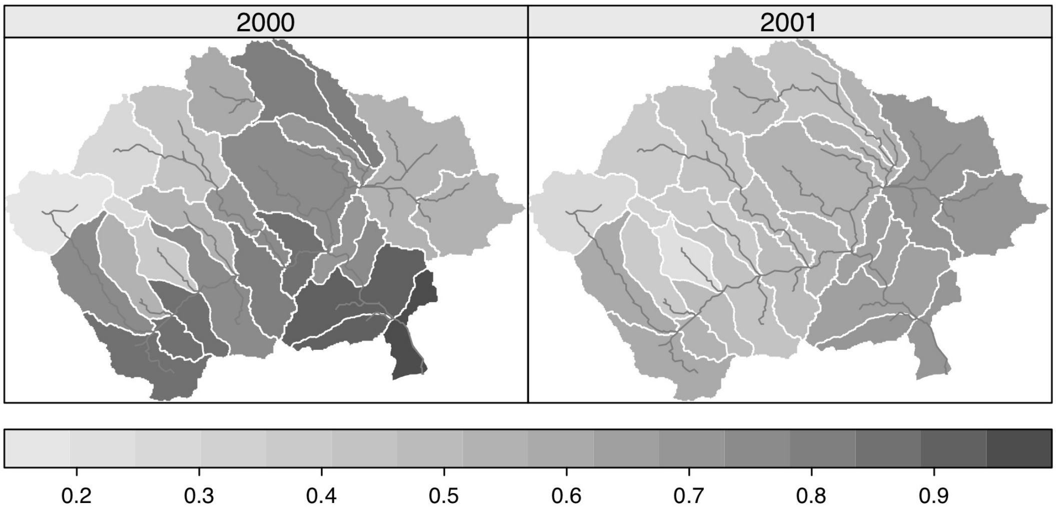


Figure 3.19 *Nitrogen retention (as a fraction) per subcatchment on a dry year (2000, 670 mm average rainfall), and a wet year (2001, 727 mm average rainfall).*

3.4.2. Uncertainties in the model exercise

Although the calibration and verification of MONERIS was successful, with high Nash-Sutcliffe efficiencies, several sources of uncertainty that either added noise to modelled values or produced biases in load estimates had to be recognized, identified, and, to the extent that this was possible, quantified. Uncertainties had their origin in the model structure, in observed loads and in input data.

As a calibrated, empirical, steady-state model, MONERIS is useful for large scale, rapid assessment and apportionment of loads, but has important limitations (Schoumans and Silgram, 2003). The most significant of these limitations concerns catchment hydrology. MONERIS does not model discharge, and groundwater flow is estimated from the water balance. This is a concern especially for losing streams, as infiltration to fluvial aquifers is not considered in the water balance of the stream, and this may result in underestimated groundwater flows. In this application to La Tordera, this means that diffuse nutrient sources (especially nitrogen) through groundwater flow must be viewed as conservative estimates. On the positive side, MONERIS allowed us to focus on data collection and analysis of data quality, and provided a robust (as measured by verification) model of the major temporal and spatial patterns in nutrient emissions. In data-starved basins such as La Tordera, more complex models might have not yielded increased predictive power (De Wit and Pebesma, 2001). On the other hand, a simpler, statistical model (e.g., Smith et al., 1997; Grizetti et al., 2005) would have not provided as rich an image of the catchment as MONERIS, as they would have been limited to a few parameters without regard to actual processes, which is a serious limitation for scenario development. As a conceptually-based, empirical model, MONERIS nicely bridges purely statistical models and complex process-based models.

So-called observed loads, which were used in the calibration, were of course not observed but estimated from daily discharge and nutrient concentrations. Because sampling frequency was low, i.e., monthly at best, load estimates were expected to show large errors (Littlewood, 1995; Johnes, 2007). Large variability in “observed” loads that is trendless and unmatched by modelled loads, especially in headwater subcatchments for phosphorus (Fig. 3.12), may be attributed to errors in load estimates from monitoring data rather than to errors in modelled data. In addition, according to ACA (2002b), discharge was systematically underestimated in some gauging stations, notably Fogars de Tordera (J062, at subcatchment 14024), and this could explain why the model consistently overestimated nutrient loads at that station.

Some of the data sources for the model were remarkably unreliable (Table 3.4), most notably N and P concentrations in topsoil and nitrogen surplus. This often points to deficiencies in the data collection by the concerned statistical agencies. For example, despite the importance of diffuse sources for surface water quality, there does not seem to be a concerted effort to collect, with the appropriate quality controls, data on inorganic and organic fertiliser application rates. This may be partly blamed on a lack of cooperation between two governmental agencies with distinct constituencies and somewhat conflicting goals (i.e., the Department of Agriculture, DARP, and the ACA, see Chapter 2). Point sources, however, are largely under the jurisdiction of the ACA, yet data on WWTP effluents and, especially, industrial effluents, was found to be wanting. Industrial point source data were only available from 2001 onwards. To correctly model temporal trends in nutrient loads, we had to assume that industrial P and N emissions were larger in the preceding years. This is a reasonable assumption, since the analysis of sources of uncertainty combined to the social analysis (see Chapter 2) highlighted that uncertainties regarding the reliability of the data were greater the more remote the period taken into consideration.

3.4.3. Uncertainty, sensitivity, and scenario development

The analysis of model uncertainty and sensitivity is useful to assess the model potential for exploring scenarios of the evolution of the catchment under different pressures or different management regimes. With this goal in mind (see Chapter 5), we focused on model sensitivity to input data. MONERIS was found to be most sensitive to changes in precipitation. This is to be expected, as the precipitation regime affects all diffuse emission pathways. However, MONERIS would not be suitable to explore climate change scenarios because it does not explicitly model the catchment hydrology. Among the other input data examined, the model was especially sensitive to the number of inhabitants (related to urban emission sources), on-site soil loss and P content in topsoil (related to P emissions through erosion), N surplus and tile drained area (related to N emissions from agricultural areas), and atmospheric deposition (Fig. 3.18). Therefore, N and P emissions should change noticeably under catchment scenarios that involve changes in any of those input data. It is worth noting that model sensitivity varies not only among nutrients, but also across subcatchments depending on their major emissions pathways, which highlights the fact that model sensitivity is always relative to a particular realisation of a model.

Analysing sensitivity to input data together with uncertainty of input data also helps identify problem areas in model application. The worst situation occurs when a model is highly sensitive to input data that are known with uncertainty, because when this occurs, errors in source data magnify and propagate to model outputs. In the application of MONERIS to La Tordera, this is the case especially of P emissions through erosion, and of nitrogen emissions originating in agricultural nitrogen surplus. Thus, model results, including scenarios, involving these pathways must be viewed with caution.

3.5. Conclusions

In this study, the application of the model MONERIS to estimate nutrient loads was successfully calibrated and validated, which allowed to produce a suitable representation of the estimated nutrient loads against observed nutrient loads. The modelling exercise of nutrient emissions to the river basin showed that phosphorus emissions were dominated by industrial and urban point sources, and paved urban areas diffuse sources, while inputs via groundwater had the greater contribution of total nitrogen emissions followed by point sources and paved urban areas diffuse sources.

Although nutrient emissions observed over time and across subcatchments between 1996 and 2002 decreased, mainly because of the implementation and improvement of urban and industrial waste water planning strategies (PSARU and PSARI), at the end of the study period La Tordera was still dominated by urban and industrial effluents, especially for phosphorus. Regarding agricultural diffuse sources, their contribution to nutrient emissions, and especially nitrogen, also declined over the study period, but more slightly; their impact still remains a problem. Interannual variability observed around the declining trend was mainly associated with variability in precipitation, which affected in-stream retention. Crucial for model calibration, in-stream retention was estimated to about 50% of nutrient emissions on an annual basis and related to many factors during nutrient transport, e.g., low flows, riparian areas (not considered in this study), among others.

During the modelling process, potential hurdles related to the model structure, observed loads and input data were encountered. Among the limitations of the model, catchment hydrology was the most significant and indicated that estimates of diffuse nutrient emissions (especially nitrogen) through groundwater flow must be considered with caution. Variability in observed loads was probably more the result of errors in load estimates from monitoring data than in modelled data. Among the input data, N and P concentrations in topsoil and nitrogen surplus presented a significant unreliability due to deficiencies in the data collection by the concerned statistical agencies mainly as a result of a lack of cooperation between them. Also the lack of data from industrial point sources caused biases in load estimates. Despite of all these hurdles, MONERIS provided a robust model of the major temporal and spatial patterns in nutrient emissions.

The analysis of the model uncertainty and sensitivity to input data provided a good basis to explore the evolution of the catchment under different pressures or management strategies and helped to identify problem areas in model application.

Chapter 4

Participatory development of socioeconomic scenarios for La Tordera, 2030 horizon*

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4.1. Introduction

Nutrient management in river basins requires not only the identification and quantification of nutrient sources but also an understanding of all relevant natural and social processes and their interactions. By allowing a synoptic perspective on the causes and effects involved (Rotmans et al., 1996), an integrated environmental assessment (IEA) (Bailey et al., 1996) facilitates an understanding of the interactions and feedbacks between the natural and the social systems involved in the dynamics of river nutrient loads. This understanding is crucial to manage effectively the various sources of nutrient emissions.

Traditionally, river basin management has been reactive, focussing on the reduction of point nutrient sources mostly through the construction of waste water treatment plants. However, it is increasingly being recognised that we also should attempt to foresee problems and take a proactive and preventive approach. Proactive management is also better suited to accommodate societal action in environmental policy development and governance (Berry and Rondinelli, 1998). This can be accomplished through a variety of approaches, including participation and policy evaluation as part of an integrated assessment modelling. Models are widely used to explore options for catchment management and to analyse the evolution of specific state variables (e.g., nutrient concentrations and loads) in relation to a driving force of interest (e.g., land use or climate change) (Hofmann et al., 2005; Brown Gaddis et al., 2007). This is done by simulating scenarios. However, models (and modellers) are by themselves inadequate for defining goals and specifying scenarios, a task that is often entrusted to a panel of experts. Yet this is an area that can greatly benefit from the involvement of stakeholders, as the European Union Water Framework Directive (WFD), adopted in 2000, recognises. With the objective of achieving the effective implementation of effective water management for the protection of all European natural water bodies, and to improve decision-making processes, the WFD encourages public participation. At its most basic, participation at the local level allows the collection of practical information for scientific assessments and policy-making, but it also serves to better adapt measures to local conditions, to include people concerned in the design process and eventually to raise public acceptance (WFD, 2002b). The WFD distinguishes between providing information, consultation and public participation (or active involvement). All these different and gradually more relevant forms of participation contribute to the participatory policy analysis which underlies Participatory Integrated Assessment (PIA) (Ridder and Pahl-Wolst, 2005), a set of methods and techniques that aim at supporting policy development by designing and facilitating active involvement of social agents, and eventually fostering debate and argumentation in an environmental management process (Hisschemöller et al., 2001). The development and use of scenarios is one of the most appropriate approaches to contribute to this aim as it is an efficient way to gather information from expert judgements.

Scenarios are useful instruments to think about the future and to build storylines about how the future might develop (Nakicenovic et al., 2000). In the definition of the Intergovernmental Panel on Climate Change (IPCC), which is commonly adopted in environmental applications, scenarios are described as alternative futures that are neither predictions nor forecasts, but contrasting images of how the future might unfold (Parry and Carter, 1998; Rotmans et al., 2000). Scenarios are widely used to explore uncertain futures, to assess possible pathways for socioeconomic development, to identify management strategies and to present alternative views or images of the future with the aim to provide insights into the present (Berkhout et al., 2002; Burt and van der Heijden, 2003; Ledoux et al., 2005). Thus, by synthesising and communicating complex and extensive information to decision makers and the public, scenarios make decision-making more robust and help identify strategies for pre-empting undesirable future developments (Carter et al., 2001; Van der Heijden, 1996).

Scenarios are not only a way to see the future. They also enable to highlight uncertainties, which will always characterise the future. Thus, rather than allowing accurate prediction, they enable “learning” by showing how the future may deviate from planned events (Van der Heijden, 1996). Although over short periods of time many important structures, processes and attitudes might remain unchanged, we are aware that over longer periods of time, social and economic relationships change, and that institutional and technological innovations modify prevailing trends. This is the domain of scenarios. In this context, the process of scenario construction can be seen as a sequence of “what if?” questions. This approach encourages participants to evaluate possible causal chains and to reflect on the series of consequences of a range of possible futures, generating scenarios that are self-consistent and comparable (Kahn and Wiener, 1967; Berkhout et al., 2002). The goal is to develop a number of diverging stories, commonly called “narratives” or “storylines”, by focusing on the nature and impact of the driving forces that are identified as being both uncertain and heavily influencing. Thus, scenarios at the catchment scale are recognised as essential tools for planning and communication (Raskin et al., 1998), and also for representing efficiently environmental changes caused by a specific socioeconomic context. When used together with a catchment model, scenarios can be run to assess the impact of relevant socioeconomic indicators on the environment.

The participatory development of scenarios applied to nutrient emissions problems at the catchment scale in the Mediterranean region is quite novel; we are not aware of any precedent published in the scientific literature. Yet it is of interest in the context of the current efforts to develop programmes of measures for river basins as required by the

WFD and the European Statement for a New Culture of Water (NCW), adopted in Madrid in 2005 by a group of European scientists. The NCW considers the WFD as an essential and necessary contribution in the pursuit of the defence of human and citizen rights in the context of democratic governance based on transparency, participation and citizen control to reach social and environmental sustainability (Arrojo, 2006).

This paper is a contribution to the elaboration of a common toolkit for scenario development, which may allow sharing and comparing experiences. We present and discuss a participatory process to develop local socioeconomic scenarios relevant to the evolution of nutrient flows in a Catalan river catchment (La Tordera, NE Spain) for the 2030 horizon. This was done for research purposes, without immediate policy implications, as part of an integrated assessment which includes a modelling effort to identify and quantify nutrient sources and emissions between 1993 and 2002, and an analysis of the social context relevant to catchment management, including the identification of stakeholders and the analysis of their interactions. The process presented here for the development of scenarios will serve as a basis for the elaboration of quantitative nutrient emissions scenarios in a separate paper. Our specific goals are: (1) to critically examine the methodology used in the participatory development of socioeconomic scenarios, (2) to present and discuss the results of a scenario-development workshop for La Tordera catchment with selected stakeholders, and (3) to discuss the translation of narrative socioeconomic scenarios into meaningful nutrient emission scenarios. Finally, we discuss the utility of scenarios for the sustainable management of nutrient sources in La Tordera.

4.2. Methodology

The scenarios developed in this paper fall into the category of explorative and external scenarios in the typology proposed by Börjeson et al. (2006). Indeed, they are elaborated with a long time-horizon (2030) and are based on forces which are not directly under the control of the stakeholders. However, the scenarios share some qualities with the normative scenarios as defined by van Notten et al. (2003), namely a consideration of the interpretations, values and interests of scenario developers. We sought to respond to the question “What can conceivably happen to the development of external (socioeconomic) driving forces that impinge on nutrient emissions to La Tordera river?” Scenarios were developed during a one-day workshop with selected stakeholders. This technique allowed us to generate, collect and work with ideas and to structure thinking with a view to produce immediate results. Based on the comprehensive views of scenario planning structure presented by Mercer (1995) and the European Environmental Agency (EEA, 2001), we conducted the workshop by applying a combination of the steps of two methods, “Futures Skills” of Graham H May (http://www.futuresskills.co.uk) and “Idon Visual Thinking” (Galt et al., 1997), for the participatory generation of scenarios. These are highly effective, quick and straightforward techniques. One of us had already experience in applying the latter method to the management of biological invasions (Rodríguez-Labajos, 2006).

