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THE WATER FRAMEWORK DIRECTIVE AND THE CHILEAN NORMATIVE: TOWARDS A COMPREHENSIVE RELATION BETWEEN WATER QUALITY AND MORPHOLOGICAL CHARACTERIZATION IN SURFACE WATER, LIMARÍ BASIN, CHILE

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Summary

Considering the European approach established by the Water Framework Directive (WFD), the Chilean normative is analyzed with a focus on water quality. In the European Union (EU), the WFD determines the minimum chemical condition of the water bodies, and these must not exceed the environmental standards of quality, these elements of quality lead to the establishment of the ecological status, which is defined under three fundamental pillars, biological parameters, hydromorphological characteristics and physico-chemical water parameters. In Chile, on the contrary there is noconsideration between the above-mentioned fundamental pillars, and they are considered and monitored separately. Although it is possible to identify certain coincidences between both regulations, nevertheless, big differences are identified and some recommendations are proposed.

This work used the available chemical information, and this was analyzed and complemented with national publications on water quality. In Chile, the typology of the water bodies was generated following European standards. This typology was used to design the field research and to extract the necessary information to establish statistically significant relationships with the chemical parameters.

One part of the field work was to generate a morphological description in the area of study, following the AQEM approach (Assessment System for the Ecological Quality of Streams and Rivers), the system used throughout Europe, based on surveys of benthic macroinvertebrates.

In order to establish a relationship between the chemical and morphological parameters of the area, SPSS (Statistical Product and Service Solution) was used to generate a chi-square (X^2) statistical analysis. The information was crossed, contrasting the water quality defined for the watershed of this study against chemical and morphological parameters, giving the result that those variables that had major associations to low water quality was the geology of the area, the conductivity, and the proximity to major cities.

Key words: *Water quality, typology, Limarí watershed*

Resumen

Considerando el enfoque europeo establecido por el Marco de agua (WFD en sus siglas en inglés) y se analiza la normativa chilena en cuanto a normas de calidad de agua. En Europa, la WFD determina el estado químico de los cuerpos de agua y éstos no deben exceder los estándares de calidad medioambientales, estos elementos de calidad guían al establecimiento del estado ecológico el que está definido bajo tres pilares fundamentales, los parámetros biológicos, las características hidromorfológicas y los parámetros físico-químicos. En Chile, por el contrario, no hay una conjunción entre los mencionados pilares fundamentales y se consideran y monitorean por separado. Se logra identificar ciertas coincidencias entre ambas normativas, sin embargo también se identifican grandes diferencias y se plantean algunas recomendaciones.

En este trabajo se tomaron los datos químicos disponibles y se hizo un análisis de ellos y fueron complementados con publicaciones nacionales sobre calidad de agua. En Chile, la información sobre la tipología de los cuerpos de agua superficiales se ha ido gestando bajo estándares europeos, dicha tipología fue utilizada para diseñar el trabajo en terreno y para establecer relaciones estadísticamente significativas con los parámetros químicos.

Como parte del trabajo en terreno se generó una descripción morfológica en el área de estudio siguiendo el enfoque de AQEM (Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates).

Con el fin de establecer una relación entre los parámetros químicos y morfológicos del área de estudio se generó un análisis estadístico de Chi-cuadrado (X^2) usando el programa SPSS (Statistical Product and Service Solution), se cruzó la información sobre la calidad del agua definida para esta cuenca y los parámetros químicos y morfológicos dando como resultado que las variables con mayor asociación a una mala calidad del agua son la geología del área, la conductividad eléctrica y la cercanía de grandes ciudades.

Palabras claves: *Calidad de agua, tipología, Cuenca del Limarí*

Zussamenfassung

Angesichts des europäischen Ansatzes, der durch die Water Framework Directive (WFD) gegründet wurde, wird der Einwohner von Chile im Fokus auf die Wasserqualität untersucht. In Europa bestimmt der WFD die chemischen Bedingungen des Gewässers. Diese dürfen nicht die Umweltstandards der Qualität überschreiten; diese Elemente der Qualität führen zur Einrichtung des ökologischen Status, der unter drei grundlegenden Stützen, den biologischen Parametern, hydromorphologischen Eigenschaften und den physikalisch-chemischen Wasserparametern definiert wird.Im Gegensatz zu Chile gibt es keine Verbindung zwischen den erwähnten grundlegenden Stützen.Diese werden einzeln betrachtet und überwacht. Obwohl es möglich ist, gewisse Übereinstimmungen zwischen beiden Regelungen zu finden, werden dennoch große Unterschiede festgestellt, und einige Empfehlungen werden vorgeschlagen.

In dieser Arbeit wurden die vorhandenen chemischen Informationen verwendet, wurden analysiert und mit den nationalen Publikationen über die Wasserqualität ergänzt. In Chile wurden die hydromorphologischen Informationen verwendet um dem deutschen Standard zu folgen; um die Typologie der Gewässer festzulegen. Diese Typologie wurde verwendet um eine Feldforschung zu entwerfen und um die notwendigen Informationen herauszufinden. Diese Vorgehensweise dient dazu, um festzulegen wie sich statistisch wichtige Beziehungen mit den chemischen Parametern verhalten.Ein Teil der Feldarbeit sollte verwendet werden um eine morphologische Beschreibung der Studie nach dem AQEM-Ansatz (Assessment System for the Ecological Quality of Streams and Rivers) benutzen zu können, basierend auf Untersuchungen von benthischen Makroinvertebraten.

Um eine Beziehung zwischen chemischen und morphologischen Parametern herzustellen, wurde eine SPSS (Statistical Product and Service Solution) verwendet damit man eine X^2 statistische Analyse entwickeln kann.Die Informationen wurden verglichen im Hinblick auf die definierte Wasserqualität der Wasserscheiden. Dazu hat man die Studie zu den chemischen und morphologischen Parametern verwendet. Die Auswertung der Variablen zeigte eine hohe Verbindung zu einer niedrigen Wasserqualität im Bezug zu den geologischen Eigenschaften des Gebietes, der Leitfähigkeit und der Nähe zu größeren Städten.

Stichworte: *Wasserqualität, Tipologie, Limarí Becken.*

Abbreviations

AQEM: Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates

BNA: *Banco Nacional de Aguas* (National Bank of Water)

CEAZA: *Centro de Estudios Avanzados en Zonas Aridas* (Centre of Advanced Studies in Arid Zones)

CONAMA: *Comisión Nacional de Medioambiente* (National Commission of Environment)

DGA: *Dirección general de aguas* (National Chilean Water Agency)

FIA: Foundation for the Agrarian Innovation

GIS: Geographical Information System

ICA: *Indice de Calidad de Agua* (Water Quality Index)

INE: *Instituto Nacional de estadística* (National Institute of Statistics)

INIA: *Instituto de Investigaciones Agropecuarias* (Institute for Agricultural Research)

INN: *Instituto Nacional de Normalización* (National Institute of Normalization)

ITT: Institute for Technology and Resources Management in the Tropics and Subtropics

MMA: *Ministerio de Medioambiente* (Ministry of Environment)

QGIS: Quantum GIS, Open Source Geographic Information System

SPSS: Statistical Product and Service Solution

SNASPE: *Sistema Nacional de Áreas Silvestres Protegidas del Estado* (National System of Protected Area of the State)

UN WWAP: United Nations World Water Assessment Programme Water and Industry

WISER: Water bodies in Europe Integrative systems to assess Ecological Status and Recovery

WFD: Water Framework Directive

WWAP: World Water Assessment Programme

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Dedicated

A mi Madre

1. Introduction

1.1 Overview

Water is a vital resource with many uses and economic values. The usefulness of water declines as water quality deteriorates, and thus high quality water has greater demand and has more value than low quality water. The concepts of water quality and water quantity were developed simultaneously throughout human history, but until recently, quantitative means of assessing water quality were unavailable (Boyd, 2000).

A wide range of human and natural processes affect the biological, chemical, and physical characteristics of water, and thus impact water quality. Contamination by pathogenic organisms, trace metals, anthropogenic pollution and toxic chemicals; the introduction of non-native species; and changes in the acidity, temperature, and salinity of water can all harm aquatic ecosystems and also make water unsuitable for human use (UN WWAP, 2009).

Urbanization in the developing world has created serious water quality problems, because despite international efforts, infrastructure development on a global basis continues to trail behind increases in population growth (Perry and Vanderklein, 1996).

The protection of water resources, of fresh and salt-water ecosystems and of drinkable water and recreational water, has become the cornerstone of environmental protection, especially in the European Union. The increasing demand by citizens and environmental organizations for cleaner rivers, lakes, groundwater and coastal beaches has been evident for considerable time. This demand by citizens is one of the main reasons why the European Commission has made water protection one of its priorities. The European Water Policy assures the cleanliness of polluted waters and ensures that clean waters are kept clean. The European Water Policy underwent a restructuring process, and a new Water Framework Directive (WFD), adopted in 2000, is the operational tool, setting the minimum objectives for water protection for the European Union into the future (http://ec.europa.eu). The Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates (AQEM) is the main result of the EU-funded project, AQEM, which, was carried out from March 2000 to February 2002. It serves the implementation of the EU Water Framework Directive and provides a system for assessing ecological quality in European streams through the use of benthic macroinvertebrates. The aims of the AQEM system are to classify a stream stretch in a quality class from 5 (high) to 1 (low), based on a macroinvertebrate taxa list, and to provide information about the cause of a possible degradation in order to help direct future management practices[1].

The European community successfully established the European Water Policy as implemented by the WFD, which manages to include citizens with the aim to protect water bodies. The creation of the AQEM system provides a great improvement with regard to the establishment of the ecological status of a water body, and the applicability of this system in other countries is a very interesting topic for study and analysis.

1.2 Chilean context

Following the return to democracy in Chile, the political leaders focused their rhetoric on the pursuit of sustainability; in 1992 an initial package was sent to the Congress proposing four amendments that would control the administration of water (Retamal *et al.,* 2013). However these intentions were not successful and these provisions allowed unrestricted private speculation on water, which has been one of the Chilean water code's most controversial aspects (Bauer, 2004).The water code doesn't consider an integrated management or environmental aspects for this reason it was tried to modify, however after several parliamentary meetings it was achieved to include only the concept of ecological flow the administration of the water is delegated in the private users from 1981 and untill today they not have obligation to manage the water quality (Fuster, 2012).

In order to develop robustwater quality management, it is necessary to possess solid scientific information as a base for establishing an appropriate normative. In Chile, information on the requirements regarding water quality is determined by the national water policy and current legislation. Chilean legislation on water quality provides clear guidance on analytical methods used for monitoring water quality, but leaves open how to determine appropriate monitoring sites and frequencies (Ribbe *et al*., 2007).

[1]http://www.aqem.de

Considering the European approach of the WFD, where it integrates the biological parameters, hydromorphological characteristics and the physico-chemical water parameters for the determination of the ecological status, the aim of this work is to establish a integrative relationship between the physico-chemical and morphological parameters in order to determine if there are statistically significant relationships between these parameters. This study used water quality data (chemical parameters) provided by the National Chilean Water Agency (DGA in spanish) together with national publications about water quality. The morphologic evaluation was executed in the principal rivers of the Limarí River watershed of northern Chile according to the criteria established by the WFD. The study used the biological typology constructed by Fuster *et al* (2011), and the use of the biological typology is a key factor in the assessment.

1.3 Problem statement

In the semi arid zone of Chile, there is a great pressure for the existing water resources, and every day there are more urgent need to develop plans for regulation and water management with a sustainable vision. The untreated discharges produced by the agricultural, industrial and urban sectors worsen the water quality in the rivers, and it is necessary to create a tailored water management program using foreign experiences that stakeholders should follow in order to protect this vital resource. Furthermore, the authorities must improve current water regulations to avoid over exploitation.

1.4 Justification

This thesis intends to provide an overview of water quality in Chile, considering the European Union approach established by the Water Framework Directive through the use of the AQEM approach.

The European Union’s WFD unifies water quality criteria toward a sustainable future of care and monitoring of the water. This type of approach does not exist in Chile, because, over the decades, the country has given priority to economic growth over environmental protections. Since 1973, the military regime introduced neoliberal economic policies that supported strong private property rights and free market trade of the various ecosystem components. The establishment of a water rights market created a big incentive for private investment in the construction and maintenance of irrigation works and increased their efficiency, so water excesses could be transferred to more valuable uses, such as irrigative, urban and industrial purposes (Retamal *et al*. 2013). Water quality for Europe is defined under three fundamental pillars: biological, hydromorphological and physicochemical parameters. In Chile, in contrast, there is no integration between the above-mentioned fundamental pillars, and they are considered and monitored separately. This means that information is not integrated for the evaluation of water quality to the same degree as in the EU under the WFD. Recognizing this fundamental difference in approach makes it very interesting to study and analyze the way of integrating these pillars of Europe's more integrative approach to water quality within a Chilean watershed in order to establish in the future the watershed's ecological status.

This work used scanty chemistry information from governmental offices, and these were compared with national publications on water quality. Morphological parameters used information that was prepared by Chilean professionals using the WFD standards together with recently established biological typologies of various water bodies under different criteria. (Although various typologies were created, this work only used the biological typology.) If it is possible to establish a relationship between water quality and the morphological parameters, it could be a useful tool to determinate the state of the aquatic resources in the region for elaborating a future water management program.

1.5 Objectives

General Objective

Establish a relation between water quality and morphological parameters in the Limarí river basin taking as a reference the standards of the European WFD.

Specific Objectives

1. Compare the European WFD and the Chilean normative approaches to water quality.
2. Compare the classification methods of river typologies in Chile and Europe.
3. Identify information and knowledge gaps, describe hydromorphological and physico-chemical parameters, and establish a relationship between water quality parameters and morphological characterization in the Limarí River watershed.

2. Literature review

2.1 Water quality the European WFD and the Chilean normative approaches

2.1.1 River environment and water quality

In the definition of a river on a wider territorial scale, it supports a complex system of interactions in space and time that give rise to many closely associated and highly dynamic processes. A river must be considered a system in which it is not always easy to separate cause from effect and where biotic and abiotic components interact continuously. This system must be defined within a wide territorial framework, which requires considerations of its entire space and its total dynamics. Also, river condition, as a structuring element of the landscape, is an extremely important aspect in regions where water is scarce and irregular both in time and space, such as the Mediterranean, and is thus factor in the composition, organization and structure of the entire territory (Arizpe *et al.*, 2008).

An inadequate understanding of rivers can also be perverse because such a limited approach can easily lead to serious mistakes, such as a) the defined priorities are not always in tune with actual needs, b) work begins without due consideration for the river's response or its potential for natural self-restoration, and c) the techniques and materials used to solve or ameliorate one problem cause new problems or worsen other existing problems (Arizpe *et al.,* 2008).

