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**ECONOMIC ELEMENTS TO SUPPORT THE ESTABLISHMENT OF  
INTEGRATED WATER RESOURCES MANAGEMENT (IWRM) IN CHILE:  
CASE STUDY OF THE VILLARRICA LAKE WATERSHED**

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## Abstract

Water is a precious resource since it is the basis of every human being's livelihood and it is a vital element which preserves the balance of our surrounding ecosystems. In order to safeguard this essential good, a sound management in quantitative and qualitative terms is crucial. The consideration of Integrated Water Resources Management (IWRM) is new in Chile such as evidences the implementation of the National Strategy of Integrated Management of Hydrographical Watersheds in 2007. Its objective is the protection of the hydrological resources on a river basin scale, in quality as well as in quantity. It further seeks to preserve the resource for human consumption purposes, but it also aims for a harmonisation between ecosystem conservation objectives and the sustainable utilisation of the resource by economic sectors. In the context of the process of establishment of a new environmental quality norm for the Villarrica Lake watershed in the south of Chile, the first scope of this study is the elaboration of a programme of measures which provides information on the total costs for the preservation of the lake's quality. The second objective is the identification and assessment of an economic instrument for the introduction of IWRM in Chile taking into account the Villarrica Lake watershed. Considering economic instruments as an integral part of the IWRM strategy, this study therefore contemplates the implementation of effluent charges for an improvement of the water quality in the river basin. The methodology includes a strong literature review, as well as semi-structured interviews with the local environmental government, the municipalities, and further institutions related to water management in the watershed.

**Key words:** Integrated Water Resources Management, economic instruments, Chile, Villarrica Lake watershed, water quality management

## Resumen

El agua es un recurso muy valioso, puesto que es la base del sustento de cada ser humano y es un elemento vital que mantiene el equilibrio de nuestros ecosistemas circundantes. Con el fin de salvaguardar este bien esencial, una buena gestión en términos cuantitativos y cualitativos es fundamental. La consideración de la gestión integrada de recursos hídricos (GIRH) es nuevo en Chile, como evidencia la aplicación de la Estrategia Nacional de Gestión Integrada de Cuencas Hidrográficas en el año 2007. Su objetivo es la protección de los recursos hídricos en las cuencas hidrográficas, en calidad tanto como en cantidad. Asimismo, busca preservar el recurso destinado al consumo humano, sino que también apunta a una armonización entre los objetivos de conservación de los ecosistemas y la utilización sostenible de los recursos por sectores económicos. En el contexto del proceso de establecimiento de una nueva norma de calidad ambiental para la cuenca del Lago Villarrica en el sur de Chile, el primer alcance de este estudio es la elaboración de un programa de medidas que proporciona información sobre los costes totales para la preservación de la calidad del lago. El segundo objetivo es la identificación y evaluación de un instrumento económico para la introducción de la GIRH en Chile, teniendo en cuenta la cuenca del Lago Villarrica. Considerando los instrumentos económicos como parte integral de la estrategia de GIRH, este estudio contempla la aplicación de cargos por efluentes para la mejora de la calidad del agua en la cuenca del lago Villarrica. La metodología incluye una revisión de la literatura, así como entrevistas semi-estructuradas con el gobierno local del medio ambiente, las municipalidades y las instituciones relacionadas con la gestión del agua en la cuenca.

**Palabras claves:** Gestión Integrada de los Recursos Hídricos (GIRH), instrumentos económicos, Chile, Cuenca del Lago Villarrica, manejo de calidad del agua

## Zusammenfassung

Wasser ist eine kostbare Ressource, da sie die Lebensgrundlage eines jeden Menschen bildet und es ist ein wesentliches Element für das Gleichgewicht unserer umgebenden Ökosysteme. Um dieses wertvolle Gut zu schützen, ist ein fundiertes Management in quantitativer und qualitativer Hinsicht von entscheidender Bedeutung. Die Berücksichtigung von Integriertem Wasserressourcenmanagement (IWRM) ist neu in Chile, wie die Umsetzung der Nationalen Strategie des Integrierten Managements der Einzugsgebiete vom Jahr 2007 zeigt. Das Ziel dieser Richtlinie ist der qualitative und quantitative Schutz der hydrologischen Ressourcen auf der Wassereinzugsgebietsebene. Sie zielt ferner darauf ab, die Ressource für den menschlichen Verbrauch zu erhalten und sie soll auch eine Harmonisierung zwischen der Bewahrung der Ökosysteme und der nachhaltigen Nutzung durch Wirtschaftssektoren gewährleisten. Im Rahmen des Prozesses der Errichtung einer neuen Umweltqualitätsnorm für das Wassereinzugsgebiet Villarrica im Süden Chiles, ist das erste Ziel dieser Studie die Ausarbeitung eines Maßnahmenprogramms, das Auskunft über die Gesamtkosten für die Bewahrung der Qualität des Sees gibt. Das zweite Ziel ist die Identifizierung und Bewertung eines ökonomischen Instrumentes für die Einführung von IWRM in Chile unter Berücksichtigung des Villarrica Einzugsgebiet. Da ökonomische Instrumente ein integraler Bestandteil der IWRM Strategie sind, analysiert diese Studie die Umsetzung einer Abwasserabgabe für eine Verbesserung der Wasserqualität im Einzugsgebiet. Die Methodik beinhaltet eine Literaturanalyse sowie semi-strukturierte Interviews mit der lokalen Umweltregierung, den Kommunen und weiteren Einrichtungen, die mit dem Wassermanagement im Flussgebiet verbunden sind.

**Schlüsselwörter:** Integriertes Wasserressourcenmanagement (IWRM), ökonomische Instrumente, Chile, Villarrica Einzugsgebiet, Wasserqualitätsmanagement

## TABLE OF CONTENTS

LIST OF TABLES .....	12
LIST OF FIGURES .....	14
ACRONYMS.....	15
1. INTRODUCTION .....	16
1.1. Justification .....	17
1.2. Research objectives and methodology .....	18
2. WHAT IS IWRM?.....	21
2.1. Water as a scarce and finite resource.....	21
2.2. Short history of the IWRM concept .....	22
2.3. IWRM and the Dublin Principles .....	24
2.4. Actual definition and the three pillars of IWRM.....	27
3. ECONOMIC INSTRUMENTS IN WATER RESOURCES MANAGEMENT .....	30
3.1. Theoretical background .....	30
3.1.1. Water as a public good.....	30
3.1.2. The polluter-pays-principle .....	32
3.1.3. Polluter-pays-principle elements in Chile .....	33
3.2. Policy instruments for water management: traditional versus modern approach .....	34
3.3. Economic instruments in water management: definition, taxonomy and functions.....	35
3.3.1. Definition of economic instruments.....	35
3.3.2. Taxonomy of economic instruments.....	36
3.3.3. Functions of economic instruments.....	37
3.4. Policies promoting economic instruments .....	40
3.5. Economic instruments to support IWRM .....	41
4. WATER RESOURCES MANAGEMENT IN CHILE.....	43
4.1. Water resources management framework of Chile .....	45
4.1.1. Institutional water management framework.....	45
4.1.2. Legal water management framework.....	48
4.1.3. Policy water management framework.....	50
4.2. Water quality management in Chile .....	52
4.3. Assessment of IWRM in Chile .....	55



5.	THE VILLARRICA LAKE WATERSHED AND THE SOURCES OF LAKE CONTAMINATION .....	57
5.1.	The natural environment of the Villarrica Lake Watershed .....	60
5.1.1.	Geography .....	60
5.1.2.	Vegetation and soil cover .....	62
5.1.3.	Climate .....	62
5.2.	Socio-economic background of the Villarrica Lake Basin .....	63
5.2.1.	Population .....	63
5.2.2.	Economic activities .....	64
5.3.	Point-source contamination of the Villarrica Lake .....	67
5.3.1.	Housing and wastewater .....	67
5.3.2.	Aquacultures .....	70
5.4.	Non-point source contamination of the Villarrica Lake .....	72
5.4.1.	Introduction to diffuse pollution and soil use .....	72
5.4.2.	Nutrient exportation from soil cover .....	73
5.5.	Desired trophy for the Villarrica Lake .....	76
5.5.1.	Current trophy of the lake and risk assessment .....	76
5.5.2.	Current and critical nutrient loads for the Villarrica Lake .....	78
6.	PROGRAMME OF MEASURES TO TACKLE THE CONTAMINATION OF THE VILLARRICA LAKE .....	80
6.1.	Point-source measures .....	80
6.1.1.	Measures for the wastewater treatment plants .....	80
6.1.2.	Measures for the aquacultures .....	85
6.2.	Non-point source measures .....	87
6.2.1.	Introduction: diffuse soil exportation and best-management practices .....	87
6.2.2.	Best-management practices: nutrient exportation through soils .....	89
6.2.3.	Environmental education programme: a further long-term best-management practice .....	92
6.3.	Conclusions and Recommendations: Measures for the Villarrica Lake Watershed .....	94
7.	ECONOMIC INSTRUMENTS IN CHILE'S WATER RESOURCES MANAGEMENT: EFFLUENT CHARGES IN THE CASE OF THE VILLARRICA LAKE WATERSHED .....	99
7.1.	Definition: Charges and taxes in environmental policy .....	99
7.2.	Example: The German Effluent Charge .....	100
7.2.1.	Who is liable to pay? .....	101
7.2.2.	Functionality and calculation of the charge .....	101

7.2.3.	Increase of the charge .....	104
7.2.4.	Reduction of the charge .....	105
7.2.5.	Use of revenue .....	106
7.2.6.	Effects of the German Effluent Charge .....	107
7.3.	Application of the Effluent Charge in Chile: Case Study of the Villarrica Lake Watershed 108	
7.3.1.	Example 1: Wastewater Treatment Plant of Pucón .....	109
7.3.2.	Example 2: Fish Farms .....	112
7.4.	Conclusion: Effluent Charging as a Step towards IWRM in Chile.....	115
8.	CONCLUSIONS AND RECOMMENDATIONS.....	116
	BIBLIOGRAPHY.....	118
	APPENDIX .....	128

## LIST OF TABLES

Table 1: Water Crisis – Facts .....	22
Table 2: Classification of economic instruments for water resources management .....	39
Table 3: Characteristics and conditions of economic instruments for IWRM .....	42
Table 4: Functions related to water management and operating institutions in Chile .....	47
Table 5: Morphometric parameters of the Villarrica Lake.....	60
Table 6: Climate characteristics of the communes within the Villarrica Lake basin.....	63
Table 7: Population in the Lake Villarrica water basin.....	63
Table 8: Total of tourists in the communes Curarrehue, Pucón and Villarrica during the summer months of January and February 2007 .....	66
Table 9: Measurements of P and N concentrations by the Pucón Treatment Plant in the time period September 2006 – September 2007.....	69
Table 10: List of operating aquaculture companies in the Villarrica Lake water basin in the year 2008.....	70
Table 11: Total nitrogen and phosphorous contribution in the development phase of alevins and smolts, considering a biomass of 275 tons of alevins (5,0g) and 420 tons of smolts (70,0g).....	71
Table 12: Land cover (in ha and % of total land cover) of the Villarrica Lake basin .....	74
Table 13: Nutrient exportation index for different soil covers.....	74
Table 14: Nutrient exportation index according to different soil uses in the Villarrica Lake catchment basin .....	76
Table 15: Summary of phosphorous and nitrogen loads (tons/annum) to the Villarrica Lake .....	78
Table 16: Maximum proposed values for each trophic parameter in different monitoring areas of the Villarrica Lake.....	79
Table 17: Typical composition of untreated domestic wastewater .....	83
Table 18: The five phases of a Sequencing Batch Reactor .....	83

Table 19: Current N total and P total discharges into the Villarrica Lake (by source) .....	94
Table 20: Choice of measures for the Villarrica Lake Water Basin, associated with the new total nitrogen and total phosphorous discharges to the lake and total capital costs .....	97
Table 21: Contaminants and pollution/damage units according to the Effluent Charges Act (AbwAG).....	102
Table 22: Development of the unit rate.....	103
Table 23: Frequency of collection of effluent charges, offsets against expenditures and rate reductions .....	106
Table 24: Concentrations of P total and N total in seven fish farms in the Villarrica Lake basin (period September 2006 – september 2007).....	113

## LIST OF FIGURES

Figure 1: Schematic representation of integrated water resources management .....	23
Figure 2: General principles for cost and value of water .....	26
Figure 3: The three pillars of IWRM: an enabling environment, an institutional framework and management instruments .....	29
Figure 4: Locating water benefits in a rivalry-exclusion quadrant.....	31
Figure 5: Water use by sector in Chile in 1999 .....	43
Figure 6: Political map of Chile with provinces.....	43
Figure 7: Map of Chile and average rainfall by latitude .....	45
Figure 8: Process for the dictation of environmental quality and emission norms in Chile .....	53
Figure 9: Diagram showing when prevention and decontamination plans enter into force according to the Chilean legislation .....	54
Figure 10: Map of the Villarrica Lake hydrographic basin.....	61
Figure 11: Contribution of each economic sector to the GDP of Lake Villarrica water basin .....	65
Figure 12: Diagram of the wastewater treatment flux for all the seventeen fish farms in the Villarrica Lake hydrographic basin.....	86

## ACRONYMS

AGIES	Análisis General del Impacto Económico y Social (General Analysis of the Economic and Social Impact of an Environmental Norm)
BMPs	Best-Management-Practices
CONAF	Corporación Nacional Forestal (National Forest Corporation)
CONAMA	Comisión Nacional del Medio Ambiente (National Environmental Commission)
DGA	Dirección General de Aguas (General Directorate of Water Resources)
EIs	Economic Instruments
GTZ	Gesellschaft für Technische Zusammenarbeit (German Company for International Cooperation)
GWP	Global Water Partnership
INE	Instituto Nacional de Estadísticas (National Institute for Statistics)
IWRM	Integrated Water Resources Management
MBIs	Market-based instruments
MMA	Ministerio del Medio Ambiente (Ministry of the Environment, Chile)
MDGs	Millennium Development Goals
NSCA	Norma Secundaria de Calidad Ambiental (Environmental Quality Norm for the protection of the environment, Chile)
SEREMI	Secretaria Regional Ministerial (Regional Ministerial Secretary in charge of Environmental Affairs)
SISS	Superintendencia de Servicios Sanitarios (Superintendency of Sanitary Services, Chile)
WWTP	Wastewater Treatment Plant

## 1. INTRODUCTION

Water is a precious good and it is essential to sustain human life. It plays a crucial role in many human activities, including industrial production, agriculture, sanitation, and transportation, in addition to sustaining ecosystems which provide valuable services to both the environment and human beings. Only 0,4% of all the water on Earth is in a form that is usable and accessible by human beings (CAP-Net, 2003). On top of that, the demand for water has drastically increased over the past centuries, due to the fact that population numbers have been rising and that many countries have developed rapidly in economic terms. The Global Water Partnership (2000) notes that global population increased by a factor of three during the 20<sup>th</sup> century, whilst water withdrawals increased by a factor of seven. Both factors, population growth and economic development, contribute to pollution from municipal waste, mining and industry, and agricultural runoff, all of which further degrade water quality and thus the amount of quality water sources, further jeopardising the quantity of usable waters (Xie, 2006). All of these aforementioned facts clearly indicate that water is a highly valuable resource for human beings, but it is also recognised that a sound management is crucial for its preservation in quantity and quality.

During the Millennium Summit of the United Nations in New York in 2000 and the World Summit on Sustainable Development in Johannesburg in 2002, the subsequent goal was formulated: by 2015, the share of people not having access to clean drinking water as well as the share of people not possessing sanitary basic services should be halved. Much hope is put into the concept of 'Integrated Water Resources Management' (IWRM), which was already recognised as an international model and general principle in the Agenda 21 and the Dublin Principles in 1992: the IWRM concept holds that through qualitative and quantitative sustainable management of the interconnected and interrelated surface water, groundwater and in some cases also coastal water, should the social and economic development of the area be promoted and the operational capability of the ecosystems be secured. IWRM is thus a process with the scope to maximise both the social and economic well-being without the deterioration of the vital ecosystems and under equitable conditions when using the resources. In this context, ecological, economic and social objectives are tied.

The need to shift from a sectoral to a cross-sectoral approach as regards water management has been recognised in many countries of Latin America, such as states the Inter-American Development Bank (2003). In Chile, the scope to implement the IWRM concept for the

management of its hydrological resources has been proclaimed quite recently, namely in the National Strategy of Integrated Management of Hydrographical Watersheds in the year 2007. For the establishment of IWRM in Chile, it would be advantageous to consider economic instruments (also known as market-based instruments or MBIs) next to traditional water resources management tools such as government standards (also known as command-and-control). MBIs use price or other economic variables to provide incentives for polluters to reduce harmful emissions or to diminish the consumption of water. They include charges, subsidies and tradable permits.

### **1.1. Justification**

Water policy in Chile is facing several major challenges: firstly, due to the nation's sustained economic growth since the 1990s, there is a rise in multiple demands for water from a variety of sectors. Secondly, there exists an increasing pressure on environmental systems and worsening problems of water contamination. The third challenge is linked to the uncertainty by climatic variability in the future (Bauer, 2004).

As a way to tackle these aforementioned challenges in the future, the establishment of IWRM for a more coordinated management of water, land and related environmental resources on a river basin scale constitutes a great priority in Chile. In fact, the most recent policies developed jointly by the Ministry of the Environment (CONAMA back then) and the General Water Directorate (DGA) seek to promote a sustainable and equitable management of hydrological basins. The most prominent is the 2007 National Strategy of Integrated Management of Hydrographical Watersheds (*Estrategia Nacional de Gestión Integrada de Cuencas Hidrográficas*). Its objective is the protection of the hydrological resources, in quality as well as in quantity, in order to preserve the resource for human consumption purposes, but it also seeks a harmonisation between ecosystem conservation objectives and the sustainable utilisation of the resource by economic sectors (CONAMA, 2009).

In the year 2010, the Ministry of the Environment decided to enact an environmental quality norm for the protection of the Villarrica Lake (*Norma Secundaria de Calidad Ambiental para la Protección de las Aguas Continentales Superficiales del Lago Villarrica*) and its surrounding environment which is located in the Region IX of Chile (Región de la Araucanía). This norm will be implemented as there is growing evidence that the Villarrica



Lake is shifting from an oligotrophic state with low levels of nutrients and productivity (i.e. low contamination) to a state of oligo-mesotrophy due to high discharges of the nutrients phosphorous and nitrogen into the lake (i.e. high contamination). In some areas, even signs of a eutrophic state have been monitored. Therefore, the utmost scope of the environmental quality norm is the establishment of quality standards in order to rehabilitate the lake's trophic state, which would most approximate the original and natural state of an Araucanian Lake. Ultimately, this would ensure the conservation of the lake's qualities as a site of scenic, touristic and environmental value.

Before an environmental quality standard enters into force, a central part of the process which the Chilean law foresees is the analysis of the economic and social impacts of the norm. More precisely, the costs and benefits to society and to the affected economic sectors have to be identified and quantified. Currently, the cost-benefit analysis of the environmental quality norm for the Villarrica Lake has been assigned a high priority in Chilean environmental policy. In this context, as a first economic element this thesis considers and assesses the costs of the measures to be implemented by each source of contamination in the river basin in order to preserve the lake's quality. Furthermore, this study carries out a ranking of the costs and the efficiencies of the measures together with an attempt to rank the measures according to their cost-effectiveness. The following step deals with the implementation of an economic incentive mechanism (economic instrument) as a new policy instrument in Chile's water resources management. So far, command-and-control tools have been the only policy instruments serving water quality management in Chile. According to Donoso and Melo (2006), however, this traditional approach to water management has not achieved sufficient reductions in water pollution levels. Therefore, it is relevant to test the benefits and potentials of economic instruments as a complement to quality standards in the case study of the Villarrica Lake watershed.

## ***1.2. Research objectives and methodology***

The general objective in this study is to quantify and assess the implementation of an economic instrument to support the establishment of IWRM in Chile illustrated by the case study of the Villarrica Lake watershed.

The content of this master thesis can be divided into three main parts:

The first two chapters present the theoretical background of the thesis. Firstly, the history and antecedents of the concept of Integrated Water Resources Management will be investigated. Further, the principles guiding this concept will be explained as well as how IWRM constitutes a paradigm shift in water management. The second chapter deals with the notion and rationale of economic instruments in water resources management, i.e. economic instruments will be defined, their functions and the importance of these incentive mechanisms for the achievement of IWRM goals will be demonstrated. The following chapter presents the Chilean water management framework (laws, institutions and policies related to water management) and it assesses whether IWRM has already materialised in Chile and what the impediments to an integrated management of water resources are. The methodology used in this part mainly includes a thorough literature review on the concept of IWRM and documents on “economic instruments” which were mostly retrieved by institutions affiliated to the European Union and the United Nation Organisations.

The second and more practical part deals with the Villarrica Lake watershed in the Region IX of Chile. Firstly, the source of the lake contamination will be established. In order to reach the nutrient loads proposed by the environmental quality norm, it seems relevant to identify the possible measures which could be implemented so as to lower the amount of nutrients emitted into the aquatic system. Therefore, as a second step, for each source of contamination a set of measures will be displayed. Thirdly, a programme of measures for the whole of the Villarrica Lake water basin will be worked out based on a selection of the most cost-efficient measures. Next to a profound literature review, much information gathered is obtained from semi-structured interviews which I carried out during my field research with municipalities, the local environmental government and further institutions related to water management in the Villarrica Lake basin.

Having identified the sources of contamination and the costs associated for the mitigation to restore the water quality in the Villarrica Lake water basin, there is the potential to internalise the environmental costs (which are the costs of damage that water uses impose on the environment and ecosystems and those who use the environment) by applying the polluter-pays-principle. Having said this, Germany’s effluent charge (*Abwasserabgabe*) as a financing and steering tool will be presented and then the application of this economic mechanism in the case of the Villarrica Lake hydrographic basin will be assessed. Here, the methodology consists of both semi-structured interviews and a literature review. The interviews and discussions on this topic will be carried out with environmental institutions in the Villarrica

Lake watershed and the Department of Environmental Economics of the Ministry of the Environment in Santiago. For this part, the literature review is based on theoretical and technical information on economic instruments mainly coming from Germany.

## 2. WHAT IS IWRM?

### *2.1. Water as a scarce and finite resource*

Currently, there exist a range of factors which put pressure on water resources and it is likely that they will direct the options and requirements for water management in the future. Most of these drivers are of socio-economic nature, yet they also include less controllable factors such as climate change. In their water management training manual, Cap-Net, GWP and EUWI (2008: 17) point to the following processes or forces which make water an issue to deal with more thoroughly:

- 1) Economic growth, leading to more demand for water, and more pollution of the existing resources
- 2) Population growth and urbanisation: the world's population will increase by about three billion people by 2050, demanding more water and producing additional wastewater and pollution
- 3) Concerns about the health of people and the environment: access to safe drinking water and basic sanitation is a fundamental requirement for effective primary health care and a pre-condition for success in fighting poverty, hunger, child mortality, gender inequality (it is also fundamental for the achievement of the UN MDGs)
- 4) Government failure to deal adequately with water issues
- 5) Market failure: the private sector should also step in to solve water quality and quantity problems
- 6) Increasing critique on the poor management of utilities and river basin organisations
- 7) The search for achieving socio-economic and environmental sustainability
- 8) Current concerns about climate variability and climate change demand improved management of water resources to cope with more intense floods and droughts

It is even argued that the world is facing an impending water crisis, as summarised in Table 1 by Cap-Net et al (2008):

**Table 1: Water Crisis – Facts (Cap-Net *et al*, 2008)**

- 1.1 billion people still do not have safe water supplies.
- Today, more than 2 billion people are affected by water shortages in over 40 countries.
- Four out of ten people around the world still use very basic sanitation facilities.
- Two million tonnes per day of human waste are deposited in watercourses.
- Each year, unsafe water and a lack of basic sanitation kill at least 1.6 million children below the age of five years.
- Half the population of the developing world are exposed to polluted sources of water that increase the incidence of disease.
- 90% of natural disasters in the 1990s were water related.
- The increase in numbers of people from 6 billion to 9 billion will be the main driver of water resources management for the next 50 years.

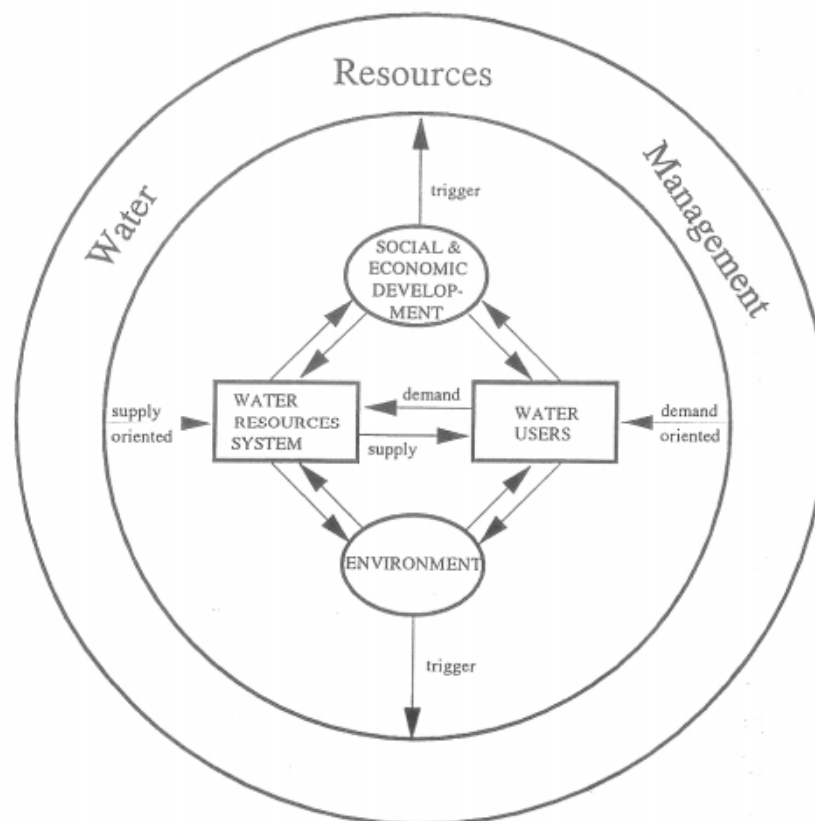
## ***2.2. Short history of the IWRM concept***

According to the UNESCO (2009), an integrated approach to river management already began in the 1930s in the United States and the concept has gained increasing attention worldwide over the last decades. In the 1980s, more attention was given to water management, as this vital resource experienced competing demands amongst various water users (Cap-Net, GWP and EUWI, 2008). Especially great support came from the UN and the concept's definition and implementation was refined at international conferences on water-related environmental issues (International Conference on Water and Environment (ICWE), 1992; UN Conference on Environment and Development (UNCED), 1992), ultimately leading to the actual concept of Integrated Water Resources Management (IWRM). In fact at the ICWE, as 500 water experts from 80 countries prepared for the UNCED conference held in Dublin in 1992, a working model for sustainable development for water resources was worked out (Snellen and Shrevel, 2004). In a conference's keynote paper entitled *Water and Sustainable Development*, the first schematic representation of integrated water resources management was included (please refer to Figure 1) This representation recognises that for sustainable development the concept of a 'carrying capacity' of the environment should stand at the forefront and be examined first, instead of just planning for a socio-economic development. In the author's own words, the figure is explained as follows:

“An approach set out in (Figure 1) could be a good model for sustainable development. In this approach, the management of water resources is stimulated through triggers stemming from the environment and society's socio-economic well-being, acting through both supply and

demand-oriented actions directed at a system that has found a balance between impacts and carrying capacity. The danger of imbalance, however, remains ever present. In periods of economic recession, people and politicians are inclined to attribute more weight to socio-economic development and accept that future generations pay the bill. The scheme (in Figure ...) needs constant support of organisations that are not influenced by political and economic instabilities” (Koudstaal, Rijsberman and Savenije, 1991 *in* Snellen and Shrevel, 2004)

Furthermore, for the first time the authors hold that the idea of an integrated management should go beyond traditional concepts such as “the coordination among water management agencies, the interaction between groundwater and surface water, or a planning approach which considers all possible strategies and impacts” (Koudstaal, Rijsberman and Savenije, 1991 *in* Snellen and Shrevel, 2004). In addition to an integrated management, the other two main and new features of this approach include the following: demand management to increase the efficiency in use and to reduce waste and the carrying capacity of the natural environment as the logical starting point instead of the traditional priority of socio-economic development (Snellen and Shrevel, 2004).



**Figure 1: Schematic representation of integrated water resources management (Koudstaal, Rijsberman and Savenije, 1991 *in* Snellen and Shrevel, 2004)**

### ***2.3. IWRM and the Dublin Principles***

According to Davis (2004:2), “international consensus exists that the basis of IWRM is founded in the Dublin principles”. It was during the International Conference on Water and the Environment in Dublin in 1992 that the principles guiding integrated water resources management on a local, national and international level had been defined. These principles further formed the foundation for the freshwater resources component of the UN Agenda for protection of freshwater resources, which can be found Chapter 18 of the Agenda 21.

The four Dublin Principles (GWP, 2000) are displayed and explained as follows:

1. Water is a finite, vulnerable and essential resource which should be managed in an integrated manner

This principle is supported by the quantitative review of the global water cycle, which portends a set annual volume of water. Fresh water is a natural resource that needs to be preserved by ensuring effective management of water resources. Furthermore, it points out that water management should be integrated as it is needed for a wide range of purposes, functions and services. This principle assigns a river basin or a catchment area to be a water management unit, which is the so-called hydrographical approach to water management (GWP, 2010).

2. Water resources development and management should be based on a participatory approach, involving all relevant stakeholders

The participatory approach implies increasing awareness of the importance of water among policy-makers and the general public. It signifies that decisions should be taken at the lowest appropriate level, with full public consultation and integration of users in the planning and implementation of water projects (Butterworth, 2006).

3. Women play a central role in the provision, management and safeguarding of water

As the GWP (2010) states, women play a pivotal role in the collection and safeguarding of water for domestic purposes, yet they have a less powerful position than men in the management and decision-making related to water. Therefore, this principle underlines the importance of the women’s role to be acknowledged.

4. Water has an economic value in all its competing uses and should be recognised as an economic good as well as a social good

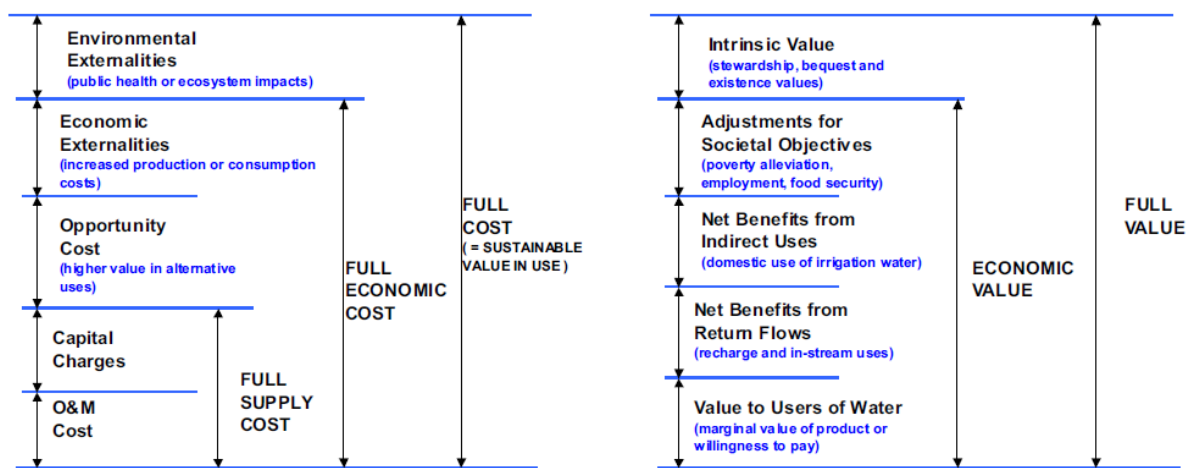
The fourth Dublin Principles which considers the economic value of water and its importance to be recognised as an economic good is further defined and explained in the following section ‘Water as a social and economic good’.