The workshop for scenario planning was conducted in a neutral place within the catchment (i.e., a music school in the town of Sant Celoni, see Fig. 3.4 in Chapter 3) and led by three of us (FC, BLL and JLR) plus another person in charge of taking notes. Scenarios were developed through a participatory process with selected representatives of stakeholders. Preparation for the workshop included an analysis of nutrient emissions and concentrations in La Tordera over the last decade, an evaluation of the socioeconomic system relevant to nutrient emissions to the river, the identification of stakeholders and a set of interviews with selected representatives of stakeholders (Fig. 4.1).

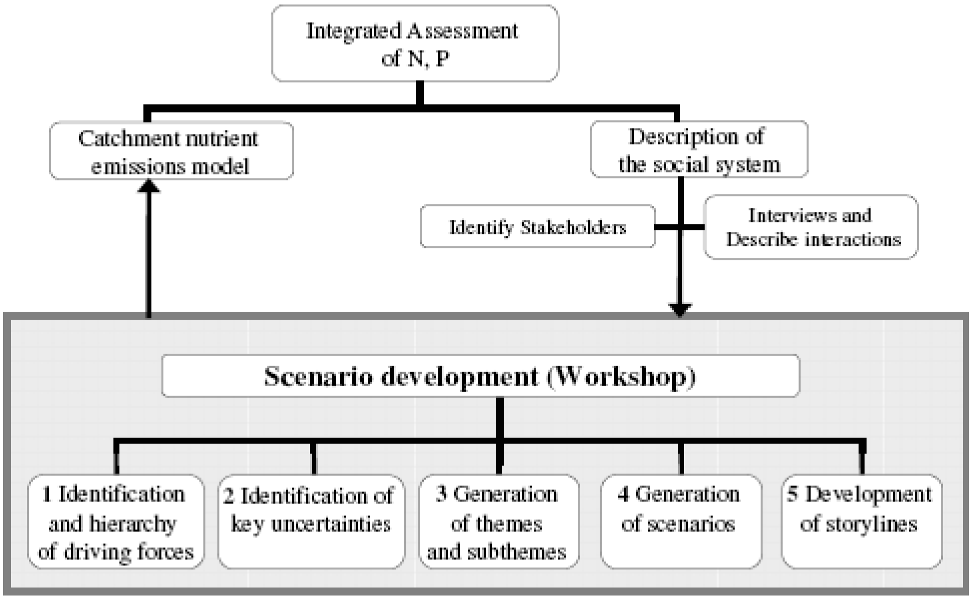

Figure 4.1 *Flowchart of the methodological process for local scenarios development through a participatory process.*

The generation of scenarios was based on a structured set of activities (see Appendix 3, workshop program), which involved the following steps: (1) identification and analysis of driving forces, (2) identification of key uncertainties, (3) generation of clusters of driving forces and scenarios, and (4) development of storylines. All activities in plenary and separate groups were tape-recorded.

4.2.1. Identification of stakeholders and selection of participants

We started by identifying the key stakeholders (Fig. 4.2) inspired by the "Shaping actors - shaping factors" method, used for the first time for "The European Challenges post-1992" (Jacquemin and Wright, 1994). We based this process on our initial analysis of the nutrient emissions, former project reports (Tàbara et al., 2004a, 2004b; http://www.observatoririutordera.org/), recommendations from academic experts and local informants, and Internet research. Stakeholders were selected to include both public and private sectors, groups with a direct effect on water quality (nutrient emitters), local and regional administrative departments with a stake in the development and implementation of policy relevant to nutrient emissions, and locally represented organisations involved in environmental conservation. Then, we explored and analysed the complex human-ecosystem interactions with the use of a series of interviews that we conducted with representatives of all the main social actors of La Tordera catchment (Fig. 4.2).

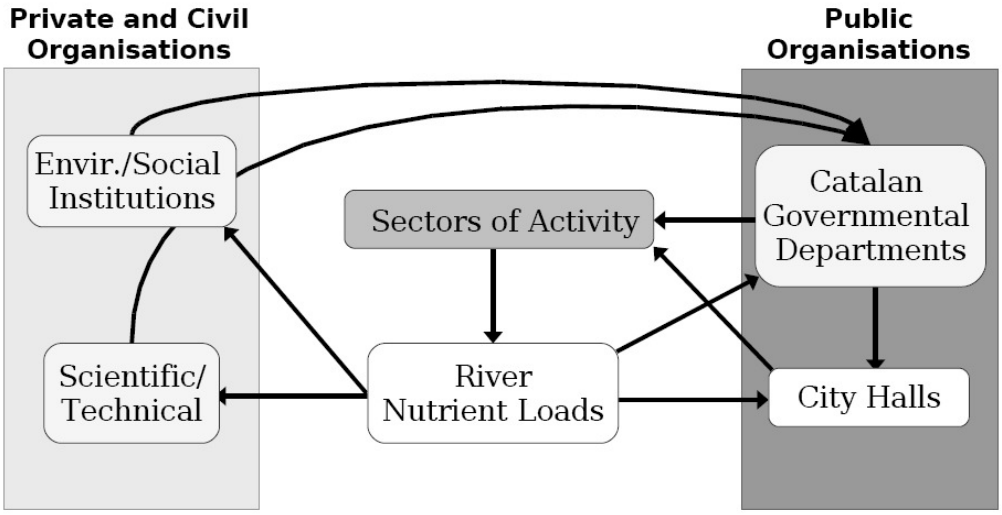

Figure 4.2 *Schematic representation on the main stakeholders identified for La Tordera catchment relative to nitrogen and phosphorus emissions. Arrows indicate the main directions of influence between stakeholder groups. Sectors of activity (agriculture, industry, and urbanisation plus tourism) affect nutrient emissions directly.*

The results were organised in an analytical framework indicating the role, pressures and impacts of all social actors as suggested by EEA (1999) and the WFD (2002a). Among all stakeholder groups, the most powerful ones in terms of their influence on decision-making are the Catalan Governmental Departments, the ACA, and the city halls (Fig.4.2).

The selection of participants is crucial for the success of any participatory process; this is why we paid special attention to this phase (Wollenberg, 2000; Kok et al., 2006). We selected participants based on our list of stakeholders and the results of personal interviews. We sought participants with knowledge on the problem at stake who expressed an interest in being involved in this exercise, had an open attitude and were communicative. Whenever possible, we sought persons who were involved in decision-making processes and could influence the implementation of the WFD in the study catchment. At the same time, we strove to have an even representation of the identified stakeholders. The workshop was held with 12 participants representing the main stakeholders (Table 4.1).

Table 4.1 *Participants to the scenario development workshop for La Tordera catchment. The different sectors of activity are indicated by the abbreviated letters as follows: A, Agriculture, U/T, Urbanisation/Tourism, and I, Industry. Regarding the urban sector, ¾ of the participants were citizens of the catchment. Participants to the scenario development workshop for La Tordera catchment.*

	Stakeholders	**Sectors**	**Websites**
Private and Civil Organisations/ Institutions	- Catalan farmers' union (Unió de Pagesos),	A	http://www.uniopagesos.es/
	- Pharmaco-chemical Industry,	I	
	- Environmental consulting group (EGAM),	U, T, I	http://www.egam.es/
	- Water diagnostic centre (CEDIA)	U, T	
	- Researchers and Environmental/Social institutions: (Observatori and Fundació Natura)	A, U, T, I	http://www.observatoririutordera.org/ http://www.fundacionatura.org/
Public Organisations/ Institutions	- Catalan governmental departments:		
	- Catalan Department of Agriculture and Fisheries (DARP),	A	http://www.gencat.net/darp/
	- Catalan Department of the Environment (DMAH, Prevention and control section),	I	http://mediambient.gencat.net/
	- Department of Territorial Policy and Public Works,	U	http://www.gencat.net/ptop/
	- Water agency (ACA),	U	http://www.mediambient.gencat.net/aca/es
	- City halls: Territorial and town planning divisions	U, T	http://www.ajmalgrat.es/

4.2.2. Main steps of the scenario development

The first step, i.e., the selection and analysis of the driving forces, was done in three phases. First, prior to the scenario development workshop, a series of face-to-face interviews with participants was conducted to develop commitment in the research and to provide a preliminary set of the main driving forces. Second, during the workshop, we started with a presentation of the participatory process and its context. This was followed with a brainstorming exercise in three separate groups defined by sectors of activity (i.e., agriculture, industry, and urbanization and tourism). Finally, a plenary brainstorming session was used to identify the main relevant driving forces at a broader, cross-sectoral level; these included industrial, agricultural, economic, political, technological, legal and societal trends (see section 4.3.1). Relevant driving forces were written on “Post-it” notes and placed on the wall. Participants were asked to assess the extent to which these driving forces were influencing sectoral evolution and affecting N and P loads, and hence water quality, and to think about current trends for each relevant factor.

One of the main aims of the participatory scenario method is to raise awareness about the unpredictability of the future and to acknowledge the fact that making decisions in the present has implications for the future. Therefore, participants, working together as a group, were asked to assess each driving force on two scales: uncertainty vs. predictability, and degree of relevance with regards to water quality and the selected time interval. The aim was to classify and place the driving forces on a grid with axes running from high to low uncertainty, and high to low relevance. Driving forces that were not considered important were discarded. Those which were qualified as important but relatively predictable (e.g., demography) were kept but only to be included in all scenarios. Therefore, the generation of scenarios was not based on these driving forces, but only on a limited number of important and unpredictable driving forces. At this point, it was essential to assess whether any linkages between driving forces existed, and to rule out any impossible scenarios. This entire process ensured that neither predictable nor impossible scenarios were considered.

After a creative and participative brainstorming, stakeholders conceptualised and qualified two main thematic groups of driving forces. These two main themes based on the socioeconomic driving forces that have an influence on nutrient emissions to La Tordera river were then used to generate two subthemes for each of the main themes. Subthemes define two distinct alternatives (i.e., extremes of the state). Thus, by combining themes and subthemes we obtain a matrix allowing the creation and development of coherent, internally consistent, and plausible descriptions of four possible future scenarios (see section 4.3.1 and Table 4.2). By emphasising the uncertainty of the future but avoiding the confusion of too many alternatives, the potential of the participatory technique can be realised. The main characteristics of each future were underlined and developed. The last step consisted in conferring a descriptive and catchy title to characterise each scenario. Titles help to remember each scenario and facilitate communication about them.

Table 4.2 *Scenarios generated by the participants to the workshop based on the combination of two themes and two alternative subthemes for each of these themes. The scenario 'Inertia' is identified as a 'Business as Usual' scenario (BAU). See text for full narratives for each scenario.*

		Sectoral Interaction	
		The market governs	**Coexistence of market and territory**
Political Planning	**Short-term**	***Inertia*** • Lack of coordination • Utilitarian management • Growth and weak control • Intensive activities and based on technology • High level of contamination	***Pact for subsistence*** • Adaptation • Fast growth with local control • Cooperation, but lack of management • Medium contamination
	Long-term	***Minimum rules*** • Stronger regulations and investment, but local conflicts • Good intentions, but passive cooperation • Low-Medium contamination	***Sustainability*** • Equilibrium between society and environment • Growth but control • Investment • No (or low) contamination

The participants, in a plenary session, learnt together to narrate one scenario to facilitate the development of the storylines. The narrative of a scenario seeks a short description of its evolution as a history explaining the driving forces and sequence of events that lead to the scenario situation. Using several elements, i.e., population and economic growth, technological development and environmental protection, participants explained the plausible evolution of each factor selected in the previous step and qualitatively described their trends.

After this learning experience, participants, as separate working groups, elaborated narratives for the three remaining scenarios. After joint deliberation, contents were synthesised and confirmed. Then, the workshop leaders built the storylines, and, a few days after the workshop, we asked participants to revise and approve them, as part of the follow-up to the participatory process.

4.2.3. Semi-quantitative evaluation of scenarios

To help quantifying the impact of the various scenarios on nutrient emissions within a modelling environment, socioeconomic scenarios need to be translated into a set of quantitative scenarios in a form suitable for input into a catchment model. In this study, the catchment model MONERIS (Modelling Nutrient Emissions in River Systems) will be used at a later stage. MONERIS is an empirical, semi-distributed model that provides estimates of nitrogen and phosphorus annual loads and partitions loads according to the main point and diffuse sources in the catchment (Behrendt et al., 2000; Riera et al., 2002). Our aim here was to relate the trends listed for each socioeconomic scenario to the list of input data used by the model MONERIS in order to examine expected impacts on emissions for each scenario.

To perform this translation, we marked the trend expected for each emission pathways under each of the four socioeconomic scenarios developed during the workshop. We then asked workshop participants by e-mail to comment on our initial evaluation and to suggest modifications. When we felt the interpretation of trends was ambiguous, we specifically asked participants to address those cases.

4.3. Results

Results of the main steps presented in the methodology for the generation of scenarios include the identification of driving forces and key uncertainties, the definition of the themes and subthemes that generated four scenarios, and the development of storylines.

4.3.1. The scenarios

Participants identified the following list of driving forces as key to the future of the catchment, yet of uncertain evolution: agricultural use change, decrease of the agricultural output production, population growth, urban pressure, tourism expansion, relocation of industrial production, planning of industrial estates, water allocations, climate change, regulations, and administrative policy.

After agreeing on the major driving forces that were relevant for La Tordera catchment, participants came up with two main themes for the generation of scenarios: ‘Political Planning’ and ‘Sectoral Interaction’, which are nonetheless quite general. The former embodied all driving forces related to the regulatory framework and the development of policies at local and regional levels addressing demographic changes, labour standards, and environmental concerns (e.g., water allocations). The latter considered all the aspects of sectoral development governed by economic development, i.e., market dynamics and competitiveness. For each of these two themes, two alternatives were defined. These were, for the political planning theme, an emphasis on either short term or long term planning, and, for the sectoral interaction theme, an economic environment in which the market rules versus one presided by a balance between economic and territorial development, including conservation. The combination of themes and subthemes produced four scenarios (Table 4.2), for which participants drafted the following narratives based on population growth, economic growth, technological development, and environmental protection.

Scenario I: Inertia

This scenario is driven by short-term planning. Sectoral development is mainly governed by market dynamics and competitiveness. The leitmotiv for this forward-looking approach is "productivity" instead of a model of production based on "Quantity and Quality" and sustainability criteria. It was identified by participants as a business-as-usual scenario (BAU).

In this scenario, both the growth of urban areas and the expansion of tourism respond only to economic criteria, i.e., property profit. Following current trends, the urban sector thrives not only along the coastal zone but also in the inland part of the catchment.

Traditional agriculture loses area or disappears, with the exception of intensive farming of ornamental plants, already an established activity. Because of a lack of information and education about environmental consequences, and of market pressure, agricultural practises such as the use of fertilisers are intensified to increase productivity and boost economic returns.

In spite of regulations, the number of water allocations increases due mainly to increased water consumption and demand. Regulations, which already are considered to be obsolete and not properly enforced, do not adapt fast enough to a constantly changing situation. The authorities responsible for drafting and enforcing these regulations do not succeed in generating a consensus to oppose the inertia.