Management efforts are further complicated by the diffuse nature of agricultural impacts. Rather than the industrial condition of easily identified outfall pipes, agricultural waste comes from many thousands of individual farms, dispersed over countless miles of rivers, streams and lakes. Sedimentation is the most significant water quality impact from agriculture for two reasons: sediment causes direct harm to biota and habitats and sediment is a carrier for both chemicals and nutrients (Perry and Vanderklein, 1996).

Agriculture pollutes through nutrients, pesticides, and increase salinity levels. Indeed, nutrient enrichment has become one of the planet's most widespread water quality problems (UN WWAP, 2009), and worldwide, pesticide application is estimated to be over 2 million metric tons per year (PAN List of HHP, 2009). Industrial activity releases about 300–400 million tons of heavy metals, solvents, toxic sludge, and other waste into the world's water each year (UN WWAP, 2009).

Water quality criteria are the quantitative or qualitative values for acceptable ranges of physical, chemical, and biological characteristics of water in stream classification, effluent limitation, drinking water standards, among others (Boyd, 2000).

The permitted water quality standard in effluents are based on experience, technical and economic processes, bioassays and other tests, ability to reliably measure the criteria, evidence of public health effects, educated guesses or judgments, mathematical models, and legal enforceability (Tchobanoglous and Schroeder, 1985).

In 2006, González *et al.* affirmed that the environmental assessment of the fluvial system is a topic of great interest, not only for scientific development concerning the ecological functioning of rivers, but also for water management. River assessment is a requirement for the European Union's Water Framework Directive in order to establish the ecological status of the water way and for proposing restoration and conservation measures.

2.2 European normative

The Water Framework Directive (WFD) provides basic standards to which all EU members must comply. Individual counties may, however, have national standards that are stricter than the WFD. According to the WFD, it is possible to understand the functions of continental water bodies under the concept of ecological quality status, which means to characterize the regularity of these systems under the three principal pillars of biological (e.g., phytoplankton, microalgae, benthos and fish), hydromorphological and physicochemical (e.g., dissolved oxygen, nutrient and specific pollutants) quality elements (WFD, 2000/60/EC).

The European Water Framework Directive (WFD, 2000/60/EC) establishes a framework for the protection of groundwater, surface waters, estuarine (transitional) waters, and coastal waters. This legislation possesses several specifics objectives:

a) To prevent further deterioration, to protect and to enhance the status of water resources;
b) To promote sustainable water use;
c) To enhance protection and improvement of the aquatic environment, through specify measures for the progressive reduction of discharges;
d) To ensure the progressive reduction of pollution of groundwater and prevent its further pollution;
e) To contribute the mitigating the effects of floods and droughts.

Besides the WFD, Article 2 (“Definitions”) defines “good status” and “chemical status.” The chemical status is achieved by a water body surface where concentrations of pollutants do not exceed the environmental quality standards established in Annex IX in the WFD (“Emission limit values and environmental quality standards”) and under other relevant community legislation that sets environmental quality standards at the community level (WFD, 2000/60/EC).

In Annex V of the WFD (2000/60/EC), the procedure for setting the ecological status by the member states is described, including concepts related with quality elements, normative definitions monitoring the ecological and chemical status for surface waters, and the classification and presentation of ecological status (WFD, 2000/60/EC). However, the

WFD does not provide clear guidance on the selection matrix to be studied for the physiological elements (Borja *et al.*, 2004). Furthermore in Annex V (WFD 2000/60/EC), is possible to find the quality elements for the classification of ecological status and general definition for rivers, lakes, transitional waters and coastal waters. The following tables provide a general definition of ecological quality in rivers for values of the biological quality (Table 1 in the Appendix A), hydromorphological elements supporting the biological elements (Table 2 in the Appendix A) and chemical and physicochemical elements supporting the biological elements (Table 3 in the Appendix A).

The WFD considers a high, good or moderate status of the water bodies. "High status" correspond to the water bodies where there are no, or only very minor, anthropogenic alterations to the values of the physicochemical and hydromorphological quality elements for the surface water body type from those normally associated with undisturbed conditions. The values of the biological quality elements for the surface normally are associated with undisturbed conditions, and show none, or only very minor, evidence of distortion. These undisturbed conditions are type-specific conditions for some biological communities (WFD, 2000/60/EC).

To catalogue water bodies as "good status", a water body must have the values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with undisturbed conditions (WFD, 2000/60/EC). The water bodies with "moderate status" present values of the biological quality elements for the surface that deviate moderately from those normally associated with undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than conditions of good status (WFD, 2000/60/EC). Whereas only macroinvertebrate data were required for the application of most prediction and assessment systems, the WFD required the sampling and interpretation of data on a broader suite of "biological quality elements", this included phytoplankton, other aquatic flora, macroinvertebrates and fish.

The Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates (AQEM) is based on a specific set of metrics for each individual stream type. Some of these metrics require species level determination; others may work with coarser taxonomic levels. In general, species level data give the best information. To conduct the evaluation using the AQEM requires a “multimetric” procedure, an index that combines several individual formulae (e.g. saprobic indices, feeding type composition), the results of which are finally combined into a multimetric result. Thus, multimetric indices integrate multiple attributes of stream communities (“metrics”) to describe and evaluate a single site condition. Within AQEM, metrics are defined as “Measurable parts or processes of a biological system empirically shown to change in value along a gradient of human influence” (Karr and Chu, 1999 *fide* AQEM, 2002).

In other words, metrics should reflect specific and predictable responses of the macroinvertebrate community to human activities, not necessarily to one single impact factor but to the cumulative effects of all events and activities within a watershed. Minimally disturbed sites are used as reference sites, against which monitoring sites are compared (AQEM, 2002). More details about the AQEM protocol found in Appendix B.

The WFD recognizes three forms of monitoring: surveillance (to provide an assessment of the overall surface water status within each catchment), operational (to establish the status of water bodies) and investigative (the source and magnitude of a specific pollutant).Surveillance monitoring includes the direct monitoring of biological assemblages.

Theother quality elements to be monitored for the classification of Ecological Status comprise hydromorphological, chemical and physiochemical elements supporting the biological elements (Furse *et al.*, 2006).

2.3 Chilean normative

In order to understand the Chilean situation and to compare it with the established system found in the European Union, the current Chilean normative will first be analyzed. A global scheme of environmental management for the control of the pollution of water is inserted into a larger scheme of water resource management that considers, among other things, the environmental quality norm (quality of the resources and water bodies associated with their uses) and the norm of emission (instruments of management of the effluent). The process that follows water pollution begins with the discharge of domestic and industrial liquid waste to sewer systems or directly into natural water bodies, which directly affects their quality. The Chilean norm is published by the National Institute of Normalization (INN in spanish). The relevant standards for water quality in Chile are:

1. Chilean norm NCh 1333/78, Water quality for different uses
2. Chilean norm NCh 409/84, Quality of drinkable water
3. Chilean norm NCh 2280, Technical standards downloads liquid industrial waste
4. Resolution Nº12600, regulates Discharges of liquid waste in seas and terrestrial navigable waters

Water quality in Chile is regulated by Chilean norm NCh 1333/78 (INN, 1978), which establishes the different levels of parameters to which it must comply through minimum standards; these measures have as an objective to protect and preserve the quality of water for specifics use. Article 1 of NCh 1333/78 establishes that the request of quality standards depending to their uses, that can be for (a) human consumption; (b) animal consumption; (c) irrigation; (d) recreation and aesthetics; and (e) aquatic life. In the cases of (a) and (b) the references values are established in NCh 409/84 (INN, 1984). For irrigation, the norm establishes minimum concentrations for twenty-six different chemical substances and of those fifteen are transition metals. Other parameters that are normalized by NCh 1333/78 are pesticides and electric conductivity, among others. Additional parameters for the case of water for aquatic life must comply with standards for biochemical oxygen demand (BOD), alkalinity, pH, temperature, color, solids, and any kind of hydrocarbon (INN, 1978) (Table 1).

The secondary norm of water quality must be elaborated for every region of the country, incorporating the environmental, economic and social reality in every territory, but also they must be homogeneous and standardized the processes to the national criteria of water quality (DGA, 2004). In the period of 2005-2011 in Chile only two regions have adopted this secondary norm of water quality, the first one it was the Serrano river basin and Llanquihue Lake (in the south of Chile); in the same period there have begun the processes of promulgation of these norm for the marine waters and estuarines areas in the region of Aysén, in Mataquito river basin, in Valdivia river basin, in Villarrica lake, in Baker river basin, in Itata river basin, in Huasco river basin and in Limarí river basin (OCDE, 2011).

Table 1: Chilean standard parameters for water quality according to the different uses. Sources (INN, 1978; INN, 1984).

Physicochemical Parameters	Unit	Norm 409/84 Drinking Water	Norm 1333/78		
			Aquatic Life	Irrigation	Recreative
Electrical Conductivity	mhos/cm	----	----	750-3000*	----
BOD_5	mg/L	----	----	----	----
Apparent Color	Pt-Co	20	----	----	100
Dissolved Oxygen	mg/L	----	≥ 5	----	----
pH	unit	6,5-8,5	6,0-9,0	5,5-9	6,5-8,3
Percentage Sodium	% Na	----	----	35	----
Dissolved Solids	mg/L	1000	----	----	----
Oil & Fat	mg/L	----	----	----	5
Temperature	°C	----	$<\Delta 3$	----	<30
Inorganic					
Ammonium	mg/L	0,25	----	----	----
Cyanide	mg/L	0,20	----	0,2	----
Chloride	mg/L	250	----	200	----
Fluoride	mg/L	1,5	----	1	----
Nitrate	mg/L	10	----	----	----
Nitrite	mg/L	1	----	----	----
Sulfate	mg/L	250	----	250	----

*Water that can have adverse effects in many cultivation and needs careful managing; it can be harmful in sensitive cultivation.

Table 1: Chilean standard parameters for water quality according to the different uses. Sources (INN, 1978; INN, 1984). Continuation.

Physicochemical Parameters	Unit	Norm 409/84 Drinking Water	Norm 1333/78		
			Aquatic Life	Irrigation	Recreative
Organic Essential Metal					
Bore	mg/L	----	----	----	----
Copper	mg/L	1,0	----	0,2	----
Chrome total	mg/L	0,05	----	0,1	----
Iron	mg/L	0,3	----	5	----
Manganese	mg/L	0,1	----	0,2	----
Magnesium	mg/L	125	----	----	----
Molybdenum	mg/L	----	----	0,01	----
Nickel	mg/L	----	----	0,2	----
Selenium	mg/L	0,01	----	0,02	----
Cobalt	mg/L	----	----	0,05	----
Vanadium	mg/L	----	----	0,1	----
Barium	mg/L	----	----	4	----
Zinc	mg/L	5	----	2	----
Lithium	mg/L	----	1/100 LTm99	2,5	----
Lithium (citric)	mg/L	----	1/100 LTm100	0,75	----
Silver	mg/L	----	1/100 LTm101	0,2	----
Cadmium	mg/L	0,01	1/100 LTm102	0,2	----
Tin	mg/L	----	1/100 LTm103	----	----
Mercury	mg/L	0,001	1/100 LTm104	0,001	----
Lead	mg/L	0,05	1/100 LTm105	5	----
Microbiology					
Fecal Coliforms	NMP/100mL	----	----	1000	1000
Totals Coliforms	NMP/100mL	----	----	----	----

2.4 The classification methods of river typologies in Europe and Chile.

2.4.1 The typological approach in Europe

Since water bodies are not homogeneous and a classification system based on their unique features would lead to a large number of types that would be unmanageable, generalization helps solve this problem by the creating broad typologies. This method is one of the key elements in the implementation of the Water Framework Directive (Bald *et al.*, 2005). The WFD requires surface waters within the River Basin District to be divided into water bodies and assign to them classification and management units (Borja *et al.*, 2004). The first stage of the WFD is to classify the water bodies into “Types”. This step must be done in order to enable “type-specific” reference conditions to become the basis for future classification schemes (Borja *et al.*, 2004).

Characterizing the surface water bodies types will bring consequences for subsequent operational aspects of the implementation of the WFD, including monitoring, assessment and reporting within the WFD (Bald *et al.*, 2005). Bald *et al*. conducted a multivariate analysis using the changes in water quality in the Basque Country, and in order to demonstrate the accuracy and potential of these methodologies in determining the physicochemical state, a factor analysis was used, which allowed for the study of the interrelationships among a large number of variables, explaining them in terms of their common underlying dimensions (factors) (Bald *et al.*, 2005).

“The member states of the European Union shall identify the location and boundaries of bodies of surface water and shall carry out an initial characterization of all such bodies in accordance with the WFD methodology” (WFD, 2000/60/EC). Surface water bodies that are inside the river basin will be identified to be within any of the following categories of surface waters: rivers, lakes, waters of transition or coastal waters or as artificial surface water bodies or highly modified water bodies. For every category of surface water, the relevant bodies of surface water in the district of the basin of the river will be differentiated according to the type. These types are defined according to System A or System B (Table 2).

Table 2: Ecoregions and surface water body, in this table is show rivers and the system A and B (WFD, 2000/60/EC).

Rivers			
System A Fixed typology	Descriptors	System B Alternative characterization	Physical and chemical factors that determine the characteristics of the river or part of the river and hence the biological population structure and composition
Ecoregion Type	Ecoregions shown on map altitude typology high: > 800 m mid-altitude: 200 to 800 m lowland: < 200 m Size typology based on catchment area small: 10 to 100 km^2 medium: > 100 to 1 000 km^2 large: > 1 000 to 10 000 km^2 very large: > 10 000 km^2 Geology calcareous siliceous organic	Obligatory factors	altitude latitude longitude geology size energy of flow (function of flow and slope) mean water width, mean water depth, mean water slope, form and shape of main river bed river discharge (flow) category valley shape transport of solids acid neutralising capacity mean substratum composition chloride air temperature range, mean air temperature precipitation

If System A is used, the surface of water bodies within the river basin district shall first be differentiated by the relevant ecoregions and according to the descriptors set out in the Table 2 for system A. If system B is used, Member States must achieve at least the same degree of differentiation as would be achieved using system A. The surface water bodies in the river basin district shall be differentiated into types using the values for the obligatory descriptors and such optional descriptors, or combinations of descriptors, as are required to ensure that type specific biological reference conditions can be reliably derived (WFD, 2000/60/EC). For artificial and heavily modified surface water bodies the differentiation shall be in accordance with the descriptors for whichever of the surface water categories most closely resembles the heavily modified or artificial water body concerned (WFD, 2000/60/EC).