#### Water as a social and economic good

The Dublin Principles on Water and Sustainable Development which were adopted by the United Nations in January 1992 serve as a guide to IWRM. One of the principle states that “water is a public good and has a social and economic value in all its competing uses” (GDRC, 2008). Thus, it is crucial to first recognise that access to clean water and sanitation at an affordable price is a basic right for each human being. The principle further highlights the importance to manage water as an economic good in order to achieve efficiency and equitable use, encourage conservation and protect the resource. The economic approach distinguishes between *valuing* and *charging* for water (Gumbo and Van der Zaag, 2001). To recognise the value of water is crucial for the rational allocation of water as a scarce resource (using the “opportunity cost” concept) whether through regulatory or economic means. In contrast, charging for water is the application of an economic instrument for a more efficient water use behaviour and conservation by providing incentives to manage demand, cost recovery and readiness of users to pay for the extra water management services (Cap-Net, GWP and EUWI, 2008). However, the principle of water as an economic good has been interpreted in many different ways and there have been concerns that “market pricing of water (...) would damage the interests of the poor and make irrigated agriculture virtually unfeasible” (Van der Zaag and Savenije, 2006:15). These authors claim that the forces of the market alone deciding on the price of water have been proven to be at odds with the concept of integrated water resources management. The reason for this is that market failures can arise, and in that case the price of water does not automatically induce a desirable allocation of water. Yet Van der Zaag and Savenije (2006) state that water should have a price in order to attain two objectives: the first one is financial sustainability through the recovery of the cost of providing the particular water service and the second one is the transmission of a clear signal to the users when water is scarce and that it should be used wisely and sparingly.



Rogers et al (1998) present in their paper “Water as a social and economic good” a framework for operationalising the concept of water as a social and economic good, which is the 4<sup>th</sup> principle of the Dublin Statement. They highlight several general principles in assessing the economic value of water and the costs linked to its provision. Firstly, it is important to understand the costs involved with the provision of water. Secondly, one can derive a value from the use of water. This value can be determined for example by the reliability of supply or by the quality of water. The following figure (Figure 2) displays the various components which add up to make the costs. There are three main elements in this composition: the full supply cost, the full economic cost and the full cost which will be further explained as follows.



**Figure 2** General principles for cost and value of water (Rogers et al., 1997 in Savenije et al, 2002)

The full supply cost includes the operation and maintenance costs and the capital charges. These costs are the costs associated with the supply of water to the consumer without the consideration of any externalities on the environment or other users. The full economic cost includes the full supply cost (just seen above), yet another dimension is added as well which is the inclusion of economic externalities and opportunity costs. The opportunity cost addresses the fact that by consuming water, the user deprives another use of the same water. If the other potential user associates a higher value to the use of water, then one talks about an opportunity costs experienced by society due to the misallocation of the resource. As regards the economic externalities, the most common one is the problem of divergent upstream-downstream availability of water or pollution imposed on downstream users. Another economic externality can be linked to over-extraction or contamination of common waters

such as lakes and underground water. Lastly, the full cost of consumption of water is denominated “Full Cost”. It includes the full economic cost plus the full supply cost and it is equal to the environmental externalities associated with public health or ecosystem impacts. Rogers et al (1998) argue that environmental externalities are more difficult to assess economically compared to the economic externalities seen above, but it is possible “to estimate some remediation costs that will give a lower bound estimate of the economic value of damages” (Rogers et al, 1998:10).

The authors reveal that for economic equilibrium and a maximization of social welfare, the value of water should equal the cost of water. The figure above shows that the value in use of water is the sum of the economic value (value to users of water, net benefits from return flows, net benefits from indirect use, adjustment for societal objectives) and intrinsic value. Intrinsic value such as stewardship, bequest values, and pure existence values, are often difficult to measure, nevertheless it reflects the value associated with water use.

#### ***2.4. Actual definition and the three pillars of IWRM***

The concept of Integrated Water Resources Management (IWRM) is defined by the Global Water Partnership (GWP, 2001) as “a process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital eco-systems” and by Cap-Net (2006) as “a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives” (Cap-Net, 2006). The IWRM concept recognises that water has many different uses, such as for agriculture, for people and livelihoods and for healthy ecosystems, therefore it requires coordinated action. In contrast to the traditional fragmented and top-down approach to water development, which has often translated into high ecological, social and environmental costs, the IWRM approach underlines a coordinated decision-making across scales and sectors. In fact, IWRM involves a paradigm shift in water management in the following three ways:

- 1) The multiple objectives and goals are crosscutting by acknowledging the interdependent uses of water resources (from a sectoral to an integrated approach)
- 2) The spatial focus is the river basin instead of a single water course

3) The departure from narrow political boundaries and perspectives are broadened to incorporate participatory decision-making of all stakeholders

There are at least five ways of integration in the concept of IWRM (GWP, 2000; Solanes y Getches, 1998 *in* UNEP, 2011):

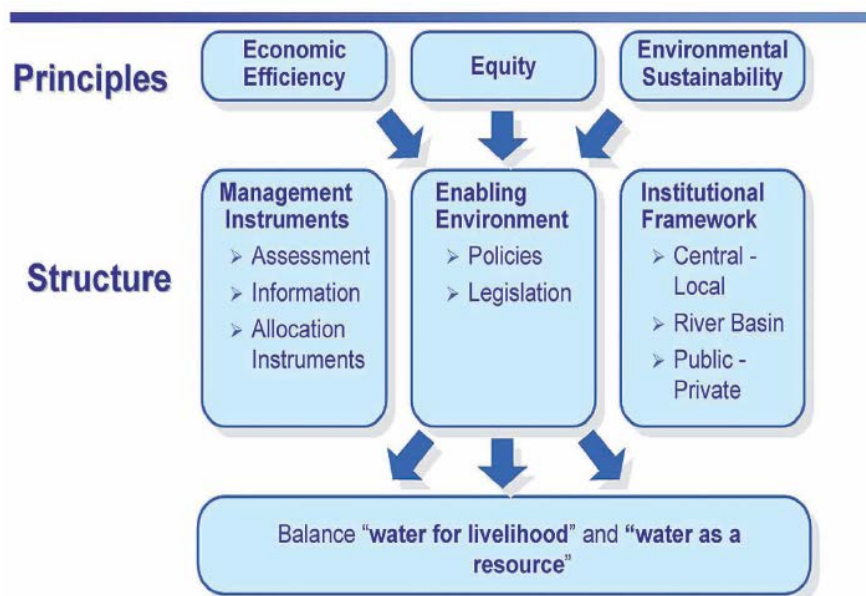
1. The integration of the interests of multiple water uses and users with the scope to reduce conflicts over this resource
2. The integration of all the aspects of water which have an influence on its use and users (quantity, quality, time of occurrence) and the management of both supply and demand.
3. The integration of the different components of water and of the phases in the water cycle (e.g.: management of surface water and groundwater)
4. The integration of the water management and land management and further natural resources which are related
5. The integration of water management in the economic, social and environmental development

The GWP continues to refine the IWRM concept into a practical river basin management tool, observing that IWRM is not an end in itself, but rather a means to achieve the three key strategic objectives. The three key strategic objectives of IWRM include efficiency to make water resources go as far as possible, equity in the allocation of water across different social and economic groups and lastly, environmental sustainability to protect the water resources base and associated eco-systems (Snellen and Shrevel, 2004).

The general framework of IWRM and important elements to address the aforementioned objectives (three pillars) are the enabling environment with suitable policies, strategies and legislations for sustainable water resources development and management, an institutional framework in order to put the aforementioned policies, strategies and legislations into practice and the introduction of management instruments which these institutions need to do their job (GWP, 2010). These three pillars of IWRM which contribute to the balance of “water for livelihood” and “water as a resource” are depicted schematically in Figure 3 of this section.

As water is mainly managed locally, the river basin approach is recognised as a comprehensive process for managing water resources in a more sustainable manner. According to the UNESCO (2009) “basin-level perspective enables integration of

downstream and upstream issues, quantity and quality, surface water and groundwater, and land use and water resources in a practical manner or improving environmental sustainability” (UNESCO, 2009: 3). For example, land-uses in a watershed, such as urban development, agriculture and forest extraction, can have far-reaching impacts on water resources in the basin and vice versa. A basin-level perspective enables water managers to address the linkages between water resources management and the management of land and other related resources effectively (*idem*, 2009).



**Figure 3: The three pillars of IWRM: an enabling environment, an institutional framework and management instruments (UNESCO, 2009)**

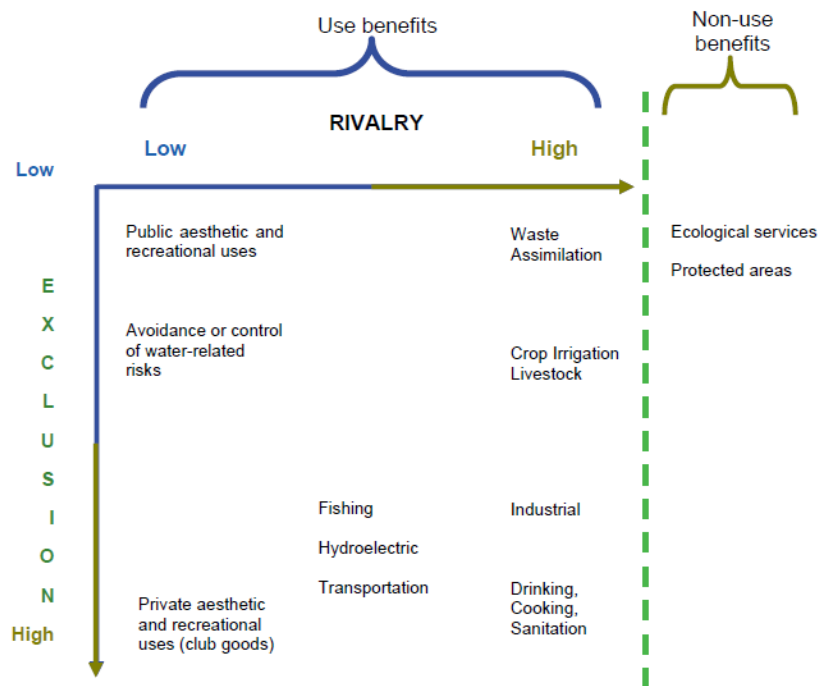
### **3. ECONOMIC INSTRUMENTS IN WATER RESOURCES MANAGEMENT**

This chapter on the use of economic instruments in water resources management is divided into two main parts. The first part presents a theoretical background explaining the characteristic of water as a public good and the problems that can arise due to this property, such as environmental externalities. Further, the definition of the polluter-pays-principle will be displayed and its application in Chile's environmental law will be reviewed. The second part specifically addresses economic instruments, their definitions, functions, advantages and disadvantages. Lastly, the policies at an international level promoting economic instruments will be described, and the importance of these incentive mechanisms for the achievement of integrated water resources management (IWRM) goals will be explained.

#### ***3.1. Theoretical background***

##### **3.1.1. Water as a public good**

Water provides several benefits for society, such as: public aesthetic and recreational use, its use for drinking, cooking and sanitation, for transportation, hydroelectric use, agricultural use (livestock and crop irrigation), amongst others. Some of the benefits that water provides have the characteristic to be non-rival and non-excludable. Non-rivalry means that the consumption of the resource by a user does not preclude someone else to consume it too. Non-excludability refers to a situation in which it is too costly or too difficult to exclude potential consumers from the good's or resource's benefits (Department of Natural Resources of Wisconsin, 1999). These benefits to society can be placed on a rivalry-excludability quadrant, such as it has been elaborated by Cap-Net, GWP and EUWI in 2008 (Figure 4).



**Figure 4: Locating water benefits in a rivalry-exclusion quadrant (Cap-Net, GWP and EUWI, 2008)**

Interpreting the above quadrant, the public good nature of water is situated in the upper-left hand corner, with the public aesthetic and the recreational uses of water being both non-rival and non-excludable. The avoidance or control of water related risks, such as measures implemented to prevent flooding, also has the characteristics of a public good. On the contrary, water services with fewer public-good features are located in the lower-right hand corner (e.g. drinking, cooking and sanitation). These have more the characteristics of private goods: they are highly excludable and rival. There are environmental services being less rival than private goods such as fishing, hydroelectric and transportation activities. In this case, water is not necessarily extracted from other potential users.

As can be seen from the quadrant in Figure 4, many water benefits have public good characteristics. Market failures, such as environmental externalities arising from the use of public goods, leave considerable social costs outside the producer's and consumer's decision calculus (Panayotou, 1994). As will be seen in the following section, the lack of market prices for environmental services is a reason why environmental externalities arise.

### **3.1.2. The polluter-pays-principle**

Environmental degradation and damage can arise from a degree of exploitation of natural components outstripping the level of the environment's self-regeneration and carrying capacity. Mostly, society has to bear the consequences of the environmental deterioration, which is translated into a reduction of the quality of life. Yet, the responsibility of such damage cannot be traced back to society as a whole. In fact, it can often be attributed to specific actors who both degrade the environment and extract a benefit from it.

Public goods, such as water resources (lakes, rivers, etc) do not have one specific owner and have the characteristics of non-rivalry and non-excludability (c.f. previous section of this chapter). Since these goods do not have clear defined property rights, they lack a price and therefore their use does not imply internal costs for anyone. From the perspective of use, they can be exploited without any restriction. Thus, anyone can use public goods and extract a benefit without having to ask for permission or to pay for it (Valenzuela, 2004).

The polluter-pays-principle tries to take up this reality in its economic perspective, and through mechanisms (such as market-based instruments) to prevent the inappropriate use of these goods. The scope is that those who receive a benefit from the environmental risky activity have to bear the real costs of use. The principle tries to operate within the framework of markets, reducing the costs to society as a whole by forcing the polluter to internalise the costs associated to the extraction, production and consumption process (Valenzuela, 2004)

In economic theory, a negative externality is a situation in which a benefit is achieved through an activity without paying a compensation for the damage incurred to third parties. For example, a negative externality arises if an environmental resource is used up to the point that it produces a degradation of it and as a consequence it affects the quality of life of the population (*idem*, 2004).

In essence, what is intended with the correct application of the polluter-pays-principle, is through the internalisation of the costs of the use of the public goods, the extraction becomes more costly and its use therefore less intensive. A possibility is that the real cost of using public goods becomes more expensive in the production process, therefore it becomes beneficial to opt for more environmental-friendly and efficient technologies.

According to Panayotou (1994), it is a combination of institutional, market and policy failures which induces the undervaluing of scarce natural resources and environmental assets. In fact,

“institutional failures such as the absence of secure property rights, market failures such as environmental externalities and policy failures such as distortionary subsidies” (Panayotou, 1994: 3) cuts a ditch between the private and social costs of production and consumption activities. The result is that producers and consumers of products and services do not receive a clear signal about the true scarcity of resources they exhaust or the cost of environmental damage they provoke. This induces both an over-production and over-consumption of commodities which are resource-depleting and environmentally damaging. After reviewing the existence of the polluter-pays-principle element in the water resources management of Chile, we will present the traditional versus the modern approach of addressing market failures at an international level.

### **3.1.3. Polluter-pays-principle elements in Chile**

Some elements of the polluter-pays-principle are incorporated in the Chilean law, especially in the General Environmental Law (Ley 19.300 de Bases del Medio Ambiente) which came into effect in 1994. This principle has been strongly promoted by management tools which this law foresees such as quality standards, prevention plans, decontamination plans and emission standards (Valenzuela, 2004). As follows, these management tools will be explained more in detail.

In Chile, environmental quality standards firstly includes the primary environmental quality norm (*Norma Primaria de Calidad Ambiental*) which establishes maximum values and concentrations of elements, substances and compounds which could potentially present a risk to the population’s health. Further, it involves the secondary environmental quality norm (*Norma Secundaria de Calidad Ambiental*) which establishes maximum values and concentrations of compounds which could present a risk for the protection or the conservation of the environment and the preservation of nature. Through both of these norms, in their productive activities the actors making use of environmental elements have to adjust to maximum contamination levels. This leads to an adjustment in the costs of production and in the way the agent uses the environmental resources (Villalobos, 2005).

Linked to environmental quality standards, there are prevention and decontamination plans which oblige polluters to assume the costs of a cleaner production processes as a reaction to environmental damage already produced (Valenzuela, 2004).



Emission standards prohibit the polluter to emit certain levels of substances indicated in the norm. In case the production process entails too high concentration of a certain pollutant, the producer will have to adjust to a cleaner production process.

Further, the Chilean environmental law incorporates non-jurisdictional mechanisms which also partially contribute to the achievement of the polluters-pays-principle such as the imposition of production (or exploitation) quotas, management plans and clean production agreements (*idem*, 2004).

### ***3.2. Policy instruments for water management: traditional versus modern approach***

The traditional approach of policy instruments to changing the behaviour of consumers consists in setting specific standards for all the polluters (command and control). This includes firstly a technology and design standards which regulate specific control technologies or production processes which the polluters have to implement in order to achieve an emission standard. Secondly, the traditional approach involves performance-based standards setting the specific amount of the emission standards which has to be met; however the polluter can choose any desirable method to meet this standard (US EPA, 2011). With this traditional approach, governments must also define enforcement policies, fines and penalties in case of non-compliance (*idem*, 2011). The main advantage of command and control instruments is that it provides the regulator a reasonable degree of predictability over pollution degradation level (Bernstein, 1993). Even though traditional approaches have had some success in achieving pollution diminishment, it has been often criticised as being economically inefficient (due to its inflexibility). Furthermore, as no extra efforts of emission reductions are required, command and control instruments provide little incentive to innovate and to adopt new technologies (Donoso and Melo, 2006).

The modern approach to changing behaviour of consumers is through market-based policies which depend on market forces to adjust producer and consumer behaviour. As Cap-Net, GWP and EUWI (2008: 26) state “experience shows that using only supply-oriented approaches, which generally ignore the use of economic instruments and demand management, is not an effective way for finding efficient, equitable and environmentally

sustainable solutions to water problems”. Besides from the difficulty to predict the extent in pollution abatement, market-based instruments are a way to overcome market failures, such as environmental externalities by incorporating the costs of environmental damages from pollution into the firm’s or consumer’s decision-making (US EPA, 2011). According to Donoso and Melo (2006: 234) and UNESCAP (2003) their main advantages are “cost-effectiveness, reduced informational requirements, development of pollution control technology and being a source of revenue for the government”. As Cap-Net, GWP and EUWI (2008: 18) and Kraemer *et al* (2003: 3) put, economic instruments are crucial tools to help achieve a number of policy objectives, such as the rational use of water, the cost-recovery of water services and the implementation of the polluter pays principle (c.f. section “Polluter-pays-principle”).

A very common approach nowadays is the hybrid one which involves a mixture of both traditional and modern instruments in environmental policy.

### ***3.3. Economic instruments in water management: definition, taxonomy and functions***

#### **3.3.1. Definition of economic instruments**

Before stating the benefits associated with the implementation of economic instruments for environmental policy purposes and environmental resources management, it seems crucial to first define the term “economic instruments”. The report entitled “The Use of Economic Instruments in Environmental Policy: Opportunities and Challenges” elaborated by the United Nations Environment Programme (2004) defines it as follows:

“Economic instruments make use of market mechanisms and provide one important approach to address this challenge. They encompass a broad array of policy tools, ranging from pollution taxes and marketable permits to deposit-refund systems and performance bonds. Economic instruments are applied across a similarly wide-ranging set of policy sectors, including land, water and air management, and control or reduction of pollutants. They either drive up the cost of environmentally harmful activities or increase the returns from sustainable approaches, thereby creating economic incentives to behave in a more environmentally responsible and sustainable manner” (UNEP, 2004:1).

The following section of the chapter provides a brief classification and description of the major economic instruments which are used in water resources management. After the definition of each instrument, the different functions of economic mechanisms for environmental policy are displayed. Then, a table with the main advantages and drawbacks of each instrument will be presented.

### **3.3.2. Taxonomy of economic instruments**

Water abstraction charge is a certain amount of money charged for the direct extraction of water from groundwater or surface water (Roth, 2001). Next to their financial function (revenue-generating), water abstraction charges can act as incentive measures. In fact, this tax can engender a change in user behaviour which results in lower water demand and a reduction in water leakage. In many countries, the revenues received through water abstraction charges are often earmarked for water management purposes solely. Therefore, the charge is indirectly returned back to those liable to pay (Kraemer et al, 2003). A main disadvantage of water abstraction charges can be that low charges have a minimal impact on the polluter and can lead to an over-utilisation of the water resource.

Water pricing is an instrument with the primary goal of financing water supply infrastructure by setting prices at a level which ensures cost-recovery in each sector (agriculture, households and industry). Savenije and van der Zaag (2002: 100) state that “water pricing is not an instrument for water allocation, but rather an instrument to achieve financial sustainability. Only if the financial costs are recovered can an activity remain sustainable”. For further details on the advantages of water prices, refer to Table 2 below.

Sewage charges and effluent charges for indirect emissions are tariffs paid for the discharge of domestic used water or effluents into the sewer system (Kraemer et al, 2003).

Water pollution charge is a direct payment based on the measured or estimated quantity and quality of pollutants discharged directly into a water body (not into a sewer). Roth (2001) claims that these charges are a crucial step towards the accomplishment of the polluter-pays-principle. Through a charge on pollution, a clear signal is sent to polluters that society is no longer willing to bear the costs of pollution. The US EPA (2011) states that the main

disadvantage is that fees, charges and taxes cannot guarantee a specific amount of pollution reduction. It can only ensure that those who pollute will be penalised.

Subsidies are defined by the OECD (1996) as “government interventions through direct and indirect payments, price regulations and protective measures to support actions that favour environmentally-friendly choices over environmentally-unfriendly ones”. Rather than charging a polluter for emissions, a subsidy rewards a polluter for reducing emissions. Examples of subsidies include grants, low-interest loans, favorable tax treatment, and procurement mandates (US EPA, 2011). The main advantages of subsidies are that they are easily understandable and that it induces eco-friendly behaviour at any rate. Conversely, their main disadvantage is that regional aspects and variations are difficult to consider and further their entail high monitoring costs (see Table 2 in Section 3.3.3.).

Tradable permits imply the creation of an efficient market in which rights of use or pollution of water are traded. The justification of water allocation through tradable rights is that in a perfectly competitive market, permits will align to their highest value use (Kraemer and Banholzer, 1999). Permit holders who gain a lower benefit from using their permits have an incentive to sell them to a water user who would value these permits more (Tietenberg, 2000).

### **3.3.3. Functions of economic instruments**

It can be stated that the functions of economic instruments in environmental policy are threefold.

Firstly, economic instruments such as taxes and charges do have an incentive function with the intention to change environmentally damaging behaviour, often without the primary scope to raise income. Contrary to regulations (such as command and control), charges can provide a steady incentive to improve in abatement technologies. Surely, the potential of incentive instruments is only at its best if rates are set sufficiently high in order to invest in abatement technologies (Kraemer *et al*, 2003).

Secondly, often economic instruments serve the purpose of a fiscal or financial function. This is specifically true when the primary goal of the government is not to change environmentally-unfriendly behaviour. In case the government wants to raise revenue, it can either add the income of a tax to the general government’s budget or it can earmark the income, which means that the revenue is allocated for a specific environmental purpose

(RIZA, 1996). There lies the distinction between a tax (income for the national budget) and a charge (earmarking for specific environmental purposes). It is often stated, that charges which are earmarked have a crucial role in enhancing the acceptability of the levy (Kraemer *et al*, 2003).

Thirdly and lastly, in addition to the characteristics presented above, economic instruments can also have soft functions. Within this category falls capacity building and improvements in implementation (Kraemer *et al*, 2003). Kessler (2003) further adds that economic instruments have the potential to stimulate innovation and the transparency of information, amongst other functions.

After having briefly described the functions of economic instruments in water resources management and the definitions of the different economic instruments, the Table 2 as follows summarises and classifies the economic instruments according to their function (incentive, fiscal or financial function) and it further provides a description of the advantages and drawbacks of each instrument, some of them which have already been displayed in the definition section above.

**Table 2: Classification of economic instruments for water resources management (Kraemer *et al*, 2003)**

<b>CLASSIFICATION OF ECONOMIC INSTRUMENTS</b>			
<b>Function</b>	<b>Economic Instrument</b>	<b>Advantages</b>	<b>Disadvantages</b>
<b>Incentive Functions</b>	<i>Water abstraction charges</i>	Adjustment of price signals to reflect actual resource costs; encourage new technologies; flexibility; generation of revenue that can be used for water management activities	Low charges/prices have a minimal impact on user/polluter behavior and can lead to resource-over-utilization
	<i>Pollution charges</i>	Same advantages as water abstraction charges; polluter-pays principle	Same disadvantages as water abstraction charges
<b>Fiscal Functions</b>	<i>Subsidies for environmental R&amp;D, tax differentiation</i>	Induce a more eco-friendly behavior at any rate; easily understandable	Rely on measurability of single components; regional aspects are difficult to consider; high monitoring costs
	<i>Pollution taxes</i>	Encourage the development of cleaner techniques; leave the choice to sources between paying taxes or investing in cleaner technology; fulfill an additional incentive function	Low willingness to accept by the public and the target group concerned
<b>Financial Functions</b>	<i>Water prices; sewerage charges</i>	In accordance with the user-pays principle; may convey an incentive function in addition to financing or cost-recovery by reflecting the true costs of a product or service	
	<i>Financial subsidies</i>	Popular with recipients, promote desirable activities rather than prohibiting undesirable ones	Require funding, may lead to economic inefficiencies, may encourage rent-seeking behavior
	<i>Earmarked taxes or charges</i>	Reduce the opposition to the tax as those liable to pay benefit in turn from the revenue	Rely on the measurability of single components; regional aspects are difficult to consider
<b>Liability Laws</b>	<i>Liability legislation</i>	Assess and recover damages ex-post but can also act as prevention incentives; provide strong incentives	Require an advanced legal system; high control costs; burden of proof

The last row of the table displays “liability legislation” which is not a direct economic instrument, yet it makes polluters pay for the damage their pollution causes through legal action and on an ex-post basis. Kraemer *et al* (2003) asserts that the intention of environmental liability laws can be twofold: “first of all they aim at inducing polluters to make more careful decisions about the release of pollution according to the precautionary principle, and, second, they seek to ensure the compensation of victims of pollution” (Kraemer *et al*, 2003: 9).

### ***3.4. Policies promoting economic instruments***

As we have seen in the previous section, the use of economic instruments presents a number of advantages in environmental policy and in water resources management. In many European and other countries around the world, these instruments have become indispensable tools (Kraemer *et al*, 2003).

The relevance of economic tools in environmental policy is stressed in both the Rio Declaration and the Agenda 21. In fact, it was emphasised that the application of economic instruments provides a tool for national authorities to support the internalisation of environmental costs and to bring to bear the polluter-pays principle in the most efficient manner. Economic instruments provide to governments a way of handling environmental and development issues in a cost-effective manner, promoting technological innovation, influencing consumption and production patterns, and further they provide a substantial source of funding (Panayotou, 1994). The fact that economic instruments can bring about the internalisation of environmental costs in sustainable development was recognised by the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992. The 16<sup>th</sup> principle of the Rio Declaration reveals that “national authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution with due regard to public interest and without distorting international trade and investment” (UN, 1992).

In the European Union, for example, the legislation supports and promotes the use of economic instruments. The European Water Framework Directive (WFD) (Directive 2000/60/EC of 23 October 2000 on establishing a framework for Community action in the field of water policy which came into force in the year 2000 provides guiding principles for all the EU member states to achieve good qualitative and quantitative status of all water bodies. The WFD is the first environmental policy directive of the European Community which explicitly calls for economic instruments in order to reach its objectives (Kraemer *et al*, 2002). In fact, both the principle of the polluter-pays and cost-recovery are embedded in the Directive. The scope is to ensure that environmental and resource costs are no longer borne by society in general, but are rather allocated to water users, therefore becoming an internal part of economic decision-making, also known as “internalisation” (Ecologic Institute, 2001). Furthermore, water-pricing policies should provide adequate incentives for the efficient use of

water resources. These incentives are meant to provide water users with correct and adequate signals on the scarcity of water resources. It should be noted however, that “while economic principles are to play an important role, Article 1 of the Directive also makes it clear that the WFD is not intended as a one-dimensional “economisation” of European water management by stating that “water is not a commercial product like any other but rather a heritage which must be protected, defended and treated as such” (Kraemer *et al*, 2002:39). In 2002, the WATECO Group (standing for WATer Framework Directive & ECOnomics) established a guiding document for member states on how to prepare an economic analysis of water uses and their economic importance. It is a legal document of non-binding character (HMUELV, 2004).

### ***3.5. Economic instruments to support IWRM***

Generally speaking economic instruments comprise the use of prices and other market-based measures to provide incentives to consumers and all water users to use water in a careful, efficient and safe manner (GWP, 2008). They are complementary to institutional, regulatory and technical tools employed in the water sector. In fact, in the IWRM literature it is often explicitly emphasised that economic tools are not effective operating alone. Here the adage “the market is a good servant but a bad master” applies (*idem*, 2008). One example of a supportive measure to economic incentives is standards for discharges or for surface water quality. Further important requirements are effective administrative monitoring and enforcement capabilities, institutional coordination and economic stability. It is often feared by many market sceptics that the introduction of economic instruments in water management translates into a complete pullback of the state. Quite the contrary such as the aforementioned examples (and requirements) by the GWP show: in the most cases the state remains an important actor because of its role to monitor, enforce and ensure the economy’s stability. Some of the advantages of economic instruments in water management stated by the GWP include “providing incentives to change behaviour, raising revenue to help finance necessary adjustments, establishing user priorities and achieving overall IWRM management objectives at least overall cost to society” (GWP, 2008). Within the toolbox of IWRM, the GWP network distinguishes between the following three economic instrument types: pricing of water and water services, pollution and environmental charges and water markets and tradable permits. In Table 3 their respective characteristics and preconditions for a good functioning (according to the network) are displayed. Lastly, it should be highlighted that market-based



mechanisms are an integral part to the IWRM concept (c.f. Figure 3 in chapter 2). In fact, allocation instruments are included in the column ‘management instruments’ being one of the three pillars of IWRM (next to the other two pillars “enabling environment” and “institutional framework”).