Following current trends, the industrial sector progressively abandons the production of goods in favour of logistics, service production and intellectual services, i.e., the tertiary and quaternary sectors of industry.

Scenario II: Pact for subsistence

This scenario combines actions in the territory driven by short-term planning with a sectoral performance that attempts to develop the market while taking into account territorial *development. The necessities of the short-term planning induce the intervention of the public administration, which takes action as problems emerge.*

This scenario is characterised by strong population growth due to the proximity and expansion of the metropolitan area of Barcelona, increased transport connexions, immigration and the strong growth of tourism. As a result, urban pressure continues to grow at a sustained rate and second homes are converted to primary residences.

The agricultural sector remains stable thanks to conventional practices supported by a moderately successful territorial planning. The agricultural configuration, practices and yield remain unchanged. An attempt is made to curb the negative impacts of the sector.

Water allocations show regular and moderate growth. In spite of regulations, the current trend towards an overexploitation of La Tordera aquifer is maintained and may become critical. Public authorities still focus on short-term planning and cannot avoid these negative outcomes in spite of the implementation of monitoring and enforcement measures on water uses.

Only industries with access to adequate financial resources are able to specialise and survive the pressures towards relocation. The autonomous authorities do not limit effectively the escalation of industrial estates (a current trend), delegating this task to the local authorities.

Scenario III: Minimum rules

This scenario combines actions in the territory driven by long-term planning with a sectoral development governed mainly by market dynamics.

This scenario is characterised by a moderate growth of the population as a result of immigration and conversion of second homes into primary residences, which initially contributes to the expansion of the urban area. Subsequently, the trend changes towards protecting the urban landscape and managing the social needs and demands of the newly established population. This leads to a more compact urban design with restrictions on the height of buildings. Second homes in dispersed developments tend to change into main residences; “sun and beach” tourism remains as today.

Agricultural production is aided by protection policies and guarantee-of-origin devices that place an added value on the local products. Nonetheless, it loses ground to the exploitation and management of forests.

Environmental protection policies and water supply planning together reduce water allocations in La Tordera catchment. However, market pressures tend to increase water demand, which is eventually met by resorting to interbasin water transfers. The Catalan government strengthens the enforcement of environmental regulations, and this generates competence conflicts with the local authorities, which are only solved through supranational guidelines or legislations, such as European policies. The social actors have an ambivalent position in relation to environmental policies. On the one hand, they request improvements in environmental quality. On the other hand, they refuse to bear economic and social costs that can foster such improvements. In this scenario, stakeholders understand that environmental costs should comprise an investment towards improving standards of living.

The economic and political situation leads to a moderate increase of industrial estates and leisure centres on country lands. At the same time, there is a trend towards the relocation of industrial activities which cannot comply with environmental regulations. A decline of the primary and secondary industrial sectors in favour of logistics is accompanied by lower production of contaminants, but brings with it other negative environmental externalities (e.g., an increase in traffic exacerbating air pollution).

Scenario IV: Sustainability

This scenario combines actions in the territory driven by long-term planning with a well-balanced sectoral performance that attempts to develop the market while taking into account territorial development.

In this scenario, urban change is characterised by the growth of the local population as second homes are converted into primary residences thanks to prosperous economic and labour opportunities. On the coast, the model of mass tourism brings about irreversible changes in the landscape; in contrast, in the mountain areas an ecological tourism model is eventually implemented contributing to the preservation of the environment and the rural landscape. Although the economic impact of this activity is not very significant in the region, it stimulates the services sector in the rural areas.

Thanks to agro-tourism activities, the agricultural sector benefits from more leeway in its mode of operation. However, doubts are raised regarding the future of this sector. Agriculture continues to be highly dependent on subsidies to guarantee the preservation of the landscape and the environment. The implementation of devices to increase the presence of agricultural producers in the distribution and commercialisation of their products alleviates this problem. Agricultural subsidies are increasingly justified by the role taken by farmers as stewards of the rural environment.

Water allocations are restricted in accordance with urban planning. A hefty but necessary investment is committed to improving waste water treatment.

Driven by globalisation and local environmental regulations, industries relocate away from the catchment. This offers an opportunity to change the industrial fabric and promote a services industry that is more environmentally friendly. Nonetheless, industries of the secondary sector remain because a significant proportion of existing companies tend to adapt to environmental regulations as long as they remain economically successful.

4.3.2. Interface with the catchment model MONERIS

Figure 4.3 summarizes, for each of the main pathways, the trends in nutrient emissions that are to be expected under each of the four scenarios developed in this study. Scenarios for modelling nutrient emissions are presented in order of decreasing impact on the river. Thus, the scenario ‘Inertia’ or BAU is expected to results in an increase in nutrient emissions, thereby worsening water quality, while the scenario of sustainability provides the largest improvement in environmental conditions relative to the current situation.

	SHORT TERM MANAGEMENT		LONG TERM PLANNING	
Scenarios Pathways	INERTIA	PACT FOR SUBSISTENCE	MINIMUM RULES	SUSTAINABILITY
Point sources				
Waste water treatment plants (WWTP)	↗	→	→	↘
Direct industrial discharge	→	→	→	↘
Diffuse pathways				
Direct Atmospheric inputs	→	→	↘	↘
Surface runoff	↗	↗	→	↘
Erosion (e.g.: N, P content in topsoil)	↗	→	↘	↘
Groundwater and tile drainage via N surplus in agricultural land	↗	↗	→	↘
Urban diffuse sources	→	↗	→	↘

Figure 4.3 *Compact representation of the evolution of N and P loads expected for each of the main emissions pathways in the model MONERIS for the four socioeconomic scenarios. For each scenario, expected trends of N and P loads relative to current conditions are indicated by arrows as follows: ↗ , increasing trend; →, no significant change; and ↘ , decreasing trend.*

Both the “Inertia” and “Pact for subsistence” scenarios suggest a decrease in the overexploitation of the aquifer. In spite of that, and an important decrease or no significant change, respectively, of extensive agriculture, the overall trend suggests an increase in emissions mainly due to the growth of urban areas, the expansion of tourism and the increase of water allocations. As for the two main characteristics related to the erosion and diffuse transport through groundwater flow pathways, i.e., phosphorus content in topsoil and nitrogen surplus, we observe an increase in the emissions into the river under the BAU scenario. Moreover, except for the “Sustainability” scenario, although the socioeconomic scenarios suggest fluctuations in the evolution of industrial and urban point sources and urban diffuse sources, the general trend for these emission pathways seems relatively unimportant.

4.4. Discussion

4.4.1. Participatory scenarios and nutrient flows modelling

To prevent further pollution and to protect and enhance the ecological state of streams and rivers, it is necessary to define and develop relevant sets of water management alternatives for the future of the catchment through the implementation of environmental policies. This strategy should ideally harmonise the conflicting needs of the stakeholders in the catchment and allow us to find the best agreement between the use and conservation of the ecosystem. Developing local socioeconomic scenarios through a participatory process can contribute, at a later stage, to modelling exercises based on the evolution of nutrient emissions into the river in the mid-term (i.e., about 30 years ahead) to assist catchment management at the same time that it underlines and promotes in an implicit way a learning process for both researchers and participants and fosters the communication among stakeholders.

The development of scenarios generated four realistic visions of the future based on uncertain driving forces. Throughout the participatory process, stakeholders had to think about uncertainties and consider the possibilities of change. Indeed, they were expected to make manifest the connections between nutrient fluxes in the river (and, more broadly, water quality and ecological status) and both local and regional socioeconomic trends or changes and management actions. In a first evaluation of scenarios by the participants at the end of the workshop, all scenarios seemed to show remarkable similarities; this was probably due to the existence of a few elements that were common to the four scenarios and corresponded to important trends on which participants tended to agree, i.e., trends that exhibited limited uncertainty. However, the development of storylines and the semi-quantitative evaluation of the consequences of each scenario for nutrient emissions helped to highlight the differences among scenarios.

The generation of narratives explaining the outcome of each scenario and the reasons for the proposed situations, allowed participants to give value and consistency to the scenarios. Taking into account all current and relevant driving forces having an influence on the evolution of each economic sector, participants agreed that the scenario of sustainability, which, out of all four scenarios, was obviously the preferable future for La Tordera catchment, could be realised.

Although the results of a modelling exercise were not the purpose of this paper, we do discuss the translation of storylines into meaningful semi-quantitative nutrient emission scenarios. Applying socioeconomic scenarios such as the ones presented here to a physical catchment model to explore their effect for nutrient emissions requires their translation into quantitative indicators useful to feed the model. Quantification of narratives using a set of indicators is subject to debate. Indeed, as Berkhout et al. (2002) explains, storylines are the result of stakeholder's future views based on uncertainty while the concept of quantitative analysis relies on an idea of neutrality and accuracy, deceptive as this may be. The first translation of each scenario into quantitative indicators for a model facilitated the interpretation of scenarios as it forced us to interpret the storylines in the form of explicit trends that could be communicated objectively, thus granting more consistency to each scenario. Later on, when values (rather than trends) are assigned to each indicator for impact assessment, scenarios might be viewed with more credibility. Nonetheless, it will be important to keep in mind that values are not definitive, but indicative and illustrative (Berkhout et al., 2002).

A further challenge is to make scenarios spatially-explicit for use with a semi-distributed catchment model. We propose to develop quantitative scenarios relative to the "inertia" (BAU) scenario, defined as the projection of current trends based on an analysis of changes over the last decade. This stage of the project will need again the collaboration of stakeholders and experts (e.g., ACA) via e-mail or personal interviews. Maintaining the communication with stakeholders over the process will ensure that they see an outcome of their contribution and feel more involved, which is also a measure of success in participatory integrated analysis (Ridder and Pahl-Wostl, 2005).

4.4.2. Assessment of the process: results, learning and integration of languages

Experiences in scenario building, e.g., urban development and sustainability and biological invasions, have revealed that, even if results provided during the process are important, there is value in the process itself (Özkaynak, 2005; Rodríguez-Labajos, 2006). The special attention dedicated to the identification of stakeholders and the selection of workshop participants is essential to guarantee the quality of the process (Burt and van der

Heijden, 2003). Although the four scenarios produced by the participants are common sense, results would probably differ, yielding a different set of scenarios, if the workshop were to be repeated with a different set of players or through a close, common sense-approach. Are these scenarios therefore “better” than what a closed session would have produced? Who is to judge? What is clear is that by not doing the participatory process, we all (stakeholders and researchers) would have missed on a precious opportunity to learn and be involved in or communicate a research exercise, modest as this may be.

While the identification of stakeholders needs to be comprehensive, striving to include all interested social actors, participants (i.e., individuals representing a particular stakeholder), also need to be selected so as to ensure their commitment to the process and their willingness to discuss constructively around conflicting issues with other participants. In the context of the Rönnea Catchment Dialogues for the Swedish Water Management Research Program (VASTRA), which focussed on the eutrophication problem, participants argued that their willingness to be involved was more likely to work out well in an area where they have personal stakes (Jöborn et al., 2005). Leeuwis (1995) also endorsed this statement with a case study where he observed that the diversity of interests among stakeholders, which is a preliminary selection problem, became an obstacle to reach a consensus.

Moreover, the current situation and the background, knowledge and experience of participants have a strong influence on their ability to think about the future and truly imagine futures, and therefore the risk exists for participants to forecast rather than think more creatively about scenarios. Throughout the process, it was necessary to use and integrate many languages and forms of knowledge. Indeed, the advantages of IEA are predicated on the contribution of knowledge from multiple disciplines (Janssen and Goldworthy, 1996; Parker et al., 2002). But this comes with a price. Heterogeneity in backgrounds and fields of expertise does not facilitate the engagement of participants in the process, because they may feel uncomfortable and insecure (Rotmans et al., 2000). Thus, involving people from different fields can lead to communication problems. Indeed, since each field has its own way of thinking and speaking, it is possible that some words might be interpreted differently across various fields. Here, the role of the workshop leaders as facilitators was crucial. Their goal was to create a friendly and encouraging atmosphere for discussion and to watch out for misunderstandings that could have stymied progress. Thus, they were informed by the opinions and sentiment of a diversity of stakeholders that allowed to guarantee that the scenarios used in modelling nutrient fluxes into the future did not simply reflect the researcher's biases. Yet the value of the formal process of scenario development presented in the paper lied precisely in its ability to facilitate an open discussion and the free and active involvement of all participants.

Interactions and discussions between participants generated strong disagreements, which were part of the process of the identification and selection of driving forces, both at the sectoral and territorial level. The 2030 horizon allowed participants to put current conflicts aside and think more dispassionately about the future of the catchment; therefore, disagreements were not as strong as if the scenario building were based on a short-term horizon. But even though participants argued to support their points of view, mostly in relation to standing conflicts and the current political context, discussions to classify key driving forces influencing water quality also revealed a common willingness to come to an agreement, and allowed to create a trusting atmosphere between the various stakeholders involved in this process. Therefore, disagreements enhanced the group's creativity and promoted scenario development. This shows that interdisciplinary co-operation can help to think about the future and generate possible futures (Joss, 2002; Ledoux et al., 2005).

4.4.3. Challenges of and lessons from the participatory process

Difficulties during the process of scenario building and a lack of guarantee that results will be obtained have been recognized as inherent to this participatory exercise and contribute to the learning process, which is one of its benefits (Leeuwis, 1995).

Given the time horizon for our scenarios (i.e., the 2030), participants could have shown a tendency to focus on unrealistic scenarios and therefore miss the objective of the workshop: developing realistic alternative views of the future. This tendency could be avoided by focusing on the goal, promoting the participation of all stakeholders and keeping their attention throughout the participatory process.

Even if we were paying special attention to keep the workshop on track, participants did not always focus on the problem at stake, i.e., developing socioeconomic scenarios with a view to exploring their impact on nutrient emissions and contributing to the sustainable management of the anthropogenic sources of these nutrients. A few participants tended to slow down the process by focusing on their own sectoral problems or current interests, and thus tended to deviate the meeting from its goal. This was probably due to the fear of loosing credibility, an inability to deal with the problem at stake, or a lack of knowledge or mutual understanding. However, it did not appear to us that participants were trying to divert the focus from our main objective. It might have just been that they wanted to ensure that their own interests would be reflected in the storylines. Thus, as facilitators we tried to redress the discussion and stimulate a more imaginative thinking about the future.

Other difficulties that we identified in the process of scenario building were that (1) it was sometimes hindered by our retention capacity; and (2) there was always a risk to fall back on forecasts, and avoid drivers that might become important in the future.

The process was sensitive to the current economic and political conditions, and consequently the driving forces identified were mainly based on current trends. This was probably due to a difficulty inherent to the process, which highlights the inability to “think outside the box”, i.e., think about driving forces and trends that participants are not familiar with. In these conditions, it seemed difficult to consider surprises, limiting the scenarios to variations of current trends. Indeed, in the multi-scale scenario work within the MedAction project, which emphasised scenario development at different scales and also the relations between scales, Kok et al. (2006) came to the conclusion that stakeholders had difficulties to work on large-scale surprising developments; also, Burt and van der Heijden (2003), working on scenario development with small and medium sized enterprise managers for strategic management and learning process, agreed with Kok et al. (2006) that stakeholders tended to prefer thinking in terms of a forecast or “single future”, feeling more comfortable with either small changes or large-scale developments that are close to daily life.