All Member States shall submit to the Commission a map or maps (in a GIS format) of the geographical location of the types consistent with the degree of differentiation required under system A (WFD, 2000/60/EC).

The establishment of type-specific reference conditions for surface water body types is characterized in accordance with the explanation above, type-specific hydromorphological and physicochemical conditions shall be established representing the quality elements specified in the characterization of surface water body types in Appendix V, the procedure for setting the ecological status (WFD, 2000/60/EC).

The ecological status relates to the relationship between the values of the biological parameters observed in a surface water body and the values for these parameters in the reference conditions applicable to that body (Borja *et al.*, 2004). Typology is based on obligatory factors: latitude; longitude; tidal range; salinity; among others and optional factors that can be found: mixing; intertidal area (depth, tidal range and shape) and residence time (Borja *et al.*, 2004). In 2006, Borja and others published a study of developing further methodological approaches to assess the risk of failing to achieve good ecological status, used a list of different anthropogenic pressures and aerial photographs, where the banks and intertidal areas of all the water bodies were scanned, and the information generated nine relevant groups of pressures in a spatial analysis with the aid of a Geographical Information System (GIS) according to the requirements of the WFD guidance on GIS (Vogt, 2002; Borja *et al.*, 2006).

Since 2000, the WFD has developed protocols for the member states to generate of a European typology, however in Chile this topic was first considered a mere few years ago, and there is a plenty work to do on this topic in the future.

2.4.2 The typological approach in Chile

The normative for water quality is primarily based in physiochemical parameters. It is one of the reasons that in the last years, some projects have been focused on extending the knowledge of biological parameters like biological indicators to provide a more complex baseline for the classification of water bodies. This would help to normalize and to monitor each ecosystem, because an essential basis for the conservation, protection, management and restoration, making the typification of water bodies within their biotic and abiotic indicators necessary. Due to the fact that Chile presents different physical conditions from Europe, it is essential to establish the thresholds for each descriptor, thus allowing for differences between the ecological systems of Chile and Europe. In short, it is necessary to clarify that the number of types of rivers that will result from a classification of Chilean rivers must reflect the real variability that exists (Fuster *et al*., 2010).

In Chile, in the recent years a system of typology has been developed where the types of water bodies are defined, using the following stages (Fuster *et al.*, 2010):

a) Evaluation of ecological state of suface waters, according to biological indicators

b) Planning of water monitoring, through the establishment of monitoring plans and networks

c) Identifying the necessary measurements needed to reach a good monitoring state of surface waters

In 2010, the process characterized the types of water bodies established in five Chilean ecoregions of fresh water (Figure 1): the Atacama and Altiplano of the high Andes, the Mediterranean-like zone of the middle of the country, the Valdivian Lakes of the next area to the south, and the Patagonian ecoregion that stretches to the far south of the country. Until Fuster *et al*. (2010) there were no defined ecoregions in Chile, and researchers used the freshwater ecoregions of the world from Abell *et al*. (2008), who defined their ecoregions according to the distribution and composition of fish fauna. From this result, Fuster *et al*. (2011) modified the limits of each ecoregion by means of ground-truthing and analysis from experts in aquatic ecosystems.

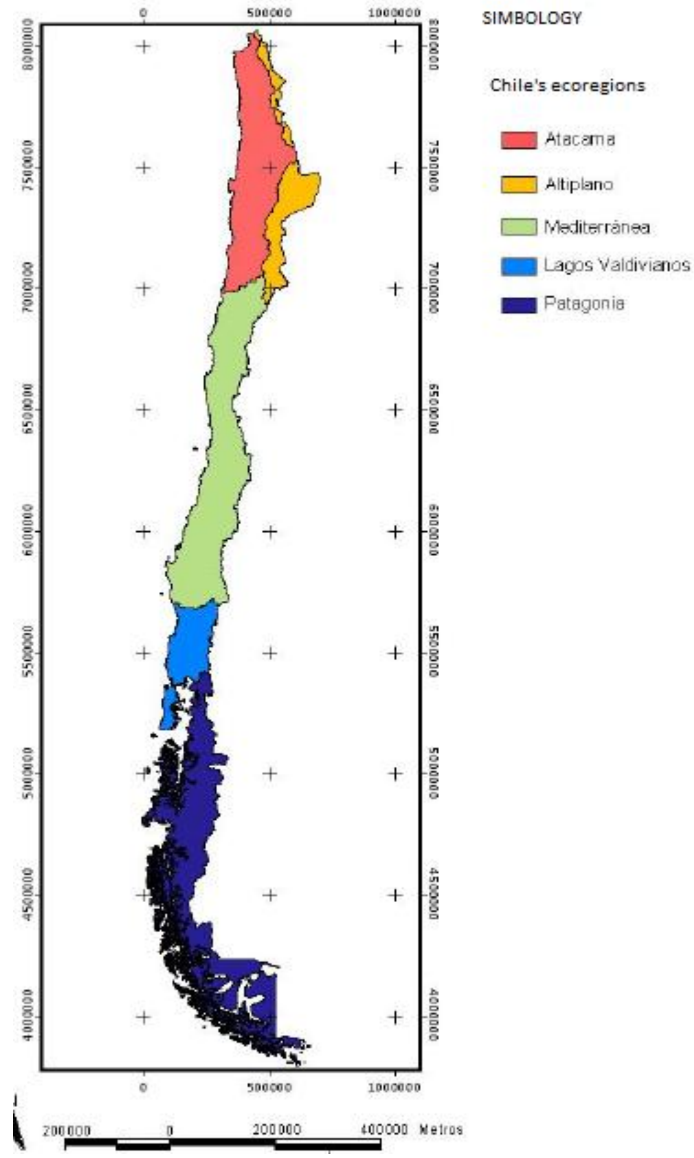


Figure 1. Ecoregions of fresh water for Chile (Fuster *et al.*, 2010).

According to the Typology of Chilean Rivers there are a total of forty types (Box 1), which are described based on physical aspects to be expected to be found in each as well as biological aspects. In the description of every river type, Fuster *et al.,* (2011) have proposed "determinant aspects", which are those factors defined by them for the type of ecosystem, and "dominant aspects", which are those aspects that prevail but that do not differentiate between two types (Fuster *et al.*, 2011).

Box 1. Rivers type for every ecoregion (Fuster *et al.*, 2011).

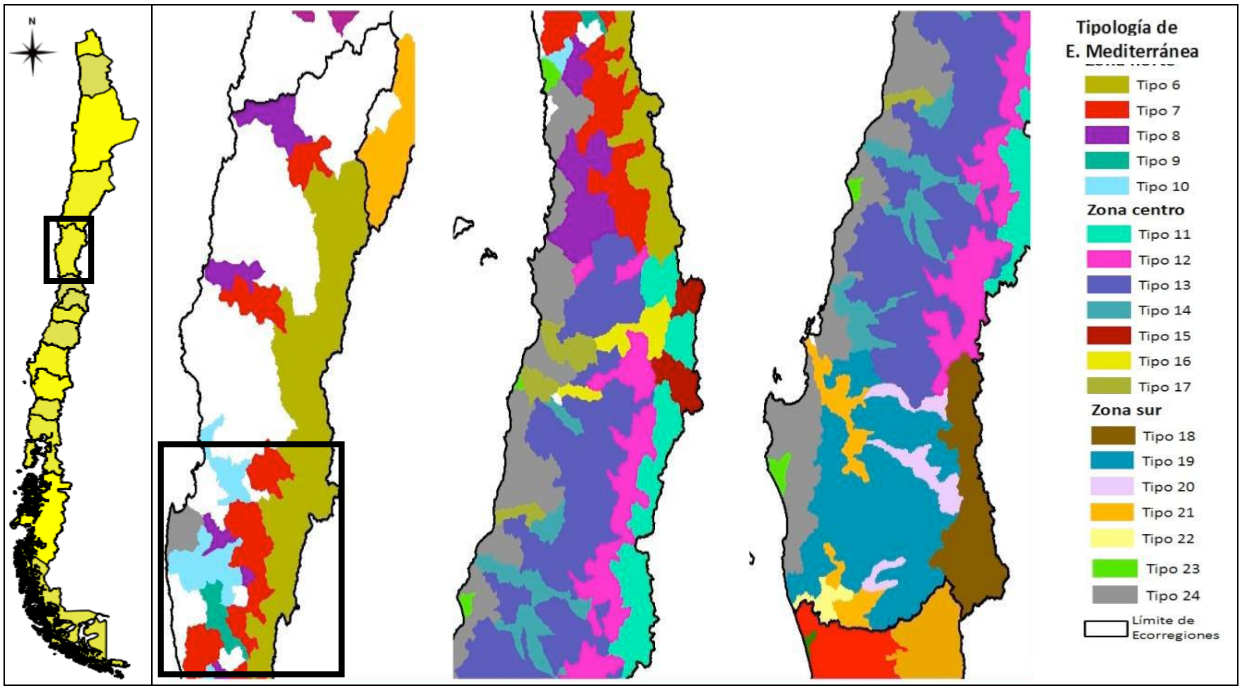
Ecoregion	Types	%
Andean plateau	3	8%
Atacama	2	5%
Mediterranean	19	48%
Valdivian Lakes	5	13%
Patagonian	11	28%
Total	40	100%

The Mediterranean ecoregion has three zones: the south zone is between the basins of the Biobio and Imperial Rivers, the central zone lies between the Maipo and Itata Rivers and the north zone is found between the Copiapó and Aconcagua Rivers. It is in the north zone where the Limarí River watershed is found. In this study, the map of the biological combination will form the foundation of the work. This typology was constructed base on the methodology that was adopted for each criteria summarized in Box 2.

Box 2. Summary of the adopted criteria in the construction of the typology (Fuster *et al.*, 2011).

Altitude class	**Class 1:**	**High**
	Class 2:	Average
	Class 3:	Low
	Class 4:	Very low
Slope of the valley	Class 1:	Low < 2%
	Class 2:	Average 2% - 4%
	Class 3:	High > 4%
Size class based on catchment area	Class 1:	< 5 m^3/s
	Class 2:	5 - 50 m^3/s
	Class 3:	50 - 200 m^3/s
	Class 4:	> 200 m^3/s
Geology class	Class 1:	Silica
	Class 2:	Deposition of evaporite and other minerals sediments
	Class 3:	Calcareous

In Figure 2, is possible to see all the country and its typology according to the biological criteria (top down). It also shows the area of Limarí in more detail (bottom-right). In Table of Appendix C, it is possible to see the physical and biological parameters (Fuster *et al.*, 2011).



Souce: Fuster *et al.*, 2011

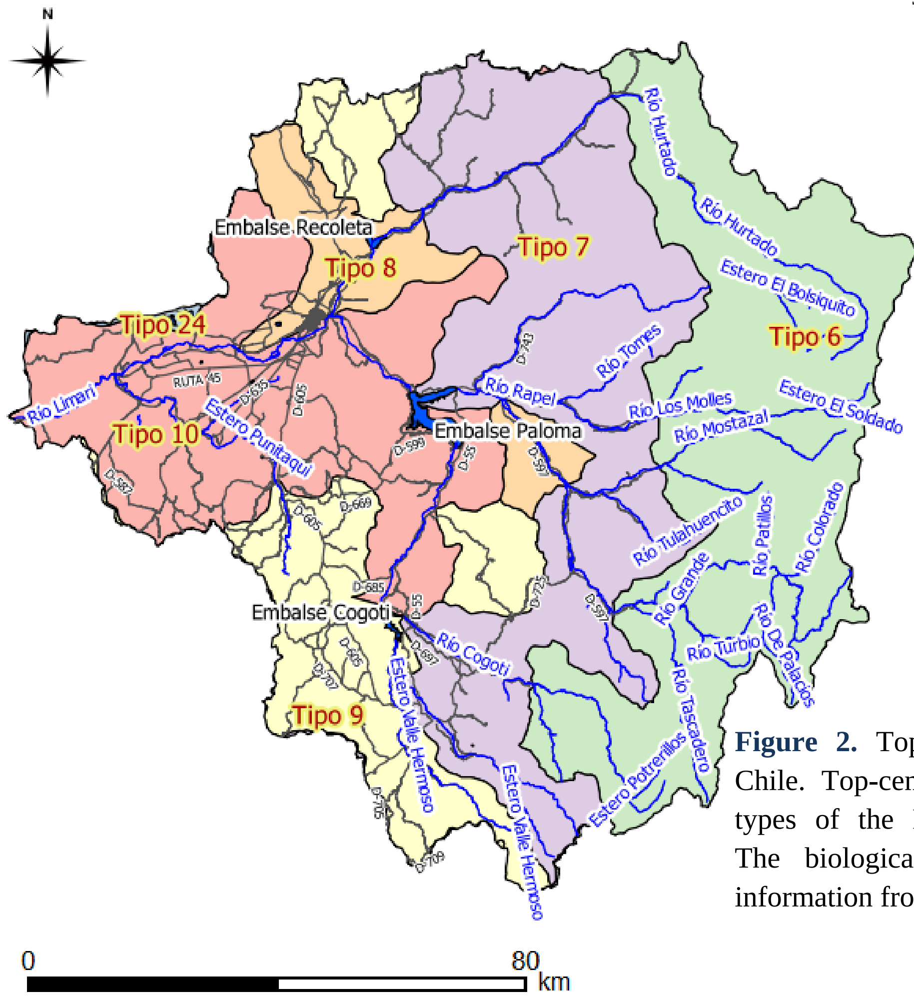


Figure 2. Top-left: political map of Chile. Top-center to –right: the river types of the Mediterranean. Bottom: The biological typology (based on information from Fuster *et al.*, 2011).

2.5 Information and knowledge gaps about water quality

2.5.1 Water quality

In 2004, DGA described the water quality index in the Limarí watershed in the frame of a national project. In the report, the conditions and the water body's quality of each region were determined proposing an indicator named ICAS (Spanish for Superficial Water Quality Index). The criteria of design of the ICAS admit limits values defined for every parameter in the water quality classes (0, 1, 2, 3, 4) this classes are indicators of the degree of the water quality degradation. The criteria consider that the quantitative values must change in a percentage scale derived from the implicit concept of quality in the Chilean regulation. In order to facilitate the use of the index, the Chilean ICAS will change between zero and hundred, assigning "zero" to water with very bad quality, whereas a value near to hundred represents a water of very good quality, ICAS's ranges can be assimilated to a nominal qualitative scale that reflects globally the water quality according to the Box 3.

Box 3. Quality ranges from ICAS (DGA, 2004).

Class	*Qi*
0	100
1	90
2	70
3	50
4	25

Range	Quality
90-100	Very Good - Excellent
70-90	Good
50-70	Regular
25-50	Bad

Note: the description of the *Qi* 's values are explained in the Appendix C.