**Table 3: Characteristics and conditions of economic instruments for IWRM (Adapted from GWP, 2008)**

Economic Instrument	Characteristics	Conditions
<b>Pricing of water and water services</b>	<ul style="list-style-type: none"> <li>• <b>Cost reflectivity:</b> charges signalling to users the true scarcity value of water and the cost of providing the service</li> <li>• <b>Environmental protection:</b> encourage conservation &amp; efficient use</li> <li>• <b>Cost recovery:</b> generation of revenues for the efficient operation of the present system &amp; its future maintenance, modernisation &amp; expansion</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Affordability:</b> includes mechanisms to protect the poorest from high charges. Avoiding subsidies to the better off.</li> <li>• <b>Acceptability:</b> clear, comprehensive &amp; fair tariffs</li> <li>• <b>Administratively feasible</b></li> </ul>
<b>Pollution &amp; environmental charges</b>	<ul style="list-style-type: none"> <li>• <b>Cost reflectivity</b> of damage to the environment from use of the resource</li> <li>• Advantage over pure regulation: more <b>flexibility</b></li> <li>• <b>Reflects environmental damage</b> imposed by pollutants</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Reflect environmental costs</b> of wastewater pollution</li> <li>• Bear <b>relation to marginal abatement costs</b> of polluters</li> <li>• <b>Generate revenue</b> for clean-up actions</li> <li>• <b>Credit</b> polluters for the release of clean effluent</li> </ul>
<b>Water markets and tradable permits</b>	<ul style="list-style-type: none"> <li>• Water transfer <b>from low to high value uses</b></li> <li>• <b>Cheaper</b> way to obtain water than alternatives (which may be creating a new source of supply)</li> <li>• <b>Buy out rights</b> for habitat or natural amenity</li> </ul>	<ul style="list-style-type: none"> <li>• Clear &amp; permissive legal framework</li> <li>• Procedure for considering impact of trades on third parties</li> <li>• Physical means of transferring water between potential users</li> <li>• Strong provision by government (legal, social, economic framework) for effective market operation</li> <li>• Regulation to avoid monopoly build up</li> </ul>

## 4. WATER RESOURCES MANAGEMENT IN CHILE

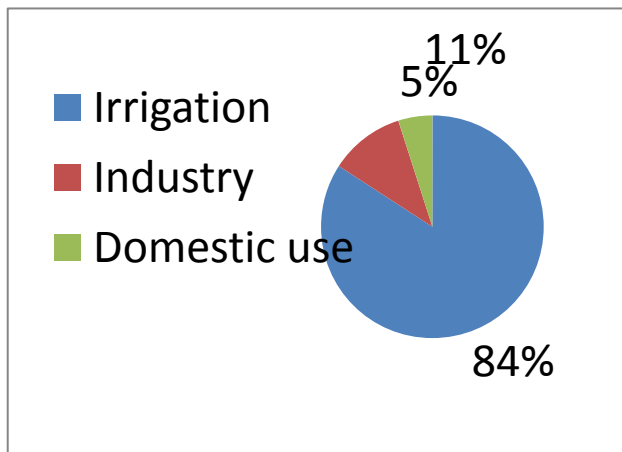


Figure 5: Water use by sector in Chile in 1999 (Gobierno de Chile, 2004)



Figure 6: Political map of Chile with provinces (Mapsofworld.com, 2010)

Chile is a country in South America bordering with Peru in the north, Bolivia in the northeast and Argentina in the east. It occupies a long narrow strip between the Andes Mountains in the East and the Pacific Ocean to the West. The Pacific coastline of Chile is 6 435 kilometres long. The extraordinary climatic diversity and precipitation of Chile can be explained by the country's unique geography with a continental North-South latitude range from 17° to 56° South Latitude (Neary and Garcia-Chevesich, 2008).

Chile has an approximate population of 17 000 000 people (census 2010) and it has a relatively low density compared to other countries of the world (with 22 people per km<sup>2</sup>). It is divided into 15 regions, each region headed by an *intendant*, appointed by the President. The second lowest level of administrative decisions are the provinces, which are headed by *gobernadores*. The third and lowest level of administrative decisions are the communes.

As regards water use in Chile, 67,8% is destined for non-consumption purposes (water power) and 32,2% for consumptive purposes (agriculture, industry, coal mining and drinking water) (Häberle, 2007). In the consumptive area, the agricultural sector is the most water-intensive

with 84% of the total use (see Figure 6). Agriculture in Chile is a very export-oriented sector: with wine, fruits, and so on (*idem*, 2007).

As aforementioned, Chile is broadly characterised by three distinct climatic zones: the northern dry region, which includes the Atacama Desert, known as one of the driest places on Earth; the central regions with a temperate and Mediterranean climate including the major urban centres Santiago and Valparaíso; the cold and rainy southern regions with a high rainfall pattern and a low population density (Universidad de Chile, 2011). The climate is one factor defining water abundance in the South and water scarcity in the north. In Arica, which is the most northern city of Chile, average annual precipitation amounts to less than 1 mm, whereas in the Chiloé National Park in the south of the country, average annual precipitation amounts to more than 4000 mm. Thus, we can clearly recognise an immense discrepancy in rainfall within the country (see figure 7). In the same line Villalobos (2005) notes that Chile is one of the longest countries in the world, therefore “this condition directly affects water management, being the most important issue for the northern regions its availability, in the central zone is the compatibility among different water uses, and in the southern extreme, its administration and the conservation of its quality” (Villalobos, 2005: 1).

For a sound water resources management in Chile further pressures on the resource affecting either its availability or quality have to be recognised and taken into account. The country’s sustained economic growth since the 1990s has translated into an ever-increasing water demand and competition, especially between the mining, agricultural and drinking water sectors (Blackburn, 2007; Matus et al. 2004; Madaleno and Gurovich, 2007). Here, the northern region of Chile is especially suffering from this competition between different water-engulfing sectors.

A further challenge in Chilean water resources management is linked to the uncertainty of the consequences on the hydrology provoked by climate change, such as the melting of glaciers in the Andes (Climate Institute, 2007; Neary and Garcia-Chevesich, 2008).

As follows, the institutional, legal and policy setting within which the country’s water resources management is embedded will be presented.

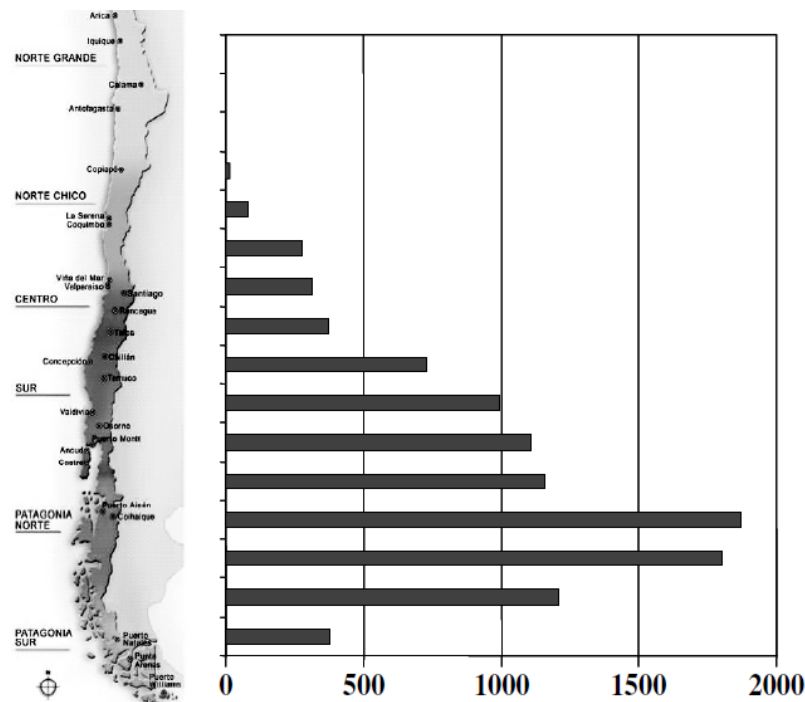


Figure 7: Map of Chile and average rainfall by latitude (Hearne and Donoso, 2005)

## 4.1. Water resources management framework of Chile

### 4.1.1. Institutional water management framework

In this section, the institutional arrangements of water resources management in Chile will be presented. First, the public and then the private bodies will be described. This part will summarise the public institutions related to water management and their functions in a table.

The creation of the National Commission of the Environment (Comisión Nacional del Medio Ambiente, **CONAMA**) was carried out during the Aylwin administration (1990-1994), which corresponds with the Rio Earth Summit in 1992 to the period of global concern for environmental protection. The functions of the CONAMA included: the coordination of national environmental policy, together with sectoral ministries, the supervision of the system of environmental impact assessment, the establishment of environmental quality norms and finally, the establishment of decontamination plans when the norms have not been met (Donoso and Melo, 2006). In the year 2010, the CONAMA was replaced by the Ministry of the Environment (Ministerio del Medio Ambiente, **MMA**). It has been assigned the design and application of policies, plans and programmes in environmental matters, as well as the protection and conservation of biological diversity and renewable natural and water resources, and ultimately promoting sustainable development.

The General Water Directorate (**Dirección General de Aguas, DGA**) is a leading government agency in water resources management which is affiliated to the Ministry of Public Works (Ministerio de Obras Públicas). The DGA is represented in thirteen regional offices throughout Chile. The main task of the Dirección General de Aguas (DGA) is the awarding of water rights. Anyone can hand in an application to the DGA in order to gain a free assignment of water use right regarding surface water or groundwater. Yet, the purpose and type of the water use is not a decisive criterion when rights are assigned by the DGA. Its areas of operation include the granting, monitoring and enforcing of water use rights. An important feature of the DGA is the gathering and maintaining of hydrologic data, as well as official registries of water rights and user's organisations in a national water cadastre. Finally, the DGA also carries out studies, plans and policy recommendations, though without a regulatory force unless approved by other authorities of the government. The only area where the 1981 National Water Code does grant the agency important discretionary force is when it comes to groundwater management, especially in times of declared drought and in approving water transactions which require a change in the river flow (World Bank, 1994).

The Directorate of Hydraulic Works (Dirección de Obras Hidráulicas, **DOH**) is also affiliated to the Ministry of Public Works. It is responsible for the regional development for the provision of water. Moreover, the DOH offers assistance in the construction and maintenance of the principal system of water provision, including the irrigation infrastructure and drainage (Brown and Peña, 2003).

The National Irrigation Commission (Comisión Nacional de Riego, **CNR**) is linked to the Ministry of Agriculture and its main task is the promotion of irrigation policies. Having said this, it supports the development of small irrigation projects under the Law on Irrigation and Drainage Development. Furthermore, it subsidises small scale, private irrigation investments and conducts studies regarding the feasibility and introduction of new irrigation and drainage undertakings such as the development of irrigation systems, i.e. the drip system in the arid north and the spray system in the humid south. The main focus of its efforts lies on vulnerable farmers and provides up to 75% subsidies for qualifying investments.

The Superintendence of Sanitary Services (**SISS**) is a regulating and auditing institution which comprises providers of drinking water and sanitation services in urban areas. The Superintendence defines the rates for sanitary services which it then passes on to the Ministry

of Economics; it oversees compliance with norms, and regulates the control of environmental waste (World Bank, 1994).

<b>Functions</b>	<b>Public institutions</b>
1) Regulation of the water resource	Dirección General de Aguas (DGA)
2) Environmental protection and conservation	Ministerio del Medio Ambiente (MMA), DGA, Dirección General del Territorio Marítimo y Marina Mercante (DIRECTEMAR)
3) Regulation of provided services	Superintendencia de Servicios Sanitarios (SISS), Comisión Nacional de Energía (CNE)
4) Efforts to develop and support/promote projects	Comisión Nacional de Riego (CNR), Dirección de Obras Hidráulicas (DOH)
5) Efforts to support the poorest sectors	Ministerio de Planificación Nacional, Instituto de Desarrollo Agropecuario (INDAP) and municipalities
6) Inspection and quality control of the resource	DGA
7) Monitoring and control of the quality of water for specific uses	Servicio Agrícola Ganadero (SAG), Servicio de Salud, Servicio Nacional de Pesca, Subsecretaría de Pesca
8) Monitoring and control of effluents	SISS, Servicio de Salud
9) Elaboration of primary and secondary environmental quality norms and emission norms to water bodies	CONAMA, Servicio de Salud, DGA, SAG, DIRECTEMAR

**Table 4: Functions related to water management and operating institutions in Chile (DGA, 1999)**

Despite the fact that water institutions such as the DGA and the CONAMA exist, it is important to point out that water users have an extremely high freedom as regards the way they deal with this precious resource (in quantitative and qualitative terms). This is particularly true in the agricultural sector which accounts for 85% of the total consumptive water use. Institutions which have a coordinating function between the state and the water users are not prevailing in Chile (Häberle, 2007).

Now we will turn to the private institutions which are related to water resources management in Chile. Dourojeanni and Jouravlev (2000) state that user management irrigation canals have already existed during the colonial era and nowadays more than 4000 water user associations can be registered. The types of water user associations in Chile are threefold. First, the water communities exist which represent any group of users sharing a common source of water. Secondly, canal user associations (Asociaciones de Canalistas) are formal bodies which possess a legal status. Thirdly, vigilance committees (Juntas de Vigilancia) are present which have a geographic outreach, namely it comprises all the user and canal associations on a river, river section or stream. These Juntas are charged to administer water and allocate water to different canals. Some of these committees administer reservoirs for irrigation water storage and assist in the financing of small hydroelectric plants.

#### **4.1.2. Legal water management framework**

Chile's water management is known worldwide for its free-market orientation, as it is still deeply embedded in the regulations set out by the Water Code (Código de Aguas) from 1981 during the military government. Since the 1967 water regulations restricted the scope for private property rights. This is why the military regime reviewed both land ownership and the 1967 Water Code (Madaleno and Gurovich, 2007). From that time on, water was considered as a national asset available for private property ("bien nacional de uso público") which can be freely traded on a market. Before the promulgation of the Water Code in 1981, the water allocation in Chile had the following characteristics: existence of comprehensive state regulation and control, water coupled to land ownership, obligation to use water under the water right, private transactions and transfers were illegal (Pedersen, 2006).

During the 1970s and 1980s, the Chilean government was advised by the US-trained free-market economists, also known as the Chicago Boys. They helped the government to re-write the Water Code and they promoted the introduction of market mechanisms in the water sector

(Bauer, 1998). They believed that market mechanisms could help motivate users to save water, sell their surplus, and trade their rights to other sectors with higher value uses (Mentor, 2001). This means more specifically that from 1981 onwards, water use corresponds to every inhabitant, yet the right to extract water is only granted to private people. Thus, in Chile the right to use water becomes an excludable commodity with the same jurisdictional protection as any other commodity (Matus et al, 2004). To put it that way: there are neither charges for the use of water, nor taxes specifically linked to water, as well as no payments for wastewater discharges. Dourojeanni and Jouravlev (2000) state that generally, one can say that there is a gratuity in the maintenance and possession of the resource, in its use, as well as in the generation of negative external effects. In that legal context and with the promotion of private initiatives to invest and take care of the functions of water, one can note that the state takes a back seat with only some subsidiary and secondary roles of regulation, development and promotion (Matus et al, 2004). Madaleno and Gurovich (2007:440) also note that “political power gave away a common and previously public commodity without minimum ecological capacity definition for streams and groundwater sources”.

Since the 1990s, a need for reforming the Water Code was perceived as imperative. A new focus on social and environmental issues was apparent reflected in an ideological shift in the thinking of the government seeking to better safeguard the health of Chilean people and their environment. An example underpinning this change is the 1994 Basic Environmental Law which is the first holistic environmental legislation which considers problems of water pollution seriously (Pedersen, 2006).

In fact, the reasons for the consideration of a Water Code Reform were the increase in observed water contamination and the accumulation of water rights in an unprecedented and excessive way. After a 12 year long debate, the new Water Code was passed in 2005 (Ley N° 20.017) which “sought to correct earlier problems and to address social equity and environmental sustainability concerns that were largely absent from the 1981 legislation” (Pedersen, 2006:4). Matus et al (2004) list the principal modifications in the Water Code of 2005 in their paper “Los Recursos Hídricos en Chile: los principales desafíos para la sustentabilidad”:

1. Justification of the water quantity applied for in function of the economic activity to carry out. The General Water Directorate can refuse those petitions which do not adjust to reality



2. Charge the patent for non-use of water as a disincentive to speculation and hoarding. This charge becomes due in case of non-existence of water capture systems. There will be a regional difference in the level of charging. For example, in the North water is scarcer, therefore more expensive.
3. Improving the mechanisms of bidding water rights. Up to the year 2005, there was a period of time of three months to bid again when there was more than one petitioner for a water right. With the 2005 Water Code this period of time was extended to six months in order to curb a competitive access to the use of the resource.

Carriger and Williams (2005) note the following changes within the 2005 Water Reform:

1. Giving the President authority to exclude water resources from economic competition in cases where doing so is necessary to protect the public interest.
2. Obliging the General Directorate of Water Resources (DGA) to consider environmental aspects in the process of establishing new water rights, especially in terms of determining ecological water flows and protecting sustainable aquifer management.
3. Charging a license fee for unused water rights and limiting requests for water use rights to genuine needs, as a deterrent against hoarding and speculation.

#### **4.1.3. Policy water management framework**

Preliminary to the water reform in 2005 and as a support to the proposed amendments to the Water Code, the General Water Directorate released a non-binding National Water Policy in the year 1999. This policy asserts that water is a “national good for public use”, but stresses the prevalent international approach of integrated water resources management and public participation and that water is an economic good, meaning that it should be handled in an efficient way (Hearne and Donoso, 2005). Moreover, this environmental guideline recommends the creation of institutions to foster a sound water planning and management at the basin and national level. As a first step towards the realisation of this goal, the DGA proposes water resources committees in each basin. These bodies would include both private and public sector participants and would support basin planning for IWRM (*idem*, 2005).

Trough the National Water Policy Plan the DGA developed water management plans which is defined as an indicative planning instrument which contributes to orientate and coordinate

public and private decisions with the scope to maximise social, economic and environmental welfare related to water (DGA, 1999). It includes the following lines of action (UNEP, undated):

- improvement of the efficiency in the use of water
- expansion of the knowledge on this resource
- stipulation of water and the environment
- technical and cultural formation and training related to water
- advocacy of the knowledge on the water resources and on mitigating floods

The most recent policies developed jointly by the Ministry of the Environment (CONAMA back then) and the General Water Directorate seek to promote a sustainable and equitable management of hydrological basins. The most prominent is the 2007 National Strategy of Integrated Management of Hydrographical Watersheds (*Estrategia Nacional de Gestión Integrada de Cuencas Hidrográficas*). Its objective is the protection of the hydrological resources, in quality as well as in quantity, in order to preserve the resource for human consumption purposes, but it also seeks a harmonisation between ecosystem conservation objectives and the sustainable utilisation of the resource by the economic sector (CONAMA, 2009). The principle activities include the following: 1) create an institution to implement the strategy, 2) adjust and optimise public instruments as standards according to the strategic objectives, 3) improve the information base for decision-making related to the management of natural and water resources and 4) put into practice a pilot experience which allows to gradually implement the scope of the management objective and adjust subsequent design if necessary (CONAMA 2007).

In order to implement this new National Strategy, a collaboration between the German Technical Cooperation Agency (GTZ) and the National Commission of the Environment (CONAMA) has been launched in 2008 (*idem*, 2009) with the project called ‘Proyecto-Cuencas GTZ/CONAMA’. The utmost scope of this project is the elaboration of an integrated river basin management plan for the watersheds in Chile based on the IWRM concept. Three pilot watersheds in this project were chosen in different geographical zones: río Copiapó, río Rapel and río Baker.

## ***4.2. Water quality management in Chile***

The political constitution of the Republic of Chile establishes that every Chilean person has the right to live in a pollution-free environment. This is developed in the General Law on the Environment Nr. 19.300 from 1994 and specific national norms translated this right, such as the Water Code, the Forest Law Nr. 4.363, the Law on Fishing and Aquaculture Nr. 430/91 and the emission norm Nr. 90/2000 which regulates the pollutants associated with the discharge of liquid waste to marine and continental water bodies (UACH, 2009; CONAMA, 2010).

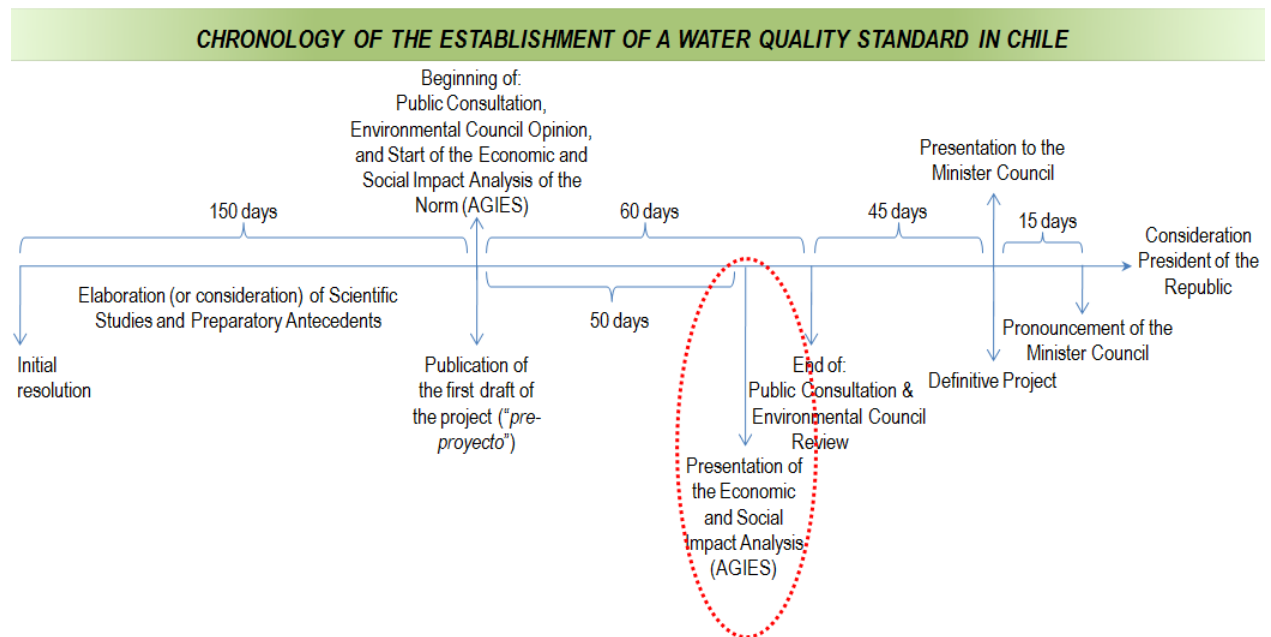
In Chile, the regulation affecting environmental management of water bodies is relatively new. Only since 1994 there have been specific environmental laws and institutions created in relation to environmental issues (Villalobos, 2005). There are three types of standards which can be established: emission standards, primary quality standards (for human health protection) and secondary quality standards (related to environmental protection). For more details on the definition of each standard, please refer to the chapter “Economic instruments in water resources management” under the section “Polluter-pays-principle in Chile”. Since 1998 three emission standards have been promulgated: one for wastewater discharged into sewage systems, one for wastewater discharged into surface water (rivers, lakes and seas) and one for the wastewater discharged into groundwater (Kraemer et al, 2003). Besides the dictation of the secondary environmental quality norm for the Lake Villarrica, there has been only one other quality standard established for a lake (Lake Llanquihue) in the year 2004 (Villalobos, 2005).

According to Donoso and Melo (2006), the traditional command-and-control instruments have been the only policy instruments serving water quality management in Chile. Further they state that this strategy has been heavily criticised as it fails to reduce water pollution levels in the country and the enforcement of traditional methods is rather weak.

The whole process of the establishment of a water quality standard in Chile requires nearly one year (please refer to Figure 8). The first phase includes the elaboration of the project supported by scientific and technical studies. Then, there exists a phase of public consultation and citizen participation and at the same time the Economic and Social Impact Analysis of the Norm, also called AGIES in Spanish (*Análisis General del Impacto Económico y Social de la Norma*), is carried out. The last phase deals with the dictation of the standard. It includes a report of the public consultation process, the elaboration of the final standard and the

presentation of the definitive standard to the environmental council and the minister council  
As a last step, the President of the Republic considers and signs the final environmental quality norm (Ministerio del Medio Ambiente de Chile, 2010).

As can be taken from the Figure 8, the General Analysis of the Economic and Social Impact of the Norm (AGIES) is quite a long process (50 days) and the results and findings of this report are of high importance for the implementation of the quality standard in Chile.



**Figure 8: Process for the dictation of environmental quality and emission norms in Chile (Adapted from Ministerio del Medio Ambiente, 2010)**

Before a secondary environmental quality norm is established (such as is presently the case for the Lake Villarrica in the Region of the Araucania), an AGIES has to be carried out with the objective to evaluate the effects or impacts derived from the implementation of the quality standard. The AGIES puts an emphasis on the costs and benefits of the future norm for the population, ecosystems, the emitting agents and those affected by the standard. More precisely, this study tries to prove that the net benefits generated through the application of the norm (resulting from the protection of the environment) outweigh the costs in distinctive productive sectors of a watershed.

The systemic relationship between the society and the environment is highlighted through the AGIES. As DGA and Applus (2008) note, the balance between the protection of the environment, the local socio-economic development and the improvement of the quality of

life for the people (the sustainability triangle) is of chief importance in the implementation of the norm.

In case the primary or secondary environmental standard is unaccomplished, the Chilean regulation foresees prevention or decontamination plans, such as shows the diagram below (Figure 9). These plans oblige polluters to assume the costs of cleaner production processes as a reaction to the environmental damage already produced (Valenzuela, 2004). In case one value reaches 80 to 100% of the standard a prevention plan has to be established, since the zone is declared as latent. And if one value exceeds the standard the area is declared as saturated. In that case, a decontamination plan is required (Villalobos, 2005).

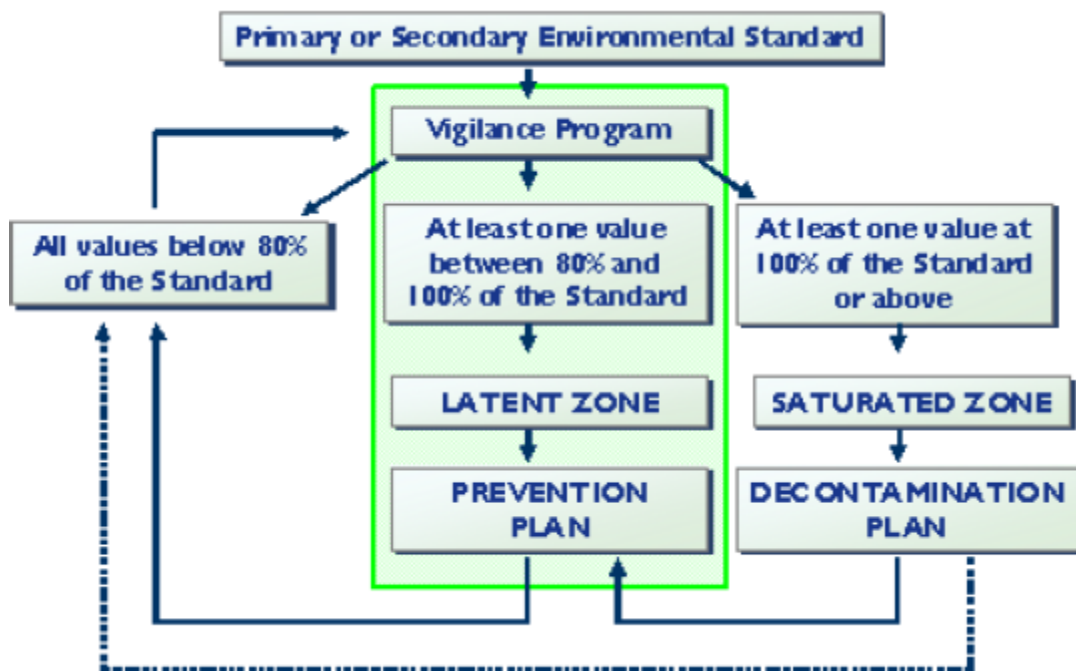


Figure 9: Diagram showing when prevention and decontamination plans enter into force according to the Chilean legislation (Villalobos, 2005)

### ***4.3. Assessment of IWRM in Chile***

This section critically assesses whether IWRM has already materialised in Chile and what the impediments to an integrated management of water resources are.

According to Davis (2004), IWRM practices “existing legislation and management practices do not address IWRM nor watershed management. Water quantity, water quality, and ecological issues are governed by separate legislation; each one does not take full cognizance of provisions in the others” (Davis, 2004:4). Even though there are some organisations and authors praising the success of Chile’s Water Code (such as the economists of the World Bank and the American Inter-Development Bank), there have been many studies by academics showing that there are still obstacles in achieving IWRM goals in Chile. These include the following:

- Economic and water use inefficiencies: According to Davis (2004), in many river basins water rights are not assigned to the user with the highest value or water rights do not serve the highest economic use. Furthermore, there is little incentive to use the water resources in an efficient way. When water rights are given away by the DGA, the water users do not have to specify / justify the purpose of the use. As a result, there are many cases of speculation, accumulation, hoarding and excessive monopoly power of water rights (Dourojeanni and Jouravlev, 2000). Water right owners rarely sell unused / “surplus” water, as they protect themselves against drought years or they believe that the value of their rights might increase over time (Bauer, 2004: 80). According to Bauer (1998), the market advantage should allow a more flexible reallocation of water resources and markets would become more active as water demand increases and scarcity rises enough to overcome transaction costs. Rios and Quiroz (1995) however find that in Chile’s water markets the transaction costs are high due to an incomplete legalisation of water titles, the lack of infrastructure (to transport water from one place to another) and due to the free-rider problem. Therefore, the water market is rather stagnant and inactive.
- Externalities and conflicts: Private water rights trades do not underlie any formal regulatory review. In Chile, the laissez-faire water policy (Water Code) encompasses externalities: water right trades can have adverse impacts on third parties due to

overconsumption or pollution of water resources by some users (Davis, 2004). Davis (2004: 5) further notes that “user conflicts exist between water user associations as well as between hydropower and other users”. Conflicts carried forward to court cases have mostly resulted in inconsistent outcomes (Bauer 1998). A further problem in Chile is that the Water Code has had mainly negative impacts on low-income stakeholders (such as peasant farmer groups or indigenous groups). The reasons are that they do not possess access to information, they are unable to participate in the market as sellers (lack of financial resources, credit to buy rights, etc.) and they lack social and political influence to defend their interests, also when it comes to the formulation of future water policies which will affect them substantially (Bauer, 1998; Davis, 2004).

- Single purpose planning in watersheds: A further evidence that IWRM has not materialised yet in Chile is the fact that single purpose planning and reservoir operation for limited objectives was prevalent in the 1990s. In many river basins, the scope of constructing dams has been mainly of economic nature. Further, the maximisation of power generation stood in the forefront. The consideration of social or environmental consequences (such as in-stream flow requirements) has been only secondary or sometimes not considered at all.

## 5. THE VILLARRICA LAKE WATERSHED AND THE SOURCES OF LAKE CONTAMINATION

In Chile, there are more than 300 lakes, all known for the beauty and transparency of their waters. The Lake Villarrica which is located approximately 700 km south of the capital city Santiago is one of them. More precisely, it can be found in the Region IX of Chile called La Araucanía. The lake and its surrounding region are a major tourist development pole, attracting visitors not only from Chile, but also from foreign countries such as Argentina and Brazil. The Villarrica Lake hydrographic basin is characterised by the presence of protected natural reserves, two lakes (Villarrica and Caburgua), the rivers Trancura, Liucura, Turbio and Claro, the active Villarrica Volcano plus valleys and rural areas which are used for rural tourism practices and sportive activities in contact with nature, such as mountain bike, horseback riding, fishing, observation of flora and fauna, photography, kayaking and so forth. Clearly, the tourism sector presents a significant source of income for the population living in the Villarrica Lake drainage basin.