The issue of climate change illustrates these points. Although it is widely accepted that “climate change” will likely have a significant impact on hydrology and nutrient export in the mid term (Ledoux et al., 2005; Wade, 2006), participants did not select it as a relevant and uncertain driving force. When the workshop leaders introduced it as a factor and asked participants to consider it when writing up narratives for the scenarios, it was still avoided. Although all participants agreed on its relevance and uncertainty, they still felt unable to think about how it might affect the catchment and saw it as an external force outside their experience and control. We also asked for hypothetical or surprise driving forces (or factors), but no convincing response was given by the participants.

The follow-up to the participatory workshop represented an additional obstacle. Although the one-day workshop was successful, it did not represent a guarantee that the follow-up to the scenarios results, i.e., individual evaluation to validate scenarios content and pre-evaluation of model indicators, would be performed. The follow-up was based on the continued good will and voluntary participation of the stakeholders, since they had no personal benefit in contributing to this exercise. Outside of the workshop context, participation was not as large as we had expected, even though stakeholders previously expressed their willingness to respond to our request to provide us with feedback. In contrast, Kok et al. (2006) reported a positive follow-up with a high rate of response to their questionnaire. The reason for this difference in response rate may lie in the technique used to get feedback. We decided on an e-mailed questionnaire with open questions, a method that relied too heavily on the willingness of respondents to think through the information sent to them and organize their ideas. Personal interviews would have elicited more information, but at a higher cost.

Based on our experience, we can propose a number of changes to improve participatory processes at the local scale. Firstly, it might be advantageous to organise the activities in a series of half day sessions; this might facilitate the progress of the activities, allowing stakeholders to better interact among themselves and granting them more time to express and defend their points of view and to debate contentious issues (Kok et al., 2006). Also, it is obvious that a participatory exercise initiated by the stakeholders themselves and facilitated by an external and professional moderator would have been very different – starting with the objectives. Thus, the collaboration of a facilitator actively involved with stakeholders would be very helpful to assist in such a process. When working on the future of La Tordera catchment, the workshop leaders were responsible for both managing and facilitating the workshop. During plenary activities, the leader in charge of the participatory process was also responsible for supporting interaction and communication between participants, which is how the standard model defines the role of a facilitator. When the activities required separate working groups, everyone in the workshop team assumed and played the part of the facilitator as best as he or she could. Thus, we tried to be actively involved with stakeholders and make them think and justify their choices by means of questions, as Mumford (2001) and Leeuwis (2000) suggest for the role of the facilitator. When disagreements arose, we attempted to enhance discussion, then refocused participants back to the topic. But even if we tried to be neutral, and attempted not to influence the process, willingly or unconsciously, with our preconceptions and biases, the simple fact that we, i.e., the researchers, came from ecology and environmental sciences university departments undoubtedly carried some weight.

In Spain, as perhaps in Mediterranean countries in general, participatory processes are increasingly being used to address environmental issues (Özkaynak, 2005; Kok et al., 2006; Rodríguez-Labajos, 2006), as it is recommended not only by current legislation such as the Water Framework Directive, but also by grassroot movements such as the New Culture of Water. However, experiences are still scarce, the process is unfamiliar to participants, and relying on a professional facilitator is not common, and even less considered as an essential element for this kind of process. Thus we see the workshop as a pilot exercise that stakeholders and management agencies, both represented at the workshop, might benefit from.

4.5. Conclusions

In the context of an integrated assessment of nutrient flows, the scenario method adapted to our case study for the development of socioeconomic scenarios for a Catalan river catchment proved to be an effective medium for interactive and structured thinking. Even though we encountered some weaknesses and challenges throughout the process (e.g., the structure of the workshop, the need for a facilitator, and the follow-up procedure), this technique allowed us and the participants to recognise the role of and need for stakeholders' participation as key to the generation of meaningful scenarios. No guarantee of success exists for a participatory process of scenario building. Despite the potentially conflicting nature of the environmental issues, the process is more likely to generate possible views of the future if there are both a trusting atmosphere and willingness to participate among the stakeholders involved. Thanks to the effort dedicated to the development of storylines, the interdisciplinary co-operation, and the group's creativity, participants conferred meaning and consistency to the scenarios. The use of scenarios as a participative tool for defining catchment management strategies uncertainty is essential (Middelkoop et al., 2000; Postma and Liebl, 2005). The translation of the generated scenarios into meaningful semi-quantitative nutrient emission scenarios allowed preparing the base for the subsequent generation of quantitative and spatially-explicit scenarios with the use of a catchment nutrient emission model. This successful pilot process might encourage catchment managers and planners to integrate scenarios and participatory processes into their toolbox.

Chapter 5

Quantitative nutrient emissions scenarios for La Tordera

5.1. Introduction

The application of the integrated environmental assessment to La Tordera basin afforded a better understanding of both the main natural processes that play a role in environmental issues associated with nitrogen and phosphorus loads, and the socioeconomic components at the basis of environmental changes (see Chapter 2). Based on this analysis, four future socioeconomic scenarios were developed through a participatory workshop with stakeholders (see Chapter 4). The aim was that these should contribute to the integrated management of La Tordera catchment, i.e., to help managers and planners to elaborate management strategies aiming to reach an optimum between the use, the conservation and the enhancement of the values and services provided by this stream ecosystem.

The narrative scenarios previously developed through a participatory process need to be quantified and presented in a form that is relevant, understandable, accessible and functional for catchment managers and planners. Socioeconomic scenarios by themselves are not sufficient to develop programmes of measures for the sustainable management of the anthropogenic sources of nutrients for river basins as required by the European Union Water Framework Directive (WFD). An analysis of the potential changes of nutrient emissions into the river catchment is essential if we are to adapt, mitigate or reverse the predicted effects of alternative socioeconomic scenarios. By linking socioeconomic tools, i.e., participation, scenario development and management strategies, with nutrient transport models, policy and management measures aiming at reducing nutrient emissions can be analysed and highlighted more effectively.

The development and the use of quantitative scenarios of future nutrient loads should thus be of great utility in the process of catchment management. The results of quantitative models and uncertainty analysis complement qualitative scenarios by showing trends and dynamics not apparent in storylines. The final results offer a much more systematic and data-rich analysis by providing more rigour, precision and consistency than results based on qualitative analyses (UNEP, 2002).

The objectives of this chapter are, 1) to translate the narrative socioeconomic scenarios developed in chapter 4 into quantitative scenarios that can be used as inputs to the nutrient emission model MONERIS, and 2) to evaluate the potential changes in nutrient flows under each of the future scenarios. The application of the model will take into account the most sensitive parameters identified in the analysis of the nutrient emission model (see Chapter 3). An assessment of the effectiveness of these scenarios in terms of nutrient loads reduction is presented in the context of catchment management.

5.2. Methods

5.2.1. Definition of socioeconomic scenarios

The socioeconomic scenarios resulting from the participatory process previously presented (see Chapter 4) were evaluated against the 1993-2002 baseline period and the targeted 2030 horizon, i.e., according to the implementation process of the WFD. Among the four scenarios developed, only three were selected to be analysed quantitatively, as two of them yielded similar conclusions. Thus, even though the “Pact for subsistence” and “Minimum rules” scenarios differed in their social, political and strategic terms, the results of these two narratives regarding the impacts on water quality, and more specifically on nutrient emissions, were very similar. Therefore, the modelling scenario analysis was performed on a reference scenario covering the present situation (the “Current” scenario), and the three following scenarios for the future: the “Inertia” or “Business as Usual” (BAU) scenario, which assumed a continuation of current practices and no active intervention in environmental management; the “Minimum rules” scenario, characterised by stronger regulations, which represented intermediate conditions; and the “Sustainability” scenario (or “Deep Green” scenario), with stronger actions directed at addressing the problem of diffuse pollution.

The BAU scenario was considered the baseline scenario regarding the temporal evolution. This scenario was driven by short-term planning and an imbalance between economic and territorial development, including conservation. The reference scenario corresponded to the year 2002, the endpoint of our modelling period (1995-2002). This scenario was chosen to compare the effect of the three scenarios on nutrient emissions.

5.2.2. Translation of narrative scenarios into quantitative scenarios

The translation of the narrative scenarios produced in Chapter 4 into quantitative scenarios suitable for input into the catchment model, MONERIS, started by relating the trends listed for each scenario to the list of input data used by the model. The trend expected for each input data item was then marked under each of the three socioeconomic scenarios developed (see Fig. 4.3 in the previous chapter). This first estimation was then evaluated via email by the participants of the workshop to make sure that they reflected their image of the scenarios. Trends were modified based on their suggestions, and the different parameters of the model MONERIS evaluated, with a particular emphasis on those to which the model was more sensitive (see Chapter 3).

Although the model is strongly sensitive to climatic parameters, in particular to annual precipitation, climate change was not considered in these scenarios for two reasons. On the one hand, the model MONERIS is not adequate for analysing impacts of climate change due to its simplified hydrological modelling, as discussed in Chapter 3. On the other hand, dynamically downscaled regional climate change projections for IPCC A2 and B2 scenarios for the Tordera region show no significant change in mean annual precipitation up to around 2075 (although they do indicate changes in precipitation regimes, with increased incidence of droughts and floods) (Fig. 5.1). Therefore, in this exercise, climate was kept constant, i.e., precipitation for each catchment and for all the scenarios, including the "Current" scenario, was calculated based on the mean annual precipitation for the period 1995-2002.

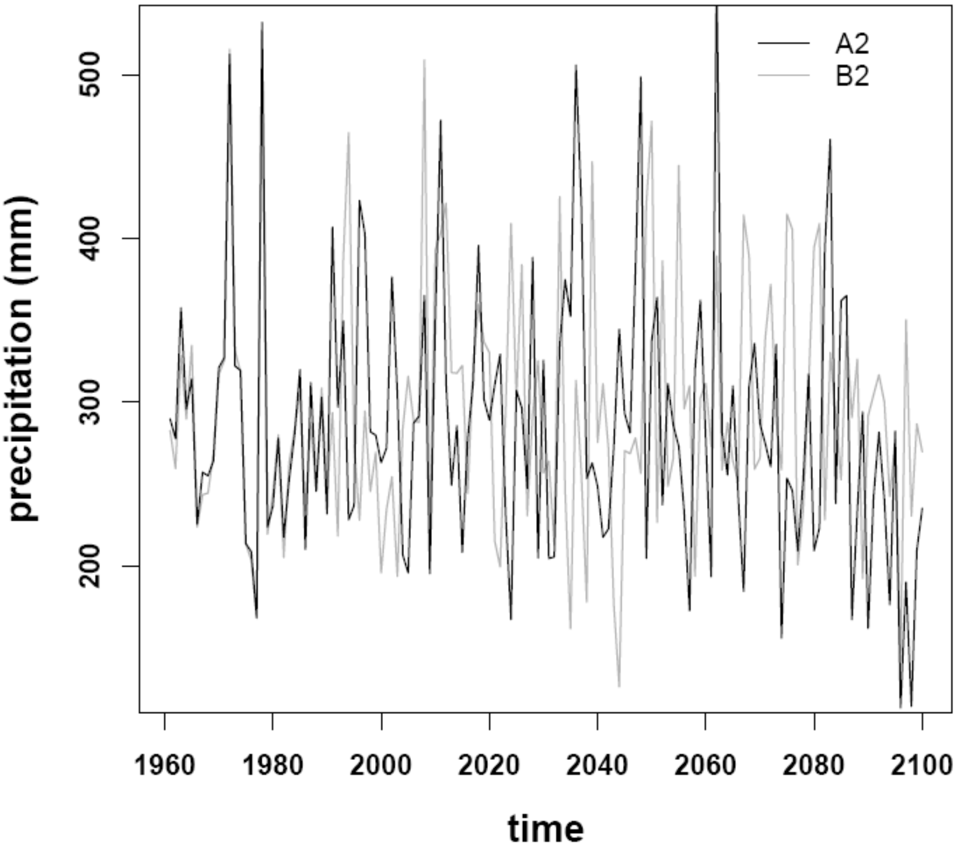

Figure 5.1 *Evolution of the precipitation for two standard climate change scenarios, A2 and B2, from 1960 to 2100, based on a dynamically downscaled regional climate model. The A2 scenario implies focus on economic growth and increasing population, while the B2 scenario focuses on environmental sustainability. Data source: PRUDENCE project (http: http://prudence.dmi.dk/).*

Thus, modelled impacts of each of the three scenarios on nutrient emissions were based mainly on the following input data: number of inhabitants and related data (i.e., related to urban and industrial point sources), atmospheric deposition, nutrient content in topsoil, tile drained area, N surplus and land uses (Table 5.1). The projected trend for each of these parameters was based on their values on the year 2002 (or 2007, if available).

Table 5.1 *Quantification of all the parameters that have an impact on nutrient emissions for the three scenarios elaborated for La Tordera basin. Percent changes refer to the "Current" scenario (see text).*

Data sources	Scenarios		
	BAU	Minimum rules	Sustainability
General input (i.e., Climatic and hydrological characteristics and diffuse sources)			
NO_x deposition	+40%	-30%	-50%
NH_x deposition	+10%	-25%	-25%
Content of P in topsoil	+50%	-25%	-50%
Content of N in topsoil	+50%	-25%	-50%
Tile drained area	-25%	Stable	-25%
N surplus	+38%	Stable	-50%
Inhabitants	Max: +57%, Min: +15%	Max: +35%, Min: +12%	Stable
% Separate	none	1/3 of sewers	1/2 of sewers
% Combined[a]	+36%	+36%	+69%
% No WWTP	-43%	-43%	-83%
% Not connected	-53%	-52%	-100%
Industrial and urban point sources (WWTPs)			
Industrial N, P load	Stable	Stable	-50%
Treated eq. inhabitants	+29%	+16%	-8%
P removal efficiency	Stable	+5%	+5%
N removal efficiency	Stable	+9%	+14%
Land use			
Arable	-20%	Stable	-20%
Forest	Stable	Stable	+2,3%
Grassland	+5%	Stable	+9,2%
Open water	Stable	Stable	Stable
Open land	Stable	Stable	Stable
Urban	+31,5%	Stable	Stable
Wetland	Stable	Stable	Stable

[a] The changes in percentage are calculated based on the "Current" scenario and the total number of inhabitants.

Based on the number of inhabitants of the year 2002 and following past and current trends over the last thirty years, the population was projected to increase by approximately 56% for the BAU scenario and 35% for "Minimum rules" scenario. For the "Sustainability" scenario, the population was projected to decrease and stabilize at the 2002 level (Fig. 5.2). According to the current planning for urban and industrial waste waters and to the management trends for each scenario, the number of treated inhabitants was projected to increase for the three scenarios, but most strongly for the “Sustainability” scenario, where 96% of the total population was projected to be connected to waste water treatment plants (or other forms of waste water treatment, such as constructed wetlands). This corresponds to an increase of 69% of the total population connected compared with 2002. Except for the BAU, which follows the current planning for waste waters, it is assumed that, for both scenarios, “Minimum rules” and “Sustainability”, the tertiary treatment of WWTPs will improve, providing nutrient removal efficiency increased by 5% for P and 9% to 14% for N. Industrial loads were assumed to decrease only for the “Sustainability” scenario (50%).