The ICAS for the Limarí watershed were composed of six obligatory parameters (dissolved Oxygen, pH, electrical conductivity, fecal coliforms, biochemical demand of oxygen and suspended solids) and ten relevant parameters: SAR (sodium adsorption ratio), dissolved solids, clorure, sulfate, boron, copper, iron, manganese, selenium and aluminum. In the work made by DGA (2004) the results obtain with this methodology show that the water quality was in generally good because most of the river have a class= 0 (Table 3). The rivers Punitaqui and low zone Limarí river was the streams with poorest water quality in the watershed (DGA, 2004). On the other hand, in 2009 the Institute of Agricultural

Investigations (INIA in spanish) executed a project that determined the water quality in the Limarí watershed generating an ICA indicator of the water quality. The INIA's research considered the water quality Report of the DGA (2004) and also the Chilean regulation established for every water use in the study area (this information is presented in the Appendix D). In the Limarí watershed it was contemplate 54 parameters measure, only 20 where considered for the calculation of the Index. With the normalization of the chemical parameters it was possible to estimate the water quality in the region of Coquimbo; in order to complete the objectives of the thesis, in the Table 4 is shown the water quality result of the ICA for the five rivers choose in this research.

Table 3: Water quality of the main river in the Limarí watershed according to the principal chemical parameters (DGA, 2004).

Sampling Point	Water Quality Class				
	0	1	2	3	4
Hurtado river in San Agustín	EC, pH, BOD_5, TSS, TFC, SAR, Cl, SO_4^{-2}, Fe, Ni, Zn, As		DO, B, Cu, Mn		
Hurtado river in Angostura of Pangue	EC, pH, BOD_5, DO, TSS, TFC, Cl, SO_4^{-2}, Fe, Ni, Zn, As, Mn		SAR, Cu, B, Se, Al		
Hurtado river to Limarí river	BOD_5, TSS, TFC, S, F, NO_2^-, NH_4^+				Sn
Limari river in Panamericana	pH, BOD_5, DO, TSS, TFC, NO_2^-, NH_4^+, Fe, Ni, Zn, As		SO_4^{-2}, B, Cu, Mn	EC, Al	SAR, Cl
Grande river in Las Ramadas	EC, pH, BOD_5, DO, TSS, TFC, Cl, SO_4^{-2}	Fe	RAS, B, Cu, Fe, Mn, Se	Al	
Combarbalá river in Ramadillas	EC, pH, BOD_5, DO, TSS, TFC, SO_4^{-2}, Cl, Fe, Ni, Zn, As, Mn	B	Cu	Al	Se
Punitaqui steam in Punitaqui	pH, BOD_5, DO, TSS, TFC, Cl, Fe, Ni, Zn, As, NH_4^+, NO_2^-, SO_4^{-2}	Mn	EC, Cu, Al		SAR, B

Note: EC: Electrical conductivity, TSS: total suspended solids, TDS: dissolved solid, TFC: total fecal coliform, DO: disolved oxygen, BOD_5: biochemical oxygen demand at five days, SAR: Sodium adsorption ratio.

Table 4: INIA's (2009) proposed water quality ICA for different water uses according to the Chilean norm in the Limarí watershed.

River	Category	ICA	Fishing and Agriculture	Aquatic Life	Recreate	Potable Water	Irrigation
Limarí	Deficient	**62**	With restrictions	Only resistant species	Doubtful	Not recommended	Land management
Hurtado	Good	**75**	Acceptable	Acceptable	Not recommended	To become drinkable	Good
Rapel	Regular	**72**	Acceptable	Acceptable	Not recommended	To become drinkable	Good
Grande	Good	**77**	Acceptable	Acceptable	Not recommended	To become drinkable	Good
Combarbalá	Regular	**73**	Acceptable	Acceptable	Not recommended	To become drinkable	Good
Punitaqui stream	Deficient	**61**	With restrictions	Doubtful for species	Not recommended	Not recommended	Doubtful

Meza and collaborators in 2009, identifies to the system of the Limarí river is the most affected by anthropological actions. Also in this report there is done an analysis of the information provided by DGA, the data hast from 1969 many gaps of information, nevertheless from 1985 it begins to register with more rigor up to today (Figure 3). In the majority of the stations it is possible to find every twice month measurement.

Considering the gaps in the information provided by the DGA in the water quality stations, the INIA manages to establish a trend of the information by seasons. The calculations were realized from the year 1985, for the parameters of: conductivity, pH, oxygen, chlorides, sulfates, nitrates, phosphorus, SAR and the stream flow. For the stream flow, the trends were realized for month and in general most of the parameters stay constant during time (Meza, 2009a).

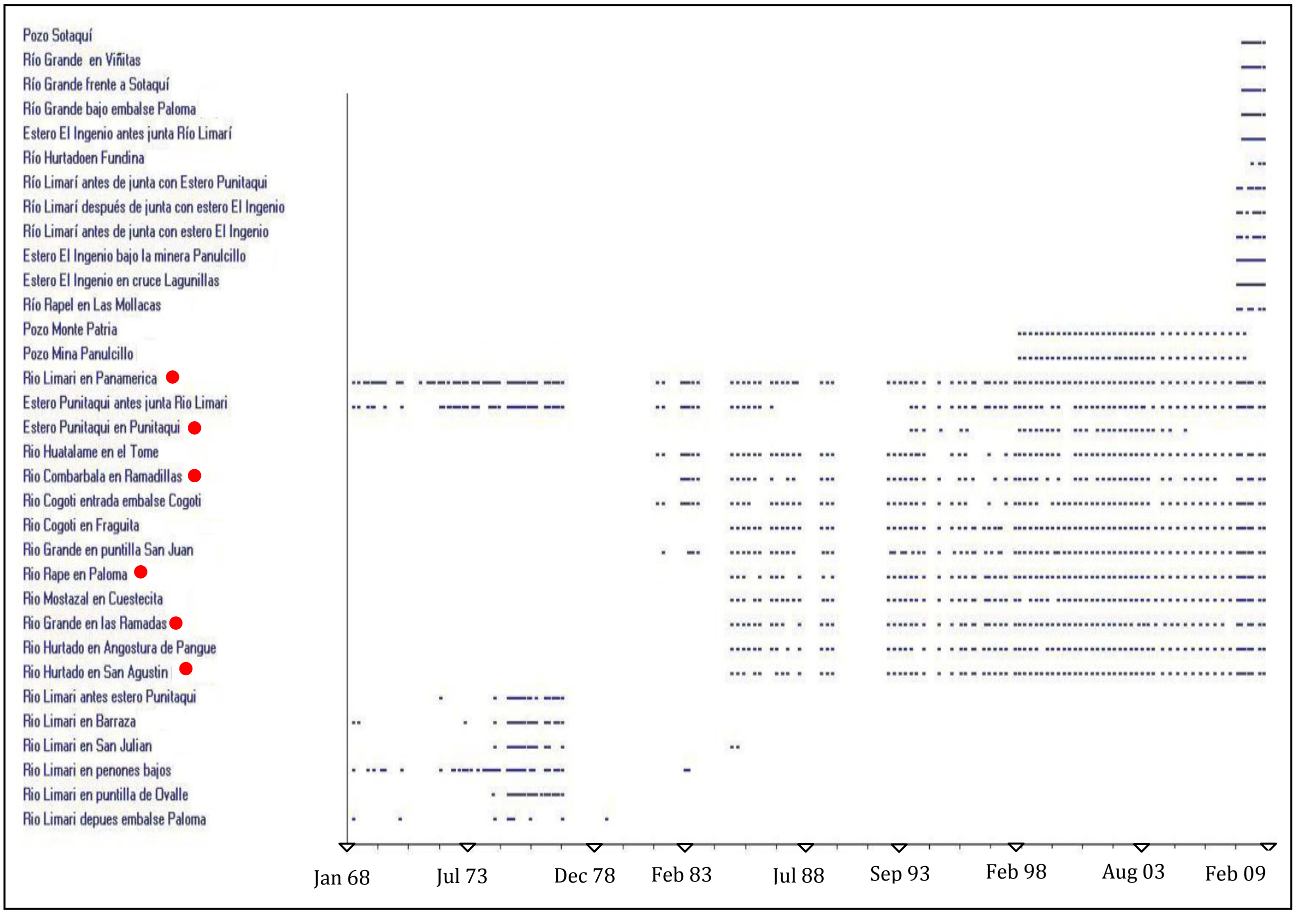


Figure 3. Global situation of the availability of the information of water quality in the basin of Limarí (1968 - 2009) according to Meza (2009a). In red dots are show the chemicalstation considerer in this thesis work.

Also in 2009 in the informs of Meza and collaborators (2009a; 2009b) include an analysis of the chemical measurements and it was compared to the NCh 1333 and determine that in the Limarí river hast a 9% of values whit high values of salinity with a bad quality (Meza *et al.*, 2009a), where a natural contribution was of 78% of chlorides, 70% of sodium and 38% of sulfates. The anthropogenic contribution is 15% of Chlorides, 12% of sodium and 37% of sulfates (Meza *et al.*, 2009a). The Ingenio stream presents a 15% of chlorides, 65% of sulfates, and 95% of manganese from mining activity (principally Ovalle Plant). The fluoride level is over NCh 1333 under Ovalle Plant with an increase of 1ppm of chrome (Meza *et al.*, 2009b).

3. Background of Study Area

In 1914, the government of Chile initiated a series of exploratory studies to look for improvements to the conditions of irrigation in the Elqui, Limarí and Choapa basins, the three principal basins of the Coquimbo Region. A law of 1928 financed an Extraordinary Plan of Public Works for the study and construction of the Recoleta Reservoir in 1934 and the Cogotí Reservoir in 1945 (León, 2009). In addition to the investment in major infrastructure, the Chilean government has been involved in the agricultural sector in the semiarid zone through a series of economic instruments.

Presently, water rights in the Limarí River watershed have been declared to be "exhausted", but before reaching this status, the water rights that had been granted were mainly used in subsistence agriculture and –in minor ways– to provide water to sanitary companies that service the city of Ovalle and other principal cities in the watershed (Fuster *et al.,* 2009).

The Limarí River basin could be considered to be a "pilot watershed", because it possesses a big government investment in infrastructure and important research institutions that create knowledge and develop projects that benefit the inhabitants. In addition, these inhabitants are organized and participate in the decision making through civilian organizations, such as *Junta de Vigilancia de río Grande, Asociación de Canalistas del embalse Recoleta, Asociación de Canalistas del embalse Cogotí, Asociación de Canalistas del canal Camarico.*

3.1 Location and general overview of the Limarí River watershed

In the Coquimbo Region, the Andes mountains rise more than 5000 m.a.s.l, the 0°C isotherm is typically found at about 2500 m.a.s.l, and snow accumulation is possible during winter in the upper elevations of the region's river basins (Figure 4). The upper portions of the river basins are snowmelt dominated with a large proportion of the river discharge flowing during the late spring and summer months (September to January). A reduction of precipitation translates to a reduction of annual mean flow, while an increase in temperature would likely change the shape of the river's hydrograph (Vicuña *et al.,* 2010). Precipitation is controlled by the topography and prevailing wind pattern, with the Andes Mountains concentrating the major quantity of precipitation to the elevations at which the humid air from the Pacific Ocean condensates. Inhibiting the ability of this vertical effect of condensation to provide more humidity and precipitation is the presence of the anticyclone in the Pacific Ocean and the cold Antarctic waters transported by the Humboldt Current. These regional climatic factors contribute to the aridity of the Coquimbo Region and set up a highly stable atmosphere and a layer of thermal inversion between 800 and 1200 m, thus restricting the formation of clouds in the coastal zone (Schneider, 1982; Ledin, 2000 mentioned in León, 2009). The Limarí River watershed is characterized by three climatic types: semi-arid with abundant clouds, temperate semi-arid climate with winter rainfall (i.e., following the winter solstice in June), and cold semi-arid with winter rainfall (DGA, 2004). The thermal variation that characterizes the zone limits the vertical movements of air and generates an arid regimen with little precipitation, following a Mediterranean rainfall pattern, one wich over 60% of rainfall occurs during winter months, with almost nothing in summer (Oyarzun, 2010) (further details in section 1.1 in Appendix E).

The three principal rivers of the Coquimbo Region – the Elqui, the Limarí, and the Choapa – are characterized by the presence of river discharge during the long summers (i.e., the driest months of the year) as well as during the periods of drought, hinting at the existence of underground storage, important to high Andean aquifers, in the form of ice; in other words, the year-round river discharge points to the existence of mountain permafrost (Ferrando, 2001) (further details in section 1.2 in Appendix E).

Climate and water availability determinate a landscape's vegetation and the possible forms of land use in an area. Squeo and others (2001) established that the coastal area of Coquimbo Region, between the Fray Jorge National Park and Los Vilos, is one of the areas of the Region with both a high species richness and also a higher number of species in conservation categories (further details in section 1.3 in Appendix E).

The Limarí River watershed is located in the Province of Limarí, inside Coquimbo Region (Region IV) in the north of Chile, between the 30°15' North and 31°20' south. Immediately to the north of the Limarí is the Elqui Valley and to the south is the Choapa Valley. Agriculture is the primary economic activity within the Limarí River watershed, but electric energy generation and industrial and mining activities are also economically relevant, even though they are less dominant than farming (DGA, 2004; Osorio, 2009). The principal crops cultivated in this area are forage, fruits, vegetables and vineyard grapes, which use a significant amount of water. For example, the 1997 demands of water for irrigation were over 790840000 m^3/year (DGA, 1991; DGA, 1996) (Further information in section 1.4 Appendix E).

The Limarí River watershed has a network of climate and hydrologic monitoring stations, and an historical data series of more than 20 years of information, including rainfall, hydrometry, and chemistry, and is under the administration of the DGA and the Meteorological Directorate of Chile (Oyarzun, 2010). This monitoring network is based on the BNA (National Bank of Water), and in this, thesis three sub-basins of the Limarí River watershed – the Hurtado, the Cogotí and the Combarbalá – were chosen based on the available information about water quality (Meza, 2007; Meza *et al.*, 2009a; Meza *et al.*, 2009b; INIA, 2009).

Natural water resources in Coquimbo Region are evaluated to be in a vulnerable state due to the high amount of water required for agriculture and mining in addition to the recent increase in urban development, all of which requires sustainable water resource management (Strauch *et al.*, 2009). Equally, this Region presents different problems, such as water pollution and water scarcity, which must be archived through water management program (Strauch *et al.*, 2009; Verbist *et al.*, 2010).