However, the tourism sector as a major source of income in this region is jeopardised by the fact that the lake has shown signs of degrading water and habitat quality in the last decade. This is evidenced by clear signs of eutrophication. Eutrophication is defined as a process whereby water bodies receive excess nutrients which stimulate excessive plant growth, e.g. algal blooms (Oxford Dictionaries, 2011). This process can be either human induced (e.g. introduction of untreated water, agricultural runoff, etc.) or naturally induced (erosion), and mostly involves the addition of nitrogen and phosphorous into the aquatic system. Some negative environmental effects can be the decrease in oxygen in the water body (hypoxia/anoxia) and it can further lead to fish death. In fact, there is growing evidence that the Villarrica Lake is shifting from an oligotrophic state with low levels of nutrients and productivity to a state of oligo-mesotrophy due to the high discharges of the nutrients phosphorous and nitrogen into the lake. In some areas, even signs of a eutrophic state have been monitored.

The fact that this region is a major tourist development pole coupled with the existence of antecedents revealing signs of a deteriorating lake and water pollution (a rise in the trophy of the lake), has pushed the government in the year 2010 to elaborate an environmental quality norm specifically for the Villarrica Lake (*Norma Secundaria de Calidad Ambiental para la Protección de las Aguas Continentales Superficiales del Lago Villarrica*). The Chilean



General Environmental Law Nr. 19.300 (*Ley de Bases del Medio Ambiente*) defines a *Norma Secundaria de Calidad Ambiental* as a norm which “establishes the values of the concentrations and periods, the minimum and maximum allowances of substances, elements, energy or a combination of these, whose presence or absence in the environment can constitute a risk for the protection or conservation of the environment, or the protection of nature” (Source: *Ley 19.300 de Bases del Medio Ambiente*). In the specific case of the Villarrica Lake drainage basin, the utmost scope is to establish quality standards for the lake in order to rehabilitate its trophic state, which would most approximate the original and natural state of an Araucanian Lake. Ultimately, this would then ensure the conservation of its qualities as a site of scenic, touristic and environmental value.

This chapter will be outlined as follows. Firstly, the geographical and socio-economic background of the Villarrica Lake hydrographic basin will be presented. This part also includes data on the soil cover and use, the climate and tourism numbers in the river basin. Secondly, the sources of lake contamination will be established, divided into point-sources (known single source of contamination) and non-point sources / diffuse contamination (not a single identifiable origin of pollution). This part is important as it highlights the economic sectors or activities within the hydrographic basin which contribute to the introduction of nutrients (phosphorous and nitrogen) into the water bodies and ultimately into the lake. Furthermore, the loads of nitrogen and phosphorous from each contamination source will be quantified (in tons per year). After the sources have been identified, the current trophic state of the lake is shown and a risk assessment will be carried out. Tightly linked to this part, is the identification and determination of a yearly critical load (in tons) of phosphorous and nitrogen, so as to prevent the lake from eutrophication. In order to reach the nutrient loads proposed by the environmental quality norm, it seems relevant to identify the possible measures which could be implemented so as to lower the amount of nutrients emitted into the aquatic system. Therefore, for each source of contamination a set of measures will be displayed in an Excel Sheet. Not only is each technical measure described, but also its potential in reducing nutrient loads (in tons per year) and the associated costs are calculated. Thus, an attempt to perform a cost-efficiency ranking for each set of measures can be carried out. Finally, a programme of measures for the whole of the Villarrica Lake water basin will be worked out based on a selection of the most cost-efficient measures (this is determined by comparing and assessing the findings in the different elaborated excel sheets). Lastly, the associated total yearly reductions in phosphorous and nitrogen, as well as the total capital

costs are also highlighted and further recommendations (such as best management practices) will be displayed.

Having identified the sources of contamination / the polluting actors and the costs associated for the mitigation to restore the water quality in the Villarrica Lake water basin, there is the potential to internalise the environmental costs (which are the costs of damage that water uses impose on the environment and ecosystems and those who use the environment) by applying the polluter pays principle. Having said this, Germany's effluent charge (*Abwasserabgabe*) as a financing and steering tool will be presented and then the application of this economic mechanism to the Villarrica Lake hydrographic basin will be assessed.

## 5.1. The natural environment of the Villarrica Lake Watershed

### 5.1.1. Geography

The Villarrica Lake corresponds to a water body located in the South of Chile, more specifically in the pre-cordilleran zone of the Araucanía Region, Region IX of Chile. It is located at a latitude 39°18'S and a longitude 72°05'W and at an altitude of 230 metres. The lake has an elliptical surface of 175 km<sup>2</sup>, a major east-west axis of 22 km and a maximum depth of 165 metres (DGA and Applus, 2008), which is relatively shallow compared to other lakes of the region, such as Llanquihue (317 m) or Caburgua (327 m). Its volume averages 21 cubic kilometres, being the 8<sup>th</sup> biggest lake of Chile (UACH, 2008; SEREMI Medio Ambiente Araucanía, 2011; CONAMA 2010). Further morphometric data of Villarrica Lake can be found in Table 5.

**Table 5: Morphometric parameters of the Villarrica Lake, adapted from Campos et al (1983) and SEREMI Medio Ambiente Araucanía (2011)**

Parameters	Value	Unit
Latitude	39°18'S	°
Longitude	72°05'W	°
Altitude	230	m
Maximum length	23,5	km
Maximum breadth	11,2	km
Mean breadth	7,6	km
Shoreline	71,2	km
Surface area	175,9	km <sup>2</sup>
Maximum depth	165	m
Mean depth	120	m
Volume	21.0	km <sup>3</sup>

The Lake Villarrica basin which, as its name reveals, also comprises the Villarrica Lake, belongs to a bigger and wider hydrographic watershed which is called the Toltén river basin. The Toltén watershed has an extension of 7 880 km<sup>2</sup>. The Villarrica Lake basin expands in the upper zone of the Toltén Basin. It comprises all the water bodies and streams which discharge their waters into the Villarrica Lake. The drainage area of the lake is 2 920 km<sup>2</sup>, which corresponds to 16,6 times the area of the lake (UACH, 2008; DGA and Applus, 2008; Campos et al, 1983). Alongside various smaller and secondary affluents, the River Trancura presents the principal tributary of Villarrica Lake, as it delivers around 90% of the entering flow rate. The average monthly flow rate of River Trancura varies between 28,7 m<sup>3</sup>/s in

March and 323 m<sup>3</sup>/s in August. Toltén river is the only effluent of Lake Villarrica and it is located at the west shore (UACH, 2009; Campos et al, 1983). Its average annual flow rate amounts to 280 m<sup>3</sup>/s (CONAMA, 2010).

Lake Villarrica is of glacial origin (DGA-UACH, 1994). Its watershed was shaped by the action of glaciers which coalesced at the altitude of present-day Curarrehue. One of the glaciers slid on a North-South axis where the Maichín river currently flows and the other glacier moved northwards where the Río Trancura flows nowadays (CONAMA, 2010). In the southern end of the lake can be found the active Villarrica volcano with 2 850 meters of height (Campos et al, 1983).

The main urban areas of the watershed are the cities Villarrica, Pucón and Curarrehue, located at 84, 109 and 142 km respectively east of the regional capital Temuco. According to the current political-administrative division of the country, the area defined by the Villarrica Lake hydrographic basin comprises not only the communal territories of Villarrica, Pucón and Curarrehue but also a small surface of the communes Cunco, Pitrufquén and Freire (see Figure 10) (DGA and Applus, 2008; UACH, 2009). The Universidad Austral de Chile (2008) has divided the Villarrica basin into fourteen sub-basins. Table 1 in the Appendix indicates the names of each sub-basin and it includes the respective extension in hectares.

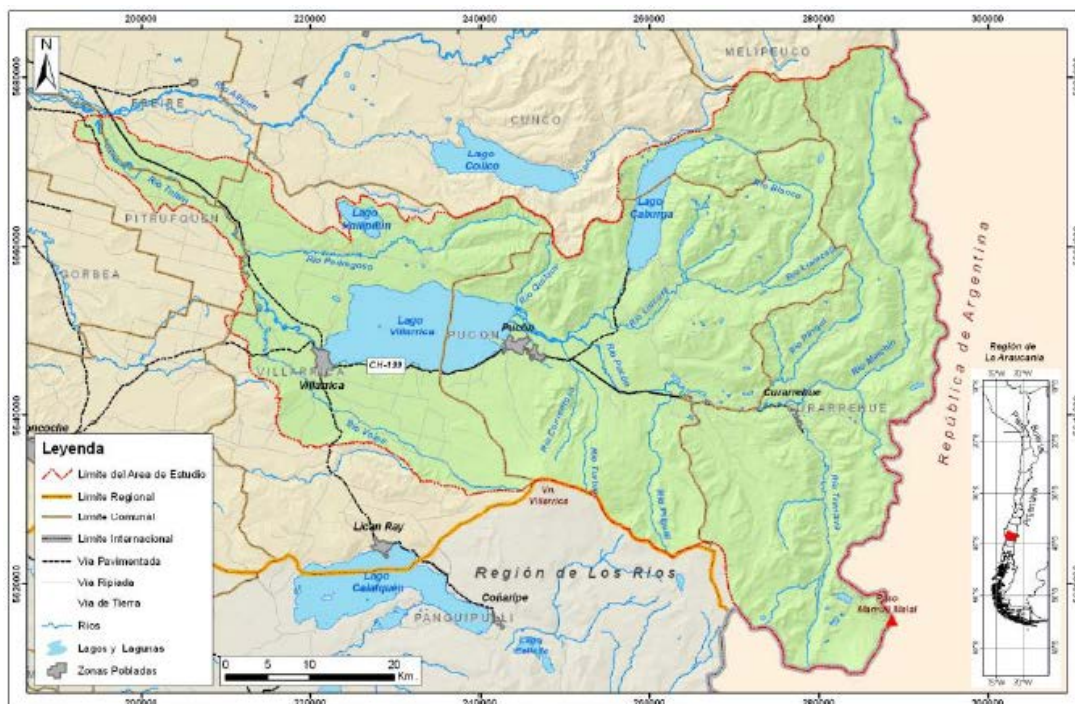


Figure 10: Map of the Villarrica Lake hydrographic basin (DGA and Applus, 2008)

### **1.1.1. Vegetation and soil cover**

As we have seen in the previous part, the surface of the Villarrica Lake hydrographic basin amounts to approximately 292 000 hectares. In this part, the vegetation and soil cover of the river basin are presented. For a map of the river basin indicating the altitudes and a map showing the land uses in the Villarrica basin, please refer to Figure 1 and Figure 2 in the Appendix.

DGA and Applus (2008) state that 12% of the watershed corresponds to valleys, 80% to a mountainous landscape and 8% of the area is occupied by the Lakes Villarrica and Caburgua. In the mountain zones, 1250 metres above sea level can be found the areas deprived of vegetation consisting of rocky outcrops, snow and recent volcanic matter. Further downhill (below 1300 metres) begins to develop the native vegetation, more specifically the Valdivian Andean Forest which is the product of high rainfall most of the year in that region. Generally speaking, the native vegetation unfolds in zones higher than 700 metres above sea level. Below that level, the soils are covered with secondary native forests and shrubs, which is referred to in Spanish as “vegetación renoval y matorral” by Chile’s National Forest Corporation, CONAF (2011). Below the secondary native forests and shrubs are located the main valleys, which are covered with perennial (31961 ha) and annual (151,4 ha) prairies and pasture. Further land uses worth mentioning are forest plantations on the slopes of mountains and in the principal valley (655 ha) and the urban areas which account for 1170 hectares (DGA and Applus, 2008).

### **1.1.2. Climate**

According to Köppen’s climate classification, the Villarrica river basin is characterised by a temperate climate with a Mediterranean influence (temperate humid intermediate) or according to Emberger’s classification scheme, a mediterranean per-humid (ever-wet) climate, characterised by short, temperate and cool summers and cold and humid winters (DGA and Applus, 2008). In the cordilleran zone the “clima de hielo de altura” is predominant. The climate is influenced by the temperatures which normally do not go beyond over 0°C due to the high altitudes (UACH, 2008). In table 6 the climatic characteristics of the three communes (Villarrica, Pucón and Curarrehue) are exposed.

**Table 6: Climate characteristics of the communes within the Villarrica Lake hydrographic basin (adapted from DGA and Applus, 2008)**

Commune	Thermal regime	Water regime	Dry months
<b>Villarrica</b>	Varies between a max. in January (23,2°C) and a min. in July (4,9°C)	Average annual precipitation: 2140 mm	Dry period of 2 months
<b>Pucón</b>	Average annual temperature: 12°C	Average annual precipitation: 2500 mm	2 months, though most rainfall occurs between April and August
<b>Curarrehue</b>	Max: 21,4°C and min: 2,1°C in July. Thermal regime is very cold during the winter and frosts all year round due to the altitude	Average annual precipitation: 3644 mm	No dry period

## 5.2. Socio-economic background of the Villarrica Lake Basin

### 5.2.1. Population

The number of inhabitants living within the Villarrica Lake hydrographic basin amounts to 73 422. This population number represents 8,4% of the total regional population (see Table 7). As regards the population density, it equals 19,8 inhabitants per square kilometre, which is less than the regional level (27,3 hab/km<sup>2</sup>). Only Villarrica with 35,3 hab/hm<sup>2</sup> exceeds the regional level (INE, 2002).

Comuna	Hombres	Mujeres	Población total	% Regional	Densidad (hab/km <sup>2</sup> )	% Pob. Rural
Villarrica	22.694	22.837	45.531	5,2%	35,3	32,2
Pucón	10.705	10.402	21.107	2,4%	16,9	34,4
Curarrehue	3.586	3.198	6.784	0,8%	5,8	72,6
<b>Total</b>	<b>36.985</b>	<b>36.437</b>	<b>73.422</b>	<b>8,4%</b>	<b>19,8</b>	<b>63,4</b>

**Table 7: Population in the Lake Villarrica water basin, (DGA and Applus, 2008)**

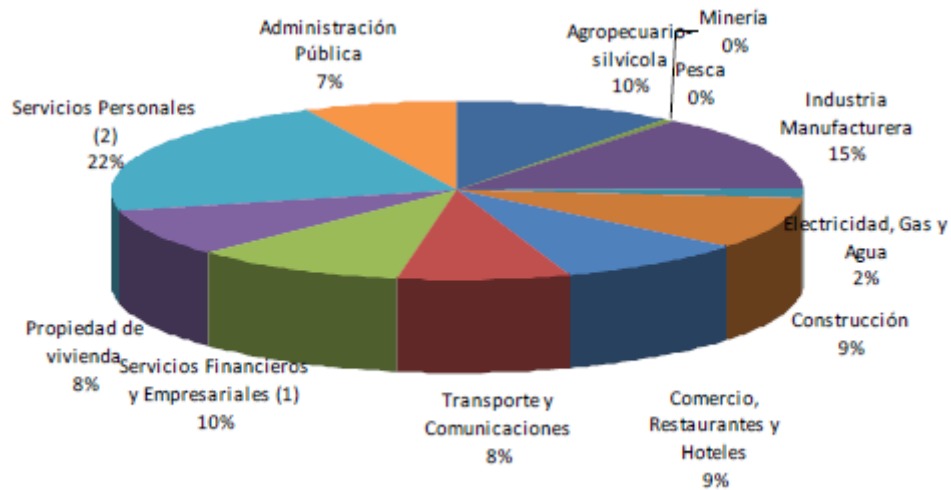
### 5.2.2. Economic activities

As within each watershed, the water components (river, streams and lakes, etc.) provide ecosystem services which are often vital for related human and economic activities. These ecosystem services, such as a good water quality, have also been important within the Villarrica basin. In fact, the basin's water quality has enabled the development of subsistence farming, an intensive exploitation of tourism services and the functioning of a series of aquacultures as economic activities of major scale. These activities effectively bring about 8,7% of the employment at regional level (INE, 2002).

According to the agricultural and livestock census of 2007, there are 4146 production systems which deal with agriculture, forest or livestock production in the communes of Villarrica, Pucón and Curarrehue, which totals 197 445 ha. The agricultural sector accounts for 87% (172 873 ha) of this surface. Comparing the three communes, Villarrica is the one which records most agricultural practices, which can be explained by its topographic conditions. In fact, Villarrica possesses smooth gradients than Pucón or Curarrehue which are located farther east closer to the mountains (DGA and Applus, 2008).

However, the most important industrial activity in the region presents the **aquaculture**. The government's environmental evaluation service (Servicio de Evaluación Ambiental) defines these aquaculture activities as "cultivation centres of diverse fish cultures which contemplate phases of incubation, breeding and reproduction" (SEIA, 2010). The revision of these projects shows that they correspond mainly to the production of juveniles and ovas of Salmonidae species (principally Atlantic salmon). These piscicultures consider the installation and equipment of hatcheries and basins for the cultivation and fattening of fishes.

Figure 11 displays the contribution of each economic sector to the GDP of the Lake Villarrica hydrographic basin in the year 2002. It shows that the first most important economic sector contributing to the basin's GDP is the personal services sector (with 22%). It includes public and private education and health, but also other weightily services related to tourism. This sector is followed by the manufacturing industry (with 15%) and then by the agricultural and forest production (10%) and the financial and business services (10%).



**Figure 11: Contribution of each economic sector to the GDP of Lake Villarrica water basin (DGA and Applus, 2008)**

As already mentioned in the previous paragraph, the **tourism sector** presents a significant source of income for the population of the Villarrica Lake water basin. This region is a major touristic pole of the country due to the presence of protected natural reserves (e.g.: Villarrica National Park), the lakes Villarrica and Caburgua, the rivers Trancura, Liucura, Turbio and Claro, plus the valleys and rural areas which are used for rural tourism practices and sportive activities in contact with nature, such as mountain bike, horseback riding, fishing, observation of flora and fauna, photography, and much more (Municipalidad de Pucón, 2007). According to the study “Tourist behaviour during peak season 2007 in the Araucanía Lake District” carried out by the National Statistical Institute of Chile (INE) and the Regional Bureau of the Araucanía, the total influx of tourists in the Araucanía Lake District during the months of January and February in the year 2007 was 147 376 (see Table 8). The total estimated contribution of the tourism sector to the economy of the Lake District zone amounts to \$18.630 millions of pesos. The income for the three communes Villarrica, Pucón and Curarrehue in January 2007 was \$8.382 millions of pesos, mainly coming from Pucón (58,2%) and Villarrica (41,5%). In February 2007, the income from tourism in the three communes totalled \$10.247 millions of pesos.



<b>Comuna</b>	<b>Enero</b>	<b>Febrero</b>	<b>Total</b>	<b>%</b>
Curarrehue	736	496	1.232	1%
Pucón	41.764	38.713	80.477	54%
Villarrica	30.251	35.416	65.667	45%
<i>Total</i>	<b>72.751</b>	<b>74.625</b>	<b>147.376</b>	<b>100%</b>
<i>%</i>	<b>49%</b>	<b>51%</b>	<b>100%</b>	

**Table 8: Total of tourists in the communes Curarrehue, Pucón and Villarrica during the summer months of January and February 2007 (INE and Dirección Regional de la Araucanía, 2007)**

In my interview with the National Tourism Service of the Araucanía Region (SERNATUR), affiliated to the Ministry of the Economy, Development and Tourism, it has been stated that the tourism in the three communes proximate to the Villarrica Lake (Pucón, Villarrica and Curarrehue) has altered in the last 15 years. The aspects of this change can be seen in the profile of the tourists enjoying the Villarrica Lake and its surroundings. In fact, the average daily expense per tourist has decreased, more people with less resources arrive, the number of tourists staying at places of residence (instead of hotels) has augmented, further translating into less expenses at restaurants for example and finally, it has been recorded that tourists of higher socio-economic status and with more financial means now prefer staying at other more remote places of the river basin, such as Lake Caburgua which is located further up the Andes. As regards the quality of the lake's water, tour operators have recorded a rise in customer complaints. Firstly, the color and transparency of the water of the lake is affected due to algal blooms in summer, especially in the beach zones of Pucón. A second negative environmental perception is the rise in motorboats being a source of noise and bad smell due to hydrocarbon traces, thus also affecting bathing activities. A third point related to the rise in the number of tourists is the increase in solid waste disposed in the environment. All in all, the tourism of Lake Villarrica has experienced an extremely asymmetrical development both in space and time: a steep rise in the number of tourists is predominantly concentrated on the southern shore of the lake and this occurs only in the summer months January and February.

In this section of the thesis, we have identified the most important productive activities, such as the industrial activities (aquaculture), tourism, agriculture, forest and livestock production. All of these economic activities greatly benefit from the ecosystem services provided by the Villarrica Lake water basin. Thus, as DGA and Applus (2008) state, it seems clear that the maintenance of a good quality of the lake is of interest for all the users of the river basin. DGA and Applus further put that this common interest shared by all the users is one essential

reason for the application of the environmental quality norm (Norma Secundaria de Calidad Ambiental del Lago Villarrica), as it would ultimately secure a high water quality standard within the basin.

Alongside to the public institutions and organisations which are involved in the development and application of the environmental quality norm (such as the regional ministries, municipalities, etc.), DGA and Applus (2008) have identified further key actors in the Villarrica Lake basin which will be most affected (either positively or negatively) by the planned environmental quality norm. These are mentioned as follows:

- Aguas Araucanía S.A. (water supply and sanitary company)
- Aquaculture companies (in the communes of Villarrica, Pucón and Curarrehue)
- Municipality of Curarrehue
- Drinking water committee of Curarrehue and other rural drinking water committees
- Peasants and agricultural communities
- Property development companies operating in the communes of Villarrica, Pucón and Curarrehue

### ***5.3. Point-source contamination of the Villarrica Lake***

#### **5.3.1. Housing and wastewater**

The Villarrica Lake is a water body which constitutes a major touristic attraction in the Region IX of Chile. The sustained growth in the tourist sector has translated into an expansion of constructions (hotels, restaurants, cabanas, campings), especially on the southern shore of the lake on the road between Pucón and Villarrica. Furthermore, constructions of private residential homes, apartment buildings and condominia have experienced a rise in the areas at close proximity to the lake.

The urban areas of Pucón and Villarrica possess a public system for the elimination of wastewater from households and both cities dispose of a wastewater treatment plant administered by the water supply and sanitary company Aguas Araucanía.

In the case of Villarrica, the operational zone of the company Aguas Araucanía covers nearly the whole of the town centre (DGA and Applus, 2008). The wastewater treatment plant in **Villarrica** is located in the sector Putúe Bajo, which discharges its water into the Toltén River

which is the effluent of Villarrica Lake. Therefore, this treatment plant is not a source of contamination or a factor for the eutrophication of the lake.

In the case of **Pucón**, the picture looks different. Even though the Pucón wastewater treatment plant does hold the environmental permits to discharge its treated water into the river Claro, there have been numerous reports of incidents and operational problems of this plant (Personal communication with the municipality of Pucón). In fact, it has been reported that there have been episodes of direct discharges into the Lake Villarrica (DGA and Applus, 2008). In my interview with the water supply and sanitary services company Aguas Araucanía, it has been stated that in the case of the wastewater treatment plant of Pucón a special type of bypass is used in episodes of abundant rain. The excess wastewater which cannot be treated directly is firstly diverted into a lagoon situated close to the plant. As soon as the capacity of the plant permits it, the excess sewage water is taken from the lagoon and treated in the plant before it is discharged into the Río Claro. Thus, I have been told by Aguas Araucanía that at no time untreated water is directly discharged into water bodies. A further point to note is that the urban growth of Pucón has exceeded the operational area of the sanitary services, meaning that in this commune there are sectors (such as Villa Trancura or Caburgua) which have implemented their own drainage solutions (such as septic tanks) (*idem*, 2008; UACH, 2009).

In the commune of **Curarrehue**, there exists a public drainage system, but there is no wastewater treatment system available. As of March 2009, the untreated water of this commune was discharged at seven spots directly into the Trancura river. These direct domestic discharges along the course of the Trancura river have implications on the quality of Lake Villarrica, since the Trancura river is the principal affluent of the lake (DGA and Applus, 2008). Assuming a medium concentration of both phosphorous and nitrogen in the untreated sewage of the commune of Curarrehue of 50 mg/L for N and 9 mg/L for P (Muttamara, 1996 and US EPA, 2000) and a population number of approximately 7000, the initial untreated wastewater which is dumped into the Trancura River equals **76,7 tons of nitrogen** and **13,8 tons of phosphorous annually**.

In the year 2006-2007, (self-control) measurements on the concentrations of phosphorous and nitrogen have been carried out in the wastewater treatment plant of Pucón. The following Table 9 displays the reported concentrations.

<b>Industrial premise</b>	<b>Period</b>	<b>P Total (mg/L)</b>	<b>N Total (mg/L)</b>	<b>Receiving body</b>
<b>PTAS Pucón</b>	06/09/06 – 26/09/07	0,2 – 1,99	0,7 – 18,3	Río Claro
<b>Average</b>		1,33	5,7	
<b>Median</b>		1,48	4,8	

**Table 9: Measurements of P and N concentrations by the Pucón Treatment Plant in the time period September 2006 – September 2007 (Adapted from UACH, 2008)**

Taking into account the reported median phosphorous and nitrogen concentrations from the above table and with an estimation of an average flow rate of 9000 cubic metres daily, the following discharges of the plant Pucón to Lake Villarrica occur: **4,9 tons of P per year and 80,8 tons of N per year** (UACH, 2008)

However, the drainage system operated by Aguas Araucanía does not cover the infrastructure expansion area located on the southern border of Lake Villarrica. These houses rather have particular solutions for the elimination of excrements (such as septic tanks) which is a factor for the phosphorous introduction into the lake. This is particularly true since the area close to the lake is characterised by sandy soils, i.e. being highly permeable, thus promoting the flush of nutrients into the lake through the groundwater (Fundación Red Nuevas Ideas, 2006). DGA and Applus (2008) also underline that the inexistence of a drainage system to eliminate the wastewater constitutes an important part of the phosphorous and nitrogen supply into the Lake Villarrica.

As has been depicted in the paragraphs above, the domestic wastewater discharges without any treatment generate multiple negative effects on the receiving water bodies. The primary impact is the deterioration of the water quality due to the insertion of organic materials, nutrients (phosphorous, nitrogen), a high biological oxygen demand (BOD), coliform bacteria, which can ultimately lead to the eutrophication of the aquatic system (Vollenweider, 1968).

In its report “Diagnosis of the Water Quality of Lake Villarrica”, the Universidad Austral de Chile calculated the influx of phosphorous and nitrogen to the lake from the houses located on the southern shoreline. Considering that the daily discharge per person amounts to 4,1gr of phosphorous and 20gr of nitrogen (Campos, 1991) and considering the seasonal variability of people residing in that area with peaks in the summertime, the study has found a total

discharge of 2,2 tons of phosphorous and of 6,1 tons of nitrogen to the Lake Villarrica per year (UACH, 2009; Fundación Red Nuevas Ideas, 2006).

### 5.3.2. Aquacultures

A further point source contributing to the contamination of the Villarrica Lake is the operation of aquacultures in the watershed. A report of the Universidad Austral de Chile in 2009 states that a total of 17 aquacultures are in place in the Villarrica Lake hydrographic basin. Most of these productions are oriented towards the procurement of eggs (ova), alevins and juveniles from salmonids (*Salmo salar*, *Onchorynchus mikiss*, *Salmo trutta*, amongs others). As regards the characteristics in the development phase, one observes that most aquacultures are oriented towards the procurement of eggs (13 of them) and alevins (15), whilst five produce smolts, three juveniles and two of them keep adults and seven maintain spawning stocks, called *reproductores* in Spanish. For a table displaying the activities of each aquaculture company, please refer to Table 2 in the Appendix. The Table 10 below presents a list of all the aquacultures in the Villarrica Lake basin, their location (i.e. commune) and the flow rate in the production process. In relation to the use of water in the production process, one can find that in total the 17 aquacultures have a demand equalling to 13 665 L/s corresponding to a total daily flow rate of 1 180 656 cubic metres.

PROPIETARIO	CÓDIGO CENTRO	SECTOR	COMUNA	Caudales empleados lt/seg
FUNDO LA CASCADA Y CIA. LTDA., SOC.	90030	LOS RISCOS	Pucón	260
FUNDO LA CASCADA Y CIA. LTDA., SOC.	90050	ESTERO LOS CHILCOS, FUNDO LA CASCADA	Pucón	800
MARINE HARVEST CHILE S.A.	90052	FUNDO LONCOTRARO	Villarrica	480
MARINE HARVEST CHILE S.A.	90055	FUNDO LONCOTRARO KM 14	Villarrica	1000
PISCICOLA HUILILCO LTDA.	90059	CARILEUFU	Pucón	110
ENTRE RIOS S.A.	90060	CABURGA	Pucón	1300
QUETRO S.A.	90062	CAMINO A RINCONADA	Curarrehue	3200
MARTINEZ NAVARRO CARMEN LUISA	90064	RINCONADA, CATRIPULLI	Curarrehue	268
METZGER BASAURE MARIANA CECILIA	90069	EL RADAL, QUETROLEUFU	Pucón	240
NICOLINI LEGUIA CARLA MARIANNA	90082	CARHUELLO	Villarrica	897
SALMONES MULTIEXPORT S.A.	90085	MOLCO ALTO	Villarrica	1000
AQUACHILE S.A.	90089	QUETROLEUFU	Pucón	450
IRIBARREN MARTON MARIA JOSEFINA	90090	FUNDO QUILENTUE	Villarrica	2000
RUIZ BUSTAMANTE CRISTIAN JUAN	90112	MOLCO	Villarrica	120
ULLOA FIGUEROA JESSICA MARITZA	90117	CAMINO A VILLARICA PUCON	Villarrica	40
PESQUERA LOS FIORDOS LTDA.	90118	CATRIPULLI	Curarrehue	1500
PESQUERA LOS FIORDOS LTDA.	90137	QUINA	Curarrehue	

**Table 10: List of operating aquaculture companies in the Villarrica Lake water basin in the year 2008 (UACH, 2009)**

As regards the loads of phosphorous and nitrogen discharged by the 17 piscicultures, the UACH (2009) has calculated that considering a medium production of 275 tons of alevins and 420 tons of smolts, the receiving water bodies would have to take up 3 370 kg of phosphorous

and 115 479 kg of nitrogen. This **equals to 3,4 tons of P and 115,5 tons of N per year**. This result for the year 2008 was found using a model by Torres and Meléndez (1988) which takes into consideration the following elements: the quantity of feeds supplied, the weight of the fishes at the beginning and the end of the development phase and the amount of phosphorous and nitrogen in the fishes and feeds administered. It should also be noted that the aquacultures in Chile need to have systems which reduce the quantities of suspended solids in their discharges. These systems have also been taken into account in the calculations of the UACH (2009). In the specific case of the 17 piscicultures in the Villarrica basin, they all dispose of either decantation basins or rotating filters (with cross-linked nets).