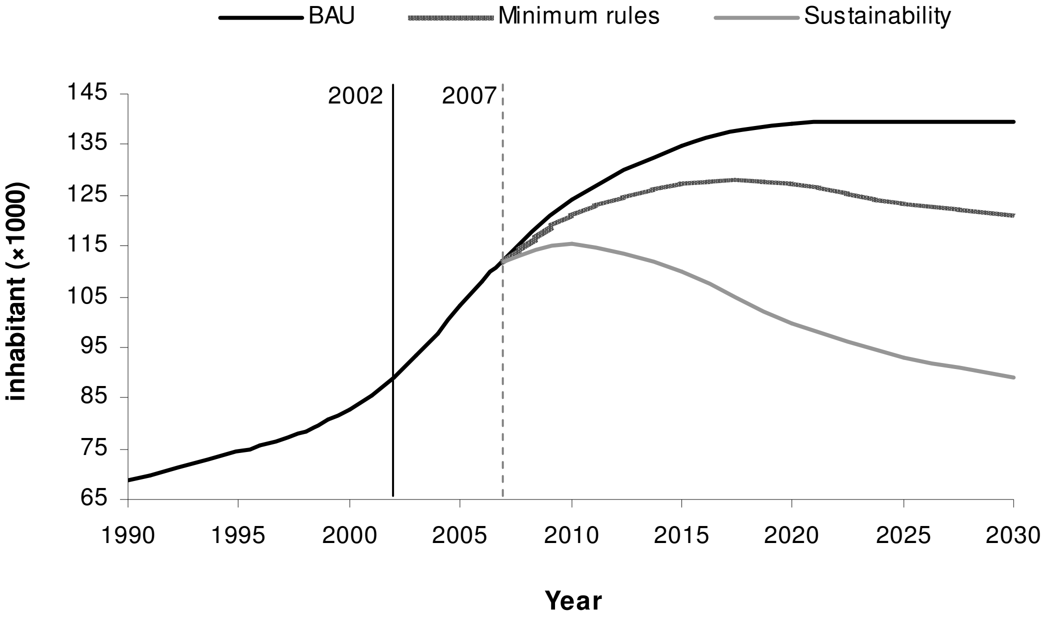

Figure 5.2 *Projected evolution of the number of inhabitants in La Tordera catchment for the three scenarios, BAU, “Minimum rules” and “Sustainability”. The years 2002 and 2007 mark the end of the modelling period and the start of the scenario analysis.*

Data on atmospheric nitrogen deposition for the 2030 horizon were based on the EMEP data and on projections of nitrogen deposition rates to land and ocean surfaces for emission scenarios equivalent to the three used in this analysis (Lamarque et al., 2005; Dentener et al., 2006). EMEP data showed that the atmospheric nitrogen deposition decreased over the 1990s, but started to increase again in the early 2000s. In 2030 and for the BAU scenario, NOx and NHx deposition were projected to increase by 50% and 10%, respectively. As for the “Minimum rules” and “Sustainability” scenarios, NOx deposition was projected to decrease by 30% and 50%, respectively, and NHx by 25% for both future views (Fig. 5.3).

In both the BAU and the “Sustainability” scenarios, the tile drained area of the agricultural land was projected to decrease, while no change in land use for the “Minimum rules” scenario was projected relative to land uses in 2002. However, nitrogen surplus in agricultural lands was projected to increase for the BAU scenario, while it was kept constant for the “Minimum rules” scenario and decreased for the sustainable future view.

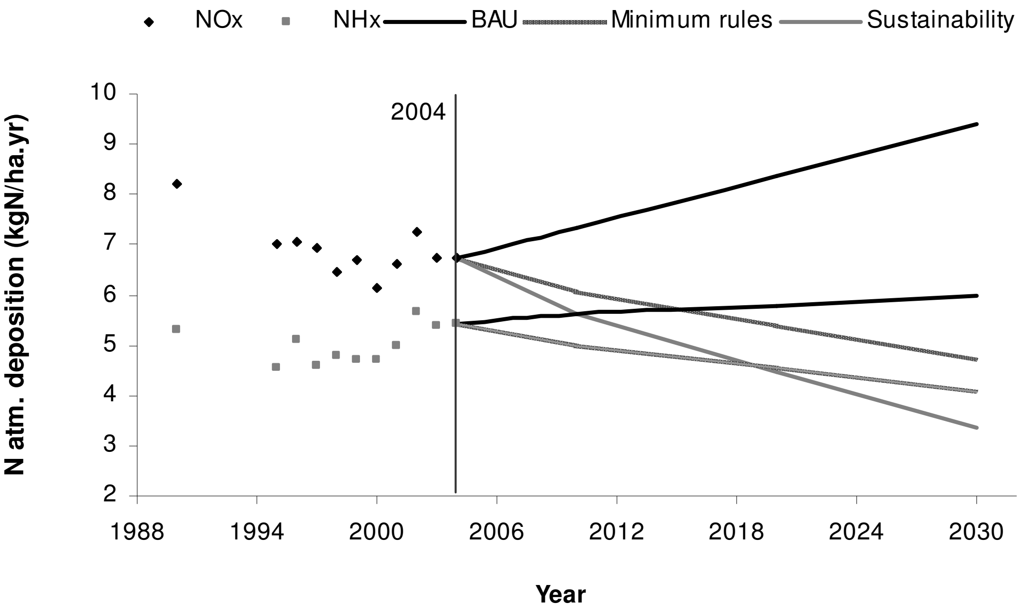

Figure 5.3 *Evolution of atmospheric deposition of oxidised nitrogen (NOx) and reduced nitrogen (NHx) for the three scenarios from 1990 to 2030. Data for the period 1990-2004 were estimated by the Unified EMEP model. The year 2004 shows the start of the atmospheric deposition evolution for the different scenarios.*

5.3. Results

5.3.1. Effect of the scenarios on nutrient emissions

According to the conditions of the three scenarios, and based on the current situation, total emissions of P into the river basin decreased by 11.9% for the "Minimum rules" and by 54.5% for the "Sustainability" scenario (Table 5.2). For the "Minimum rules" scenario, the dominant pathways that contributed to this decrease were the urban areas with a reduction of 26.7% of P emissions followed by the urban point sources (13.7%). With a smaller but important contribution to the total emissions (2.4%), inputs via erosion and surface runoff were also reduced by 24.8% and 20.3%, respectively. The model evaluation of a sustainable management applied on the basin showed that the most relevant input sources, i.e., industrial and urban WWTPs, and diffuse urban system sources, were reduced respectively by 50%, 30.7% and 78.2%. Among the other sources of P emissions (13%), the contributions from erosion, tile drainage and surface runoff decreased by 58.4%, 25.7% and 7.6%, while the inputs through groundwaters increased by 3.4% (Table 5.2 and Fig. 5.4).

Table 5.2 *Contribution of different sources to the emissions of phosphorus into the river basin in tonnes/yr for the BAU, "Minimum rules" and "Sustainability" scenarios, compared to the "Current" scenario. The changes in percentage are calculated based on the "Current" scenario.*

Pathway	Phosphorus Emissions						
	Current	BAU		Minimum rules		Sustainability	
	t/yr	t/yr	%	t/yr	%	t/yr	%
WWTP	9.79	13.98	42.8	8.45	-13.6	6.78	-30.8
Industry	28.48	28.48	0.0	28.48	0.0	14.24	-50.0
Urban system	22.75	18.82	-17.3	16.68	-26.7	4.97	-78.1
Atm. deposition	0.09	0.09	0.0	0.09	0.0	0.09	0.0
Surface runoff	0.79	0.63	-19.6	0.63	-19.8	0.73	-7.5
Erosion	1.01	1.27	25.8	0.76	-25.0	0.42	-58.1
Tile drainage	0.74	0.62	-16.0	0.74	0.0	0.55	-25.0
GW	2.07	2.00	-3.1	2.06	-0.4	2.14	3.3
Total Emissions	65.71	65.90	0.3	57.89	-11.9	29.92	-54.5
Retention	29.76	29.65		25.92		13.37	
Load	35.95	36.25		31.97		16.55	

In contrast, following current trends focused on economic and population growth, phosphorus emissions projected for the BAU scenario increased by about 0.3%. The major part of this increase was due to urban point sources (+42.7%) while the contribution of the total P inputs into the river from the other pathways was almost the same as the current situation (Table 5.2 and Fig. 5.4).

Regarding nitrogen, total emissions into the river basin decreased by 4.8% and 34.5% for the “Minimum rules” and “Sustainability” scenario, respectively (Table 5.3). This reduction was mainly due to a decrease of the diffuse sources, in particularly from urban areas (29.9%) and from agricultural lands through groundwater (7.4%), which are an important contribution of N emissions in the “Minimum rules” scenario. This diffuse source was followed by the following diffuse pathways, surface runoff (34%), erosion (25%) and atmospheric deposition (24.6%).

The implementation of strong actions addressed to the problem of diffuse pollution for the “Sustainability” scenario, allowed to reduce the inputs coming from the different diffuse pathways, and particularly from agriculture through groundwater flow (24%) and from urban areas (83%). Emissions through atmospheric deposition and tile drainage, which made up about 11% of total emissions of nitrogen, were reduced by 52.8% and 57.2%, respectively. The remaining diffuse sources, i.e., surface runoff and erosion, were projected to decrease by approximately 50%, while the urban point sources emissions (WWTPs) showed a 24.6% increase. This was due to the larger fraction of inhabitants connected to WWTPs, which increased compared to the “Current” scenario (Table 5.3 and Fig. 5.5).

Table 5.3 *Contribution of different sources to the emissions of nitrogen into the river basin in tonnes/yr for the BAU, “Minimum rules” and “Sustainability” scenarios, compared to the “Current” scenario. The changes in percentage are calculated based on the “Current” scenario.*

	Nitrogen Emissions						
Pathway	**Current**	**BAU**		**Minimum rules**		**Sustainability**	
	t/yr	**t/yr**	**%**	**t/yr**	**%**	**t/yr**	**%**
WWTP	117.2	154.8	32.1	148.1	26.4	146.0	24.6
Industry	76.0	76.0	0.0	76.0	0.0	38.0	-50.0
Urban system	135.6	109.9	-19.0	95.1	-29.9	22.6	-83.3
Atm. deposition	3.1	2.9	-5.7	2.4	-24.6	1.5	-52.8
Surface runoff	8.7	7.5	-13.0	5.7	-34.0	4.2	-51.2
Erosion	1.3	1.6	25.8	1.0	-25.0	0.5	-58.1
Tile drainage	50.0	55.2	10.4	50.0	0.0	21.4	-57.2
GW	212.9	214.7	0.9	197.2	-7.4	161.9	-24.0
Total Emissions	604.7	622.7	3.0	575.4	-4.8	396.2	-34.5
Retention	305.2	309.3		286.1		196.2	
Load	299.5	313.4		289.3		199.9	

In contrast, nitrogen emissions for the BAU scenario increased by about 3%. This net increase was mainly attributed to the increased urban point sources (32.1%), tile drainage (10.4%) and erosion (25.8%), which partially counterbalanced by a decrease of the emissions from the urban areas and surface runoff. Groundwater, which is the most important pathway for nitrogen emissions, increased slightly (0.9%) (Table 5.3 and Fig. 5.5).

In general terms, increases of P and N emissions from WWTPs for the three scenarios coincided with a decrease of the emissions from urban areas, particularly along the main valley, where the urban and industrial areas concentrate. This observation corresponded also to an increase of N emissions from groundwaters, mainly for the “Sustainability” scenario. Regarding the “Sustainability” and “Minimum rules” scenarios, the increase of N emissions from WWTPs corresponded also to a decrease of the emissions coming from the industries. Although the total P inputs from industries were reduced by 50% for the “Sustainability” scenario, this source still represented an important fraction of the P emission sources, especially from WWTPs (Figs. 5.4 and 5.5).

The reduction of arable lands projected for the BAU and “Sustainability” scenarios contributed to an increase of N emissions coming from WWTPs, due to conversion of a fraction of arable lands into urban lands, and to a decrease of emissions through groundwater for the “Sustainability” scenario (Tables 5.2 and 5.3).

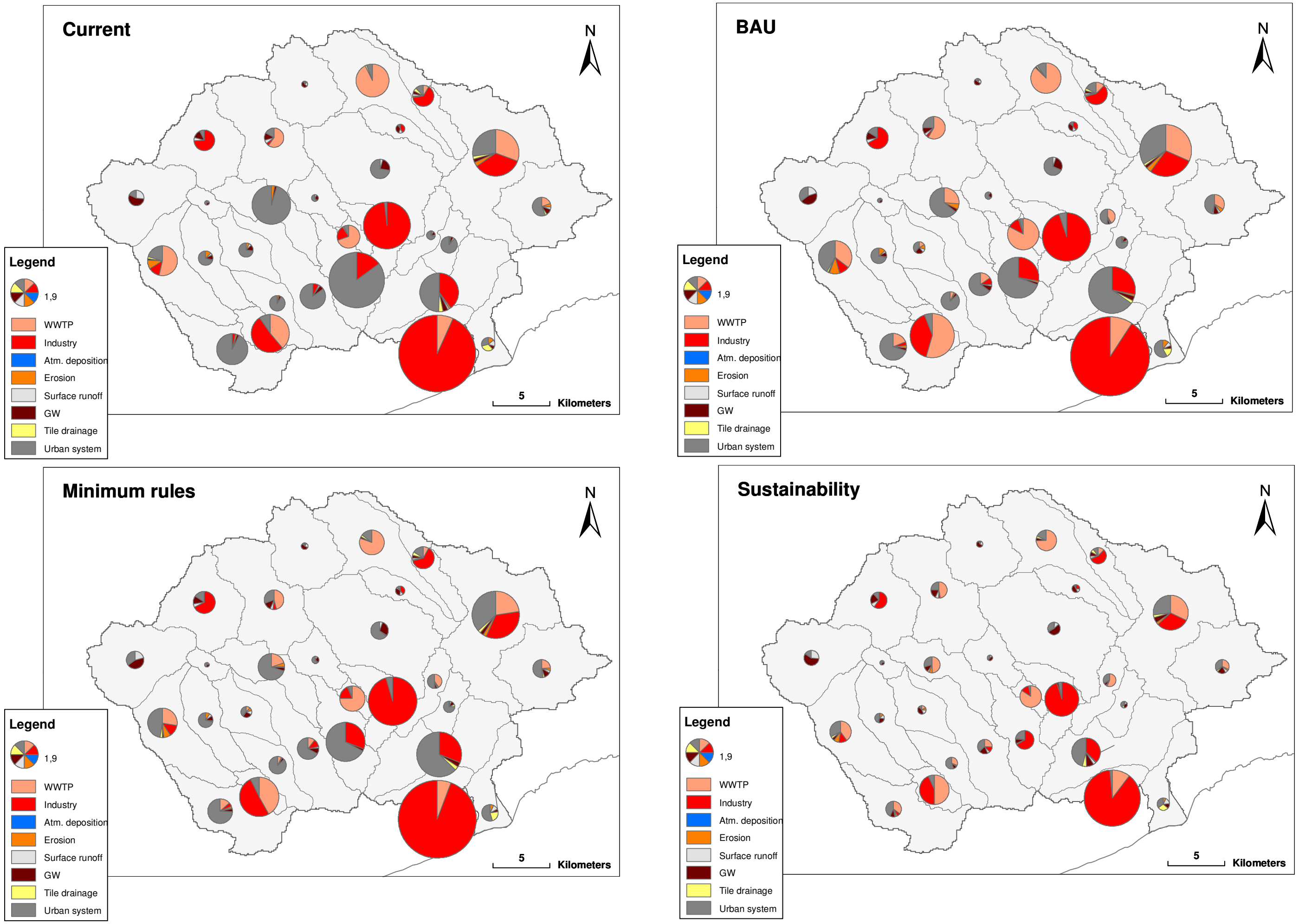

Figure 5.4 *Partitioning of the total emissions of P by emission pathway in La Tordera basin for the BAU, “Minimum rules” and “Sustainability” scenarios compared to the “Current” scenario. Pie sizes are proportional to total emissions of P.*