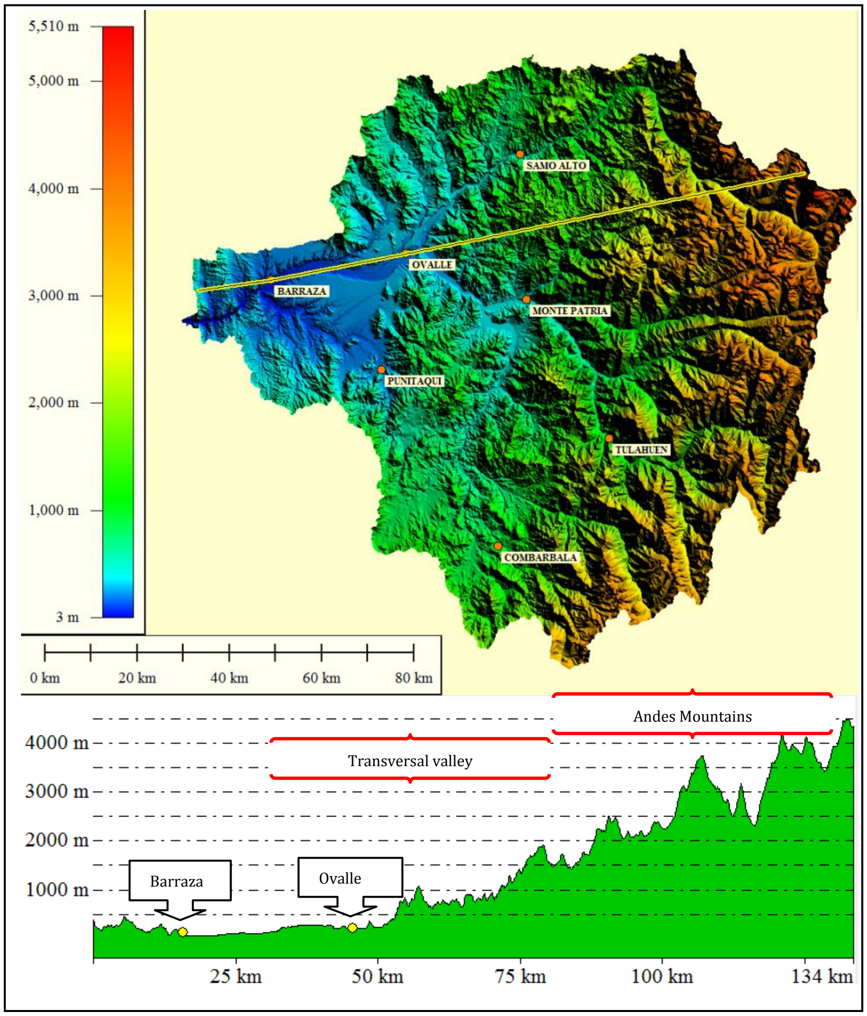


Figure 4. Profile of one transect from east to west along the Limarí River watershed. Own production

4. Methodology

In order to achieve the objectives, this study first makes a Comparison of the Chilean normative and EU approach, second makesa morphological characterization and finally conducts anintegration of physical morphology and water quality information. This thesis described three consecutively dependent methodologies. The first objective required a review of the available information concerning the Chilean normative and comparing it to the EU approach. The second objective required recognition of the current state of the typology in the study area. The third objective required the collection of information about water quality in Chile, followed by an analysis of the interaction between water quality and morphological parameters. The morphological assessment was used the AQEM method adapted to the context of this research and used to conduct the fieldwork.

The methodology was selected according to the information obtained from the national institutions in Chile; Figure 5 diagrams the various methodologies used in this thesis.

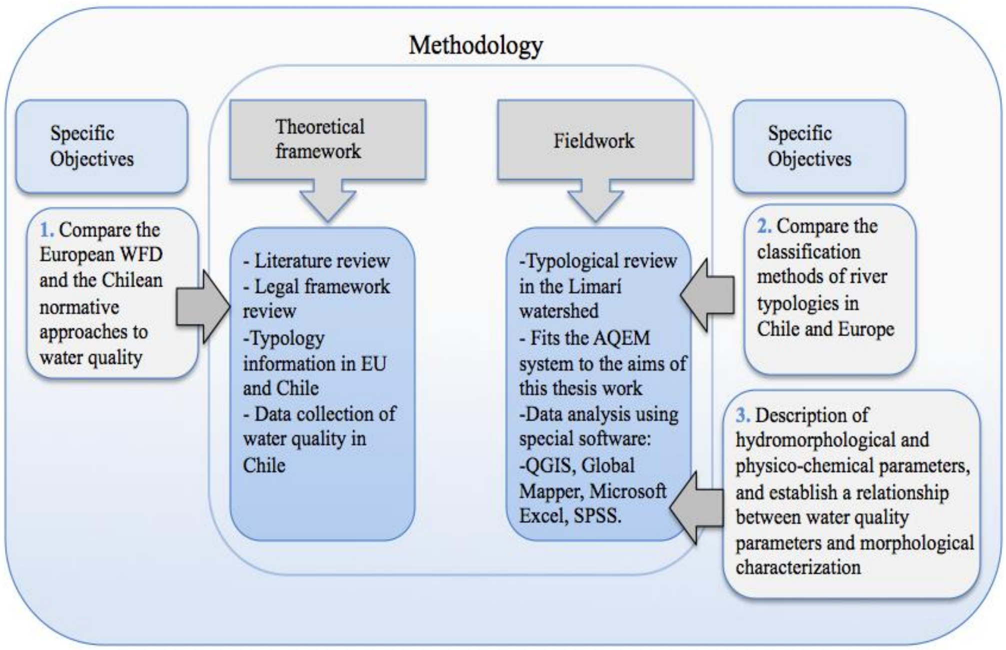


Figure 5. Diagram of methodology.

4.1 Comparison of the Chilean normative and EU approach

In order to assess the differences between the Chilean normative and the EU approach regarding the assessment of water quality, the relevant information was downloaded from the governmental sites. For the EU, the portal of the WFD was used and for the Chilean case, all the laws and regulations were available on the senate web page. The information was read, analyzed and summarized in order to find the points of similarity and differences between both normatives.

4.2 Current typology of the Limarí River watershed

The GIS shapefiles with the information about biological typology was delivered by Professor Rodrigo Fuster, Msc, as part of the information published by his scientific group in 2011 concerning the classification of water bodies in Chile. This typology was generated using GIS analysis and was not ground-truthed. Some of the adopted criteria in the construction of the typology included the altitude class, the valley slope, the size class based on the catchment area and the geology class in the area. The Limarí River watershed from Fuster *et al*. (2011) had five biological typology regions (Figure 2, further details in Appendix C): Type 6, Semiarid Andean (> 1500 m.a.s.l) with absence of fish and the most common macro invertebrates being mainly Diptera and Oligochaeta; Type 7, Semiarid Transitional (< 1500 m.a.s.l) the more common fish genera being *Dyplomistes, Cheirodon,* and *Basilichthys*; Type 8, River–mouth, Semiarid (< 800 m.a.s.l); Type 9, Semiarid of transition with calcareous dominance (100-1500 m.a.s.l); and Type 10, River-mouth, Semiarid with calcareous dominance (< 800 m.a.s.l). Types 8, 9 and 10 have similar fish compositions as that Type 7. A final type found nearest the coast of the watershed was Type 24: Mediterranean, the fish genera present here are *Geotria, Percillia, Percichthys, Basilichthys* and *Trichomycterus*. However Type 24 was not included in the field research, because the border line of this type included the neighboring watershed of La Serena city.

In order to conduct field assessments of water quality, a number of sites were chosen to act as field stations for the study. The location of these field stations were based on the five biological types of the Limarí River watershed. The initial expectation was to have at least three field stations within each of the five typological areas. Field station sites were selected based on the accessibility of each site (i.e., proximity to road crossings, vertical distance to the river, etc.) as well as an attempt to ensure the sampling of all the Hurtado, Cogotí and Combarbalá tributary systems. Due to the issues of physical access, Type 6 had only two field station, Type 7 had six field stations, Type 8 had only one field station, Type 9 had only no field stations, and Type 10 had five field stations. There was also one field station in a typologically unclassified area.

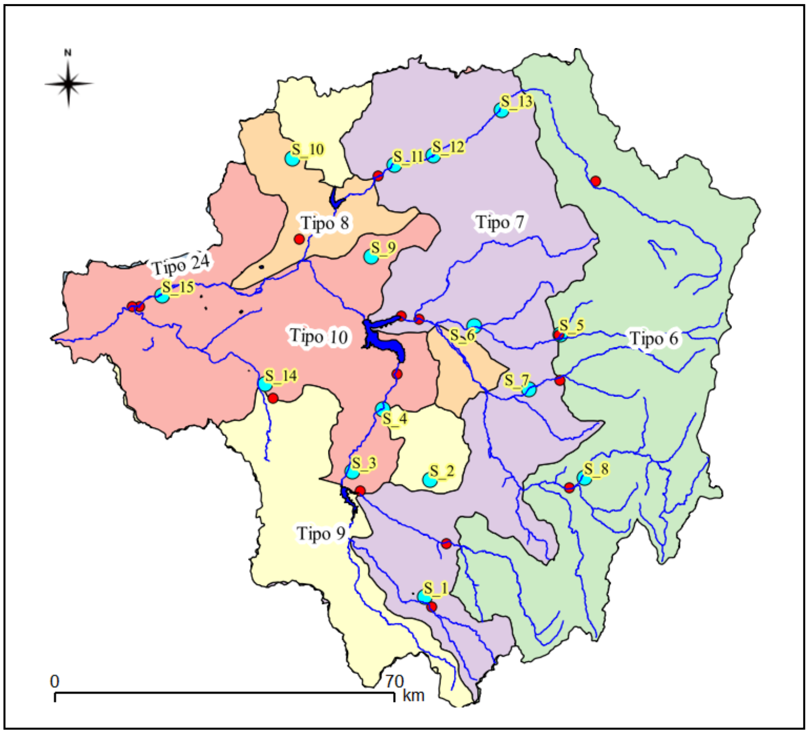


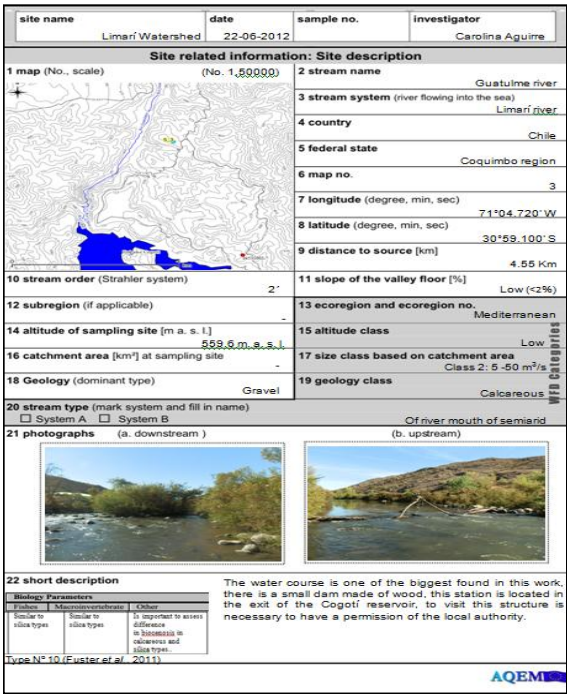
Figure 6. It show the Limarí River watershed, the principal rivers and reservoir; in red spots is the chemical stations (DGA), in cyan spots is represented the station for collect morphological information used in this research. Map mounted with information of Fuster *et al.*, 2011.

The fieldwork undertaken at each of the fifteen field stations was designed to follow the AQEM approach. In gathering the morphological information, only two sheets of the AQEM schedule were used in the fieldwork, because biological compilations and measurements of chemicals parameters in situ were not in the scope of the thesis. Each site was supplemented by additional site information.

Physical information of the general area for each field station used in the modified AQEM schedule (i.e., items #1-20 on the AQEM data sheet) was taken from the GIS shapefiles built by Fuster *et al* (2011), which assumed the average values thought the yearfor the physical parameters. Sample-related information (i.e., items #22 and 25–45 on the AQEM data sheet) was based on measurements and observations made in the field at each station. Field measurements and observations were conducted from 23–25 June 2012.

4.2.1 Station fieldwork

For each station, items #1–22 and #25–46 from the AQEM schedule (i.e., pages 1 and 3) were completed. In order to do this, was necessary to use the GIS-based biological typology of the river basin (items #1, 10–13, and 15–20), a GPS unit (items #7, 8, and 14), a camera (item #21 and the additional information sheet), a measuring tape (item #27), and physical observation (items #25, 26, 28–46).



site name	date	sample no.	investigator
Limarí Watershed	22-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)	**2 stream name** Guatulme river
	3 stream system (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo region
	6 map no. 3
	7 longitude (degree, min, sec) 71°04.720' W
	8 latitude (degree, min, sec) 30°59.100' S
	9 distance to source [km] 4.55 Km
10 stream order (Strahler system) 2'	**11 slope of the valley floor** [%] Low (<2%)
12 subregion (if applicable) -	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 559.6 m. a. s. l.	**15 altitude class** Low
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Class 2: 5 -50 m³/s
18 Geology (dominant type) Gravel	**19 geology class** Calcareous

WFD Categories

20 stream type (mark system and fill in name) ☐ System A ☐ System B Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

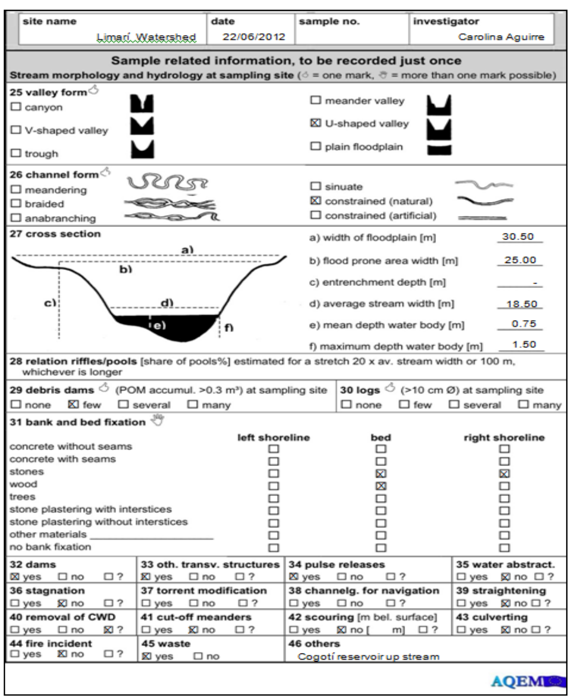
The water course is one of the biggest found in this work, there is a small dam made of wood, this station is located in the exit of the Cogotí reservoir, to visit this structure is necessary to have a permission of the local authority.