Etapa	Fósforo (Kg)		Nitrógeno (Kg)	
	Particulado	Soluble	Particulado	Soluble
Alevines	679	871	2.475	49.500
Smolts	755	1.064	3.024	60.480
<b>Total</b>	<b>1.434</b>	<b>1.935</b>	<b>5.499</b>	<b>109.980</b>

**Table 11: Total nitrogen and phosphorous contribution in the development phase of alevins and smolts, considering a biomass of 275 tons of alevins (5,0g) and 420 tons of smolts (70,0g) (UACH, 2009)**

Throughout my interviews with environmental institutions and municipalities in the region, it has been portrayed that fish farms in the Lake Villarrica basin have a rather negative environmental impact. Even though some aquacultures have signed up to clean production agreements, their bad reputation in the region has been continuously expressed. The first problem highlighted is that new installation permits to fish farms have been too lax and some of the companies find ways to escape the obligation to carry out environmental impact studies. Normally for each fish farm installation, an environmental permit needs to be given out and citizens have the capacity to express their concerns over it. However in my interviews I have conducted, the concern has been expressed that not the whole information is disclosed to the public. With partial information citizens therefore do not have the capacity to oppose themselves to a certain project. A further problem addressed is that the quality of the fish farms' industrial water discharges (*residuos líquidos industriales "RILES"*) are not monitored and controlled in an assiduous and sufficient way. Lastly, the environmental representative in the municipality of Pucón said that an environmental norm for the Villarrica Lake hydrographic basin defining the capacity of the fish farm discharges in the whole area has

been lacking up to now. To date, many aquacultures have been installed which supposedly fulfill the allowed concentration rates, yet the effect of all the seventeen fish farms together has not been computed. To this effect, it is stated that the future environmental quality norm for the Villarrica Lake will present an important step in the right direction.

## ***5.4. Non-point source contamination of the Villarrica Lake***

### **5.4.1. Introduction to diffuse pollution and soil use**

As we have seen in the previous sections, the water quality of the Villarrica Lake water basin is partly affected by localised sources of contamination such as from households, wastewater treatment plants or from other types of industrial activities. A further and considerable source of water pollution in this river basin comes from nonpoint sources. In the Villarrica basin, soil erosion is a major factor for the introduction of nutrients into the water bodies. The coefficient of nutrient exports is high from agricultural grounds, but as we will see in this part, the basin area covered by native forests is also a major criterion.

As regards the entire Araucanía Region (Región IX), the changes in soil uses between the years 1993 and 2007 are as follows. The major percental change between the years 1993 and 2007 occurred in the use of urban and industrial areas, with a 20,1% rise to 2 287,8 hectares. In absolute terms, the soil use with the biggest increment experienced the woodland with 179 440, 1 hectares, an increase of 13,1% between 1993 and 2007 (CONAF, 2009). However, in order not to be misled by this figure, it is important to clarify that the woodland augmentation is mainly due to the rise in forest plantations (220 854 hectares, 62,9%), whereas the native forests (which are worth conserving) show a cover decrease of -4,1% in that region. In the same line, as Chile's National Forest Corporation states, the gain of forest cover is reflected in the replacement of native forests by plantations and also by grass- and shrublands (*idem*, 2009).

The loss in native forest cover in favour of forest plantations is not only a specific problem of the Region IX of the Araucanía. In Chile, the lucrative wood extraction for commercial and export purposes has experienced a steady rise in the last years. As the figure of the UNECE and FAO (2002) shows, since 1990 the value of forest products exports has more than doubled, reaching \$2,200 million in 2001, which represents 13% of Chile's total exports in

that year. In July 2008, the government of Chile has enacted a law on the recuperation of the native forest and forestry development (Ley N° 20.283 *Sobre Recuperación del Bosque Nativo y Fomento Forestal*), in order to prevent further native forest losses in the future. This recent law seeks to protect, rehabilitate and improve the native species of the country, securing forestry sustainability through management plans and through preservation efforts (BCN, 2008).

Throughout the interviews I carried out in the region of the Lake Villarrica hydrographic basin, it has been highlighted that the 2007 law on recuperation of the native forest did not have a considerable impact up to now. On the contrary, the previous government incentive from 1974 which subsidises the reforestation of any species is still the most influential law. The environmental affairs representative in the commune of Pucón told me that the 1974 government reforestation incentive is still valid and in use nowadays. The issue linked to this incentive is that it does not differentiate between the reforestation of exotic or native species, the latter species not having the capacity to filter and absorb nitrogen and phosphorous from the soils. The result has also been a substitution of soils covered with native species to soils with plantations, thus generating a drastic boost in the market of exotic species such Eucalyptus and Oregon Pine in that region. A further important point to mention from the interviews with the municipality of Villarrica and the National Forest Corporation of the Araucanía Region (CONAF) is that a decree had been established in the 1970s which specifically obligates the preservation of the riparian vegetation of the Villarrica Lake. However, both the CONAF and the municipality of Villarrica stated that unfortunately due to a lack of control and monitoring (*fiscalización*) in the river basin, the compliance of this preservation decree has been rather poor.

#### **5.4.2. Nutrient exportation from soil cover**

In order to assess the export of nutrients from soils, first the soil cover and land use of the Villarrica water basin will be presented and then the nutrient export coefficients for the different types of land uses and covers will be displayed. The last part combines these two aspects and exhibits the total yearly amount of phosphorous and nitrogen introduced into the Villarrica Lake from soils (diffuse pollution).

According to the Universidad Austral de Chile (2008), the three most important soil uses in the Villarrica basin are the following: 31,8% of native forests, 25,4% of secondary forest



(renoval) and 17,9% of grassland. The soil uses and their respective surfaces (in hectares) are displayed in Table 12.

<b>Land cover (2008)</b>	<b>Area (in ha)</b>	<b>% of Total Land Cover</b>
Water bodies	23,457.4	8,01
Native forest	93,258.7	31,8
Shrubland	27,094.0	9,2
Snow	6,069.6	2,1
Plantations	3,201.3	1,1
Grassland	52,382.8	17,9
Bare soil	12,365.8	4,2
Secondary forests	74,481.6	25,5
Agriculture	19.6	0,01
Urban	439.9	0,15
<b>Total</b>	<b>292,770.7</b>	<b>100</b>

**Table 12: Land cover (in ha and % of total land cover) of the Villarrica Lake hydrographic basin (Adapted from UACH, 2008)**

The nutrient concentrations exports differ between soil cover types. Table 13 contrasts between different land uses: agricultural land concentrates most nitrogen (314,7  $\mu\text{g/L}$ ), followed by grassland (199,1  $\mu\text{g/L}$ ) and shrubland (180  $\mu\text{g/L}$ ). As regards phosphorous concentrations, bare areas deprived or with little vegetation (e.g. grassland), bring about most concentrations, more precisely 67,3  $\mu\text{g/L}$  and 35,3  $\mu\text{g/L}$  respectively.

<b>Usos del suelo</b>	<b>NH<sub>4</sub>-N (<math>\mu\text{g/L}</math>)</b>	<b>NO<sub>3</sub>-N (<math>\mu\text{g/L}</math>)</b>	<b>N-total (<math>\mu\text{g/L}</math>)</b>	<b>P-total (<math>\mu\text{g/L}</math>)</b>
Agrícola	17,1	253,7	314,7	28,7
Agua *	34,7	20,4	95,6	8,6
Bosque nativo	17,9	26,1	67,3	9,2
Matorral	14,6	123,4	180,0	15,1
Nieve	6,3	6,5	67,8	67,3
Plantaciones	23,7	44,9	94,8	30,1
Pradera	19,0	135,2	199,1	35,3
Bosques renovales	21,0	38,3	73,3	44,0
Suelo desnudo	6,3	6,5	67,8	67,3

\* Agua corresponde a precipitaciones.

**Table 13: Nutrient exportation index for different soil covers (UACH, 2008)**

According to UACH (2005), the vegetation cover can help to prevent landslides on a small scale. Yet, big landslides are not influenced in any appreciable form by the vegetation cover in sectors with steep gradients. In fact, in areas with cliffy gradients, the natural rate of erosion is considerable, independent of the vegetation cover. Since the Region IX of Chile, including the Villarrica Lake drainage basin, is a very mountainous area with an important surface of native forests and forest plantations, the natural erosion potential (without anthropogenic interference) is already high.

On the basis of studies realized on the biogeochemistry of native forests and nutrient exports in micro-basins with distinct soil uses in the Andean Precordillera in the South of Chile (carried out by Godoy et al. 2001, Oyarzún & Huber 2003, Oyarzún et al. 2004), indices of nitrogen and phosphorous export can be established for each soil use or vegetation cover such as for native forests, secondary forest, forest plantations, grassland, agriculture, shrubland and bare soils (UACH, 2008).

According to the Universidad Austral de Chile (2008), the supply of nutrients in the Villarrica basin only through precipitation amounts to N total 48,17 tons/yr and P total 19,50 tons/yr. This export is calculated considering the average precipitation of the period 1998-2007 which equals to 2148,1 mm/yr. The total **supply of nutrients through rivers and estuaries** to the Villarrica Lake accounts for **P total 320,88 tons/yr and N total 900,74 tons/yr**. As the study by the UACH demonstrates, most of the nutrients came from the Maichín sub-basin located in the mountain zone of the basin (N-total = 168,53 tons/yr and P-total = 54,27 tons/yr). This can be explained by the big cover of native and secondary forests in that area. The second sub-basin which exports most nutrients is Palguin lies in the middle section of the Villarrica basin (N-total = 108,94 tons/yr, P-total = 44,25 tons/yr). In contrast to the first location, in Palguin the nutrients originate from both a small surface of grassland having a high export coefficient and from a big surface of secondary forests.

In general terms, most of nitrogen discharges come from grasslands amounting to 303,54 tons/yr, even though this soil use represents only 17,9% of the whole river basin's surface. This can be explained by the high concentration index of NO<sub>3</sub>-N, as displays Table 14. As regards the total discharge of phosphorous into the lake, most of it comes from native forests with 100,82 tons per annum and secondary forests with 94,74 tons per annum, representing respectively 31,8 and 25,5% of the basin. Here again, the export coefficient is rather small,

thus the nutrient export can be explained by the big surface of these soil types in the basin (UACH, 2008).

Soil use	NH4-N (tons/yr)	NO3-N (tons/yr)	N-total (tons/yr)	P-total (tons/yr)
Agriculture	0,01	0,15	0,18	0,02
Water	17,48	10,28	48,17	19,50
Native forest	48,25	70,36	181,42	100,82
Shrubland	11,50	97,18	141,76	11,89
Snow	1,10	1,14	11,86	11,78
Plantations	2,26	4,28	9,04	2,87
Grassland	28,97	206,12	303,54	53,82
Secondary forests	45,22	82,47	157,83	94,74
Bare soils	2,26	2,33	24,28	24,10

**Table 14: Nutrient exportation index according to different soil uses in the Villarrica Lake catchment basin (Adapted and translated from UACH, 2008)**

## ***5.5. Desired trophy for the Villarrica Lake***

### **5.5.1. Current trophy of the lake and risk assessment**

Due to the diversity of economic activities existing close to the Villarrica Lake and in the entire river basin, there is a considerable amount of nutrients and sediments entering this water body. The Universidad Austral de Chile, whose studies constitutes the basis of the environmental quality norm, has found that “the lake is shifting from an oligotrophic state with low levels of nutrients and productivity to a state of oligo-mesotrophy due to the high discharges of the nutrients phosphorous and nitrogen” (UACH, 2009:56).

As we have seen in the previous sections of this chapter, the sources of nutrient supplies are twofold. On the one hand, there are the direct discharges of human-related activities, such as the filtration of septic tanks on the shoreline of the lake and the operation of piscicultures

and wastewater treatment plants which do not always function as optimally as they should. On the other hand, we have indirect discharges related to the agricultural and livestock activities and the exploitation of forests.

As already mentioned in the section “Socio-economic background of the Villarrica Lake basin”, tourism presents an important source of income in the watershed. This means that in this region the stake is high for a qualitative and pristine environment. The fact that this region is a major tourist development pole coupled with the existence of antecedents revealing signs of a deteriorating lake (a rise in the trophy of the lake), has pushed the government to elaborate an environmental quality norm (Norma Secundaria del Lago Villarrica). The utmost scope is to establish quality standards for the lake which would then ensure the conservation of its qualities as a site of scenic, touristic and environmental value.

For the environmental quality norm of the Villarrica Lake, the Universidad Austral de Chile (2009) proposes to use few parameters to classify and monitor the trophic state of the lake. These are the following:

- Secchi depth: indicator for the transparency of the water, alters as trophic level changes (light absorption by algae)
- Soluble and total phosphorous (PT): causer and indicators of eutrophication
- Ammonium, nitrite, nitrate and total nitrogen (NT): causer and indicators of eutrophication
- Dissolved oxygen: reflects the metabolic activities of the organisms
- Chlorophyll a: is the most important predictor of phytoplankton biomass

According to UACH (2009), the scope of the environmental quality norm (norma secundaria) is to conserve/rehabilitate the trophic state of the Villarrica Lake, which would most approximate the original and natural state of an Araucanian Lake. Before human intervention, the Villarrica Lake was ultra-oligotrophic with Chlorophyll a levels below 1 µg/L. The decision on the limits which are proposed by the law draft (*anteproyecto de la norma secundaria*) is based on international experience (see Table 3 in the Appendix for the international concerted levels for oligo- and mesotrophic states) and the evaluation of the existing data on the Lake Villarrica.

### 5.5.2. Current and critical nutrient loads for the Villarrica Lake

The estimated nutrient load for the Villarrica Lake amounts to 343 tons of phosphorous and 1173 tons of nitrogen per year. As we have seen in the section “Sources of pollution of the Villarrica Lake basin”, most of the total nitrogen loads came from grassland (303,54 tons/annum), even though this type of soil use only represents 17,9% of the total surface of the river basin. In the case of phosphorous, most of the load arises from native forests (100,82 tons/annum) and secondary forests (94,74 tons/annum), which represent 31,8 and 25,4% of the watershed’s surface respectively (SEREMI de la Araucanía, 2011). For a summary of the nutrient loads P and N and the pollution sources, see Table 15.

	<b>PT (tons/annum)</b>	<b>NT (tons/annum)</b>
Aquaculture	3,4	115,5
Treatment plant Pucón	4,9	80,8
Soils	320,9	900,7
Curarrehue Wastewater	13,8	76,7
<b>Total</b>	<b>343</b>	<b>1173,7</b>

**Table 15: Summary of phosphorous and nitrogen loads (tons/annum) to the Villarrica Lake (Adapted from UACH, 2009)**

The critical nutrient load reflects the nutrient load (expressed in tons of nutrients per year) entering the lake and if exceeded, it would lead to the eutrophication of the lake.

For the Villarrica Lake, the Universidad Austral de Chile calculated the critical nutrient load, taking into consideration the following elements: the critical total phosphorous concentration ( $\text{mg}/\text{m}^3$ ), the average depth (metres) of the lake and the renewal time/period of the lake’s water (years). In order to conserve the concentration of P total below 0,010 mg P/l, the estimated **critical load of P total amounts to 70-120 tons of P/annum**. On the basis of a relation N:P of 7:1 (per weight) the **estimated critical load for N is between 490 and 840 tons of N/annum**. Comparing the critical load with the estimated load (from Table 15) it can be reasoned that the P load into the lake is three times too high and the N load exceeds the acceptable load by 1,4-2,2. Thus, it can be concluded that in the current situation the lake receives excessive amounts of nutrients so as to keep it at an oligotrophic state (UACH, 2008; UACH, 2009).

For the protection of the water quality and for the conservation of the trophic state of the Villarrica Lake, the draft of the environmental quality norm (Norma Secundaria del Lago Villarrica) establishes quality levels for different monitoring areas of the lake, many of them which are not met to date (CONAMA, 2010). These quality levels can be found in Table 16.

Tabla 2; Niveles de Calidad por Áreas de Vigilancia en el lago Villarrica.

PARAMETRO	UNIDAD	CRITERIO	ÁREA DE VIGILANCIA					
			PEL	LIT-Poza	LIT-Pucón	LIT-Norte	LIT-Villarrica	LIT-Sur
Trofia deseada			Oligo-trófico	Oligomeso-trófico	Oligomeso-trófico	Oligomeso-trófico	Oligomeso-trófico	Oligomeso-trófico
Transparencia (Secchi)	M	Promedio anual	≥ 9	≥ 7	≥ 7	≥ 7	≥ 7	≥ 7
		Mínimo	≥ 5	≥ 4	≥ 4	≥ 4	≥ 4	≥ 4
P disuelto	mg P/l	Promedio anual	≤ 0,010	≤ 0,015	≤ 0,015	≤ 0,015	≤ 0,015	≤ 0,015
		Máximo	≤ 0,015	≤ 0,025	≤ 0,025	≤ 0,025	≤ 0,025	≤ 0,025
P total	mg P/l	Promedio anual	≤ 0,010	≤ 0,015	≤ 0,015	≤ 0,015	≤ 0,015	≤ 0,015
		Máximo	≤ 0,015	≤ 0,025	≤ 0,025	≤ 0,025	≤ 0,025	≤ 0,025
Saturación Oxígeno	%	Mínimo	≥ 80	≥ 70	≥ 70	≥ 70	≥ 70	≥ 70
N disuelto *	mg N/l	Promedio anual	< 0,10	≤ 0,15	≤ 0,15	≤ 0,15	≤ 0,15	≤ 0,15
		Máximo	≤ 0,15	≤ 0,30	≤ 0,30	≤ 0,30	≤ 0,30	≤ 0,30
N total	mg N/l	Promedio anual	≤ 0,15	≤ 0,15	≤ 0,15	≤ 0,15	≤ 0,15	≤ 0,15
		Máximo	≤ 0,20	≤ 0,30	≤ 0,30	≤ 0,30	≤ 0,30	≤ 0,30
Clorofila "a"	µg/l	Promedio anual	≤ 3	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
		Máximo	≤ 6	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10

Nota: (\*) es la suma de N-nitrato, N-nitrito y N-amonio.

**Table 16: Maximum proposed values for each trophic parameter in different monitoring areas of the Villarrica Lake (CONAMA, 2010)**

## 6. PROGRAMME OF MEASURES TO TACKLE THE CONTAMINATION OF THE VILLARRICA LAKE

### 6.1. *Point-source measures*

#### 6.1.1. Measures for the wastewater treatment plants

One of the main source of nutrient release in the Villarrica Lake catchment basin comes from the discharge of domestic wastewater, the major one being Pucón. However, since 2000 the commune of Pucón possesses a wastewater treatment plant (Butkus and Durán, 2000). This Sequencing Batch Reactor is a biological wastewater treatment plant which has a single treatment tank. The primary treatment works through a grid system which separates the solids. Then the effluent reaches a biological treatment (activated sludge with extended aeration), also called secondary treatment, diminishing the concentrations of nitrogen, phosphorous and organic matter. After the mixing system, the solids are allowed to settle and the disinfection is realised with chlorine gas in a contact pool before being evacuated in the River Claro (Municipality of Pucón, 2007; URI, 2006).

Current studies in the Villarrica Lake watershed show that the wastewater treatment plant in Pucón still emits high levels of phosphorous and mostly nitrogen into the lake with **4,9 tons of P per year and 80,8 tons of N per year** (UACH, 2008). An upgrade and improvement of the plant in Pucón has been suggested by several studies such as the ones from Butkus and Durán (2000), Fundación Red Nuevas Ideas (2003) and the Universidad Austral de Chile (2009). In addition to the primary and secondary treatment, often a tertiary treatment is suggested for the elimination of nutrients. Tertiary treatments correspond to advanced treatments of sewage water, wherein the elimination of the compounds which provoke eutrophication is sought (SEIA, 2010). Metcalf and Eddy (1991) also underline the fact that tertiary treatments are often used for wastewater which impacts lakes and reservoirs. Advanced treatment systems are different from traditional systems in a variety of ways, the main difference being that they further treat the wastewater before it is dispersed to the soil environment (URI, 2006). More specifically, tertiary treatment technologies can be “extensions of conventional secondary biological treatment to further stabilize oxygen-demanding substances in the wastewater, or to remove nitrogen and phosphorus. Tertiary treatment may also involve physical-chemical separation techniques such as carbon

adsorption, flocculation/precipitation, membranes for advanced filtration, ion exchange, dechlorination and reverse osmosis” (Water.siemens.com, 2011). According to Jeong *et al* (2006), the main advantage of adding a tertiary treatment is that its capital cost is much lower than that of constructing a new advanced treatment system.

In the year 2000, the United Nations Environment Programme in conjunction with the International Environmental Technology Centre worked out a training manual entitled “Planning and Management of Lakes and Reservoirs: an Integrated approach to Eutrophication” and set out the different available wastewater treatment methods for reduction in organic matter and nutrients together with their efficiencies and the costs (per m<sup>3</sup> of wastewater treated). Many measures of this module have been incorporated in the toolbox of measures for the wastewater treatment plant of Pucón. The table with the set of measures presented by UNEP-IETC can be found in Table 4 from the Appendix.

An Excel Sheet has been elaborated with the different options of measures and their associated effectiveness and costs for an advanced treatment system for the Pucón wastewater treatment plant. **Please refer to the document “Toolbox for the Wastewater Treatment Plant of Pucón” which can be found in both the Appendix and as an Excel Sheet in the attached documents.** Furthermore, a ranking of the costs and the efficiencies has been carried out together with an attempt to rank the measures according to their cost-effectiveness. This procedure ultimately eases the selection process of the measures for the Pucón wastewater treatment plant. Also, the source of literature where the measures have been extracted from is at hand in the Excel Sheet. As can be extracted from the sheet, most of the measures are destined for either nitrogen reduction or for phosphorous removal. The only exception presents the measure “ion exchange” which is designed for both nitrogen and phosphorous removal.

In order to **reduce the phosphorous** loads from the Pucón wastewater treatment plant, the most efficient measures constitutes an advanced wastewater treatment with biological nutrient removal, a chemical addition and the set up of a two-stage filtration with a total efficiency of up to 99,67% to remove P, down to 0,095 tons of P yearly discharge (US EPA, 2007). However, this measure is the second most costly within the set of measures presented, with an annual cost of US\$ 1 643 589. The second most efficient method at abating P levels from the discharge of the wastewater plant Pucón is a mechanical type of tertiary treatment called



“Actiflo process”. It exhibits an efficiency of 98,9% to remove phosphorous, down to 328,5 kilograms of P yearly discharge. Here again, the costs are accordingly high with an investment cost of US\$ 2 000 000 and a yearly running cost of US\$ 49 295 (Richards, 2006). A relatively affordable and at the same time effective measure is a **tertiary filtration** which incorporates a **rapid sand filter with coagulants and a UV reactor with an efficiency of 95%** and in absolute terms a reduction of **phosphorous down to 1,48 tons per year** with a capital cost of US\$ 720 000 and an annual maintenance cost of US\$ 350 000 (Heinonen-Tanski *et al*, 2003).

As regards the **nitrogen removal** from the discharges of the wastewater treatment plant in Pucón, ion exchange presents an interesting method with an efficiency of 87% approximately to reduce the nitrogen, which would amount to a discharge of 21,4 tons of N per year. This is however a costly measure for the wastewater treatment plant of Pucón with a yearly cost of US\$ 1 700 000 (UNEP-IETC, 2000). A possible measure to diminish nitrogen from the wastewater of the Pucón plant could be a **denitrification in tertiary filtration** process with the application of methanol which would amount to approximately US\$ 700 000 as an investment cost and with a running cost of US\$ 595 854 per year. The effect of implementing this measure is the **reduction of nitrogen by 80%** from 80,8 to **32,87 tons yearly** (Koch and Siegrist, 1997; Farabegoli *et al*, 2003).

A further contamination source is the domestic wastewater discharge of the commune of Curarrehue. As has been in Chapter 5 (Section 5.3.1.), the commune of Curarrehue does have a sewage system, yet it does not possess a plant to treat this wastewater. Currently the nutrient-laden water is being directly discharged into the River Trancura and it eventually reaches the Lake Villarrica, being thus an important factor for the eutrophication of the lake (DGA and Applus, 2008). **For this source of contamination, the “Toolbox for the Curarrehue plant” can be found in both the Appendix and as an Excel Sheet in the attached documents.** With a population number of approximately 7000 it can be estimated that the wastewater flow of this commune to be treated amounts to approximately 4 200 m<sup>3</sup> per day. According to Muttamara (1996) and the US EPA (2000), untreated sewage flowing into a municipal wastewater facility has total nitrogen concentration ranging from 20 to 85 mg/L and a total phosphorous concentration ranging from 4 to 15 mg/L (see Table 17).

Constituent	Concentration		
	strong	medium	weak
Solids, total (mg/l)	1200	720	350
Dissolved, total (mg/l)	850	500	250
Fixed (mg/l)	525	300	145
Volatile (mg/l)	325	200	105
Suspended, total (mg/l)	350	220	100
Fixed (mg/l)	75	55	20
Volatile (mg/l)	275	165	80
Settleable solids (ml/l)	20	10	5
Biochemical oxygen demand 5-day, 20°C (BOD <sub>5</sub> , 20°C; mg/l)	400	220	110
Total organic carbon (TOC; mg/l)	290	160	80
Chemical oxygen demand (COD; mg/l)	1000	500	250
Nitrogen (total as N; mg/l)	85	40	20
Organic (mg/l)	55	15	8
Free ammonia (mg/l)	50	25	12
Nitrites (mg/l)	0	0	0
Nitrites (mg/l)	0	0	0
Phosphorus (total as P; mg/l)	15	8	4
Organic (mg/l)	5	2	1
Inorganic (mg/l)	10	5	3
Chlorides <sup>a</sup> (mg/l)	100	50	30
Sulfate <sup>a</sup> (mg/l)	50	20	30
Alkalinity (as CaCO <sub>3</sub> ; mg/l)	200	100	50
Grease (mg/l)	150	100	50
Total coliform (No./100 ml)	10 <sup>7</sup> -10 <sup>9</sup>	10 <sup>7</sup> -10 <sup>8</sup>	10 <sup>6</sup> -10 <sup>7</sup>
Volatile organic compounds (VOCs; µg/l)	> 400	100-400	< 100

<sup>a</sup> Values should be increased by amount in domestic water supply.

Note: 1.8°C + 32 = °F.

**Table 17: Typical composition of untreated domestic wastewater (Adapted from Muttamara, 1996)**

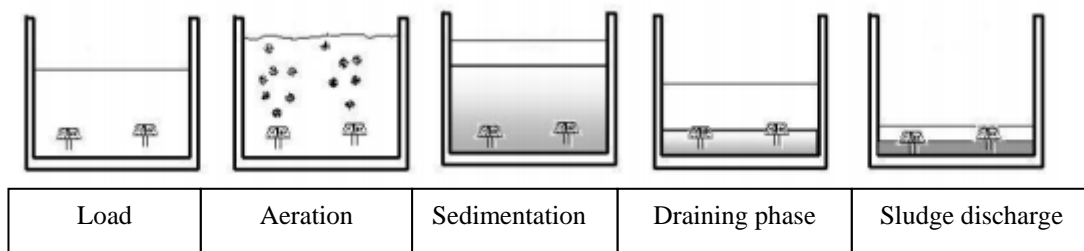
Assuming a medium concentration of both phosphorous and nitrogen in the untreated sewage of the commune of Curarrehue of 50 mg/L for N and 9 mg/L for P, the initial untreated wastewater which is dumped into the Trancura River equals **76,7 tons of nitrogen** and **13,8 tons of phosphorous annually**. The way to countervail this source of nutrient emission is firstly through the construction of a wastewater treatment plant for the commune of Curarrehue. A primary and secondary treatment plant type Sequencing Batch Reactor is one option. The capital cost for the construction of such a treatment plant amounts to **US\$ 2 000 000** and the **maintenance cost of US\$ 500 000 per year** (US EPA, 1999; US EPA, 2007, Brett Mandarano, 2002). In Table 18 below the different treatment phases of a Sequencing Batch Reactor are enlisted.

**Table 18: The five phases of a Sequencing Batch Reactor (Diez et al, 2007)**

In a Sequencing Batch Reactor the following five phases take place in an alternating way:

1. Load: in this phase the wastewater enters the Sequencing Batch Reactor. In this phase, the influent can have undergone a primary treatment such as sedimentation or sieving, or it enters the reactor without any previous treatment.
2. Aeration: in this step of the treatment the wastewater is aerated. The aeration system works through a submerged diffuser or through superficial aerators. In this way oxygen is provided to the microorganisms which is necessary for the metabolic activity, and thus for the degradation of the polluting substances. A further consequence of the aeration is a complete mixing.
3. Sedimentation phase: in this phase no aeration is realised, as this is the resting phase in the Sequencing Batch Reactor. The activated sludge can therefore decant through sedimentation. A clarified and purged water is formed in the superior part and at the bottom, a sludge layer appears.
4. Draining phase of the clarified water: in this phase the biologically clarified water is drained from the Sequencing Batch Reactor. Here special care needs to be taken to only take the superior part of the water.
5. Discharge phase of the excess sludge: in this phase the excess sludge is extracted from the Sequencing Batch Reactor which was formed during each cycle. The excess sludge is sucked up from the bottom of the tank.

The five phases which have been explained in detail are presented schematically below:




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Such a Sequencing Batch Reactor has the potential to remove nitrogen down to 8 mg/L and phosphorous down to 2 mg/L. In the case of the commune Curarrehue this would imply a new discharge of **phosphorous amounting to 3,07 tons** annually and a discharge of **nitrogen of only 12,2 tons per year**. This nutrient abatement triggered by this measure is very significant and efficient as it corresponds to an emission **diminishment of 84% for nitrogen and of**

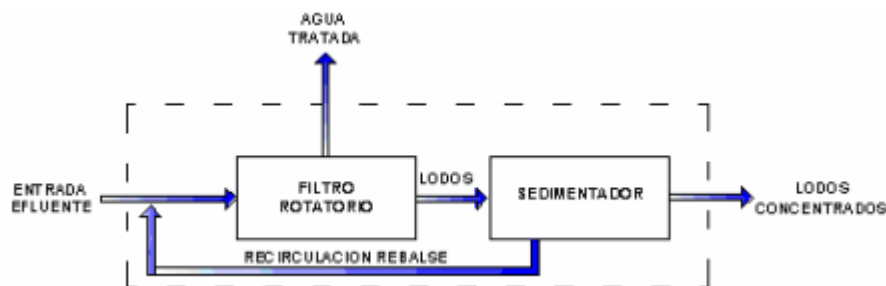
**77% for phosphorous.** In addition to the measure to construct a new wastewater treatment plant for the commune of Curarrehue, there is the potential to further reduce the levels of total P and total N from this source through tertiary treatment steps. For example, in order to reduce the nitrogen levels in the wastewater further down to 5 mg/L and phosphorous down to 0,5 mg/L, there exists the option to improve the efficiency of the treatment plant with a so called “Tier 3 Upgrade”. This upgrade comprises an additional aeration in the first treatment step, a secondary anoxic zone plus a methanol addition which is needed to achieve the additional denitrification in the secondary anoxic zone. Further it includes an additional clarification tank (for the nitrogen reduction) and chemical additions (Chesapeake Bay Programme, 2002). The **Tier 3 Upgrade** involves a **capital cost of US\$ 1 200 000** and an annual **operation and maintenance cost of US\$ 85 725**. The yearly discharge of **nitrogen** after this measure is implemented amounts to **7,7 tons** and for **phosphorous 0,77 tons**. With a **Tier 4 Upgrade** in the sewage treatment plant of Curarrehue, the potential to reduce the nutrient concentrations are as follows: up to 3 mg/L for N and 0,1 mg/L for P. This measure involves the construction of deep bed denitrification filters (for the abatement of nitrogen) and metal salt additions with microfiltration (for the abatement of phosphorous) (*idem*, 2002). Implementing this measure in the case of Curarrehue would translate into an annual discharge of **0,15 tons of P** and **4,6 tons of N**. The total **capital costs** for this procedure (including the investment for both P and N) amounts to **US\$ 2 700 000** and a total yearly **operation and maintenance cost of US\$ 270 000**. Clearly, this upgrade is the most costly since it also achieves record high abatements, i.e. 98,9% for total phosphorous and 94% for total nitrogen (considering the initial annual sewage discharges: 76,7 tons for N and 13,8 tons for P).