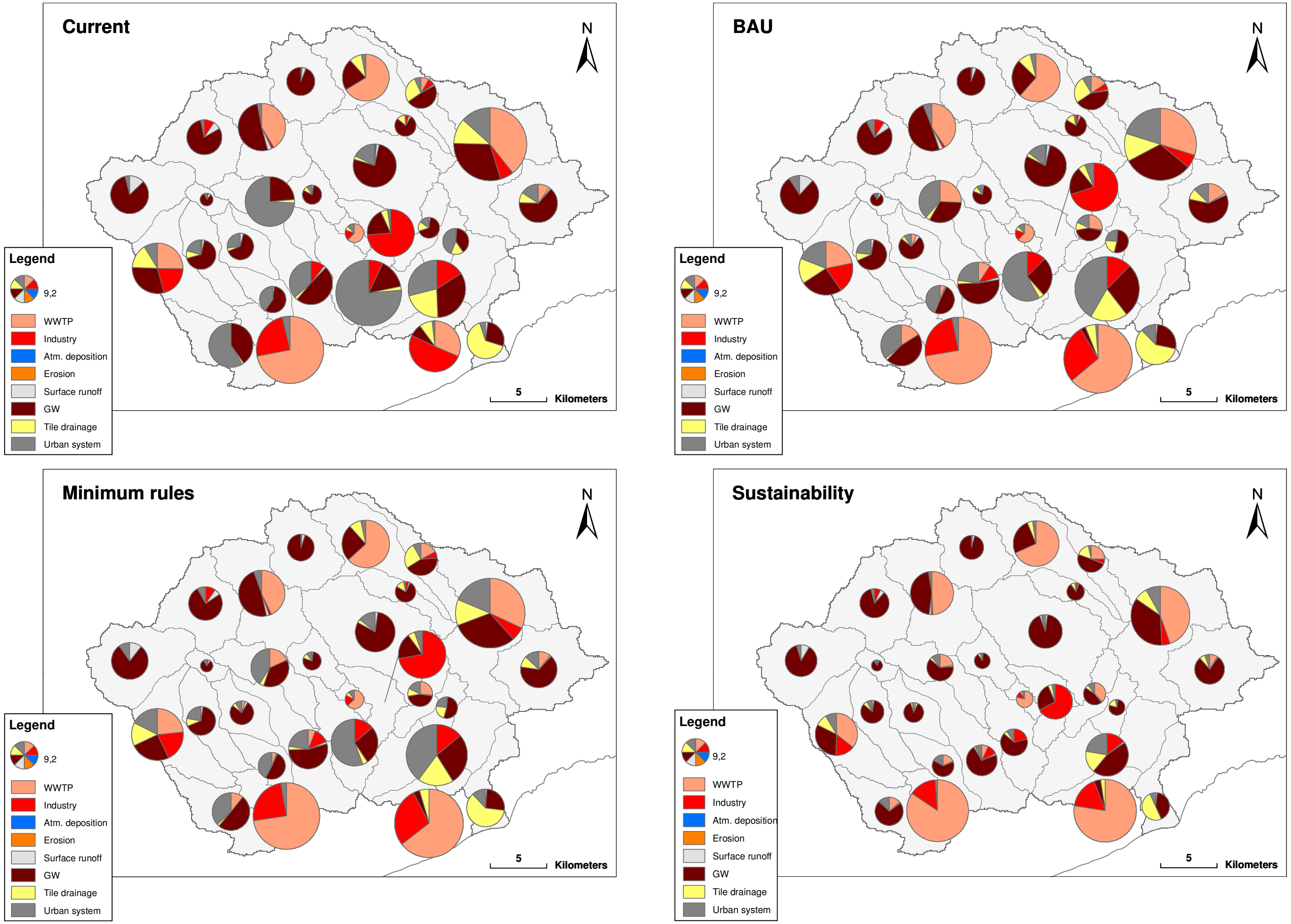

Figure 5.5 *Partitioning of the total emissions of N by emission pathway in La Tordera basin for the BAU, “Minimum rules” and “Sustainability” scenarios compared to the “Current” scenario. Pie sizes are proportional to total emissions of N.*

5.4. Discussion

5.4.1. Impact assessment of the various scenarios

The continuation of current practices and the lack of important interventions for active environmental management assumed for the BAU scenario showed an increase of the nutrient loads. P and N loads come as much from the point sources as from the diffuse sources and are driven by an increased number of inhabitants and industrial uses in a catchment that is becoming increasingly attractive for residents and enterprises as new or improved infrastructures bring the valley closer to the metropolitan area of Barcelona. This scenario suggests the need to proactively define a specific set of coherent management actions to control nutrient emissions at the source or during transport in the view of increased potential emissions.

The implementation of new stronger regulations or the reinforcement of current regulations on water and nutrient sources management in both the “Minimum rules” and “Sustainability” scenarios, results in a reduction of nutrient loads. The participants in the workshop agreed that the “Sustainability” scenario represented the desired goal, but felt nonetheless that it could probably not be realised by 2030. In contrast, the “Minimum rules” scenario was considered plausible, and would be sufficient at least to sustain the trend towards lowered nutrient emissions that has prevailed over the last fifteen years.

This analysis revealed that a significant active management of nutrient emissions directed towards the control of point and diffuse sources, such as the urban and industrial WWTPs and the agricultural land, reduced nutrient loads, and consequently, point and diffuse pollution. By improving the sewage system and waste treatment, and agricultural practices at the basin scale, nutrient emissions can be reduced by 54.5% for P and 34.5% for N. Other modelling exercises applied to future scenarios have also observed significant reductions of nutrient emissions thanks to stronger management plans focused on the improvement of waste water treatment and the implementation of new WWTPs, for instance in the Vistula and the Po river basins (Kowalkowski and Buszewski, 2004; Palmeri et al., 2005).

Legislation and regulations focused on restrictions, e.g., the use of fertilisers, that are effectively transposed into management strategies allow significant reductions of nutrient loads and contribute to a better water quality and the preservation or enhancement of ecosystem values and services.

5.4.2. Implementation of scenarios and programme of measures

The application of MONERIS to different scenarios allowed predicting changes in nutrient emissions under distinct management regimes, showing that the model could be used as a decision support tool for the elaboration and evaluation of different management strategies aiming at preserving or enhancing the ecological quality of the river catchment.

The analysis of the changes in nutrient emissions that were predicted for each of the three scenarios allowed the identification of a set of relevant measures that could be implemented to reduce nutrient contamination and improve river water quality. These include the improvement of sewage system and treatment, the reduction in the application of fertilisers, the shift of arable land to pasture or forest, and the restoration of riparian zones and wetlands (Table 5.4). Consistent with the observation that La Tordera is dominated by urban and industrial emissions, especially for P (see Chapter 3), the scenarios strongly highlight the need to reduce industrial emissions.

Based on a study of the changes in river N export to the world's oceans and the relative contributions from point and nonpoint sources for the 1970-2030 period, Bouwman et al. (2005) showed that, in Europe, a decrease of river N loads by 20% is expected as a consequence of the projected decrease of fertiliser inputs and animal manure production and continued improvement of waste water treatment. All these measures are effective ways to reduce river N loads and relevant for an immediate implementation for the scenarios BAU and "Minimum rules". However, for the "Sustainable" scenario, the restoration of riparian areas and wetlands would be needed to attain the more ambitious environmental goals of this better management of the nutrient sources of La Tordera river basin.

Table 5.4 *Possible measures to manage better nutrient sources in the river basin of La Tordera for each of the three scenarios. A grayscale is used to show the order of relevance regarding the implementation of the measures; darker grey means higher priority.*

Measure	**Scenario**		
	BAU	**Minimum rules**	**Sustainability**
Improvement of sewage system and treatment	▓	▓	░
Reduction in fertiliser applications	▓	▓	░
Shift back from arable to pasture or forest	▒	▓	░
Restoration of riparian zones. wetlands	░	▒	▓

It is important to acknowledge the limitations and highlight the advantages of this analysis. First of all, MONERIS is not a dynamic model, and the results of scenarios application using steady-state, empirical models have to be considered carefully if we are to evaluate management strategies (Grizzetti et al., 2005). In particular, MONERIS does not give any indication of transient dynamics: model results assume that the catchment emissions are at steady-state, and this depends on the response time of the system to management actions, where system here means both the natural system and the socioeconomic systems. Delays would occur during negotiation of environmental goals, drafting and approval of legislation and regulations, and implementation and enforcement of measures. Once action is taken, the response to measures will depend strongly on the emission pathway, with fast response to end-of-pipe, engineering solutions to point sources and slow response to actions aiming at the control of diffuse sources, which would depend, for example, on the residence times of soil and groundwater compartments.

Additionally, MONERIS gives only information of the magnitude and apportionment of emissions, but offers no indication about critical time periods or about the statistical distribution of nutrient concentrations in the stream, which would be critical for the management of ecological quality since episodic, extreme events can have a strong impact on stream communities (Allan, 1995; Gasith and Resh, 1999). It does, however, indicate that waste water treatment overflows, which are responsible for peaks in the concentration of pollutants in streams, are a significant problem in La Tordera, which may be aggravated by a higher frequency and magnitude of extreme precipitation events in Mediterranean regions. These shortcomings would need more sophisticated models to provide useful data for the design of specific actions, in particular coupled urban engineering models, WWTP models, and catchment and river models.

Restoration of riparian buffers and wetlands and enhancement of in-stream nutrient retention, i.e., management of nutrients during transport, are suggested by modelling and scenario analysis as key for attaining the more stringent goals of the “Sustainability” scenario, or, one could argue, as complementary measures to the control of diffuse emissions at the source. Progress in this area would not be so much a matter of better modelling as a matter of better experimental data, as the factors that drive or constrain these riparian and stream ecosystem services are poorly known, and especially complex in Mediterranean areas (Sabater et al., 2003).

Although in principle environmental decisions must be anchored in solid scientific knowledge, in practice both strategic plans and specific actions are often based on incomplete knowledge and expert assessment. The reasons are at least two-fold. On the one hand, collecting the necessary knowledge would unacceptably delay action. On the other hand, managers increasingly acknowledge that catchments and streams, and the socioeconomic system that interacts with them, have a fair amount of inherent uncertainty (Bradshaw and Borchers, 2000; Ludwing, 2001; Clark, 2002). This shift from top-down, science-driven management to adaptive management is accompanied also by an increasing acknowledgement of an active role for stakeholders in catchment management. Dealing with uncertainty and participatory management can both make good use of scenario analyses, which allows the explicit exploration of plausible outcomes of environmental management strategies (or the lack thereof), and the effective communication of science-based projections in a visually informative form that is useful for participatory management. Our analysis of scenarios for La Tordera illustrates the potential of these techniques. In particular, the approach followed in this study highlights catchment management needs under a diversity of plausible scenarios while explicitly acknowledging uncertainties in our knowledge base and our modelling techniques.

5.5. Conclusions and outlook

The application of the model to test the impact of each socioeconomic scenario on nutrient emissions and to estimate the changes in the river catchment emissions of P and N showed that the reduction of diffuse sources, such as the agricultural pressures, was a relevant issue for N loads. Regarding P loads, the improvement of sewage systems and the efficiency of the treatment plants were the most effective actions to improve water quality.

The prediction of changes in nutrient emissions through scenarios is essential for water managers to work on nutrient pollution (Langan et al., 1997; Kronvang, 1999). Applied to La Tordera river basin, this analysis suggested some basic management options based on source (and transport) management with the aim to reduce point and diffuse sources at the river basin scale for the three scenarios.

Making research outputs relevant to decision making, i.e., linking scientific outputs with decision-making with the aim to achieve integrated catchment management, is one of the most important challenges of environmental management nowadays. The application of suitable tools that integrate the current scientific knowledge and understanding, and methods that assess management strategies and decisions, could help end users, e.g., water managers or policy makers, to overcome a variety of management problems. Such a framework is available, for instance through a Decision Support System (DSS). Applied to La Tordera river catchment, a DSS that included multicriteria analysis and the assessment of the cost-effectiveness of alternative management programmes, could help decision makers to establish specific measures and quantify them with the aim to reduce the nutrient emissions into the river basin.

Chapter 6

Conclusions

6.1. Conclusions

La Tordera river basin has been and will likely continue to be under significant ecological stress as a result of the development of human activities in its catchment and the existence of anthropogenic sources of nutrients. In this study an integrated and interdisciplinary environmental assessment (IEA) of nutrient flows has proved to be essential to assess the causes and consequences of the human alteration of nutrient cycles in La Tordera basin for the past (i.e., early 1990s to early 2000s) and future (i.e., the 2030 horizon) as summarized below. The analysis conducted and the results obtained are of direct relevance to the implementation of the European Water Framework Directive (WFD), and future sustainable management of La Tordera catchment.

The application of the model MONERIS to the river basin for the past and future, which was done after a successful calibration and verification process, proved to be useful to estimate nutrient loads. Through this process, the main sources of nutrient emissions for both phosphorus (P) and nitrogen (N) were identified underlying the importance of point sources for P emissions, and diffuse sources, especially inputs via groundwater, for N emissions. Despite potential hurdles related to the model structure, observed loads and input data that were encountered during the modelling process, MONERIS provided a good representation of the major temporal and spatial patterns in nutrient emissions. This representation showed interannual variability, which was mainly associated with variability in precipitation affecting in-stream retention. Because the difference between the observed transport and emissions is mostly caused by retention processes, it was crucial to consider the retention term in the calibration process to avoid large errors in river loads (Behrendt and Optiz, 2000). However, the understanding of the factors driving nutrient retention still requires more studies, such as analysis of riparian areas, wetlands or hyporheos.

The decreasing trend of nutrient emissions observed over time and across subcatchments during the period 1995-2002 brought to light that the implementation and improvement of urban and industrial waste water planning strategies (PSARU and PSARI) were the main policy changes that contributed to this progressive decline. This observation was supported also by the results of the social analysis.

With the aim of reaching a sustainable relationship between human beings and their environment, the social analysis proved to be crucial to analyse the problem at stake on an integrated whole. By using a framework focused on pressures and impacts analysis, the results from interviews allowed a deeper understanding of the interactions and feedbacks between the natural and social system, and of the impacts of human activity on surface waters both over the past, i.e., from 1993 through 2003, and the present. This analysis also showed that a stronger policy structure in each sector of activity played a central role in the improvement of environmental conditions. Apart from the PSARU and PSARI, changes in water rates, and the development and improvement of monitoring and services were other relevant policy changes that contributed to considerable progress over the last decade. Most of these improvements were related to surface water quality, urban and industrial nutrient emissions and, to some measure, the restoration of the environment.

However, more work remains to be done in order to devise economically and socially acceptable ways of further reducing diffuse nutrient emissions, in particular with respect to the negative impact of agricultural practices. Indeed, model estimates observed that even though the contribution of agricultural diffuse sources to nutrient emissions (especially nitrogen) decreased over the period 1995-2002, their impact still remains a problem. In sum, this critical review and analysis of past river basin management policies together with the application of the catchment model to La Tordera river for the estimation of nutrient emissions from 1995 to 2002, has served to identify the main nutrient sources, best practices and management strategies.