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

Type N° 10 (Fuster *et al.*, 2011)

AQEM

In more detail, page 1 of the AQEM schedule contains basic information about the site, and it was necessary to use the GIS shapefile data of the biological typology to complete many items. Item #20 ("stream type") remains incomplete with regard to the European classification system, since the typology project in Chile is still in process. For item #22 ("short description"), the biological parameter determined by Fuster *et al.* (2011) in order to describe the different biological types for the Limarí River watershed were used.



site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once
Stream morphology and hydrology at sampling site (= one mark, = more than one mark possible)

25 valley form ☐ canyon ☐ V-shaped valley ☐ trough ☐ meander valley ☒ U-shaped valley ☐ plain floodplain

26 channel form ☐ meandering ☐ braided ☐ anabranching ☐ sinuate ☒ constrained (natural) ☐ constrained (artificial)

27 cross section

a) width of floodplain [m] 30.50
b) flood prone area width [m] 25.00
c) entrenchment depth [m] -
d) average stream width [m] 18.50
e) mean depth water body [m] 0.75
f) maximum depth water body [m] 1.50

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams (POM accumul. >0.3 m³) at sampling site ☐ none ☒ few ☐ several ☐ many

30 logs (>10 cm Ø) at sampling site ☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation

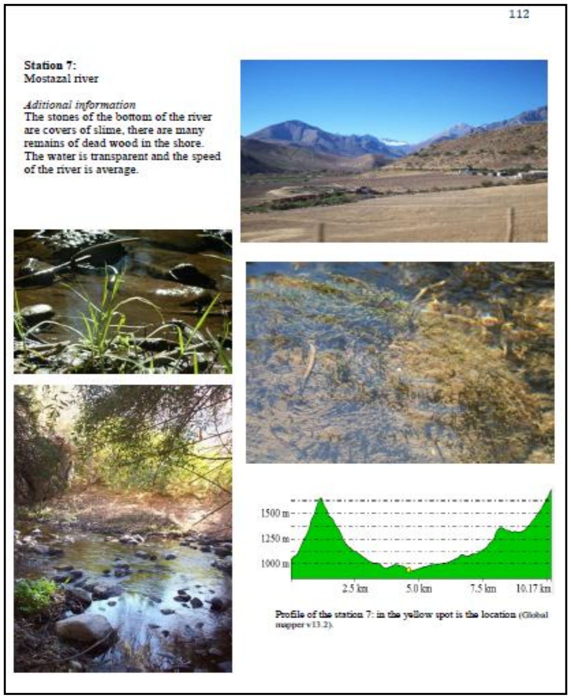
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☒	☒
wood	☐	☒	☐
trees	☐	☐	☐
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ______	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☒ yes ☐ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☒ yes ☐ no ☐ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☐ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☒ no [m] ☐ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others** Cogotí reservoir up stream	

AQEM

Page 2 of the AQEM sheet described mineral and organic substrates and compositions of a field station. This page was not used in this thesis investigation, since such measurements fell outside the scope of the current project.

Page 3 of the AQEM sheets contained basic information about stream morphology and hydrology at each field station. The measurements of each stream were performed using a measuring tape, but it was impossible to determine the exact entrenchment depth of the stream, so this measurement (item #27c) was estimated a priori. Information about dams, transversal structures, waste, etc., was filled by personal observation or by information provided by locals.



The additional page of information gives information of the field station site, with many pictures to provide a visual impression of the landscape. This additional page also includes a cross-sectional profile created using Global Mapper V13.2.

4.2.2 GIS-derived data

The biological typology information delivered in GIS shapefiles was processed using Quantum GIS (QGIS), an Open Source Geographic Information System, that is licensed under the GNU Public License[2]. Using Global Mapper V13.2[3] (two-week trial license), the cross-sectional profiles of the Limarí River watershed were built (Appendix F). Finally, the statistical software, SPSS, was used to establish a relationship between chemical and morphological parameters (see section 4.3).

[2]http://www.qgis.org /
[3]http://www.globalmapper.com/downloads/global_mapper_setup_64bit.exe

4.3 Integration of physical morphology and water quality

The information on water quality is free, but it must be requested from the DGA. The data from the monitoring stations in the Limarí River watershed were requested for conducting this thesis investigation. Part of the chemical information is organized and updated in the *R-Bis* portal that Chile and the Institute for Technology and Resources Management in the Tropics and Subtropics (ITT) created as cooperative project between Chile and Germany. In addition, some information was received from the Center of Advanced Studies of Arid Zones (CEAZA), specifically regarding the Limarí River watershed. Finally, all reports by Meza (i.e., Meza, 2007; Meza *et al.*, 2009a; Meza *et al.*, 2009b and INIA, 2009) were acquired from the INIA (Instituto de Investigaciones Agropecuarias), under Chile's transparency law (N° 20285[4]).

In the Limarí River watershed there are thirteen monitoring stations controlled by the DGA. However, this thesis considered only those six stations that possessed a major quantity of information. The water quality data from the six selected stations (INIA, 2009) are located in the main tributary systems of the watershed (Figure 7), the data collection consider the period 1970–2011 (with certain data gaps). Six parameters were chosen for the current analysis of water quality: ammonium, nitrates, phosphate, copper and chlorides. In this thesis investigation, since the raw data values for river discharge were not available, it was only possible to use summarized river discharge values in the main rivers. The chemical parameters analyzed at the six water quality stations were pH, electrical conductivity, nitrate, phosphate, chloride, and sulfate. Unfortunately, it was not possible to obtain information about biological oxygen demand, but information about dissolved oxygen was included.

The water quality in the Limarí River watershed is established by the INIA (2009) through the elaboration about the ICA (see Section 1.2 in Appendix D). This thesis investigation considers the ICA results of the six selected stations (Table 4).

[4]Biblioteca del Congreso Nacional de Chile. http://www.leychile.cl/Navegar?idNorma=276363

An initial boxplot analysis, along with the calculation of each parameter's decadal average and standard deviation, was performed on these parameters using SPSS 15.0[5]. Parameters that were heavily skewed were log-transformed in order to approach normality.

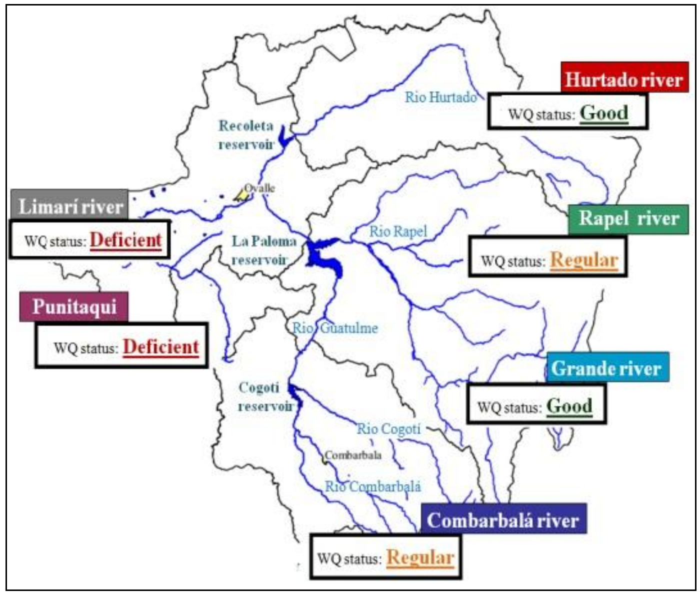


Figure 7. The Limarí River watershed showing the principal tributaries, reservoirs, and the six stations used in this research, each with qualitative information of the water quality status (INIA, 2009). Map created using information from Fuster *et al.*, 2011

4.3.1 Assessment of independence

In order to produce a correlation between the biological typology data and the water quality data, it is first necessary to determine if the two sets of data are statistically independent. The relationship between two categorical variables cannot be established by simply observing their frequencies in a contingency table, nor can such observations provide a definitive conclusion. To determine if two variables are related, it is necessary to use some associated measurement, accompanied with a significance test. The chi-square (X^2) test proposed by Pearson (1911) allows for the confirmation of the hypothesis that the criteria of the classification (two categorical variables) are independent. In order to do this,

[5]http://www.spss.com

one compares the observed frequencies with the expected frequencies. The formula of the chi-square test is:

$$X^2 = \sum_i \sum_j \frac{(n_{ij} - m_{ij})^2}{m_{ij}}$$

Where *nij* it refers to the observed frequencies and *mij* to the expected frequencies. X^2 will have a value of zero when the variables are completely independent (since the observed frequencies and the expected frequency ones will be equal), the value of X^2 will increase as the independence of the two frequencies diminishes (Díaz, 2009). In order to determine if value of X^2 shows the two frequencies to be independent, the probability must be determined. The X^2 has a distribution model of probability with a resultant degrees-of-freedom value obtained by multiplying the number of rows minus one by the number of columns minus one:

$$df = ([J-1][K-1])$$

If the probability is very small (less than or equal to 0.05), it is possible to reject the hypothesis of independence and to conclude that the variables are related.

4.3.2 Assessment of correlation using contingency tables

Once independence between the two parameters – biological typology and water quality – is determined to be independent, it is possible to assess their correlation. Correlations are determined using correlation coefficients, derived from tests, such as Pearson and Spearman correlation tests. Both the Pearson and Spearman tests are linear associations, but the Pearson correlation is more adapted to study the relationship between interval or ratio variables, while the Spearman correlation is more useful for assessing ordinal variables. Both coefficients have little usefulness in studying the relationshipsfound a typical contingency table, since contingency tables are used for crossing variables of nominal or ordinal type that have a few levels (Díaz, 2009).

The chi-square statistic allows us to confirm the hypothesis of independence of a contingency table but he does not say anything about the force of the association between the studied variables. The value of X^2 depends not only on the degree to which the information adjusts to the model of independence but also on the sample size. With measures of correlation, however, there is little effect due to the sample size. The measures based in X^2 try to correct the statistical value of X^2 to take a value between 0 and 1 and to minimize the effect of the sample size on the quantification of the degree of correlation (Pearson, 1913; Cramer, 1946 mentioned in Díaz, 2009). In 2×2 contingency tables, the correlation coefficient, *phi* (*Φ*) adopts values between 0 and 1, and its interpretation is similar to that of a Pearson's correlation, but in contingency tables larger than 2×2, the values of *phi* can be greater than 1.

$$\phi = \sqrt{\mathrm{X}^2 / n}$$

In order to conduct this investigation, a matrix was made with the morphological and the chemical parameters. The values in this matrix were water quality data and morphological values (Table 5). The water quality data were extracted from the DGA data sets, using their water quality index. The morphological values came from the typology maps (Fuster *et al.,* 2011) and the fieldwork observations and recorded on the AQEM sheets (See Section 4.2.1). Each value in the matrix was given an ordinal value (Table 6) for a phi correlation assessment. If the 2000 – 2010 average for a chemical parameter was at or below the Chilean normative requirement, it was given a score of 1. If it exceeded the normative requirement, it was given a score of 2. Nominal data were given numerical values (see Box 4).

Table 5: Contingency table for the ICA (i.e., water quality) values in each of the six water quality stations, segmented by the chemical and morphologic. Chemical parameters are reported as means over the period of 2000 – 2010.

Parameter	Limarí	Hurtado in Serón	Rapel	Grande	Combarbala	Punitaqui
ICA	Deficient	Good	Regular	Good	Regular	Deficient
pH	8.07	7.71	7.84	7.92	7.71	8.35
EC (mhos/cm)	2301.82	242.64	288.34	190.88	85.89	774.94
NO_3 (mg/L)	0.18	0.28	0.17	0.14	0.2	0.3
PO_4 (mg/L)	0.025	0.147	0.067	0.014	0.014	0.07
DO (mg/L)	16.31	8.37	8.73	8.7	8.97	8.96
Sulfate (mg/L)	251.1	72.92	67.63	29.02	1.95	120.83
Chloride (mg/L)	454.51	6.01	5.27	12.89	2.28	55.87
Geology class	Calcareous	Silica	Silica	Silica	Silica	Calcareous
Slope field	Low	Low	Average	Average	Low	Low
Land uses	Agricul.	Bushes and succulents	Agricul.	Agricul.	Agricul.	Agricul.
Influence of big cities	yes	no	no	no	no	yes

Table 6: Contingency table for the ICA (i.e., water quality) values in each of the six water quality stations, segmented by the chemical and morphologic. Ordinal data values are taken from the codification matrix created in SPSS. (The codification for morphological parameters is shown in Box 4):

Parameter	Limarí	Hurtado	Rapel	Grande	Combarbalá	Punitaqui
ICA	2	3	1	3	1	2
Ph*	1	1	1	1	1	1
EC mhos/cm	2	1	1	1	1	2
NO3 mg/L	1	1	1	1	1	1
DO mg/L	1	1	1	1	1	1
Sulfates mg/L	2	1	1	1	1	1
Chloride mg/L	2	1	1	1	1	1
Geology class	1	2	2	2	2	1
Slope field	1	1	2	2	1	1
Land uses	1	2	1	1	1	1
Influence of big cities	2	1	1	1	1	2

*For the chemical parameters it was consideredto be 1 if below the Chilean normative NCh 1333 or 2 if above the Chilean normative.

Box 4. Codification for SPSS

Codification for SPSS	Parameter	1	2	3
	ICA	Good	Deficient	Regular
	Geology class	Calcareous	Silica	
	Slope field	Low	Average	
	Land uses	Agricultural areas	Bushes and succulent	
	Influence of cities	No	Yes	

Using the converted values for the parameters of water quality and morphology, *phi* correlation coefficients were calculated in order to produce a cross-correlation of water quality and morphology.

5. Results and discussion

5.1 Comparison of the Chilean normative and EU approach

This section compares the Chilean national water quality standards against the EU-wide WFD. While, on the one hand, this is a comparison between the standard of one nation (Chile) against multiple nations (EU) it is, on the other hand, a comparison of water quality standards within a unified political area governed by a unified set of directives. In other words, this comparison is not one that tries to compare Chile with every water quality standard of every nation within the EU, but to compare Chile's trans-regional standard with the trans-national standard of the EU. Still, even with this recognition of different political scales, there are several differences between the Chilean normative and the European case. In Chile, biological factors are not taken into account as in Europe, where phytoplankton, macro algae, benthos and fishes are the primary bases for ecological status. Nor are regional typologies used in the management of water bodies, since it is a new technique that is has only recently been created. The Chilean normative is based mainly in physicochemical parameters (INN, 1978; INN 1984), and the numerical values between both zones differ, and in most cases Chilean legislation is more permissible than the Europe Union's. The differences between both practices can be observed in Table 7.