### **6.1.2. Measures for the aquacultures**

A considerable economic activity within the Lake Villarrica river basin present the seventeen fish farms in operation. As has been shown previously, the overall flow rate used in the production process totals 13 665 liters per second and this is associated with an annual discharge into the receiving water bodies amounting to **3,4 tons of P** and **115,5 tons of N**. This nutrient discharge is one factor for the increasing eutrophication of the Lake Villarrica, with a considerable inflow of nitrogen.

An Excel Sheet has been elaborated which includes an overview of the seventeen fish farms and their respective flow rates used in the production process (in L/s), their relative share in the river basin (in %), the treatment methods for each aquaculture at the present time (rotating

filter, sedimentation basin or even both in some cases), and the relative nutrient discharge into the water bodies (in kg per year). **Please refer to the document “Toolbox for the Fish Farms” which can be found in both the Appendix and as an Excel Sheet in the attached documents.** As can be extracted from the Excel Sheet, thirteen out of seventeen fish farms do only possess sedimentation basins as a method to remove total nitrogen and phosphorous. Yet, as the literature evidences, sedimentation basins only possess a 15% average of efficiency to remove the nutrients P and N from the water bodies whereas rotating filters have the potential to remove up to 89% of total nitrogen and up to 74% of total phosphorous (SEIA, 2004; SEIA, 2009). Thus, the proposed measure for this non-point source of pollution is an upgrade of the wastewater treatments of the thirteen fish farms from a sole sedimentation basin to a treatment which also includes a rotating filter in each aquaculture. As is depicted in Figure 12, the nutrient-laden water from all the seventeen aquacultures of the Villarrica Lake basin would therefore first enter the rotating filter and at a later stage it would reach the settling pond as a second treatment step. The requirement of the addition of rotating filters has also been recommended by the Fundación Red de Nuevas Ideas (2006) and the Fundación Gentexpresa.



**Figure 12: Diagram of the wastewater treatment flux for all the seventeen fish farms in the Villarrica Lake hydrographic basin (SEIA, 2004)**

The overall potential to reduce nitrogen and phosphorous emissions with an upgrade of the thirteen remaining fish farms and with a technological efficiency to remove 89% of nitrogen and 74% of phosphorous, eventually adds up to **40 612 kg of nitrogen per year** (40 tons/yr) and **1 173 kg of phosphorous per year** (1 ton/yr). Considering that the initial emissions from this source were 115,5 tons of N and 3,4 tons of P, it can be concluded that it represents a **65% reduction of phosphorous**, as well as a **65% removal of nitrogen** from all the fish farms in this river basin.

As regards the cost estimations associated with this nutrient reduction, each one of the thirteen aquacultures will have to invest in a rotating filter which has a capital cost of between US\$ 43

000 and US\$ 93 000 (Aquamedia, 2003). The maintenance costs for each rotating filter ranges between US\$ 11 500 and US \$18 300 yearly (*idem*, 2003). Summing up the investment for all the thirteen aquacultures, the **total capital cost amounts to US\$ 709 100**. This cost estimation can be compared with a cost analysis of nitrogen and phosphorous reduction in piscicultures carried out by Buschmann (2001) in his work “Impacto Ambiental de la Acuicultura: El Estado de la Investigación en Chile y el Mundo”. This study suggests that the cost to remove 1kg of nitrogen from a water body in aquaculture amounts to approximately US\$ 9 and around US\$ 3,5 per kg of phosphorous removed. Applying this cost estimation to the case of the fish farms in the Villarrica Lake water basin, the total cost to reduce the nitrogen discharge from 115 479 kilograms to 40 612 kilograms per year (a removal of 74 867 kg of N) totals US\$ 673 803. Likewise, the cost to remove 2 227 kilograms of phosphorous (from the current discharge 3 400 kg/yr to the discharge after the new effluent treatment has been set up: 1 173 kg/yr), would amount to US\$ 7 794. Summing up these two cost estimations adds up to a capital cost of **US\$ 681 597**. It can be observed that the outcomes of both cost assessments are very similar, thus the number found is rather significant and reliable.

## **6.2. Non-point source measures:**

### **6.2.1. Introduction: diffuse soil exportation and best-management practices**

As we have seen in the section on the sources of the eutrophication within the lake, most of the nutrients (P and N) entering the Lake Villarrica stem mainly from the different soil uses existent in the Villarrica Lake water basin. More specifically, the total **supply of nutrients through rivers and estuaries** to the Villarrica Lake accounts for **P total 320,88 tons/yr and N total 900,74 tons/yr**. As these numbers show and according to UACH (2009), a control of the nutrient entry from soils is crucial and this could translate into the uptake of best management practices of the vegetation and soils in the watershed. Best management practices (BMPs) are defined as managerial techniques which are recognised to be the most effective and practical means to control non-point source pollutants, yet are compatible with the productive use of the resource to which they are applied (US EPA, 2003). In other words, they are methods that have been determined to be the most effective, practical means of preventing or reducing pollution from non-point sources. UACH (2009) states that best management practices could imply the creation of buffer zones around the lake margins and at

the riverbanks around the incoming streams of the lake. This further translates indirectly into the application of the Law N° 20 283 on the Protection of Native Forests and Forest Development which states in its article 17 that this regulation will also foster the administration and protection of the water bodies (*idem*, 2009). In the same line, there are other institutions, such as the Fundación Red Nuevas Ideas, which also recommend the promotion of a massive reforestation / revegetation plan in zones near affluents and rivers so as to create a buffer effect between the shrub- and grasslands and the water bodies. A further recommendation is to limit the felling of trees, or even the promotion of agro-ecological management techniques for the few agricultural lands in the river basin. In fact, in my interviews with the National Forest Corporation CONAF, the municipality of Pucón and the SEREMI Medio Ambiente (regional ministerial secretary in charge of environmental affairs) it has been highlighted that more importance should be given to measures applied to agriculture (such as the use of less fertilisers). Furthermore, the negative impact of livestock on soils has not been considered and quantified in the past. Therefore, studies on the numbers of livestock allowed per hectare of grassland are highly recommended as well.

A toolbox in an Excel Sheet has been elaborated for the measures of non-point pollution sources leading to the eutrophication of the Lake Villarrica and the findings in the toolbox will be highlighted as follows. **Please refer to the document “Toolbox for nutrient exports: BMPs” which can be found in both the Appendix and as an Excel Sheet in the attached documents.** The diffuse source of pollution toolbox includes some possible measures to tackle the entry of nutrients from diffuse sources into the water bodies. More specifically, these measures are intended to remedy against nutrient exports from soils. They are meant to act as a buffer between the land areas with high coefficient exports and the streams which eventually attain the Lake Villarrica. In this toolbox again the measures are mentioned together with their respective efficiencies to remove the phosphorous and nitrogen loads. Furthermore, not only the cost per km of shoreline to apply this technique is given, but also a further column presents the cost (in US\$) and effects (in tons per year) on nitrogen and phosphorous loads to apply the measure on 1% of the total riparian zone of the river basin. This procedure is useful as it gives an idea of the potential total N and P reductions in the future. Since the length of the shoreline in the whole river basin amounts to 980 km, 1% translates into 9,80 km.

### 6.2.2. Best-management practices: nutrient exportation through soils

The first possible measure which could be applied to the Lake Villarrica case is the installation of **fences** close to the shorelines of the rivers. The reason to build such fences is the protection of streams from the impacts of livestock and sometimes also people on the areas close to the water bodies. For example, direct animal contact with surface waters can result in surface water contamination and damage to waterways. In fact, livestock, if allowed access to watercourses, have a detrimental effect on the stream water quality (SEPA, 2011). Furthermore, they destroy the grass cover on the river bank, leaving it susceptible to erosion and nutrient runoff from adjacent farmlands. As the toolbox exhibits, the efficiency of such a measure is quite low as it only **reduces nitrogen by 20% and phosphorous by 25%**, it is known as a low-cost method to obtain erosion protection (approx. US\$ 60 000/km), but the annual maintenance costs are high. Not only is the efficiency of this practice limited, but also the benefice of such a measure in the case of the Villarrica Lake water basin must be questioned. In this region, livestock tenure is not widely spread, thus livestock shouldn't present any major problem in trampling down grass covers adjacent to river banks and in contributing indirectly to the eutrophication of the lake.

A further best management practice widely recommended by many institutions which have studied the eutrophication process in the Lake Villarrica river basin, is the introduction of woodland and tree cover in the areas near to the river banks. **Riparian woodlands** form a very important edge habitat between agricultural land (or generally land with high nutrient export coefficients) and the aquatic zone. Moreover, as SEPA (2011) states “good management secures a number of significant benefits for water, including the retention of diffuse sediment and nutrient pollutants draining from adjacent land, stabilising banksides so reducing erosion and siltation within streams, providing shade, shelter and food for aquatic life, and helping to slow down flood flows”. This technique brings about high nutrient removal rates, especially for nitrogen which is the nutrient most exported through soils (such as the first paragraph of this section demonstrates). For **nitrogen**, the **removal efficiency** accounts for **80%** and for **phosphorous** the discharges into water bodies can be **diminished by 70%**. This means in the case study of the Villarrica Lake hydrographic basin, that **the yearly phosphorous load** can be reduced **down to 0,96 tons** on 1% of the shoreline and **down to 1,8 tons of total nitrogen** on the same area of the streambank. According to Lake (2003), the cost to implement this strategy lies at US\$ 16 404 per km and if it is implemented



on 1% (9,8 km) of the shoreline in the river basin it would amount to US\$ 160 759. The maintenance cost is relatively high, being 50% of the investment cost (SEPA, 2011).

In the state of Hessen in Germany, for the establishment of new forests spanning an area of more than 2 hectares, there exist some rules to follow for a prevention of nutrient losses/leakages with the seeping water. These rules consider the initial nitrogen content in the raw water and they depend on whether the soil (which is about to be afforested), was cultivated land or grassland previously. These rules might be of interest as best management practices for some future event of afforestation in the Villarrica Lake water basin and these can be found in table 5 of the Appendix.

The introduction of **dry filter strips** is another relatively efficient measure to prevent that nitrogen and phosphorous is further dumped into the affluents of the Lake Villarrica. These are areas of grass or other permanent vegetation that intercept runoff before it enters a water body. Filter strips collect sediment, nutrients and organic materials, and provide wildlife habitats. Herbaceous vegetation will filter runoff water by intercepting or trapping field sediment, organics, nutrients, pesticides and/or other potential pollutants before they are able to reach streams, lakes, or rivers (ADEQ, 2005). They can encourage sedimentation by slowing overland flow through short vegetation. Also, there is no definitive width for these strips, although experience shows that strips having less than 5 metres width do not have any effect. In general, the wider the filter strip and the denser the vegetation, the higher the efficiency (SEPA, 2011). Comparing this measure to the other available techniques, its cost-effectiveness is kept within a certain limit. In fact, considering that the efficiency of this measure equals to **65% for phosphorous and 60% for nitrogen** (the interception being much less efficient than, for example, with the riparian woodlands), further that the **capital cost per km** is one of the highest, amounting to **US\$ 13 000**, it can be concluded that this measure is not the preferred option of the ones presented.

Lastly, the proposed option for the control of nutrient inflow into the water bodies is the **wet riparian buffer strip**. This represents a strip of natural or naturalised wetland vegetation, usually ranging from 1-50 m wide situated alongside watercourses, particularly adjacent to small streams. By contrast with the dry vegetation buffer strips, the wet ones have a higher capacity to **take up nitrogen**, with an efficiency of **up to 85%**. For total **phosphorous** the removal effect of this implementation equals to **60%**. Since, nitrogen is the nutrient being of most concern in the river basin, this measure can be considered as an effective one to be implemented in the future in order to mitigate the transition from a mesotrophic lake to one

which is eutrophic. Truly, if this measure were implemented on 1% of the shoreline of the streams of the Villarrica, watershed it could diminish the **phosphorous** load down to **1,28 tons** and the **nitrogen** discharge down to **1,35 tons yearly** at an investment cost of approximately US\$ 99 000. Furthermore, the maintenance costs of this measure is the second-lowest, being US\$ 1 500 per km per year.

Thus considering these four strategies, **reforestation of streambanks** and **wet buffer strips** alongside the shoreline are the two preferred options to reduce the nutrient inflow into the river streams and ultimately into the lake. From a cost-efficiency standpoint the riparian buffer strip performs best, yet the reforestation strategy is the most efficient in terms of reducing the total nitrogen loads. This has to be weighted equally substantially, since nitrogen is by far the biggest source of eutrophication in the Villarrica Lake with current discharges of 900 tons of total N per year coming from soil exportations. Lancaster and Theisen (2008) underline that prevention is the most efficient and cost-effective form of erosion control. Furthermore, the most cost effective, environmentally-friendly and aesthetically pleasing way of prevention is through the use of vegetation. Needless to say, success of the introduction of such strategies highly depends on the proper application, installation and maintenance of these vegetative best management practices.

Further **best management practices** can be applied to the nutrient exports from **agricultural lands**. In the international literature often conservation tillage, no-till farming and depth contour greening are recommended as best management practices to reduce soil erosion, and ultimately to diminish the entry of nutrients into streams and lakes (Glover, 2008). For example in Germany, the results of five studies analysing the effects of agricultural measures to reduce erosion finds that the strategy with most effect to reduce erosion is the transformation of cropland into grassland with an abatement of up to 90% (HLUG, 2008). The second best measure is no-till farming, tillage being the agricultural preparation of the soil by mechanical agitation of various types, such as digging, stirring and overturning, with an erosion reduction of 82% (Triplett and Sprague, 1986; Sani, 2011). In the case of Villarrica a study entitled ‘Modelling the Response of Phosphorous Loading to Lake Villarrica, Chile’ has been carried out by Butkus and Durán of the Living Earth Institute of Washington in the year 2000. A water quality model has been created to help assess alternative pollution control solutions for the protection of Lake Villarrica. One part of the lake response model was also employed to prognosticate the effect of agricultural best management practices on phosphorous loads to the reservoir. For this purpose three practices

were tested with the model: reduced tillage systems (P removal efficiency: 45%), terrace systems (70%) and filter strips for agricultural lands (75%). According to the findings of Butkus and Durán (2000), the model shows that the lake's total phosphorous concentration would not change by applying these strategies. In fact, as we have seen in the previous part dealing with the sources of nutrient into the streams and into the lake, that agricultural land in the river basin only exports 0,02 tons of total phosphorous and 0,18 tons of total nitrogen into the water bodies. Thus, applying agricultural best management practices in these areas would not make any significant difference for the mitigation of the eutrophication process in the Villarrica Lake.

Another source of contamination which has not been examined in more detail so far is the introduction of nutrients from **diffuse sources** coming from **housing** close to the shoreline of the Villarrica Lake, especially between the communes of Pucón and Villarrica. UACH (2008) and DGA-Appplus (2008) state that in order to quantify the contribution of nutrients from the diffuse sources stemming from housing, one needs up to date information on the numbers of houses on the shoreline of the lake which do not possess drainage systems and information on how many of these houses use particular solutions, such as septic tanks. Furthermore, information is required on the period of time these buildings are inhabited. This would help to generate a correlation between the number of inhabitants and the average time these houses are in use in order to estimate the nutrient load. In addition, it is fundamental taking into account the significant expansion of constructions on the shoreline of the Villarrica Lake in the last couple of years.

### **6.2.3. Environmental education programme: a further long-term best-management practice**

Lastly, it is worth noting that more long-term solutions for the protection of the Lake Villarrica have to be contemplated. In Chile, the lakes are all known for their magnificence and transparency of their waters and they represent a natural heritage of great importance. This is also the case for the Lake Villarrica and its surroundings which present a great source of income from activities such as fishing, aquaculture and tourism. In fact, Lake Villarrica is one of the principal centres of tourism in Chile and represents the main source of income for the people living in the communes of Pucón, Villarrica and Curarrehue. A report from the Living Earth Institute found that most authorities in Chile agree that environmental education,

both formal and informal, represents a central and critical factor for the short and long term protection of the lakes, “because only through this education it becomes possible to create and promote values that allow the change of habits, practices and general conduct that have contributed to the degradation of the environmental quality of these precious lakes” (Living Earth Institute, 2000:1). In the case of Lake Villarrica, the degradation is represented by the evidence that in the last decade the lake altered from an ultra-oligotrophic status to a mesotrophic one. And the degradation can further be seen in some places of the lake which already show signs of eutrophication. Educational programmes are thus a way to inform people about the problems prevailing in the lake and its basin, and about possible solutions which could be implemented to remedy these issues. The interest shown by the government and the municipalities has pushed the Living Earth Institute to elaborate an **environmental educational plan** consisting of the following four steps: 1) elaboration of a programme incorporating the teaching of ecological issues as they relate to the lakes (in pilot schools in the communes of Curarrehue, Pucón and Villarrica), 2) develop and apply an educational unit (including the elaboration of learning material: posters, videos, CDs, etc.) on the theme of the lakes in grade schools in the three communes, 3) set up a community awareness programme (ecology fairs, flyers, radio programme, etc.) and finally, 4) creation of a comprehensive community monitoring programme for the quality of the lake (*idem*, 2000). The institute calculated the approximate total expenses for the implementation of such an environmental educational 16-month plan, amounting to **US\$ 97 131**.

### **6.3. Conclusions and Recommendations: Measures for the Villarrica Lake Watershed**

This section reviews and concludes on the selection of measures applicable to the contamination sources which contribute to the eutrophication of the Villarrica Lake. As we have seen throughout this chapter, there are several sources responsible for the high nutrient content in the lake. The four main founts considered are the following: an inefficient wastewater treatment plant in Pucón, the lack of a wastewater treatment plant in Curarrehue, water contamination in the production process of fish farms dispersed in the basin and last but not least, nutrient exports from soils. Thus, a final toolbox has been worked out which is entitled “Toolbox of Measures for Villarrica (All Sources)”. **Please refer to this document which can be found both in the Appendix and as an Excel Sheet in the attached documents.** As follows, the selection of measures for each source of nutrient discharge will be explained briefly. The table with the initial nutrient discharges of the four contamination sources is given again, so as to be able to continuously compare the new/potential loads with the current ones:

	<b>PT (tons/annum)</b>	<b>NT (tons/annum)</b>
Aquaculture	3,4	115,5
Treatment plant Pucón	4,9	80,8
Soils	320,9	900,7
Curarrehue wastewater	13,8	76,7
<b>Total</b>	<b>343</b>	<b>1173,7</b>

**Table 19: Current N total and P total discharges into the Villarrica Lake (by source) (Adapted from UACH, 2009)**

As regards the source of contamination from **aquaculture**, the most sensible strategy to undertake is an upgrade of all the piscicultures with a rotating filter. Thirteen of seventeen fish farms do only possess a settling pond, which is by far not as efficient as a rotating filter in removing the nutrients from the water used in the production process. Thus, the choice for this source of contamination is clear. The capital cost to upgrade the thirteen piscicultures amounts to US\$ 681 597 with a new nutrient P load of 1,1 tons and N 40,6 tons annually. As can be extracted from the **Toolbox of “All the Measures” which can be found in both the Appendix and in the attached documents**, compared to the other strategies this one is by far the less costly per kg of P and N reduced.

For the **wastewater treatment plant in Pucón**, the nutrient which presents most concern is nitrogen. In fact, 80,8 tons of N total are discharged yearly directly into the lake versus 4,9 tons of P. As this wastewater treatment already features a primary and secondary treatment, the most expedient measure we find is the plant's upgrade to a tertiary process. The most cost-efficient treatment is thus a denitrification in a tertiary filtration with the application of methanol. As opposed to the initial N total discharge before the treatment (80,8 tons/yr), this measure has the potential to achieve a reduction down to 32,87 tons/yr at a capital cost of US\$ 700 000.

For the sewage water dumped into the River Trancura from the **commune of Curarrehue**, the best strategy is to build a treatment plant for the wastewater. If the abatement resulting from this measure is not enough, further upgrades can be considered. However, and as many organisations have also recognised, the first step to undertake is the construction of a new treatment plant. The capital cost for this undertaking adds up to US\$ 2 000 000 with a corresponding 77% annual reduction of P total (down to 3,9 tons) and 84% of N total (down to 76,7 tons).

As we have examined in the previous section of this chapter, **reforestation of streambanks** and **wet buffer strips** alongside the shoreline are the two preferred options to reduce the nutrient inflow into the lake from soil exports. From a cost-efficiency standpoint the riparian buffer strip performs best, yet the reforestation strategy is the most efficient in terms of reducing the total nitrogen loads. This has to be weighted equally substantially, since nitrogen is by far the biggest source of eutrophication in the Villarrica Lake with current discharges of 900 tons of total N per year coming from soil exportation. In the toolbox, the abatements and costs have only been calculated for 1% of the shoreline. Yet, in order to make a difference in the future, the strategy should be implemented on a major array of the shoreline. In order to do so, as follows we will calculate the nutrient reductions and the associate costs, assuming that on 40% of the shoreline riparian woodland is introduced and on another 40% of the shoreline wet buffer strips are installed.

**40% of the shoreline represents 392 km.**

**40% of the initial P discharge** from soils (initial inflow: 320,9 tons per year) represents **128,36 tons of P** per year.

**40% of the initial N discharge** from soils (initial inflow: 900,7 tons per year) represents **360,28 tons of N** per year.

Applying the measure riparian woodlands to 40% of the total shoreline, would thus lead to the following reductions:

- P total from 128,36 tons per year to **38,5 tons of P/yr**
- N total from 360,28 tons per year to **72,05 tons of N/yr**

At a capital cost of:

- US\$ 16 404 (cost per km) times 392 km (40% of the shoreline) equals: **US\$ 6 430 368**

Applying the measure wet buffer strips to another 40% of the total shoreline, would thus lead to the following reductions:

- P total from 128,36 tons per year to **51,34 tons of P/yr**
- N total from 360,28 tons per year to **54,04 tons of N/yr**

At a capital cost of:

- US\$ 10 200 (cost per km) times 392 km (40% of the shoreline) equals: **US\$ 3 998 400**

The rest 20% of the riparian area of the river streams flowing into the Lake Villarrica would not undergo any of both treatments, which is **196 km**. Thus the load of total phosphorous and total nitrogen from the remaining area account for **64,18 tons of P/yr** and **180,14 tons of N/yr**. Taking into account all the above calculations, this means that after the implementation of the riparian woodland on 40% of the shoreline and wet buffer strips on another 40% of the riverside, the new discharge of nutrients will amount to **154,02 tons of P** and **306,23**.

The following table (Table 20) summarises the selected and recommended measures, the respective new discharges and total capital costs for the protection of the Villarrica Lake hydrographic basin. It should be noted that some strategies only apply for either N or P, this is why some fields are left blank. In the case of the long-term best management practice “environmental education programme”, no specifications on the nutrient reductions can be given.

<b>Measure (or pollution source without measure)</b>	<b>Source tackled</b>	<b>New discharge P (tons/yr)</b>	<b>New discharge N (tons/yr)</b>	<b>Capital cost (USD)</b>
Application of a Rotating Filter	Aquaculture	1,1	40,6	681 597
Denitrification in Tertiary Filtration: Application of Methanol	Wastewater Treatment Plant of Pucón		32,87	700 000
No treatment for the discharge of P from the Wastewater Treatment Plant in Pucón	Wastewater Treatment Plant Pucón	4,9		
Construction of a Sequential Batch Reactor Plant (Primary & Secondary Treatment)	Commune of Curarrehue	3,07	12,2	2 000 000
Riparian woodland (40% of the shoreline)	Soil exports	38,5	72,05	6 430 368
Wet buffer strips (40% of the shoreline)	Soil exports	51,34	54,04	3 998 400
Nutrient export from the remaining 20% shoreline without treatment	Soil exports	64,18	180,14	No cost
Environmental education programme (16 months)				97 131
<b>Total</b>		<b>163,13</b>	<b>391,9</b>	<b>13 907 496</b>

**Table 20: Choice of measures for the Villarrica Lake Water Basin, associated with the new total nitrogen and total phosphorous discharges to the lake and total capital costs. Own elaboration**

In conclusion, as can be withdrawn from this table, the introduction of all the recommended measures would translate into a total nitrogen reduction of 52% and a total phosphorous abatement of 66,6% at a total capital cost of US\$ 13 810 365. Amongst these strategies, the most cost-effective one is the application of rotating filters in thirteen of the seventeen fish farms, followed by the wet buffer strips to tackle nutrient exports through soils. As we have



seen in a previous section of this chapter (Chapter 5), the calculated critical load to preserve the Lake Villarrica at a mesotrophic state constitutes a P load between 70 and 120 tons and a N load between 490 and 840 tons annually. Comparing the critical load with the findings in this table, the measures perform well for the amount of nitrogen discharged, yet the phosphorous load goes beyond the recommended load by 40 tons yearly approximately. Surely, the potential of the environmental education programme could not be quantified in this table and it might lessen further nutrient discharges. However, as we have seen in the table above that the practice of applying wet buffer strips is the second most cost-effective, further phosphorous reductions could be extracted from a wider application of this measure in the future.

## **7. ECONOMIC INSTRUMENTS IN CHILE'S WATER RESOURCES MANAGEMENT: EFFLUENT CHARGES IN THE CASE OF THE VILLARRICA LAKE WATERSHED**

Before assessing the potential of an economic instrument as a way to enhance the water quality of the Villarrica Lake and as a way to generate revenue so as to cover the costs of the measures to be implemented, it seems important to define the category of economic instruments we will talk about, namely charges and taxes. As a next step, the German wastewater charge, that is to say its history, its rationale, its mode of operation and a discussion on its effectiveness will be presented. Finally, the application of an effluent charge in the Villarrica Lake hydrographic basin will be assessed. This includes the calculation of an effluent charge as regards the parameters phosphorous and nitrogen applied to the wastewater treatment plants and the fish farm Molco in the Villarrica Lake water basin.

### ***7.1. Definition: Charges and taxes in environmental policy***

The OECD Observer (1997) defines emission charges or taxes as “direct payments on the quantity and quality of pollutant discharged. They are applied to cope with many environmental concerns, such as air and water pollution and noise (...). Charges on waste discharge are also quite common, but with different degrees of sophistication and coverage” (OECD Observer, 1997:23). Another definition of the OECD in the year 2001 states that an effluent charge is “a fee or tax to be paid on discharges into the environment, based on the quantity and/or quality of discharged pollutants” (OECD, 2001). Similarly, UN ESCAP (2003) defines it as “a fee that is imposed on a pollutant in proportion to the amount of the pollutant released into the environment”. Further, charges can be classified into different categories, one of them being emission (or effluent) charges based on the actual amount of the pollutant discharged. In most countries environmental charges operate in combination with regulations and discharge permits. According to the German Federal Environment Agency, through the application of effluent charges, the polluter-pays principle is brought to bear, since point source dischargers are held liable for at least a portion of the costs of the utilisation/contamination of the environmental resource of water.

## **7.2. Example: The German Effluent Charge**

In Germany, the Effluent Charge Law (*Abwasserabgabengesetz – AbwAG*), which was first promulgated on the 13<sup>th</sup> of September 1976 and last changed in December 2004, provides guidelines by the federal government which have to be implemented by the State Environment Ministries (Länder). The first collection of the charge started in the year 1981 (Ecologic Institute, 2001). The main scope of this law is to oblige polluters to pay a charge for the contamination of sewage water which is directly dumped into water bodies, such as into rivers or lakes (Umweltschutz-news.de, 2011). Commercial organisations and households which discharge into municipal sewerage facilities do not have to pay this effluent charge directly (WHO and UNEP, 1997). The type of contaminants for which the contribution applies is defined in the Effluent Charge Act and they are the following: oxidisable substances in chemical oxygen demand (COD), phosphorous, nitrogen, halogen compounds, metals (mercury, cadmium, chromium, nickel, lead, copper) and fish toxicity (Annex 1 of § 3 *AbwAG*, 2004).

Lohaus (2001) puts that in Germany back in the 70s, the general situation of the quality of water bodies was insufficient. The quality of the water had deteriorated as a result of growing industrial production, increasing consumption of e.g. washing powder and the extension of the sewer systems. According to Lohaus (2001), the main objectives of the effluent charges thus were:

- Intensification of investments in the improvement of wastewater treatment plants
- Improvement of wastewater technology
- Development and support of production processes with reduced or without sewage flow
- Economical utilisation of products which can only be produced with a high quantity of wastewater

The effluent charge law acts upon the maxim of the polluter-pays-principle as it is characterised by its incentive function and effect with the scope to improve the water quality. Thus through its steering function it reduces the discharge of polluting substances into water bodies and through its incentive function it encourages investments in the area of sewage water (Landesanstalt für Umweltschutz Baden-Württemberg (2005). From an economic perspective, the effluent charge provides the opportunity to choose the most cost-effective

action alternative between the payment of the effluent charge or the investment in wastewater abatement measures (*idem*, 2005). The main scope of the Effluent Charges Law is not to achieve revenue for the state. Therefore this act allows under certain conditions that polluters offset the charges which they would have to pay against investments in the improvement of their wastewater treatment plants to reduce the contaminated discharges.

### **7.2.1. Who is liable to pay?**

According to the Ecologic Institute (2001), in Germany, Denmark and Spain effluent charges are only levied on direct discharges of outflows into water bodies and not on discharges into the sewage system (indirect discharges). Indirect dischargers are affected by the charge via the ordinary waste water user fee. Direct discharges include the following:

- Industrial effluents
- Agricultural discharges
- Discharges from sewage treatment plants
- Discharges from landfills
- Direct rainwater discharges
- Minor effluents such as domestic sewage from decentralised treatment facilities.

In Germany, there are about 8,000 municipal sewage treatment plants and 4,000 industrial direct dischargers (Hitchens et. al., 1998: 166).

### **7.2.2. Functionality and calculation of the charge**

The effluent charge acts in accordance with the harmfulness of the effluent. The harmfulness of the discharge is determined on the basis of single criteria (contaminant parameters and contaminant group parameters), which altogether give an overall picture of the pollution impact of the effluent. Through the parameters monitoring value (*Überwachungswert*) and yearly amount of sewage water (*Jahresschmutzwassermenge*) one can compute the yearly contaminant loads (*Jahresschmutzfracht*) and out of this the pollution/damage units (*Schadeinheiten*).

In order to calculate the number of **pollution units**, the following steps have to be taken into account. The evaluation of the pollutant parameters occurs through the conversion of the total annual load (*Gesamtjahresfracht*) into damage units. In order to carry out this conversion, the annex of the § 3 Effluent Charge Law (AbwAG) provides information on parameter-specific

measurement units in kg or grams (see Table 21). For example, as Table 21 shows, one pollution unit corresponds to 25 kg nitrogen or to 3 kg of phosphorous. In addition, threshold values for the concentrations and for the annual loads are determined. For example, for nitrogen the threshold concentration is 5 mg/L and the threshold load is 125 kg/year. For phosphorous the threshold concentration is 0,1 mg/L and the threshold load is 15 kg/year. In case none of these two threshold values are exceeded, the assessment of the damage is dropped and therefore no charge has to be paid for this parameter (Regional Office for Environmental Protection Baden-Württemberg, 2005). One pollution unit corresponds roughly to the harm caused by the raw wastewater produced by one inhabitant in one year (inhabitant equivalence) (BMU and UBA, 2001).