The elaboration of future socioeconomic scenarios regarding the evolution of nutrient flows in the catchment through a participatory process, as the WFD recommends, was useful for identifying ways to manage sustainably the anthropogenic sources of nutrients in La Tordera. The participatory process proved to be an effective medium for interactive and structured thinking. It also proved that the technique used during the process demonstrated that stakeholders not only can, but should play a central role in the generation of meaningful scenarios.

The use of this process exhibited some weaknesses and challenges related, for example, to the structure of the workshop, the need for a facilitator, and the follow-up procedure. These potential hurdles explain why the use of a participatory process to build scenarios does not guarantee a successful outcome. Nonetheless, difficulties can be mitigated and possible views of the future are more likely to be generated if stakeholders are eager to contribute and can do so in a setting that is conducive to collaboration (i.e., where trust is established and where they feel safe to express their perspectives).

By enhancing openness and disagreements, and fostering the group's creativity for scenario development, the participatory process allowed participants to confer meaning and consistency to the scenarios. This demonstrates that the use of scenarios is fundamental and essential in order to define and evaluate optimal management strategies for the anthropogenic sources of nitrogen and phosphorus. This implies a management process that has to be continuous and adaptive, and carried out by a mix of public and private entities.

In order to help catchment managers and planners develop programmes of measures for the sustainable management of nutrient sources and better contribute to the integrated management of La Tordera catchment, the narrative scenarios developed at the participatory workshop were quantified to be used by the model. Focusing the application of the model on the most sensitive input data, e.g., the number of inhabitants and agricultural pressures, identified in the analysis of the nutrient emission model, the estimation of changes in nutrient flows under each scenario allowed to assess the effectiveness of these scenarios in terms of nutrient loads reduction. For the purpose of managing the river catchment, this allowed the identification of the most effective actions or measures on source and transport management to be considered with the aim to reduce point and diffuse sources. For instance, key actions on the reduction of diffuse sources (e.g., agricultural fertilisers' use) for N loads were relevant while for P loads an improvement of sewage system and treatment plant efficiency was essential to improve river water.

In summary, this integrated and interdisciplinary environmental assessment of nutrient flows in La Tordera catchment, viewed as a pilot process, is a rewarding and powerful evaluation that may help and encourage catchment and water managers and planners to devise paths to the sustainable management of the anthropogenic sources of nutrients. However, a methodology to develop, assess and implement management options and sets of measures to mitigate current impacts or prevent probable negative consequences of anthropogenic pressures based on the scenarios that were identified is crucial and represents nowadays an important challenge. In this context, a Decision Support System (DSS) could be useful to make research outputs even more relevant to decision makers, water managers and planners. Thus, associated to a test of cost-effectiveness, a DSS could help decision makers to evaluate measures and management options, quantify them and facilitate their implementation.

6.2. Outlook

From the study undertaken, several points have been identified that would require further work and a deeper analysis using La Tordera catchment as a Mediterranean pilot basin:

With the aim to compare, but also to develop specific actions, the application of more complex models would be useful for the purpose of catchment management. These would include, at a minimum, models that explicitly consider catchment hydrology. The application of dynamic, process-based catchment models, possibly linked to urban engineering models, WWTP models, and river models would be a plus, provided there is an effort to fill the gaps in and improve input sources and stream monitoring data. This analysis could facilitate the connection between science and decision making, i.e., the use of more realistic models could actually help managers to make decisions about which actions are the best, and where and when to apply them.

The analysis of the riparian areas, which are hot spots of nutrient retention, would help to understand better the factors that drive the complex interactions between riparian function and stream ecosystem services in Mediterranean catchments. In addition, further study of the agricultural diffuse sources and their impacts on nutrient loads would help control their contribution to nutrient emissions.

A better understanding of the links between the stream and the large fluvial aquifer of La Tordera would allow an enhanced understanding of how this link affects nutrients during transport.

Linking catchment nutrient emission models to a Geographic Information System (GIS) and an expert system into an environmental Decision Support System (DSS) for the management of Mediterranean rivers would be useful. Including a multicriteria analysis, a DSS helps visualise the goals, priorities and positions of different stakeholders in a participatory decision context. The application of suitable tools that integrate solid science, but also assess economic, political and social costs that is available in a DSS could overcome a variety of management problems.

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Appendix

Appendix 1: Questionnaires

Social system analysis conducted with the support of specific questionnaires for each of the following sectors of activity: Agriculture, Urbanisation and Tourism, and Industry.

I. Agriculture

(Analysis and understanding of agricultural factors interacting with and controlling N and P cycles)

A. Land (or Land Tenure)

1. What are the characteristics of the land available for farming (size, existence of or potential for irrigation, topography, and land cover)?
2. How long have farmers been farming the land for?
3. What changes have you observed in the catchment/region over the last 10 years (from 1993), based on land use and practices in relation with water quality?

B. Water

(To know their points of view/perception of water quality and management)

1. How much water do farmers use for farming their land?
   Has the use of water increased or decreased since farmers started farming the land? Why?
2. What water-carrying methods are used to bring water to crops?
3. Is the water of good quality? Why?
4. Do you feel concerned by questions of water quality and water supply?
5. And what about the nutrient unbalance?
6. Is the water quality (in the catchment) improving or declining? Why?
7. What type of catchment management is used?

C. Agricultural Practices

(Info on crop, fertilisers use and soil enrichment)

1. What crops are grown and why? Since when? Has the type of crop changed?
2. Is there crop loss? If yes, what are the major causes of crop loss?

3. What fertilising practices are used, if any?
4. Is manure used as a fertiliser?
   If yes, is it the only one fertilising practice?
5. Describe the relationship between
   i) fertiliser application and crop response,
   ii) fertiliser application and nutrient amount, and
   iii) fertiliser application and water quality
6. Are precautions being taken to avoid over-fertilisation?
7. Do farmers use inorganic fertilisers?
8. Does the crop require the use of inorganic fertilisers?
9. Have farmers been trained in the use of fertilisers and techniques for crops?
10. With regards to the use of fertilisers and good practices, how are farmers informed?
11. What conservation practices exist on the land they farm?
12. Do local agricultural practices promote or otherwise enhance catchment management and soil conservation?
13. Are farmers willing to construct and maintain these additional conservation practices on your land that reduce nitrate levels in runoff? Why or why not?

Additional questions:
(1) Perception of erosion problems and techniques to avoid it?
(2) Are there artificially drained agricultural areas? And how are they drained?

D. Policies and economic factor

1. Are farmers familiar with water policies, water management?
2. What do they think about European policies and Water Framework Directive?
3. Do they undergo/suffer any constraint, pressure from the government, economic market...? How do they perceive the pressures?
4. Do they follow instructions or do they think that they are doing well and producing more?
5. With regards to the use of fertilisers, how do you assess the improvement?

E. Personal opinion

1. Who/Which stakeholder/social actor do you think is the main responsible of the N, P cycles' impact? Do you think they control these cycles?

F. Questions for MONERIS data addressed to 'la Unió de Pagesos'

1. With regards to the topsoil of the Tordera catchment, do you have any idea about the nutrient content, Nitrogen and Phosphorus concentration in arable topsoil? Has your organisation sampled and analysed arable topsoil of the Tordera catchment? If yes, would you allow us to have a look at and use them for this case study?
2. Do you have any data on agricultural tile drainage (location, N and P concentration)?
3. Fertiliser application rates (manure/inorganic; timing)

II. Urbanisation and tourism

(Analysis and understanding of urban factor interacting with and controlling N and P cycles)

A. Land (or Land Tenure)

1. How do you define the urbanised area of the catchment?
2. Who owns the lands in the catchment?
3. Are the lands of the catchment titled or registered? (info on regulations, policies…etc to know about unauthorised land use)
4. Have you observed changes on lands registration? If yes, which one? Since when?
5. What changes have you observed in the catchment/region for the last 10 years (from 1993) based on:
   i) the landscape transformation, natural areas, wildlife,
   ii) the urbanisation (housing and habitat),
   iii) the demography, and
   iv) water quality and its practices?
6. Has urbanisation increased? Since when?
7. Who owns or controls water sources and water rights?

B. Water

(To know their points of view/perception of water quality and management)

1. From your point of view, how is stream water quality?
2. What do think about stream water and water quality?
3. Is the water of good quality? Why? Do you feel concerned?
4. How much water are inhabitants using?
5. What has been the trend in water usage over the past few years?
6. What does the phrase “water quality problems” means to you?

7. What do you think about nutrients? And what about the nutrient imbalance?
8. Is the water quality (in the catchment) improving or declining? Why?
9. What recreation activities do inhabitants/families participate in?
10. What parks or other natural areas do they use for recreation or find interesting in other ways?

C. Polluting practices

(Info on land use and improvement practices)

1. Do people use fertilisers in urban zone? If yes, what fertilising practices are used?

D. Water management

1. Where does water in local streams come from?
2. What does the water system mean for you? What about septic tank and waste water system/treatment? How long have the different urban areas been using these systems?
3. Where does sanitary sewage go when it leaves houses? And after it leaves the septic tank or municipal treatment plant?
4. What type of catchment management is used?
5. Do local urban practices promote or otherwise enhance catchment management and soil conservation?
6. Have you participated in any local bond issues, public forums, or other events focused on land use or land management issues? If so, which ones?
7. Are you familiar with the following home conservation practices: rain water gardens, rain barrels, native landscaping to reduce lawn size, alternative fertilisers?
8. Are you familiar with water policies/ACA?
9. WWTP, septic systems, and in case of storms, what happens?

E. Policies and economic factor

1. Are inhabitants familiar with water policies, water management?
2. Do they follow instructions or bid higher thinking that they are doing well and producing more? (Urban land, recreation areas)? Why?
3. Do they undergo/suffer any constraint, pressure from the municipality, the government?
4. With regards to the use of fertilisers, how do you assess the improvement?

F. Personal opinion

1. Who/Which stakeholder/social actor do you think is the main responsible of the N, P cycles' impact? Do you think they control these cycles?

III. Industry

We used the questionnaire of the urban sector adapted to the industrial sector.

Appendix 2: Tables related to Chapter 3

Table 3.a *Land use distribution in the 28 subcatchments of La Tordera basin for the year 1992. Source: ICC.*

ID	Urban area	Industrial area	Arable land	Grassland	Forest	Openland	Open water
				km^2			
14001	0.01	0.00	2.08	9.57	35.65	0.05	0.00
14003	2.27	0.16	5.30	1.47	27.72	0.09	0.00
14002	1.42	0.15	10.43	0.69	27.58	0.06	0.00
14004	0.84	0.29	0.28	0.33	9.27	0.12	0.00
14005	0.42	0.22	5.00	0.92	18.75	0.03	0.00
14006	1.28	0.26	0.73	0.98	15.71	0.27	0.00
14007	0.00	0.00	0.01	0.96	5.06	0.00	0.03
14008	0.12	0.02	2.53	0.43	16.42	0.00	0.00
14009	3.55	0.31	2.29	2.05	33.93	0.39	0.00
14010	0.53	0.17	5.37	1.13	19.78	0.04	0.00
14011	1.02	0.18	4.29	2.46	22.11	0.04	0.00
14012	0.00	0.02	1.36	2.02	37.45	0.00	0.00
14013	0.78	0.10	3.38	0.52	46.70	0.11	0.00
14014	0.02	0.00	1.50	0.50	13.14	0.00	0.00
14015	0.20	0.23	2.65	0.78	1.26	0.06	0.00
14017	0.04	0.00	0.87	0.10	36.11	0.00	0.00
14018	1.32	0.23	4.31	2.29	34.96	0.15	0.00
14019	0.45	0.39	9.06	1.39	8.58	0.09	0.00
14020	0.00	0.00	2.95	5.98	6.84	0.16	0.00
14021	4.72	0.02	9.94	5.75	26.61	0.21	0.00
14022	9.55	0.84	38.62	12.60	22.10	0.43	0.00
14023	2.19	0.01	3.81	18.92	48.69	1.21	0.00
14016	1.35	0.30	4.58	2.06	12.88	0.20	0.00
14024	2.15	0.02	2.26	3.24	7.03	0.27	0.00
14025	1.34	0.00	3.46	2.55	4.40	0.33	0.01
14026	5.11	0.35	11.84	14.00	20.59	0.85	0.15
14027	0.35	0.23	3.44	0.84	9.25	0.09	0.00
14028	1.97	0.43	9.61	2.65	3.81	1.06	0.39

Table 3.b. *Land use distribution in the 28 subcatchments of La Tordera basin for the year 1997. The numbers in bold indicate the main changes in land use distribution. Source: ICC.*

ID	Urban area	Industrial area	Arable land	Grassland	Forest	Openland	Open water
				km^2			
14001	0.01	0.00	1.53	10.28	35.55	0.01	0.00
14003	**3.65**	0.17	**4.44**	1.08	27.22	0.45	0.00
14002	**2.02**	0.12	9.71	1.10	27.08	0.29	**0.02**
14004	0.94	0.29	0.22	0.16	9.32	0.19	0.00
14005	0.43	0.20	4.78	1.22	18.64	0.07	0.00
14006	**1.58**	0.24	0.59	0.73	15.68	0.40	0.00
14007	0.00	0.00	0.02	0.97	5.03	0.00	**0.04**
14008	0.13	0.01	**1.74**	**6.40**	**10.73**	**0.51**	0.00
14009	3.87	**0.42**	1.88	**8.09**	**27.29**	**0.95**	0.00
14010	0.57	0.17	**4.51**	**5.58**	**15.96**	0.24	0.00
14011	1.12	0.18	4.22	**4.38**	**19.82**	**0.36**	0.00
14012	**0.53**	0.02	0.99	2.60	36.64	0.06	0.00
14013	**1.89**	0.11	2.51	1.27	45.36	0.46	0.00
14014	0.02	0.00	**0.95**	**6.58**	**7.57**	0.04	0.00
14015	0.21	**0.25**	2.58	**1.12**	**0.91**	**0.12**	0.00
14017	**1.02**	0.00	0.74	0.72	34.56	0.07	0.00
14018	**2.35**	0.23	**2.43**	**4.89**	32.88	0.47	0.00
14019	0.55	0.41	**7.52**	1.68	**9.67**	0.12	0.00
14020	0.00	0.00	**1.76**	**9.23**	**4.18**	**0.75**	0.00
14021	**5.26**	0.02	9.13	4.10	28.38	0.34	0.00
14022	**10.42**	0.85	**33.73**	10.85	**27.47**	0.81	0.00
14023	2.28	0.01	2.80	**30.86**	**35.90**	**2.97**	0.00
14016	1.40	**0.26**	**3.89**	**6.09**	**9.25**	0.47	0.00
14024	**3.13**	0.01	**1.47**	2.55	7.51	0.26	**0.03**
14025	**1.52**	0.00	**2.79**	2.07	**5.41**	0.29	**0.02**
14026	5.33	0.35	10.81	11.45	**23.76**	0.97	**0.21**
14027	**0.55**	0.23	2.95	0.96	9.39	0.13	0.00
14028	**2.41**	0.42	9.16	2.32	4.31	0.97	**0.35**

***Table 3.c**. Land use distribution in the 28 subcatchments of La Tordera basin for the year 2002. The numbers in bold indicate the main changes in land use distribution. Source: ICC.*