Table 7: A comparison of quality elements and parameters for determining water quality between the European Union approach through the WFD (2000/60/EC) and the Chilean legislative approach through NCh 1333/78, NCh409/84 (INN, 1978; 1984).

Quality Elements			Parameters	EU	*AML	Chile	*AML
Biological	Aquatic Flora	Phytoplankton macrophyte and phytobenthos	Composition and Abundance	yes	-	no	-
	Fauna of benthic invertebrates	-	Composition and Abundance	yes	-	no	-
	Ichthyology Fauna	-	Composition Abundance and Age structure	yes	-	no	-
Hydromorphology	Hydrologic Regimen	Rates and hydrodynamics flow	Velocity flow	yes	-	no	-
	River Continuity	-	Water level Discharged rate	yes	-	no	-
	Morphological Conditions	Depth and width Substrate Structure of costal area	Transversal profiles, particle size, costal flora	yes	-	no	-
	General	Thermic condition, oxygenation, salinity, acidification, nutrients	T° Dissolved O_2 E. Conductance pH Nt	yes yes yes yes yes	(1) (1) (1) (1) <50mg/L [a]	yes yes yes yes yes	(2) Increased ≤3°C [e] 5 mg/L [e] >750 μs/cm [e] 5,5-9 [c] <50mg/L [a]
Physicochemical	Specific Pollutant	Priority substance Specific pollutant Other substances	Total	33		26	
			Lead	yes	Not applicable		5 mg/L
			Mercury	yes	0,07 μg/L		0,001mg/L
			Cadmium	yes	<0,45 to 1,5 μg/L [3]		0,01mg/L

*AML: Allowed maximum level

[a] human consumption; [b] drinkable for animals; [c] irrigation; [d] recreation and aesthetic, [e] aquatic life; according to INN(1978, 1984)

(1) Undisturbed conditions versus anthropogenic alterations in EU

(2) Undisturbed conditions versus anthropogenic alterations depending of the use in Chile

(3) Authority takes decision depending of necessities

The WFD includes biological parameters in order to assess the Ecological Status, and it generates a biological index to evaluate water quality. The WFD classification of the chemical status of the water body is based on the compliance with the ecological quality standards (EQS), and the frequency of monitoring of priority substances in the water column is one per month (once every three months for river-basin-specific pollutants). In constrast, while the Chilean normative considers the water quality index (ICA) to be an instrument for decision making, the ICA only includes chemical parameters registered by the DGA every two months. Tocalculate this index, a seriesare used, which could be complicated to understand and to apply. These indices apply to the whole country generating problems to areas where there are natural sources that worsen water quality.

In some areas is possibletofind local problems of low water quality caused by natural conditions that are higher than the government limits, in these cases the EU takes expert opinion into account, and there can be special allowances made for individual cases. In Chile, by contrast, there is no consideration within the normative for these kinds of cases, because the normative is classified only by the water uses and does not include natural sources of pollution.

The creation of an integrated measure in Chile is technically feasible, andit is possible to collaborate with government authorities in order to generate greater investments in chemical monitoring and training professionals according to the European approach, which combines the three fundamental pillars to assess ecological status. I think it is possible to continue with these types of studies in the Limarí River watershed, because there is a great amount of information available within this system, which contrasts with the availability of data for other river basins in the country.

5.2 Morphological characterization

In the Appendix F is possible to see the raw data obtain in the field in the 15 station considered in the Limarí River watershed. Summarized results are found on Tables 8, 9, 10 and 11. The field station number indicates the biological typology in which the station is found (i.e., Type 6 – 10), as well as the station number (i.e., station number 1 – 15). Therefore "10_4" indicates biological typology Type 10, and field station number 4.

Type 6 (Semiarid Andean) included field stations #5 and 8, the stream order included 1st and 2nd order streams, at altitudes ranging from 1379 to 1195 m.a.s.l, with average slopes. The geology class of these streams comprised silica, and at each station, the dominant observed geology was gravel. The valley-forms of these streams were, U and V shaped, and the channel-forms observed at each field station were sinuate. Floodplain widths ranged from 10.24 to 33.1 meters, and the flood-prone areas ranged from 9.24 to 33.2 meters. Average stream widths were 5.00 to 21.55 meters, mean depths were 0.30 to 0.70 meters, and maximum depths ranged from 0.60 to 0.70 meters. Human modifications seen in these streams were at station #5, a small bridge and the hydroelectric station of Los Molles located upstream of the station.

Type 7 (Semiarid Transitional)included field stations #1, 6, 7, 11, 12 and 13, the stream order included 2th and 3th order streams, at altitudes ranging from 539 to 1272 m.a.s.l, with low slopes. The geology class of these streams was silica at each station, and the dominant observed geology included sand and gravel. The valley form of these streams were meander (stations #1 and 6), U-shaped (field stations #7, 11, 12) and V-shaped (station #13). The channel-forms observed at each field station were meandering, constrained, sinuate and anabranching. Floodplain widths ranged from 22.5 to 30.5 meters, and the flood-prone areas ranged from 5 to 30.5 meters. Average stream widths were 3.0 to 18.5 meters; mean depths were 0.3 to 0.5 meters. The human impact in these streams was mostly garbage, especially in field station #6.

Type 8 (river mouth semiarid), comprised field station #10, the altitude was 1195.0 m.a.s.l, and the slope was average. The geology class of this stream was silica, and the dominant observed geology was gravel. The valley-form of this streams was U-shaped, and the stream form observed at this field station was sinuate. This stream was completely dry.

Type 10 (River mouth of semiarid with calcareous dominance) included field stations #3, 4, 9, 14, and 15, and the stream order included only 2th order streams at altitudes ranging from 483 to 559.6 m.a.s.l., with low slopes. The geology class of these streams were calcareous at each station, and the dominant observed geology included sand and gravel. The valley-forms of these streams were U- and V- shaped. The channel-forms observed at each field station was meandering, constrained, sinuate and anabranching. Floodplain widths ranged from 22.5 to 30.5 meters, and the flood-prone areas ranged from 5 to 25 meters. Average stream widths were 3 to 18.5 meters, mean depths were 0.05 to 1.0 meters, and maximum depths ranged from 0.1 to 2.0 meters. Human modifications seen in these streams were most prominent in field station #15, which showed stagnation, straightening and waste.

Table 8: Site description, in the table is possible to see the basic information about the samples sites, taken from GPS and GIS. Further information can be found in Appendix F.

Station codes	Stream name	Datum WGS 84 S	W	Accuracy (m)	Map number	Stream order	Altitude m.a.s.l.
0_2	Near Cogoti river	31° 06.313'	70° 54.424'	11.3	2	1'	950.2
6_5	Palomo river	30° 44.635'	70° 37.186'	10.8	5	2'	1195
6_8	Grande river	31° 00.567'	70° 34.661'	16.8	8	2'	1379
7_1	No name	31° 13.378'	70° 55.610'	6.4	1	2'	1272
7_6	Rapel river	30° 43.231'	70° 48.090'	9.8	6	3'	751.6
7_7	Mostazal river	30° 50.878'	70° 41.668'	11.3	7	2'	888.6
7_11	Hurtado river in Huapulla	30° 25.370'	70° 58.448'	12.6	11	2'	539
7_12	Hurtado river in Pichasca	30° 24.522'	70° 53.198'	7.8	12	3'	682.9
7_13	Hurtado river in Serón	30° 19.637'	70° 44.792'	8.8	13	2'	951.2
8_10	El Ingeniero in Lagunillas	30° 24.309'	71° 11.668'	21.8	10	1'	426.9
10_3	Huatulme river	30° 59.100'	71° 04.720'	10.2	3	2'	559.6
10_4	Huatulme river	30° 52.952'	71° 01.127'	7.8	4	2'	479.3
10_9	Quebrada seca	30° 35.771'	71° 08.859'	8	9	2'	232.1
10_14	Punitaqui stream	30° 49.823'	71° 15.814'	8.3	14	2'	202.1
10_15	Limarí river	30° 39.222'	71° 28.972'	7.8	15	2'	48.3

Table 9: Site information, based on typology information taken from Fuster *et al.* (2011). Further information, see Appendix F.

Station codes	Stream name	Slope field	Altitude class	Size class (*)	Substrate (dominant type)	Geology class	Stream type
0_2	Near Cogoti river	N C	N C	N C	N C	N C	N C
6_5	Palomo river	Average	High	Class 2	Gravel	Silica	Andean semiarid
6_8	Grande river	Average	High	Class 2	Gravel	Silica	Andean semiarid
7_1	No name	Low	Average	Class 2	Gravel	Silica	Andean semiarid
7_6	Rapel river	Low	Average	Class 2	Sand	Silica	Andean semiarid
7_7	Mostazal river	Low	Average	Class 2	Sand	Silica	Andean semiarid
7_11	Hurtado river in Huapulla	Low	Average	Class 2	Sand	Silica	Andean semiarid
7_12	Hurtado river in Pichasca	Low	Average	Class 2	Sand	Silica	Andean semiarid

*****Average catchemt flow
NC: Non classified

Table 9: Site information, based on typology information taken from Fuster *et al.* (2011). Further information; see Appendix F. (continuation).

		Mediterranean ecoregion					
Station codes	Stream name	Slope field	Altitude class	Size class (*)	Substrate (dominant type)	Geology class	Stream type
7_13	Hurtado river in Serón	Low	Average	Class 2	Sand	Silica	Andean semiarid
8_10	El Ingeniero in Lagunillas	Low	Low	Class 1	Sand	Silica	On transition
10_3	Huatulme river	Low	Very low	Class 2	Gravel	Calcareous	ORMS**
10_4	Huatulme river	Low	Very low	Class 2	Sand	Calcareous	ORMS**
10_9	Quebrada seca	Low	Very low	Class 2	Sand	Calcareous	ORMS**
10_14	Punitaqui stream	Low	Very low	Class 2	Sand	Calcareous	ORMS**
10_15	Limarí river	Low	Very low	Class 2	Sand	Calcareous	ORMS**

*****Average catchemt flow
******ORMS: of river mouth of semiarid

Table 10: Stream morphology and hydrology, in the table is possible to see information taken on field, further information in Appendix F.

Station codes	Stream name	Valley form	Channel form	Width Floodplain (m)	Flodd prone area width (m)	Average Stream (m)	Mean Depth (m)	Maximum Depth (m)
0_2	Near Cogoti river	Meander valley	sinuate	17.56	11.6	10.1	0.3	0.6
6_5	Palomo river	U_shaped	sinuate	33.1	32.1	21.55	0.3	0.6
6_8	Grande river	V_shaped	sinuate	10.24	9.24	5.00	0.7	0.6
7_1	No name	Meander valley	meandering	-	-	-	-	-
7_6	Rapel river	Meander valley	constrained	-	-	-	-	-
7_7	Mostazal river	U_shaped	sinuate	17	8.0	5.5	0.3	0.6
7_11	Hurtado river in Huapulla	U_shaped	anabranching	45	25	16.5	0.3	0.5
7_12	Hurtado river in Pichasca	U_shaped	sinuate	37	32	22	0.45	0.8
7_13	Hurtado river in Serón	V_shaped	sinuate	0.5	8.2	5.6	0.8	1.5
8_10	El Ingeniero in Lagunillas	U_shaped	sinuate	-	-	-	-	-
10_3	Huatulme river	U_shaped	sinuate	30.5	25	18.5	0.75	1.5
10_4	Huatulme river	U_shaped	sinuate	22.5	7.5	15.8	0.05	0.1
10_9	Quebrada seca	U_shaped	sinuate	-	5.0	3.0	0.3	0.6
10_14	Punitaqui stream	U_shaped	constrained	-	-	-	-	-
10_15	Limarí river	U_shaped	anabranching	24.5	13.0	8.0	1.0	2.0

* The averages streams in the different stations correspond to a priori values.

Table 11: Stream morphology and hydrology, this information was taken on field and some information obtain from local people, further information in Appendix F.

Station codes	Stream name	Debris	Dams	Transversal structure	Pulse releases	Water abstraction	Stagnation	Straightening	Cut-off meanders	Culverting	Waste
0_2	Near Cogoti river	none	no	no	?	no	no	No	no	no	no
6_5	Palomo river	none	no	yes	?	yes	no	No	no	no	no
6_8	Grande river	none	no	no	?	no	no	No	no	no	no
7_1	No name	none	no	no	no	no	no	?	no	no	yes
7_11	Hurtado river in Huapulla	none	no	yes	?	no	no	No	no	no	yes
7_12	Hurtado river in Pichasca	none	no	yes	?	no	no	No	no	no	no
7_13	Hurtado river in Serón	none	no	yes	?	no	no	No	no	no	no
7_6	Rapel river	none	no	yes	?	no	no	No	no	no	yes
7_7	Mostazal river	none	no	no	?	no	no	No	no	no	no
8_10	El Ingeniero in Lagunillas	-	-	-	-	-	-	-	-	-	-
10_14	Punitaqui stream	-	-	-	-	-	-	-	-	-	-
10_15	Limarí river	none	no	yes	?	no	yes	Yes	yes	yes	yes
10_3	Huatulme river	few	yes	yes	yes	no	no	No	no	no	yes
10_4	Huatulme river	none	no	yes	?	?	yes	No	no	no	yes
10_9	Quebrada seca	none	no	yes	?	no	no	No	no	no	no

5.2.1 Discussion about morphological characterization

Longitudinal trends in water quality.

In general, the water quality of the Limarí River watershed could be seen to change from upstream to downstream field stations. Upstream, the streams were small and was usually fast-flowing, cold, clean, transparent, and lacking any odors. Locals would draw water directly from these streams. In mid-basin sites, the streams were wider, and – when there was flow – it was slow and moderate, the water was cool, often transparent, and lacked obvious odor. In contrast, downstream, the Limarí River was at its widest, but it was obviously impacted from a variety of sources, including the nearby city. The water was still cool, but the surface had foam and the river bottom was choked with strands of algae, and there was a foul odor coming from the river.

Field stations #1 and 6 were completely covered with dense vegetation, and it was impossible to reach the flowing water. However it was possible to estimate the floodplain areas, and in both cases, it was relatively small. Field station #6 proved to be used as a clandestine trash dumping point for local residents.

Most of the field stations that were in small streams (e.g., field stations #7 and 9) are responsible for maintaining the agricultural industry of the area.

In some areas, the river was completely dry (e.g., field stations #10 and 14), and there was evidence that people were using groundwater. Even in June – the winter months – people were already using groundwater, and people pointed to the previous year's drought as the main cause for their groundwater use.