Rated contaminants and contaminant groups	Measurements constituting one pollution unit
Oxidizable substances in chemical oxygen demand (COD)	50 Kilograms Oxygen
Phosphorus	3 Kilograms
Nitrogen	25 Kilograms
Halogen compounds as adsorbable organic halogen compounds (AOX)	2 Kilograms Halogen as organic chlorine
Metals and their compounds:	
Mercury	20 grams
Cadmium	100 grams
Chromium	500 grams
Nickel	500 grams
Lead	500 grams
Copper	1000 grams metal
Toxicity to fish	3000 cubic meters of wastewater divided by the dilution factor $G_F$ , by which wastewater is no longer toxic to fish

**Table 21: Contaminants and pollution/damage units according to the Effluent Charges Act (AbwAG) (BMU and UBA, 2001)**

The number of damage units is calculated by means of the monitoring value, the annual effluent load and the pollutant-specific conversion factor, such as depicts the following equation:

$$\begin{array}{l} \text{Monitoring value} \times \text{Yearly effluent} \times \frac{\text{Conversion factor}}{\text{Unit of measurement}} = \text{Damage Unit} \\ \text{(mg/L)} \qquad \qquad \qquad \text{(m}^3\text{)} \end{array}$$

To give an example (Source: Landesanstalt für Umweltschutz Baden-Württemberg, 2005):

$$\begin{array}{lclclcl}
 \text{CSB :} & 55 & \times & 1.200.000 & \times & \frac{0,001}{50} & = & 1.320 \\
 \\
 \text{N}_{\text{ges}} : & 18 & \times & 1.200.000 & \times & \frac{0,001}{25} & = & 864 \\
 \\
 \text{P}_{\text{ges}} : & 2 & \times & 1.200.000 & \times & \frac{0,001}{3} & = & 800
 \end{array}$$

As regards the rate per damage unit, it has altered over the years. It started at a low level, at DM 12 (€6,14) in 1981 and has increased during the first six years. Further increases and reduction followed by the various amendments to the act. Currently and since 1997, the unit rate is fixed at DM 70 (€35,79). In Germany the charge of €35.79 per pollution unit is uniform in the entire country (Ecologic Institute, 2001). Table 22 shows the historic development of the unit rate.

	unit rate	unit rate
Starting		
- from 1. January 1981*	12,-- DM	~ 6,-- S
- from 1. January 1982*	18,-- DM	~ 9,-- S
- from 1. January 1983*	24,-- DM	~ 12,-- S
- from 1. January 1984*	30,-- DM	~ 15,-- S
- from 1. January 1985*	36,-- DM	~ 18,-- S
- from 1. January 1986*	40,-- DM	~ 20,-- S
- from 1. January 1991**	50,-- DM	~ 25,-- S
- from 1. January 1993**	60,-- DM	~ 30,-- S
- from 1. January 1997**	70,-- DM	~ 35,-- S
- from 1. January 2002**	35,79 €	~ 35,-- S

\* fixed in the original act    \*\* changed through subsequent amendments

**Table 22: Development of the unit rate. Sources: Lohaus (2001) and AbwAG § 9, Par. 4 (2004)**

Taking into account all of the aforementioned information, it is now possible to set up the equation which computes the effluent charge. According to the Ecologic Institute (2001), the yearly effluent charge is a function of the charge rate, the number of pollution units discharged in one year and the consideration of the number of pollutant parameters. The result is the following basic equation:

$$EC = f(a_i, p.u.i); 1 \leq i \leq n$$

**EC:** Effluent charge for one year.

**a:** charge rate.

**p.u.:** pollution units discharged in one year.

**n:** number of pollutants entering the calculation; the German effluent charge system considers more than one pollution parameter.

Lohaus (2001) states that the amount of the effluent charge for each pollutant or pollutant class is calculated as follows:

$$\frac{\text{Value}^* \times \text{yearly wastewater flow}^*}{\text{toxicity unit}} \times \text{unit rate} = \text{amount of charge}$$

\* according to permit

### 7.2.3. Increase of the charge

This paragraph highlights the conditions which induce an increase in the damage unit. Operators of wastewater treatment plants or other direct dischargers have to complete a form indicating which monitoring values they will comply with in the following chargeable year. Of course, the values indicated for each parameter by the operators have to comply with the permissible values stated by the Water Ordinance Act and the water authorities. In case one or more monitoring values (which had been filled out by the operator in the charge calculation form) exceed the permissive value in the chargeable period and in case this is detected by the official monitoring authorities, then there is an additional penalty fee to pay. This manifests itself in an increase in the amount of pollution units established in the § 4 Paragraph 4 of the German Effluent Charges Act. The increase in the damage units is determined according to the percentage rate over which the highest measured individual value has exceeded the permissive monitoring value. In case the monitoring value is exceeded only once then the additional pollution units are cut by half. The unit rate for each pollution unit always stays the same. If the monitoring value is exceeded more than once by the discharger in the chargeable period then the additional pollution units have to be paid fully at the unit rate stated in the effluent charges law (Landesanstalt für Umweltschutz Baden-Württemberg, 2005).

#### **7.2.4. Reduction of the charge**

This paragraph discloses the options for direct dischargers to obtain a reduction on the unit rate of the effluent charge. As Lohaus (2001) points out, from the beginning on it was not the intention of the Effluent Charges Law to achieve revenue for the state, but it should act as an incentive to reduce the harmfulness of the wastewater emitted to public water bodies. This can be done, for example, through an optimised wastewater treatment. Therefore the legislation opens several possibilities to the operators to reduce their charge while at the same time improving the quality of the sewage water.

The first possibility to reduce one's effluent charge is to comply with the requirements of the permit and the Wastewater Ordinance as described in the chapter before. By this means, the charge is cut in half (§ 9 Paragr. 5AbwAG; BGBl. I S. 114). This leads to a low charge for all modern wastewater treatment plants. On the other side, the old plants with their old permits and still high allowed effluent values have to pay the full charge. The higher costs should move the discharger to improve their plants on their own initiative.

The logical basis for calculating effluent charges is usually the actual (measured) quantity of pollutants in the effluent. The emission data the effluent charges are based on are derived from self-monitoring by the dischargers and compliance monitoring by environmental authorities. For administrative reasons, the values set in discharge permits (i.e. the maximum amount of pollution allowed in any one case) are used to calculate the effluent charge in Germany. Rebates are given when the actual quantities are less than those. Therefore, the second way to obtain an effluent charge rebate, is to declare lower monitoring values or a lower wastewater quantity than determined in the permit (§4 Paragr. 5AbwAG). However, this leads only to a reduced effluent charge if the declared values or wastewater quantity are at least 20% lower than the targets in the permit. Furthermore, the declaration must be valid at least for a period of three month. This can be an interesting possibility for operators referring to nutrient removal in the warm period or for companies who have a campaign business (Lohaus, 2001; §4 Paragr. 5AbwAG, BGBl. I S. 114)

The third possibility is to invest money into the wastewater plants to improve them or into the construction of a new treatment plant. In this case the operator can offset his effluent charges for three years against investment costs he undertakes in this period. But the offset is only



possible if the pollution load of at least one parameter is reduced by at least 20 %, provided that the overall amount of pollution decreases as well. Compared with the situation twenty years ago, wastewater treatment plants in Germany have improved substantially. So today and in the future it gets more and more difficult to use this possibility to reduce charges since the threshold of 20 % is very high (Ecologic Institute, 2001; Landesanstalt für Umweltschutz Baden-Württemberg, 2005).

The following table (Table 23) established by the European Commission (2001) summarises the discount situations seen above. In this table, the incentive function of the German charging system becomes clear: firstly, investments can be offset against effluent charges and secondly, rate reductions apply when the quality of the sewage water is improved.

Member State	Frequency of collection	Offset against expenditures	Rate reductions
D	Per annum.	Yes, e.g.: 1. for construction or expansion of treatment plants that may result in reduction of harmfulness by at least 20 %; or 2. for construction or expansion of treatment plants in former East Germany.	1. If effluents meet the BAT-derived ELV, the charge is reduced by 50 %; 2. Charges are reduced when the monitored values are lower than stated in the permit; 3. Parameters which do not exceed specific threshold values or dilution factors are not included in calculation.

**Table 23: Frequency of collection of effluent charges, offsets against expenditures and rate reductions (European Commission, 2001)**

### 7.2.5. Use of revenue

In Germany, the Länder (State Environmental Ministries in Germany) are the competent authorities for water management and legislation and are responsible for the reception and distribution of the revenues raised through effluent charges. The total income raised by effluent charges in Germany is quite high, especially given the possibility for offsetting the charge against investments, which would rather reduce the revenue. In 1999, the total revenue raised from the effluent charges amounted to €365 million, with the administrative costs being about 10% of the total revenue, thus €36 million (Ecologic Institute, 2001). With a population number of 82,8 million the revenue per inhabitant totalled 4,41€ in 1999. The Federal Environment Agency (Umweltbundesamt) estimates that 60 % of the income is derived from municipalities and 40 % from industry (RIZA, 1995:107).

The whole income through the effluent charging systems and after deducting administration costs must be spent for measures which lead to an improvement of water protection. It does not constitute a general income for the government. The range of activities funded by these revenues vary, covering, for example, the issuing and control of discharge permits, the funding of sewage treatment plant construction, as well as other measures for the improvement of the quality of surface waters, such as water quality programmes (BMU and UBA, 2001).

The allowed range of utilisation of the proceedings of the effluent charges are regulated in §13 of the Effluent Charges Act (§13 AbwAG, BGBl. I S. 114). The seven measures are:

- 1) Building of wastewater treatment plants
- 2) Building of stormwater retention tanks and plants for the purification of stormwater
- 3) Building of sewers to protect dams, lakes and ocean coasts
- 4) Building of plants for sewage sludge disposal
- 5) Measures to monitor and improve water quality
- 6) Research and development in the field of water protection
- 7) Training and further education of operators

#### **7.2.6. Effects of the German Effluent Charge**

As we have seen the Effluent Charges Act has been designed with an aim to steer and provide strong incentives for pollution abatement among direct dischargers. With this in mind, the German effluent charges system allows for reductions and discounts when certain parameters are kept below given limits and it provides for an offset of charges against investments in pollution abatement. In Germany, this fostered the removal of dangerous substances from industrial discharges and bolstered the adoption of best available technologies over the last three decades (Ecologic Institute, 2001). Moreover, the revenue is used to maintain and improve the quality of water and it also fulfils a financing function. The effects of the effluent charge in Germany to date are summarised by the European Commission (2001) as follows:

- Investment in effluent treatment, to avoid or reduce water pollution and effluent charges
- Investment in cleaner production technology (adoption of best available technologies)

- Pre-treatment or adoption of procedures (by industry, small and medium-sized enterprises, and in municipal sewage treatment plants) to avoid discharges of dangerous substances, or of substances that are expensive to monitor
- Reduction of water consumption in production processes and establishment of recycling schemes (to reduce the volume and improve the quality of the effluent)
- Reduction in pollution loads, notably nitrogen (N) and phosphorous (P)
- General improvements in the administration, monitoring and control of effluent discharges and in recipient water quality

It is worth highlighting that through the effluent charge not only the quality of the discharged water has been improved, but it has also induced a reduction in water consumption through the introduction of recycling schemes in the production processes of industries.

As regards a future improvement of the German effluent charge's effectiveness, an increase of the acceptance by operators and the steering effect could be ameliorated if polluters didn't have to pay for the permitted discharge values, but rather for their real pollution loads. However, this would require a huge amount of samples which consequently would lead to an adoption of the existing data from self-monitoring. As Lohaus (2001) suggests, a self declaration like practiced for tax return could be imagined. In that case, the task of water authorities would limit itself to control the self-monitoring of the operators.

### ***7.3. Application of the Effluent Charge in Chile: Case Study of the Villarrica Lake Watershed***

This section attempts to compute an effluent charge for the wastewater treatment plant of Pucón and for the plant in the commune of Curarrehue which is bound to be constructed in the future. It is crucial that the effluent charge in the Villarrica Basin fulfils a **steering and incentive function** in the same manner as the German charging system. More precisely, the discharge of polluting substances into the Villarrica Lake could be reduced through a steering function, thus through rate reductions when the quality levels of the wastewater are kept within a permissible value. At the same time, the incentive function of the charging system has the potential to encourage investments in pollution control equipments and/or processes in wastewater treatment plants. This could be translated into possibilities to offset investments

against the effluent charge. Furthermore, the revenue raised by the levy could be used by the government to exclusively promote measures improving the water quality of the Villarrica Lake.

### 7.3.1. Example 1: Wastewater Treatment Plant of Pucón

The wastewater treatment plant in the commune of Pucón has a daily water effluent amounting to 9000 cubic meters. Adding up this amount to a yearly basis, the effluent totals 3 287 178 cubic meters. In order to calculate the value of the effluent charge for the contaminant phosphorous in the Pucón wastewater treatment plant, the following information needs to be known: the minimum requirement determined in the Chilean Law (i.e. the emission standards stated in the “Norma de Emisión Descarga Residuos Líquidos a Aguas Marinas y Continentales Superficiales”, also known as *DS 90*), the threshold value and the monitoring value. In Germany, the threshold values are defined in the Effluent Charges Act. For the Chilean case, these threshold values can be adopted from Germany.

#### Calculation of the effluent charge for the contaminant Phosphorous (WWTP Pucón):

- Minimum Requirement stated in Chilean legal text (DS 90): **2,0 mg/L** (same value in Germany)
- Threshold Value in legal text (in the German Effluent Charges Act): In Germany: **0,1 mg/L** and **15 kg/annum**. In Chile, this threshold value currently does not exist, so for the sake of it the German value can be adopted.
- Monitoring value: **2,0 mg/L**

$$\begin{aligned}\text{Yearly Contamination Load} &= \text{Effluent water} * \text{Monitoring Value} * \text{Conversion Factor} \\ &= 3\,287\,178 * 2 * 0,001 \\ &= \underline{\underline{6574}}\end{aligned}$$

Unit of measurement (given in the Effluent Charges Act of Germany): **for P: 3 kg**

Damage units = Contamination Load / Unit of Measurement = **2191**

Charge rate (in Germany): EUR 35,79.

Thus the **effluent charge for P** without any reductions for the **Pucón WWTP** would be = **EUR 78 415,89** (Damage units \* Charge Rate), or **US\$ 114 000** (Cost per inhabitant of the Villarrica Lake watershed: US\$ 1,55)

In case the measured value of P (in mg/L) in snap samples does not exceed the monitoring value of P (2 mg/L), then there is no extra charge for the operator of the wastewater treatment to pay (in addition to “damage units \* charge rate).

The **incentive and steering mode of operation** of the wastewater charge could be designed with the following rules (the same applies for the other WWTP in the Villarrica Lake basin and the fish farms):

- IF the WWTP of Pucón does stay below the Threshold Value, then it does not have to pay an effluent charge (though this is not often the case);
- In order to obtain an effluent charge rebate, the operator of the WWTP Pucón can declare lower monitoring values or a lower wastewater quantity than determined in the permit (§4 Paragr. 5AbwAG). This leads only to a reduced effluent charge if the declared values or wastewater quantity are at least 20% lower than the targets in the permit. Furthermore, the declaration must be valid at least for a period of three months. The amount of damage units for this period of time can be calculated according to the declared concentrations.
- IF the WWTP exceeds the Monitoring Value once PLUS an investment is made, then the charge to pay equals the Damage Unit caused TIMES the charge rate. The charge which would have been payable (all the rest which did not exceed the values) is subtracted from the investment cost of the plant. The value which arises is the investment which can be deducted to the charge in the following year;
- IF NO INVESTMENT is made, then the full charge (damage units TIMES charge rate) has to be paid PLUS, if applicable, the exceeding damage unit charge;
- IF an INVESTMENT is made, then the payable effluent charge can be deducted from this investment;
- In case the measured value exceeds the monitoring value (2,0 mg/L in the case of P), then an increase in the damage unit applies. It is determined according to the percentage rate over which the highest measured individual value has exceeded the permissive monitoring value. The following two cases apply:

- In case the monitoring value is exceeded only once then the additional pollution units are cut by half
- In case the monitoring value is trespassed more than once by the discharger in the chargeable period then the additional pollution units have to be paid fully at the unit rate stated in the effluent charges law

In order to enlighten the last case from the list above, an example is given as follows.

- In case the monitoring value 2,0 mg/L (for P) is exceeded once by a concentration of 4,3 mg/L, then a 57,5% augmentation of the damage units is incurred, meaning  $(2191 * 57,5) / 100 = 1259$  additional damage units. In this case the monitoring value is exceeded only once, therefore the additional damage units are cut by half, i.e.: 629. The additional charge to pay equals to  $629 * 35,79 = \text{EUR } 22\ 530$ . This amount would have to be paid in addition to the effluent charge EUR 78 415.
- In case the monitoring value 2,0 mg/L (for P) is exceeded twice, once with a concentration of 2,1 mg/L and then again with a concentration of 2,5 mg/L, then a 25% augmentation of the damage units occurs. In this case, the damage units computed above were 2191. Thus, the additional damage units amount to:  $(2191 * 25) / 100 = 548$ . This translates into **EUR 19 612**, which is payable in addition to the effluent charge EUR 78 415, equalling to EUR 98 027. As can be seen in this case, the additional pollution units have to be paid fully, since the monitoring value is exceeded twice.

#### **Calculation of the effluent charge for the contaminant Nitrogen (WWTP Pucón):**

- Minimum Requirement stated in legal text (DS 90 / in Abwasserverordnung): **10,0 mg/L** (different value in Germany: 18 mg/L)
- Threshold Value in legal text (in the German Effluent Charges Act): In Germany: **5 mg/L** and **125 kg/annum**. In Chile, this threshold value currently does not exist, so for the sake of it we adopt the German value
- Monitoring value: **10,0 mg/L**

$$\begin{aligned} \text{Yearly Contamination Load} &= \text{Effluent water} * \text{Monitoring Value} * \text{Conversion Factor} \\ &= \mathbf{32\ 871} \end{aligned}$$

Unit of measurement (given in the AbwAG): **for N: 25 kg**

$$\text{Damage units} = \text{Contamination Load} / \text{Unit of Measurement} = \mathbf{1\ 314}$$

Charge rate (in Germany): EUR 35,79

Thus the **Pucón WWTP's effluent charge for contaminant P** would be = **EUR 47 059,24** (Damage units \* Charge Rate), or **US\$ 68 108** (Cost per inhabitant of the Villarrica Lake watershed: US\$0,93)

### **7.3.2. Example 2: Fish Farms**

Next to the wastewater treatment plants in the Lake Villarrica water basin there is a second major direct liquid waste discharger to the rivers and the lake. These are the seventeen fish farms in operation in the basin. Supposedly the fish farms fulfil the concentration requirements of the Chilean DS 90 Norm on industrial liquid waste (for maximum allowed concentration levels, refer to tables 6 and 7 in the Appendix). In Chile, the organism in charge of monitoring the industrial establishments generating industrial liquid waste is the Superintendency of Sanitary Services (SISS). From information provided by the SISS, the UACH (2008) generated the following table (Table ...) displaying seven of the seventeen piscicultures of the river basin and their respective total phosphorous and nitrogen loads into water bodies.

It should be noted though, throughout my interviews it has been consistently critically asserted that not only the permits of instalment for aquacultures are too lax, but also their monitoring and control is not assiduous and sufficient enough. As can be extracted from the table below, the average phosphorous and nitrogen discharges in one year are extremely low (0,29 mg/L of P and 1,03 mg/L of N). The numbers displayed in the table below should thus be handled warily.

Piscicultura	P Total (mg/L) Min-max	N Kjeldahl (mg/L) Min - max	N Total (mg/L)	Cuerpo receptor
Loncotraro (1)	0,2 - 0,49		0,2- 10,0	Estero Loncotraro
Loncotraro (2)	0,2 - 1,03	0,1 - 2,48		Estero Los Chilcos
Los Chilcos (1)	0,2 - 1,76	0,1 - 1,45		Estero Los Chilcos Este
Los Chilcos (2)	0,2 - 0,42		0,1 - 2,48	Estero Los Chilcos Oeste
La Cascada	0,2 - 1,03	0,1 - 1,63		Estero Atravesado
Molco Alto	0,2 - 4,2	0,1 - 4,5		Estero Chehuilco
Molco	0,2 - 0,5		0,1 - 3,18	Estero Molco
promedio	0,29	0,70	1,03	
Mediana	0,20	0,47	0,78	

Fuente: SISS

**Table 24: Concentrations of P total and N total in seven fish farms in the Villarrica Lake basin (period September 2006 – september 2007) (UACH, 2008)**

The Chilean norm on emission standards “*Norma de Emisión para la Regulación de Contaminantes asociados a las Descargas de Residuos Líquidos a Aguas Marinas y Continentales Superficiales*” differs between the discharge of liquid waste into rivers and the discharge into lakes (see table 6 and 7 in the Appendix). The maximum permitted concentrations of phosphorous and nitrogen dumped into lakes is far more stringent than into river bodies: for lakes, the maximum allowed concentrations are as follows: 2 mg/L of P Total and 10 mg/L of N Total. For rivers, the numbers are: 15 mg/L P Total and 75 mg/L N Total Kjeldahl.

The small-size fish farm Molco in the commune of Villarrica will serve as an example in order to calculate a yearly effluent charge of a pisciculture in the river basin. For the charge to have an incentive and steering function, the same rules can be extracted from the above example on the WWTP of Pucón, both the wastewater treatment plant and the fish farms being direct dischargers of liquid waste into water bodies. An investment incentive could for example be the implementation of a further treatment wastewater treatment process, such as a rotating filter.

In its production process, the fish farm Molco has a flow rate of 120 liters per second (see toolbox from Chapter 6), thus its water use amounts to 10 368 cubic metres per day. On a yearly basis this fish farm needs 3 786 808 cubic metres of water.



### Calculation of the effluent charge for the contaminant Phosphorous (Fish Farm Molco)

- Minimum Requirement stated in Chilean legal text (DS 90): **15,0 mg/L**
- Threshold Value in legal text (in the German Effluent Charges Act): In Germany: **0,1 mg/L** and **15 kg/annum**. In Chile, this threshold value currently does not exist, so for the sake of it the German value can be adopted.
- Monitoring value: **0,3 mg/L**

$$\begin{aligned}\text{Yearly Contamination Load} &= \text{Effluent water} * \text{Monitoring Value} * \text{Conversion Factor} \\ &= 3\,786\,808 * 0,3 * 0,001 \\ &= \underline{\underline{1136}}\end{aligned}$$

Unit of measurement (extracted from the Effluent Charges Act of Germany): **for P: 3 kg**

$$\text{Damage units} = \text{Contamination Load} / \text{Unit of Measurement} = \mathbf{379}$$

Charge rate (in Germany): EUR 35,79.

Thus the Molco Fish Farm's **effluent charge for the contaminant P** would be = **EUR 13 564, 41** (Damage units \* Charge Rate), or **US\$ 19 562** (Cost per inhabitant of the Villarrica Lake watershed: US\$ 0,27

### Calculation of the effluent charge for the contaminant Nitrogen (Fish Farm Molco)

- Minimum Requirement stated in Chilean legal text (DS 90): **10 mg/L**
- Threshold Value in legal text (in the German Effluent Charges Act): In Germany: **5 mg/L** and **125 kg/annum**. In Chile, this threshold value currently does not exist, so for the sake of it we adopt the German value
- Monitoring value: **1,5 mg/L**

$$\begin{aligned}\text{Yearly Contamination Load} &= \text{Effluent water} * \text{Monitoring Value} * \text{Conversion Factor} \\ &= 3\,786\,808 * 1,5 * 0,001 \\ &= \underline{\underline{5\,680}}\end{aligned}$$

Unit of measurement (extracted from the Effluent Charges Act of Germany): **for N: 25 kg**

$$\text{Damage units} = \text{Contamination Load} / \text{Unit of Measurement} = \mathbf{227}$$

Charge rate (in Germany): EUR 35,79.

Thus the Molco Fish Farm's **effluent charge for the contaminant P** would be = **EUR 5 675** (Damage units \* Charge Rate), or **US\$ 8 184** (Cost per inhabitant of the Villarrica Lake watershed: US\$ 0,11).

#### ***7.4. Conclusion: Effluent Charging as a Step towards IWRM in Chile***

On the basis of the definition provided in the second chapter as IWRM being “a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives” (Cap-Net, 2006), one can assess whether an effluent charge might have the capability to (partially) fulfil the scopes which IWRM seeks. As follows some potential social, environmental and economic consequences and concerns of an effluent charge in the Villarrica Lake basin are mapped:

**Social objectives:** in the case of the Villarrica Lake basin, the negative externalities and costs generated by the contamination the water bodies through wastewater treatment plants (sewage water) and the production process of fish farms normally have to be borne by society. Through an effluent charge these externalities have the potential to be internalised by providing incentives to polluters to act in a socially responsible way by reducing their contamination loads to the rivers and to the lake in the watershed.

**Environmental objectives:** the consequence of introducing an effluent charge has clear environmental benefits in the Villarrica Lake basin. By the decrease in nutrient loads from direct dischargers into water bodies, the lake is bound to stay at an oligo-mesotrophic level. Thus, it can act as a preventive measure. The effluent charge not only has a steering function, but it is also characterised by its financing function. In fact, the proceedings of the effluent charges should be intended solely for water quality and sewage plant improvements in the basin.

**Economic objectives:** clearly, by implementing an effluent charge the question arises whether it might induce a competitive disadvantage between firms by increasing the costs in the production processes of some companies and not in others. However, experience with effluent charges in several European countries has shown that the increment in costs to the firms due the charge is not that considerable that it would lead to a competitive disadvantage. Quite the contrary, often by introducing more efficient technologies, production costs can be reduced on a long term basis.

## 8. CONCLUSIONS AND RECOMMENDATIONS

This thesis focused on the assessment of economic elements to support water quality management in Chile.

In the context of an environmental quality standard which is to be established for the preservation of the quality of the Villarrica Lake, the following necessary steps were performed before the introduction of an economic instrument in the study area was assessed. Firstly, the sources of contamination have been identified, together with the current amounts of nutrient loads discharged into the lake. Then, the total influx of nutrients stemming from point-source and diffuse pollutions were compared to the critical load of nutrient discharge, so as to keep the lake at an oligo-mesotrophic level. With this information at hand, for each source of contamination a set of measures has been worked out. This includes the description of each technical measure, its potential in reducing nutrient loads (in tons per year) and the associated calculation of the costs. Finally, an attempt to perform a cost-efficiency ranking for each set of measures was carried out and a programme of measures for the whole of the Villarrica Lake basin was elaborated. The results found in this part constitute useful information which can be fed into the cost-benefit analysis (AGIES) of the environmental quality norm for the Villarrica Lake. It further helps to give an idea of the environmental costs which need to be internalised and of the proportions of the costs which have to be borne by each group of polluter in order to keep the lake with low nutrient levels, i.e. low level of contamination.

Having identified the sources of contamination / the polluting actors and the costs associated for the mitigation to restore the water quality in the Villarrica Lake water basin, there is the potential to internalise the environmental costs (which are the costs of damage that water uses impose on the environment and ecosystems and those who use the environment) by applying the polluter pays principle. Up to now only command-and-control tools have been serving water quality management in Chile. However, as international experience shows, economic instruments have the potential to act as an incentive function in either reducing the demand for water or in improving the quality of water at the lowest possible cost to society. Since data about the discharges of the wastewater treatment plants and the fish farms were available, it

was possible to map and quantify the potential of the introduction of an effluent charge as a steering and financing function in the specific case of the Villarrica Lake watershed.

As we have seen in the chapter on IWRM, it is crucial to consider economic instruments in order to shift towards a fully integrated management of the water resources. As a first step in Chile, economic instruments could be incorporated in the decontamination plans of environmental quality norms, i.e. the situation when polluters have to assume the costs of cleaner production processes when the quality norm could not be met.

As regards water quantity management, especially in the dry north of Chile where intelligent solutions for a better quantitative management are urgently needed, it would also be highly recommended to assess the potential of an economic instrument in reducing water demand. This could for example be tested with a groundwater abstraction charge or tax.

Yet, it should be highlighted that the introduction of economic instruments as a new policy tool in water management can present substantial difficulties and obstacles. The reason is that this shift entails important institutional changes in terms of experience, monitoring and revenue, which ultimately can cancel the relative savings of the costs. Therefore it is advised that, before introducing economic or market-based instruments, policy-makers evaluate the balance between the potential cost savings with such a system and the increment in the costs associated to its implementation and monitoring.

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## APPENDIX

**Table 1: Name and Surface of each sub-basin of the Villarrica Lake river basin (adapted from UACH, 2008)**

Basin number	Name	Surface in ha
1	Maichín	49667,1
2	Trancura	35452,3
3	Caburgua	36188,2
4	Liucura	33871,8
5	Pangui	12500,4
6	Pucon 1	27196,2
7	Palguin-Menetue	37376,7
8	Quelhue	4824,2
9	Pucon-El Claro	6038,1
10	Rivera norte Lago Villarrica	7669,1
11	Volcan Villarrica	3842,4
12	Candelaria – Los Chilcos	5420,1
13	Molco	4232,7
14	Huincacara	6297,5
	<b>Subtotal</b>	<b>270576,7</b>
	Lago Caburgua	5204,7
	Lago Villarrica	17356,7
	<b>Total</b>	<b>293138,1</b>

**Table 2: Production activities of the 17 aquacultures in the Villarrica Lake river basin (UACH, 2009)**

Código Centro	Ovas	Alevín	Smolt	Juvenil	Adulto	Reproductor
90030	X	X				
90050	X	X				X
90052	X	X		X		X
90055	X	X				X
90059	X	X		X	X	X
90060	X	X				
90062	X	X			X	X
90064	X	X	X			
90069	X	X				X
90082	X	X				
90085	X	X				
90089	X	X	X			
90090	sd	sd	sd	Sd	Sd	sd
90112		X	X			
90117		X				
90118	X	X	X	X		
90137			X			X

**Table 3: Trophic classes of lakes, (Adapted from Carlson, 1975)**

TI	Chl	P	SD	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5—<0.25	Hypereutrophic

**Table 4: Generally applied wastewater treatment methods for reduction in organic matter and nutrients (UNEP-IETC, 2000)**

Method	Goal	Efficiency % with good practice	Costs (year 2000) (\$/100m <sup>3</sup> )
Mechanical treatment	BOD <sub>5</sub> reduction	20-35	3-8
Biological treatment	BOD <sub>5</sub> reduction	70-90	25-40
Flocculation	Phosphorus removal BOD <sub>5</sub> reduction	30-60 40-60	6-9
Chemical precipitation Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> or FeCl <sub>3</sub>	Phosphorus removal BOD <sub>5</sub> reduction	65-95 50-65	10-18
Chemical precipitation Ca(OH) <sub>2</sub>	Phosphorus removal BOD <sub>5</sub> reduction	85-95 50-70	12-18
Ammonia stripping	Ammonia removal	70-95	25-40
Nitrification	Ammonium → nitrate	80-95	20-30
Denitrification	Nitrogen removal	70-90	15-25
Ion exchange	Phosphorus removal Nitrogen removal	80-95 80-95	70-100 45-60
Waste stabilization ponds	Reduction of BOD <sub>5</sub> Nitrogen removal	70-90 50-70	2-8
Constructed wetland	Reduction of BOD <sub>5</sub> Nitrogen removal Phosphorus removal	20-50* 70-90 0-80**	5-15
Activated carbon adsorption	Reduction of organic toxic compounds, BOD <sub>5</sub>	40-95	60-90

\* Presumes a pretreatment (BOD<sub>5</sub> ≤ about 75 mg/l)

\*\* The removal is dependent on the adsorption capacity of the soil applied and whether harvest of the plants is foreseen.



**Table 5: Best-management practice: rules for reforestation in the State of Hessen, Germany**

NB: For the establishment of new forests there are no negative aspects to fear on groundwater recharge when there is a forest proportion of already more than 80% within a water protection area.