ID	**Urban area**	**Industrial area**	**Arable land**	**Grassland**	**Forest**	**Openland**	**Open water**
	km^2						
14001	0.01	0.00	1.57	9.74	35.96	0.09	0.00
14003	3.66	0.19	4.12	1.00	27.42	0.62	0.00
14002	2.13	**0.27**	**7.46**	1.73	27.79	**0.93**	0.03
14004	0.95	**0.34**	0.18	0.09	9.53	**0.04**	0.00
14005	0.50	0.20	**3.68**	**2.09**	18.73	0.15	0.00
14006	1.61	**0.34**	0.58	0.86	15.63	**0.21**	0.00
14007	0.00	0.00	0.06	**0.64**	**5.31**	0.01	0.04
14008	**0.28**	0.01	1.48	**5.53**	**11.81**	0.40	0.00
14009	**4.14**	0.39	1.53	7.74	**28.25**	**0.47**	0.00
14010	**0.84**	0.17	**3.42**	5.54	**16.67**	0.38	0.00
14011	**1.34**	**0.27**	4.14	4.08	19.75	0.50	0.00
14012	0.52	0.02	0.81	3.07	36.39	0.03	0.00
14013	1.99	**0.22**	2.46	**3.36**	**43.17**	0.40	0.00
14014	**0.16**	0.00	0.88	**5.58**	**8.39**	0.15	0.00
14015	0.20	**0.36**	**2.17**	**0.78**	**1.30**	**0.36**	0.00
14017	1.02	0.02	1.17	**2.06**	**32.77**	0.07	0.00
14018	2.41	0.25	3.19	**5.94**	**30.92**	0.56	0.00
14019	0.61	**0.48**	7.67	1.70	**8.86**	**0.63**	0.00
14020	0.00	0.00	1.93	9.43	3.97	**0.60**	0.00
14021	**5.61**	0.06	8.62	3.48	29.03	0.43	0.00
14022	**10.69**	**1.13**	32.04	9.51	**29.24**	**1.47**	**0.05**
14023	2.36	0.01	2.78	**28.93**	**38.15**	2.59	0.00
14016	1.43	**0.34**	3.92	**3.98**	**11.35**	0.34	0.00
14024	3.17	0.01	1.49	**2.12**	**7.97**	0.14	**0.06**
14025	1.52	0.00	2.87	1.77	5.64	0.23	**0.06**
14026	**5.70**	**0.60**	10.65	**9.76**	**24.95**	0.88	**0.37**
14027	0.58	**0.26**	2.99	0.59	9.42	**0.37**	0.00
14028	**3.25**	**0.40**	8.86	2.05	4.06	0.99	0.33

***Table 3.d**. Distribution of the tile drained area in the different subcatchments of La Tordera basin for the following years: 1992, 1997 and 2002. The numbers in bold indicate the main changes in tile drained area. Source: ICC.*

ID	**Name of subcatchment**	**Tile drained area**		
		1992	**1997**	**2002**
			Km^2	
14001	Tordera A E.A. A0026 (La Llavina)	0.00	0.00	0.00
14003	Vallgorguina Completa	0.42	**0.24**	0.17
14002	Tordera A E.A. A0015 (St. Celoni)	4.20	**3.60**	**2.73**
14004	Tordera Aigua Amunt de la Pertegàs	0.05	**0.01**	0.00
14005	Pertegàs Completa	1.30	**0.96**	**0.49**
14006	Tordera Aigua Amunt de la Gualba	0.06	**0.03**	0.04
14007	Gualba a l'Embassament	0.00	0.00	0.00
14008	Gualba Completa	0.23	0.24	0.20
14009	Tordera Aigua Amunt de la Riera de Breda	0.64	**0.39**	**0.30**
14010	Breda Completa	0.44	0.48	**0.38**
14011	Tordera Aigua Amunt de la Riera d'Arbúcies	1.00	**0.63**	0.54
14012	Arbúcies a Capçalera	0.00	0.00	0.00
14013	Arbúcies a Bosc de les Gavarres	0.04	0.03	0.02
14014	Arbúcies A E.A. A0056 (Hostalric)	0.10	0.12	**0.22**
14015	Arbúcies Completa	0.32	**0.15**	0.17
14017	Sta. Coloma a Capçalera	0.00	0.00	0.00
14018	Sta. Coloma Aigua Amunt de l'Esplet	1.78	**0.92**	**1.31**
14019	Esplet Complet	1.90	**1.50**	**1.87**
14020	Sta. Coloma Aigua Amunt de la Sils	0.31	0.36	0.40
14021	Sils a Capçalera	0.96	1.09	**0.89**
14022	Sils Completa	3.75	**4.19**	4.13
14023	Sta. Coloma A E.A. A0081 (Fogars)	0.27	0.28	0.32
14016	Tordera a la Confluència amb la Sta. Coloma	1.19	**1.02**	**0.73**
14024	Tordera A E.A. A0089 (Fogars)	0.55	**0.38**	0.44
14025	Tordera A E.A. A0062 (Fogars)	1.23	**0.90**	**0.73**
14026	Tordera Aigua Amunt de la Vallmanya	5.78	5.78	**4.91**
14027	Vallmanya Completa	1.99	**1.77**	**1.48**
14028	Tordera Completa	7.06	**6.55**	**6.08**

Table 3.e. *Database to estimate emissions coming from point sources presented for the 3 periods studied between 1995 and 2002. For each plant, when the data are available, nutrient emissions were estimated based on nutrient loads and discharge in waste water, and when there is no value for TN and/or TP loads, emissions were estimated based on the connected inhabitants. The boldface names are new WWTPs. Source: ACA.*

ID	Name of WWTPs	Load		Discharge	Inhabitant			Removal efficiency	
		TP	TN		Treated	Connected	Industrial	P	N
		t/yr		m3/s				%	
				1995-1997					
14004	Sant Celoni	-	-	0.044	24167	11809	12358	78	70
14013	Arbúcies	-	6.7	0.019	7238	3638	3600	78	70
14018	Santa Coloma de Farners	6.6	15.5	0.036	14257	7787	6470	57	75
14019	Riudarenes	-	-	0.004	1037	863	174	78	70
14022	Caldes de Malavella	-	8.2	0.020	3423	2395	1028	78	55
14022	Sils_Vidreres	0.9	7.1	0.022	6929	4929	2000	85	78
14022	Maçanet de la Selva	-	-	0.014	14410	2128	12282	78	70
14027	Tordera	-	-	0.017	8844	6685	2159	78	70
				1998-2000					
14002	**Santa Maria de Palautordera**	1.7	4.5	0.016	8082	4040	4042	68	86
14004	Sant Celoni	-	-	0.047	22739	12045	10694	81	70
14013	Arbúcies	-	11.1	0.016	4829	3929	900	81	47
14015	**Hostalric**	-	2.7	0.006	3333	2881	452	81	77
14018	Santa Coloma de Farners	-	13.1	0.032	15055	8098	6957	81	82
14019	Riudarenes	-	-	0.004	1453	898	555	81	70
14022	Caldes de Malavella	-	7.2	0.020	3366	2658	708	81	66
14022	Sils_Vidreres	0.8	11.6	0.026	7321	5471	1850	89	70
14022	Maçanet de la Selva	-	-	0.014	15557	2405	13152	81	70
14027	Tordera	-	-	0.024	11423	7220	4203	81	70
				2001-2002					
14002	Santa Maria de Palautordera	1.4	7.6	0.024	7777	4606	3171	78	84
14004	Sant Celoni	2.0	35.5	0.062	19690	12527	7163	88	76
14013	Arbúcies	1.9	12.5	0.021	5844	4322	1522	85	53
14015	Hostalric	1.2	1.9	0.009	7833	2939	4894	85	92
14018	Santa Coloma de Farners	4.5	11.3	0.050	16352	8746	7606	85	88
14019	Riudarenes	0.5	2.5	0.004	1059	969	90	85	74
14021	**Aigua Viva Parc**	-	-	0.007	1792	1254	538	85	74
14022	Caldes de Malavella	2.2	5.5	0.022	3568	3004	564	85	72
14022	Sils_Vidreres	1.1	13.1	0.035	7188	6237	951	89	70
14022	Maçanet de la Selva	1.0	2.4	0.011	6152	2789	3363	85	74
14027	Tordera	5.7	36.3	0.032	9846	7942	1904	85	74

Table 3.f. *Number of inhabitants in urban areas connected to sewage systems, i.e., to combined sewers (sewer and WWTP), or to sewers but not to WWTP, or to neither sewer nor WWTP, for the 1995-2002 baseline period. Data for the whole period are based on the year 2001, because of no data available (PSARU 2002; ACA, 2002). The main changes that correspond to the connection of new WWTPs are highlighted by the period concerned. Then, if the period is not specified, data are equal for the whole period, i.e., from 1995 to 2002. Source: ACA.*

ID	**Total inhabitant**	**Period**	**Sewage system**		
			Sewer & WWTP	**Sewer only**	**Not connected**
				%	
14001	531		0.0	0.0	100.0
14003	2895		0.0	72.8	27.2
14002	5518	1995-1997	0.0	75.5	24.5
		1998-2000	73.2	2.3	24.5
14004	12142		97.2	2.5	0.3
14005	807		0.0	46.7	53.3
14006	1175		0.0	30.5	69.5
14007	33		0.0	100.0	0.0
14008	339		0.0	85.3	14.7
14009	1922		0.0	73.7	26.3
14010	3820		0.0	84.5	15.5
14011	9661		0.0	97.2	2.8
14012	342		0.0	0.0	100.0
14013	3887		93.6	0.4	6.0
14014	169		0.0	33.9	66.1
14015	2968	1995-1997	0.0	99.3	0.7
		1998-2000	97.1	2.2	0.7
14017	20		0.0	0.0	100.0
14018	7818		99.6	0.0	0.4
14019	1163		74.2	8.6	17.2
14020	46		0.0	0.0	100.0
14021	2029	1995-2000	0.0	6.6	93.4
		2001-2002	61.8	25.4	12.8
14022	12677		74.5	8.7	16.8
14023	1179		0.0	67.6	32.4
14016	376		0.0	0.0	100.0
14024	510		0.0	0.0	100.0
14025	821		0.0	100.0	0.0
14026	5468		0.0	22.9	77.1
14027	6805		98.2	0.0	1.8
14028	517		0.0	0.0	100.0

Appendix 3: Workshop program for the elaboration of scenarios

ACTIVIDAD 1

Identificación de los factores relevantes en los procesos de perturbación de los flujos de nutrientes (N, P)

- **En 3 grupos**, uno para cada sector: **Agrícola, Urbano y Industrial**

- Los participantes generarán una **lista** de posibles **factores**:
  - que **influyen en la evolución** del sector
  - que **afectan** directa o indirectamente a las **emisiones de N y P**
  - actuales y seguros, o hipotéticos (factores sorpresa)

- **15 – 20 minutos**

ACTIVIDAD 1

Identificación de los factores relevantes en los procesos de perturbación de los flujos de nutrientes (N, P)

Agricultura	**Urbanismo**	**Turismo**	**Industria**
•… •… •…	•… •… •…		•… •… •…

ACTIVIDAD 1

Identificación de los factores relevantes en los procesos de perturbación de los flujos de nutrientes (N, P)

- **En plenaria**, y a partir de las listas por sector, los participantes generarán una **lista de factores relevantes a nivel territorial**
- **¿Faltan otros factores?**
- **15 – 20 minutos**

Lista de Factores relevantes
•… •… •… •…

ACTIVIDAD 2

Jerarquía de factores

- En plenaria, a partir de la lista anterior y de manera preliminar, los participantes clasificaran los factores en función de si resultan
  - **RELEVANTES / No RELEVANTES**
  - **INCIERTOS / Relativamente PREVISIBLES**
- **RELEVANTE**
  Importante para la evolución de la cuenca en relación con la calidad del agua
  - **no relevante = no importante**
- **INCIERTO**
  Difícil de prever y de incidir sobre él en nuestro horizonte temporal, (el futuro).
  - **no incierto = previsible**

ACTIVIDAD 2: Jerarquía de factores

- **Más previsible = menos incierto, más importante = más relevante**
- **15 – 20 minutos**

Puntuación Relevancia	**Factores**	**Puntuación Incertidumbre**
	…	

ACTIVIDAD 3
Identificación de las incertidumbres claves y de las alternativas

- En plenaria, el mapa de los factores permitirá **generar grupos temáticos de factores** centrándonos en los factores más relevantes y menos previsibles

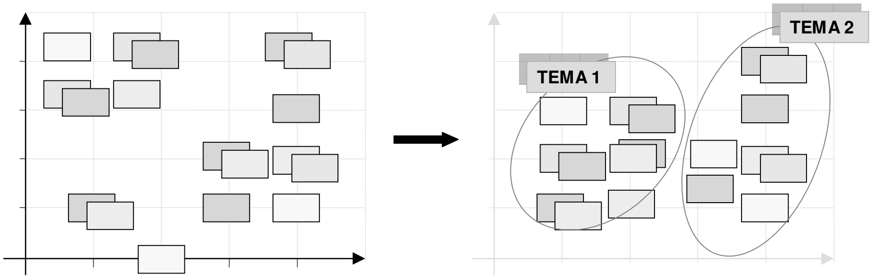
  35 – 40 minutos

- A partir de esta agrupación, la plenaria decidirá los **temas subyacentes clave**, en la base de los escenarios a desarrollar

  35 – 40 minutos

ACTIVIDAD 3
Identificación de las incertidumbres claves y de las alternativas

Ejemplo:



- **Tema 1**
- **Tema 2**

Temas subyacentes clave:

- **Tema 1.A,**
  “ 1.B
- **Tema 2.A,**
  “ 2.B

ACTIVIDAD 4
Generación de escenarios

- A partir de la combinación de los diferentes temas clave, se generarán **4 escenarios básicos**:

		Tema 2	
		Tema 2.A	Tema 2.B
Tema 1	Tema 1.A	**ESCENARIO I**	**ESCENARIO II**
	Tema 1.B	**ESCENARIO III**	**ESCENARIO IV**

- **En plenaria**, los participantes **generarán y titularán** los **4 escenarios**.

ACTIVIDAD 5
Elaboración y desarrollo de los escenarios

- **En plenaria**, los participantes generarán las **narrativas de un escenario** identificando el desarrollo/evolución de cada factor conseguido en la actividad 1
- **En plenaria**, intentarán **relacionar los factores** relevantes de cada escenario con **los indicadores del modelo** MONERIS:

  ➡ **"semi-cuantificación de las consecuencias de los varios escenarios"**

  45 min. – 1 hora
- **En 3 grupos**, los participantes **desarrollarán** los **3** otros **escenarios**

  45 min. – 1 hora

ACTIVIDAD 5
Elaboración y desarrollo de los escenarios

- **Nombre del escenario I:**
- **Escenario I = tema 1.A + tema 2.A**

Factores	Evolución	Descripción del factor
	↗	
	↓	
	↗	
	→	
	→	
	↑	
	↘	
…	…	

➡

Narrativas

ACTIVIDAD 5

Elaboración y desarrollo de los escenarios

- **Nombre del escenario I:**
- **Escenario I = tema 1.A + tema 2.A**

Factores	Evolución
	↗
	↘
	↗
	→
	→
	↘
…	…

➡

Indicador del modelo	Evolución	Estimación (%)

⬇

Because of a lack of time, we decided to change this activity, sending an e-mailed questionnaire with open questions.

Appendix 5: Paper related to chapter 5

Paper published as F. Caille, J. L. Riera, B. Rodríguez-Labajos, H. Middelkoop, and A. Rosell-Melé (2007), Participatory scenario development for integrated assessment of nutrient flows in a Catalan river catchment, Hydrol. Earth Syst. Sci., 11, 1843-1855.