In Hessen, the rules for the establishment of new forests (afforestation) are as follows:

In case of the establishment of new forests with an area of **more than 2 hectares** or if the **raw water has a nitrogen content of 25mg/l**, the following measures for a prevention of nutrient losses/leakages with the seeping water are required:

**$N_{org}\text{-content} \geq 2,5 \text{ mg /100g soil}$**

1. Soil use as cultivated land previously
  - 1.1 In the last year of cultivated soils  
No cultivation of corn, grain legumes, oleaginous fruits and potatoes (since they have more N- profile and material value), no late fertilization, for example, with wheat.
  - 1.2 After the cultivation of the main crop in the summer/late summer:  
  
Rapid greening with plants which have a high N- absorption capacity, no fertilization
  - 1.3 The following March/April  
  
Establishment of forests with the cultivation of accompanying plant species
2. Soil used as grassland previously:
  - 2.1 Intensively used grassland needs to be used as extensive grassland as a minimum for 2 years in order to minimise the nitrogen impact

**$N_{org}\text{-content} < 2,5 \text{ mg /100g soil}$**

1. Soil previously use as cultivated land  
Autumn plants with accompanying plants are allowed
2. Soil previously used as grassland  
Cultivation of plants as strips

**Table 6: Maximum permitted levels for the discharge of liquid waste to lakes (CONAMA, 2000)**

TABLA N°3  
LIMITES MAXIMOS PERMITIDOS PARA LA DESCARGA DE RESIDUOS LIQUIDOS A  
CUERPOS DE AGUA LACUSTRES

CONTAMINANTE	UNIDAD	EXPRESION	LIMITE MAXIMO PERMISIBLE
Aceites y Grasas	mg/L	A y G	20
Aluminio	mg/L	Al	1
Arsénico	mg/L	As	0,1
Cadmio	mg/L	Cd	0,02
Cianuro	mg/L	CN <sup>-</sup>	0,5
Cobre Total	mg/L	Cu	0,1
Coliformes Fecales o Termotolerantes	NMP/100 ml	Coli/100 ml	1000-70 *
Indice de Fenol	mg/L	Fenoles	0,5
Cromo Hexavalente	mg/L	Cr <sup>6+</sup>	0,2
Cromo Total	mg/L	Cr Total	2,5
DBO <sub>5</sub>	mgO <sub>2</sub> /L	DBO <sub>5</sub>	35
Estaño	mg/L	Sn	0,5
Fluoruro	mg/L	F <sup>-</sup>	1
Fósforo	mg/L	P	2
Hidrocarburos Totales	mg/L	HCT	5
Hierro Disuelto	mg/L	Fe	2
Manganeso	mg/L	Mn	0,5
Mercurio	mg/L	Hg	0,005
Molibdeno	mg/L	Mo	0,07
Níquel	mg/L	Ni	0,5
Nitrógeno Total **	mg/L	N	10
PH	unidad	pH	6,0 - 8,5
Plomo	mg/L	Pb	0,2
SAAM	mg/L	SAAM	10
Selenio	mg/L	Se	0,01
Sólidos Sedimentables	ml/1/h	S SED	5
Sólidos Suspendidos Totales	mg/L	SS	80
Sulfatos	mg/L	SO <sub>4</sub> <sup>2-</sup>	1000
Sulfuros	mg/L	S <sup>2-</sup>	1
Temperatura	°C	T <sup>o</sup>	30
Zinc	mg/L	Zn	5

**Table 7: Maximum permitted levels of liquid waste discharge into rivers taking into consideration the capacity of dilution (CONAMA, 2000)**

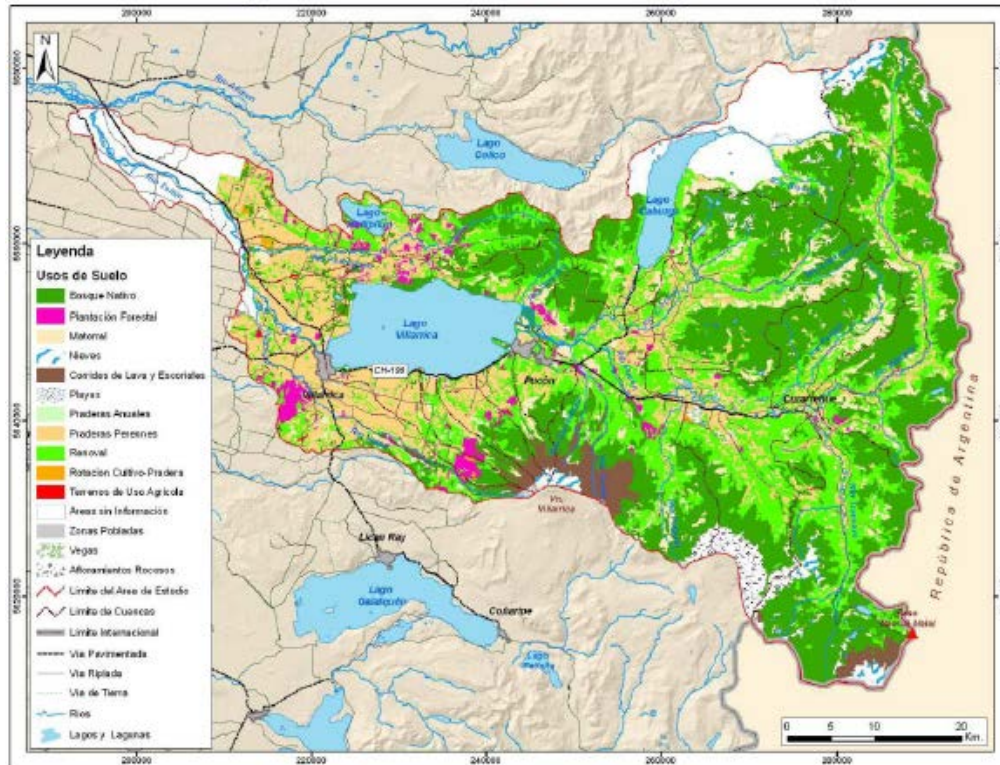
TABLA N° 2

LIMITES MAXIMOS PERMITIDOS PARA LA DESCARGA DE RESIDUOS LIQUIDOS A CUERPOS DE AGUA FLUVIALES CONSIDERANDO LA CAPACIDAD DE DILUCION DEL RECEPTOR

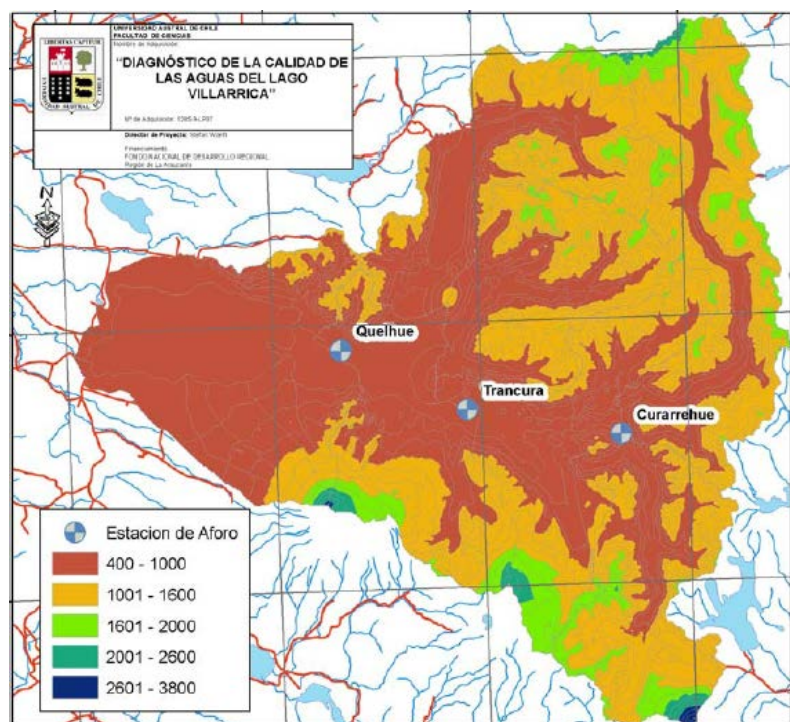
CONTAMINANTE	UNIDAD	EXPRESION	LIMITE MAXIMO PERMISIBLE
Aceites y Grasas	mg/L	A y G	50
Aluminio	mg/L	Al	10
Arsénico	mg/L	As	1
Boro	mg/L	B	3
Cadmio	mg/L	Cd	0,3
Cianuro	mg/L	CN <sup>-</sup>	1
Cloruros	mg/L	Cl <sup>-</sup>	2000
Cobre Total	mg/L	Cu	3
Coliformes Fecales o Termotolerantes	NMP/100 ml	Coli/100 ml	1000
Indice de Fenol	mg/L	Fenoles	1
Cromo Hexavalente	mg/L	Cr <sup>6+</sup>	0,2
DBO <sub>5</sub>	mgO <sub>2</sub> /L	DBO <sub>5</sub>	300
Fluoruro	mg/L	F <sup>-</sup>	5
Fósforo	mg/L	P	15
Hidrocarburos Fijos	mg/L	HF	50
Hierro Disuelto	mg/L	Fe	10
Manganeso	mg/L	Mn	3
Mercurio	mg/L	Hg	0,01
Molibdeno	mg/L	Mo	2,5
Níquel	mg/L	Ni	3
Nitrógeno Total Kjeldahl	mg/L	NKT	75
Pentaclorofenol	mg/L	C <sub>6</sub> OHCl <sub>5</sub>	0,01
PH	Unidad	pH	6,0 – 8,5
Plomo	mg/L	Pb	0,5
Poder Espumógeno	mm.	PE	7
Selenio	mg/L	Se	0,1
Sólidos Suspendidos Totales	mg/L	SS	300
Sulfatos	mg/L	SO <sub>4</sub> <sup>2-</sup>	2000
Sulfuros	mg/L	S <sup>2-</sup>	10
Temperatura	°C	T <sup>o</sup>	40
Tetracloroetano	mg/L	C <sub>2</sub> Cl <sub>4</sub>	0,4
Tolueno	mg/L	C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	7
Triclorometano	mg/L	CHCl <sub>3</sub>	0,5
Xileno	mg/L	C <sub>6</sub> H <sub>4</sub> C <sub>2</sub> H <sub>6</sub>	5

**Figure 1: Map of the soil use in the Villarrica Lake watershed (UACH, 2008)**

Legend: Dark green - native forest; Light Green - Secondary forest; Purple - Forest plantations; Beige - Grassland



**Figure 2: Altitude ranges in the study area (Villarrica Lake watershed) (UACH, 2008)**



**TOOLBOX FOR THE WASTEWATER TREATMENT PLANT OF PUCÓN**  
Please also refer to the interactive Excel Document as an attached document to this PDF

Point source MEASURES	Description	Efficiency P removal	Efficiency N removal	Total yearly P discharge (in tons after treatment) *4	Total yearly N discharge Villarrica Case (after treatment) *5	Capital and O&M Costs	Total costs for Villarrica (yr)*	Literature Source	Ranking Efficiency P removal (*1)	Ranking Costs P removal (*2)	Ranking most cost-efficient measure for P removal	Ranking Efficiency N removal (*1)	Ranking Costs N removal (*2)	Ranking most cost-efficient measure for N removal
<b>Secondary treatment by alum flocculation</b>	Phosphorus removal	95%	not applicable	1,48 (assuming initial untreated total P: 9 mg/L)	n.a.	USD\$ 73/ 3 800 000 liters (or \$0,02/m3)	US\$ 63 148 per year	<a href="http://www.gfredlee.com/Nutrients/MalhotraNutrRe">http://www.gfredlee.com/Nutrients/MalhotraNutrRe</a>	3	3	3	not applicable	not applicable	not applicable
<b>Secondary treatment by lime precipitation</b>	P removal	90%	not applicable	2,96	n.a.	USD\$ 40 / 3 800 000 liters (or \$0,01/m3)	US\$ 32 871 per year	<a href="http://www.gfredlee.com/Nutrients/MalhotraNutrRe">http://www.gfredlee.com/Nutrients/MalhotraNutrRe</a>	4	1	2	not applicable	not applicable	not applicable
<b>Tertiary treatment: Actiflo Process</b>	Mechanical type of tertiary treatment technology	98,9% (down to 0,1 mg P/L)	not applicable	0,3285	n.a.	USD\$ 2 000 000 (2006) and \$49295 O&M costs per yr (US\$ 0,014 /m3)	USD\$ 2 000 000 (2006) plus 49 295 US\$ per year (includes O&M costs)	<a href="http://www.mississippimills.ca/Document/s/170/Revis">http://www.mississippimills.ca/Document/s/170/Revis</a>	2	2	1	not applicable	not applicable	not applicable
<b>Chemical precipitation</b>	P removal	90%	not applicable	2,96	n.a.	USD 15 / 100 m3** (or \$0,15/m3)	US\$ 493 076/yr	<a href="http://www.bvsde.paho.org/bvsacd/aqua">http://www.bvsde.paho.org/bvsacd/aqua</a>	4	6	6	not applicable	not applicable	not applicable
<b>Denitrification</b>	Nitrogen removal	not applicable	80%	n.a.	32,8	USD 20 / 100m3** (or \$0,2/m3)	US\$ 657 435/yr	<a href="http://www.bvsde.paho.org/bvsacd/aqua">http://www.bvsde.paho.org/bvsacd/aqua</a>	not applicable	not applicable	not applicable	3	2	2
<b>Ion exchange</b>	N and P removal	87%	87%	3,84	21,4	USD 85/ 100 m3 for P (or \$0,85/m3); USD 52 / 100 m3 for N (or \$0,52/m3) **	US\$ 2 797 201/yr for P; US\$ 1 709 332/yr for N	<a href="http://www.bvsde.paho.org/bvsacd/aqua/euro.pdf">http://www.bvsde.paho.org/bvsacd/aqua/euro.pdf</a>	5	8	8	2	3	2
<b>Flocculation</b>	Phosphorus removal	45%	not applicable	16,27	n.a.	US\$ 7,5 / 100 m3 (or \$0,075/m3) **	US\$ 246 538 per year	<a href="http://www.bvsde.paho.org/bvsacd/aqua/euro.pdf">http://www.bvsde.paho.org/bvsacd/aqua/euro.pdf</a>	6	5	7	not applicable	not applicable	not applicable
<b>Tertiary filtration: rapid sand filter with</b>	P removal	95%	not applicable	1,48	n.a.	Capital cost: US\$ 720 000, Maintenance costs: US\$ 350 000	US\$ 720 000 once and US\$ 350 000 yearly	Costs of tertiary treatment of municipal	3	4	4	not applicable	not applicable	not applicable
<b>Secondary clarification with UV</b>	N removal	not applicable	95,6% (down to 2,2 mg/L N total)	n.a.	7,23	USD 0,7 / m3 (includes O&M and investment costs)	US\$ 2 301 024 / yr	US EPA: Advanced Wastewater	not applicable	not applicable	not applicable	1	4	2
<b>Advanced wastewater treatment: BNR, chemical</b>	P removal	99,67% (down to 0,029 mg P / L)	not applicable	0,095	n.a.	USD 0,5 / m3 (includes O&M and investment costs)	US\$ 1 643 589 / yr	US EPA: Advanced Wastewater Treatment to Achieve Low	1	7	5	not applicable	not applicable	not applicable
<b>Denitrification in Tertiary Filtration: Application of Methanol</b>	N removal	not applicable	80% (removal of total N: 10 mg N/L)	n.a.	32,87	US\$ 0,18 / m3 (literature: 3.80CHF/kg N removed)	US\$ 700 000 once and US\$ 595 854 / yr (or CHF 499 654 /yr)	<a href="http://www.informaworld.com/smpp/content?db=al&amp;content=a713630209&amp;frm=abslink">http://www.informaworld.com/smpp/content?db=al&amp;content=a713630209&amp;frm=abslink</a> ; <a href="http://www.sciencedirect.com/science?_ob=MiameImageURL&amp;_imagekey=B6VDY-3X1N34W-F-1&amp;_cdi=59">http://www.sciencedirect.com/science?_ob=MiameImageURL&amp;_imagekey=B6VDY-3X1N34W-F-1&amp;_cdi=59</a>	not applicable	not applicable	not applicable	3	1	1
<b>Transformation of ammonia into molecular nitrogen N2</b>	N removal	not applicable	55%	n.a.	74	Investment of 150 000 CHF per ton of yearly nitrogen reduction is needed (The cost of this measure consists mainly of capital costs)	US\$ 16 120 557 per yr (13 500 000 CHF / yr)	<a href="http://www.sciencedirect.com/science?_ob=MiameImageURL&amp;_imagekey=B6VDY-3X1N34W-F-1&amp;_cdi=59">http://www.sciencedirect.com/science?_ob=MiameImageURL&amp;_imagekey=B6VDY-3X1N34W-F-1&amp;_cdi=59</a>	not applicable	not applicable	not applicable	4	5	3

\* with a daily average treated flow of 9 000m3 in the Pucón Wastewater Treatment Plant

\*\* Investment on electricity, labour, chemicals and maintenance, plus 10 percent of the investment to cover interest and depreciation per year is calculated as the running cost.

\*\*\* Curarrehue has 7000 hab, thus 4200 m3 water have to treated approx. per day

(\*1) From the most efficient to the least efficient

(\*2) From the least costly to the most costly

\* 4 assuming initial untreated total P: 9 mg/L

\*5 assuming initial N total: 50 mg/L

## TOOLBOX FOR CURARREHUE PLANT

Please also refer to the interactive Excel Document as an attached document to this PDF

Point source measures	Description	Efficiency P removal	Efficiency N removal	Total yearly P discharge (after treatment)	Total yearly N discharge (after treatment)	Capital and O&M Costs for removal P total	Capital and O&M Costs for removal of N total	Total costs for Villarrica (yr)*	Literature Sources
<b>Construction of a Sequential Batch Reactor Plant* (Primary &amp; Secondary Treatment)</b>	N and P removal	Down to approx. 2 mg/L total P	Down to approx. 8 mg/L total N	<b>3,07</b>	<b>12,2</b>	Capital cost: <b>US\$ 2 000 000</b> , O&M: <b>US\$ 500 000/yr</b>	see "Capital and O&M costs for removal P total" as it includes the cost for both P and N removal	Total capital cost: <b>US\$ 2 000 000</b> , O&M total: <b>US\$ 500 000/yr</b>	<a href="http://www.epa.gov/owm/mtb/sbr_new.pdf">http://www.epa.gov/owm/mtb/sbr_new.pdf</a> ; <a href="http://www.puntoambiental.com/infor">http://www.puntoambiental.com/infor</a>
<b>Tier 2 Upgrade: extended aeration process and denitrification zones (for N) and chemical addition (for P)</b>	N and P removal	Down to approx. 1 mg/L total P	Down to 8 mg/L total N	<b>1,5</b>	<b>12,2</b>	<b>Capital cost: US\$ 170 000 and O&amp;M costs** = USD\$ 5 942/ yr for chemicals, US\$ 47 200/yr labour cost, USD\$ 3 400/yr for maintenance</b>	Capital cost: <b>US\$ 2 500 000</b> , O&M: <b>US\$ 29 000/yr</b>	Total capital cost: <b>US\$ 2 670 000</b> ; O&M total: <b>US\$ 85 542/yr</b>	<a href="http://www.chesapeakebay.net/content/publications/cbp_13136.pdf">http://www.chesapeakebay.net/content/publications/cbp_13136.pdf</a>
<b>Tier 3 Upgrade: additional aeration, a secondary anoxic zone plus methanol addition, additional clarification tankage (for N) and additional chemical costs (for P)</b>	N and P removal	Down to 0,5 mg/L total P	Down to 5 mg/L total N	<b>0,77</b>	<b>7,7</b>	(**1); O&M = <b>US\$ 4 125/yr</b> (for chemicals), <b>US\$ 47 200/yr</b> (labour cost) and <b>US\$ 3 400/yr</b> (maintenance)	Capital cost: <b>US\$ 1 200 000</b> , O&M: <b>US\$ 31 000/yr</b>	Total capital cost: <b>(**1) plus US\$ 1 200 000</b> ; O&M Total: <b>US\$ 85 725/yr</b>	<a href="http://www.chesapeakebay.net/content/publications/cbp_13136.pdf">http://www.chesapeakebay.net/content/publications/cbp_13136.pdf</a>
<b>Tier 4 Upgrade: deep bed denitrification filters (for N) and metal salt addition with microfiltration (for P)</b>	N and P removal	Down to 0,1 mg/L total P	Down to 3 mg/L total N	<b>0,15</b>	<b>4,6</b>	Capital cost: <b>US\$ 1 400 000</b> plus O&M: <b>US\$ 190 000/yr</b>	Capital cost: <b>US\$ 1 300 000</b> , O&M: <b>US\$ 80 000/yr</b>	Total capital cost: <b>US\$ 2 700 000</b> ; O&M total: <b>US\$ 270 000</b>	<a href="http://www.chesapeakebay.net/content/publications/cbp_13136.pdf">http://www.chesapeakebay.net/content/publications/cbp_13136.pdf</a>

\* with a daily average treated flow of 4 200m<sup>3</sup> in the new Curarrehue Wastewater Treatment Plant (Curarrehue has 7000 hab)

\*\* amount of liquid alum required to reduce the plant's total phosphorus concentration to 1mg/L is calculated for the yearly chemical cost.

(\*\*1) Capital cost here is zero, since tier 3 is enacted after tier 2. The wastewater plant would already have chemical phosphorus removal systems in place.

## TOOLBOX FOR THE FISH FARMS

Please also refer to the interactive Excel Document as an [attached document](#) to this PDF

Name of fish farm	Flow rate used for production	% of total L/s	Current treatment of water	N discharge after treatment -	P discharge after treatment -	N discharge after rotating filter (with	P discharge after rotating filter (with 74% efficiency*) and settling basin	Capital costs for N and P removal (*1)	Annual costs for N and P removal (*1)
Fundo La Cascada (Los Riscos)	260	1,91	Settling basin (SISS)	2205	65	43	6	43010	11500
Fundo La Cascada (Los Chilcos)	800	5,85	Settling basin (SISS)	6755	199	725	20	43010	11500
Marine Harvest Chile Fundo Loncostraro	480	3,51	Rotating filter and settling basin (SISS)	4053	119	4053	119	no further treatment	no further treatment
Marine Harvest Chile Fundo Loncostraro (Km 14)	1000	7,32	Rotating filter and settling basin (SISS)	8454	249	8454	249	no further treatment	no further treatment
Piscicola Huililco (Carileufu)	110	0,81	Settling basin ( <a href="http://www.pisciculturahuililco">http://www.pisciculturahuililco</a> )	936	27	100	3	43010	11500
Entre Rios (Caburgua)	1300	9,52	Rotating filter and settling basin (SEIA)	10993	323	10993	323	no further treatment	no further treatment
Quetro (Camino a Rinconada)	3200	23,41	Settling basin (SEIA)	27034	797	2906	85	93000	18300
Martinez Navarro (Rinconada Catripulli)	268	1,96	Settling basin ( <a href="http://www.e-seia.cl/archivos/Adenda_N_3_P_piscicultura_Catripulli.pdf">http://www.e-seia.cl/archivos/Adenda_N_3_P_piscicultura_Catripulli.pdf</a> )	2264	67	328	7	43010	11500
Metzger Basaure (El Radal, Quetroleufu)	240	1,76	Settling basin	2034	61	218	6	43010	11500
Nicolini Leguia (Carhuello)	897	6,56	Rotating filter only (SEIA)	7576	223	7576	223	no further treatment	no further treatment
Salmones Multiexport	1000	7,32	Settling basin (SISS)	8453	249	1228	26	93000	18300
Aquachile	450	3,29	Settling basin	3799	112	407	11	43010	11500
Iribarren Marton (Quetroleufu)	2000	14,63	Settling basin	16894	497	1816	53	93000	18300
Ruiz Bustamante (Molco)	120	0,88	Settling basin (SISS)	1017	30	109	3	43010	11500
Ulloa Figueroa	40	0,29	Settling basin	334	10	42	1	43010	11500
Pesquera Los Fioridos (Catripulli)	750	5,49	Settling basin	6339	186	807	19	43010	11500
Pesquera Los Fioridos (Quina)	750	5,49	Settling basin	6339	186	807	19	43010	11500
<b>Total</b>	<b>13 665 l/s</b>	<b>100</b>							

<b>Total yearly and cost estimates n°1:</b>	Current N discharge into the lake: <b>115 479 kg/yr</b>	Current P discharge into the lake: <b>3 400 kg/yr</b>	N discharge after new treatment: <b>40612 kg/yr</b> (65% N removal in total)	P discharge after new effluent treatment: <b>1173 kg/yr</b> (65% P removal in total)	<b>Total capital costs: USD 709 100</b>	<b>Total annual costs: USD 169 900</b>
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Cost estimates n°2 according to Buschmann (2001) (\*2) :

(\*2) 74 867 kg N removed \* USD 9 : **Total annual costs: USD 169 900**  
673803 PLUS 2227 kg P removed \* USD 3,5 : 7794 EQUALS **USD 681 597**

\* Settling ponds - N removal: 15% efficiency; P removal: 15% efficiency (Source: Servicio de Evaluación Ambiental Chile, SEIA; [http://www.e-seia.cl/archivos/f8d\\_Anexo\\_10\\_Memoria\\_Sistema\\_de\\_Tratamiento\\_Caren\\_Alto.pdf](http://www.e-seia.cl/archivos/f8d_Anexo_10_Memoria_Sistema_de_Tratamiento_Caren_Alto.pdf))

\*\* highest possible removal rate (of N and P) for a rotating filter

(\*1) According to Aquamedia.com (2003): Engineering and economics of effluent treatment (Source: [http://www.aquamedia.org/FileLibrary/10/Loix\\_1.pdf](http://www.aquamedia.org/FileLibrary/10/Loix_1.pdf))

(\*2) The cost to remove 1kg of N from a water body is approx. US\$ 9 per kg and US\$ 3,5 per kg of P removed, according to Buschmann (2001): "Impacto Ambiental de la Acuicultura: El Estado de la Investigación en Chile y el Mundo"

## TOOLBOX FOR NUTRIENT EXPORTS (BMPs)

	Description	P removal efficiency	N removal efficiency	Cost (per km)	Total cost for Villarrica if the measure would be applied to 1% (9,8 km) of the affluents' shoreline	Maintenance cost per km (US\$/yr)	Reduction P in this case (tons/yr)	Reduction N in this case (tons/yr)	Literature source	Ranking efficiency	Ranking cost
Fencing	Constructing fences along streambank	25%	20%	US\$ 7 000 OR GBP 3,50 per	US\$ 54 880 - US\$ 68 600	US\$ 5000	Discharge into affluents	Discharge down to 7,2 tons of N/yr	<a href="http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80">http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80</a>	4	1
Reforestation	Riparian woodland forms a very important edge habitat between agricultural land and the aquatic zone	70%	80%	US\$ 16 404	US\$ 160 759	US\$ 8 000	Down to 0,96 tons of P per 9,8 km per yr	Down to 1,8 tons of N per 9,8 km / yr	<a href="http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80">http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80</a>	2	4
Vegetation Filter (dry)	Filter strips are areas of grass or other permanent vegetation that intercept runoff before it enters a water body. Filter strips collect sediment, nutrients and	65%	60%	US\$ 13 000	US\$ 127 400	US\$ 1 300	Down to 1,12 tons of P per 9,8 km per yr	Down to 3,6 tons of N per 9,8 km/yr	<a href="http://nem.o.snr.arizona.edu/nemo/BMPdocs/Streambank">http://nem.o.snr.arizona.edu/nemo/BMPdocs/Streambank</a>	3	3
Riparian buffer strip (wet)	Strips of natural or naturalised wetland vegetation or woodland, usually ranging from 1-50 m wide situated alongside watercourses, particularly small streams.	60%	85%	US\$ 10 200	US\$ 99 960	US\$ 1 500	Down to 1,28 tons of P per 9,8 km per yr	Down to 1,35 tons of N per 9,8 km / yr	<a href="http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80">http://apps.sepa.org.uk/bmp/ShowPractice.aspx?bmpNumber=80</a>	1	2
	: the two preferred options to reduce the nutrient inflow into the river streams										



## SELECTION OF MEASURES FOR THE VILLARRICA LAKE WATERSHED

Measure	Source of pollution to tackle	Efficiency P removal for this specific source of pollution - in %	P discharge in absolute numbers after measure (tons/yr)	Efficiency N removal for this specific source of pollution - in %	N discharge in absolute numbers after measure	Capital costs removal P	Capital costs removal N	Initial total P discharged from source	Initial total N discharged from source	Cost per kg P reduced (USD)	Ranking efficiency P measure	Ranking Cost-Efficiency of Measures	Cost per kg N reduced (USD)	Ranking efficiency N measure	Ranking Cost-Efficiency of Measures for N	Choice of measures for the Villarrica Lake river basin
<b>Application of a Rotating</b>	Aquaculture	65%	<b>1,1</b>	65%	<b>40,6</b>	<b>US\$ 7 794</b>	<b>US\$ 673 803</b>	<b>3,4</b>	<b>115,5</b>	3,38	6	<b>1</b>	8,98	6	<b>2</b>	<b>X</b>
<b>Tertiary Filtration: Rapid Sand Filter with</b>	Wastewater treatment plant Pucón (P removal)	95%	<b>1,48</b>	not applicable	not applicable	<b>US\$ 720 000</b>	not applicable	<b>4,9</b>		210	2	<b>7</b>	not applicable	not applicable	not applicable	
<b>Denitrification in Tertiary Filtration: Application of</b>	Wastewater treatment plant Pucón (N removal)	not applicable	not applicable	80%	<b>32,87</b>	not applicable	<b>US\$ 700 000</b>		<b>80,8</b>	not applicable	not applicable	not applicable	14,6	5	<b>5</b>	<b>X</b>
<b>Construction of a Sequential Batch Reactor</b>	Commune of Curarrehue	77%	<b>3,09</b>	84%	<b>12,2</b>	<b>US\$ 2 000 000</b>		<b>13,8</b>	<b>76,6</b>	20,8	4	<b>2</b>	15,5	4	<b>4</b>	<b>X</b>
<b>Tier 3 Upgrade: additional aeration, a secondary</b>	Commune of Curarrehue	94%	<b>0,77</b>	90%	<b>7,7</b>	<b>US\$ 1 200 000</b>				123	3	<b>5</b>	23,5	2	<b>6</b>	
<b>Tier 4 Upgrade: deep bed denitrification filters (for N)</b>	Commune of Curarrehue	98,90%	<b>0,15</b>	94%	<b>4,6</b>	<b>US\$ 2 700 000</b>				142	1	<b>6</b>	27	1	<b>7</b>	
<b>Riparian woodland</b>	Non-point source: Soil	70%	<b>0,96 *</b>	80%	<b>1,8 *</b>	<b>US\$ 160 759 *</b>		<b>320,9</b>	<b>900,7</b>	35	5	<b>4</b>	11,1	5	<b>3</b>	<b>X</b>
<b>Wet buffer strips</b>	Non-point source: Soil	60%	<b>1,28 *</b>	85%	<b>1,35 *</b>	<b>US\$ 99 960 *</b>				26	7	<b>3</b>	6,5	3	<b>1</b>	<b>X</b>
								<b>343</b>	<b>1173,7</b>							

\* For the measure tackling nutrient exportation through soils, the costs and the reduction displayed represent the implementation of the measure on 1% of the total river shoreline in the watershed. Since the watershed possesses 980 km shoreline, 1% represents 9,8 km.