5.3 Integration of physical morphology and water quality

This section presents an analysis of the results of the water quality at the six selected water quality stations that compared the reported chemical parameters for the last 20 years. In addition, observations of the variations in pH, electrical conductivity, nitrate, phosphate, chloride, sulfate and dissolved oxygen are reported. Finally reviews of articles related to the condition of the water quality in the Limarí River watershed are included for explanatory purposes.

5.3.1 Historic water quality in the Limarí River watershed

There are not many previous water quality assessments that have been published about the Limarí River watershed. However, in 2007, Meza *et al.* established the water quality status of ten principal water courses in the Limarí River watershed. Three of them had bad quality in relation to the NCh 1333/78 standard: El Ingeniero Stream, Punitaqui Stream and the Limarí River. These water courses registered high levels of salinity, which means high chlorine concentrations of 516 mg/L, 46% of sodium and sulfates with 620 mg/L. However the authors indicated that this condition could be from natural origin. Several physical factors could influence the water quality of rivers. In 2011 Astudillo suggests that in the zone of the Limarí River watershed, there exists a tight relationship between its two principal economic activities (agriculture and mining industry), and both negatively impact the water quality on local surface water bodies. However, diminished water quality metrics can be of anthropogenic or natural origin. The natural factors correspond mostly to the chemical compositions between the different lithologies and to the changes in the hydrodynamic regime along the fluvial basin. The anthropogenic factors would relate to agroindustrial activities, mining activities, the degree of urbanization and the presence of reservoirs (Astudillo, 2011).

Astudillo (2011) reported that the mining industry generates heavy metal and fluvial sediment pollution, with the lowest part of the Limarí River witnessing chromium pollution, and the upper section of the Hurtado River suffering from copper, arsenic, cadmium, and zinc pollution. The lowersection of the Grande River is polluted with copper and chromium, and the upper section of Punitaqui Stream contains copper and mercury contamination.

- **Water quality station 1: The Limarí River in Barraza**

According to the INIA (2009), in the area of Barraza, the Limarí River has an electrical conductivity in the soils that is very high, between 7.5 to 20.7 dS/m. (Soil is considered to be saline at concentrations of ≥4 dS/m), and in this locality the pH of the soils is moderately alkaline. The excess of sodium suggests the presence of sodium chloride, which negatively affects plant growth, andbicarbonates also generate problems in vegetables when its concentration is higher than 4 mmol/L (INIA, 2009). The sulfate content is moderately high, but while this ion does not present a toxic effect, it does have a saline effect (INIA, 2009). The authors indicate that the factors that determine the salinization of the soils in Barraza are: a) poor irrigation management, b) poor drainage of the soils, and c) low water quality used in irrigation. Finally, discharge from the sewage treatment plant in the city of Ovalle doubles the concentration of sulfates in the Limarí River (Meza, 2009).

- **Water quality station 2: The Hurtado River**

Agricultural activity in the Hurtado River sub-basin centers around the production of grapes. Nevertheless other fruit trees and some vegetables are produced in this zone. According to Astudillo (2011), sediments of the upper portion of the river provide a strong enrichment in metals. The origin of these elements are related to a zone of hydrothermal alteration located in the high mountain, corresponding to the metallogenic band of the

Neogen; there are no mining activities of importance in this zone, so the explanation of this methyl concentration points to natural sources (Astudillo, 2011).

- **Water quality station 3: The Rapel River in Paloma**

In the upper portion in the course of the Los Molles River contains high concentrations of arsenic, zinc, cadmium, and molybdenum, probably associated with the zone of hydrothermal alteration observed in the upper portion of the Hurtado River. The Rapel river, has high values of silver down stream of the Tulahuén Fault, a sector that contains some silver mining (Astudillo, 2011).

- **Water quality station 4: The Grande River in Ramada**

In spite of draining from the same geological units as the downstream portions of the Hurtado River, the chemical signature of this river is slightly different, since the Grande river is intruded by granitic bodies dating to the late Cretaceous. This sector is associated with small scale mining activities, and down stream, metallic elements, like mercury, gold, scandium, tin, and barium were detected (Astudillo, 2011).

- **Water quality station 5: The Combarbalá River in Ramadilla**

In the sector are many zones of hydrothermal alteration. The Central zone of this alteration contains deposits of combarbalita, (typical rock of Chile) these rock is distributed by numerous isolated sectors in the sub basin (Astudillo, 2011).

- **Water quality station 6: Punitaqui Stream**

The principal economic activity in this locality is agriculture, but nevertheless in the upper portion of the river course, mining developed around deposits of gold, mercury, and copper.The water in this zone has a strong presence of organic matter, which is demonstrated in high levels of total carbon detected. Other chemicals that are abundant in this section of the stream isphosphate (e.g., P2O5) related to agricultural fertilizers and chromium, related to industrial and urban waste (Astudillo, 2011).

5.3.2 Chemical parameters

Using the information of pH, electrical conductivity, nitrate, phosphate, chloride, sulfate and dissolved oxygen that was provided by the DGA, an analysis of information from the six water quality stations over the past twenty years was conducted. Using SPSS, box plots were generated along with the decadal averagesand standard deviations for each chemical parameter.

pH. In the lower zones of the Limarí River and in Punitaqui Stream the pH becomes more basic registering average values up to 8.35. Before the confluence with the Limarí River, Punitaqui Stream experiences a slight increase in the pH. The range of pH in the watershed is in accordance with the water quality regulation for irrigation water (NCh 1333) of a pH between 5.5 and 9.0. Since the ideal pH for elemental solubility is 6.5 (INIA, 2009), pH in the Limarí River is generally high, and if pH increases further, it could influence the form and the availability of nourishing elements within irrigation water.

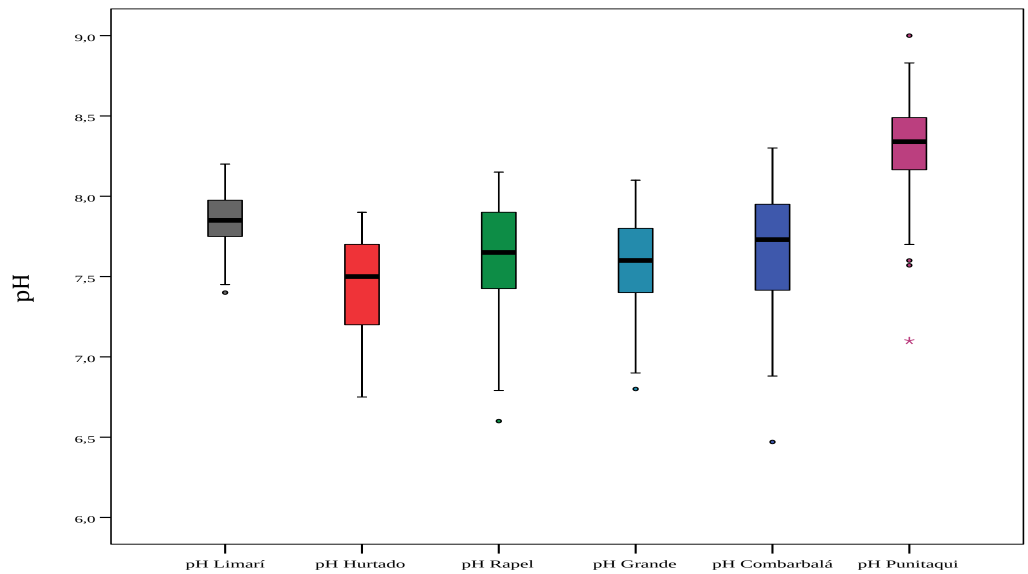


Figure 8. Box plot generated using SPSS for pH in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 12: Decadal averages and standard deviations for pH with information from the DGA for the period of 1970-2000.

pH	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1970s	7.82	0.23	7.47	0.31	7.61	0.40	7.56	0.33	7.70	0.38	-	-
1980s	7.92	0.38	7.47	0.43	7.69	0.47	7.96	0.45	7.52	0.43	-	-
1990s	7.89	0.47	7.43	0.57	7.69	0.45	7.86	0.55	7.75	0.42	8.13	0.47
2000s	8.07	0.36	7.71	0.49	7.84	0.51	7.92	0.45	7.71	0.47	8.35	0.32

Electrical conductivity (EC). Electrical conductivity can be considered to be a reflection of the net ionic content of the waters and an analogue for salinity. In the upstream portions of the watershed, the conductivity is below the Chilean regulation (NCh 1333) that it fixes a maximum of 750 mhos/cm. However, Punitaqui Stream registered values slightly over this regulation, and the Limarí River historically has been above the regulation, registering averages from 1307.4 to 2301.8 mhos/cm.

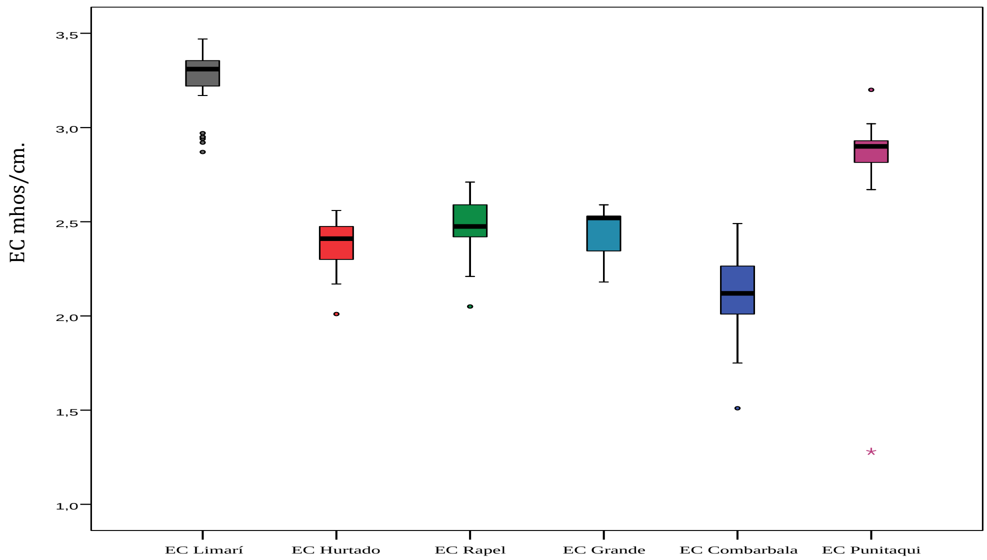


Figure 9. Box plot generated using SPSS for EC in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 13: Decadal averages and standard deviations for EC with information from the DGA for the period of 1970-2000.

EC mhos/cm	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1970s	2166.58	548.95	264.92	54.23	331.89	90.14	276.56	58.87	151.73	60.75	-	-
1980s	1307.45	457.73	226.92	89.37	289.7	58.01	210.5	60.7	122	53.49	-	-
1990s	1788.19	805.49	271.08	83.46	328.88	96.9	263.53	93.1	139.21	75.05	763.47	146.02
2000s	2301.82	852.84	242.64	56.96	288.34	60.86	190.88	45.86	85.89	33.63	774.94	292.65

Nitrate (NO3). The nitrate concentration in groundwater and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural land or contamination from human or animal wastes as a consequence of the oxidation of ammonia and similar sources. This basin presents high values of NO3 in the mountains, while the lower concentrations are in Combarbalá. In the Huratdo River and in PunitaquiStream, the highest values in the last 20 years (0.26 mg/L) are found, which are far below the established limits from the NCh 1333.

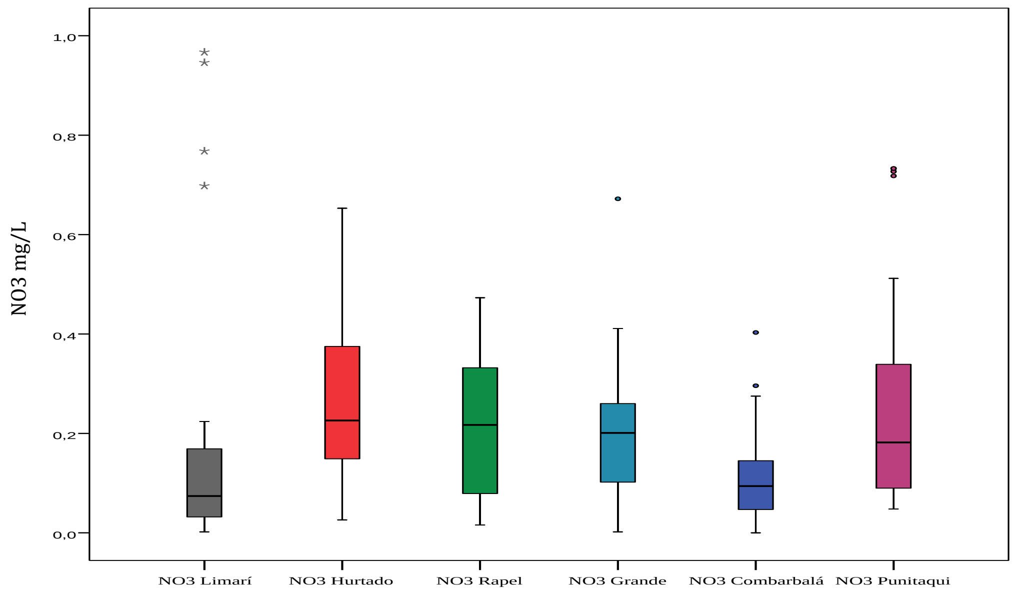


Figure 10. Box plot generated using SPSS for NO3 in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 14: Decadal averages and standard deviations for NO3 with information from the DGA for the period of 1970-2000.

NO3 mg/L	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1970s	0.05	0.05	0.15	0.14	0.18	0.18	0.14	0.06	0.07	0.10	-	-
1980s	0.17	0.32	0.15	0.08	0.18	0.17	0.13	0.12	0.16	0.14	-	-
1990s	0.18	0.25	0.29	0.13	0.22	0.13	0.23	0.14	0.13	0.09	0.31	0.24
2000s	0.18	0.20	0.28	0.19	0.17	0.07	0.14	0.07	0.20	0.77	0.30	0.34

Phosphate (PO4). The phosphorus of natural origin corresponds to natural reserves and phosphoric rocks, the point sources from anthropogenic activities include domestic and industrial waste waters; the not-point sources are associated with the run off of agricultural and domestic areas. In Chile, regulation NCh 1333 does not stipulate a reference value, and it is left to the a competent authority to set the criterion. In the decade of the seventies, low values of phosphorus were registered, in the eighties it increased and in the last years the concentration of phosphorus diminished again. In 2009, in the INIA investigation, a certain stability of the values registered from 1970 to 2010 was determined.

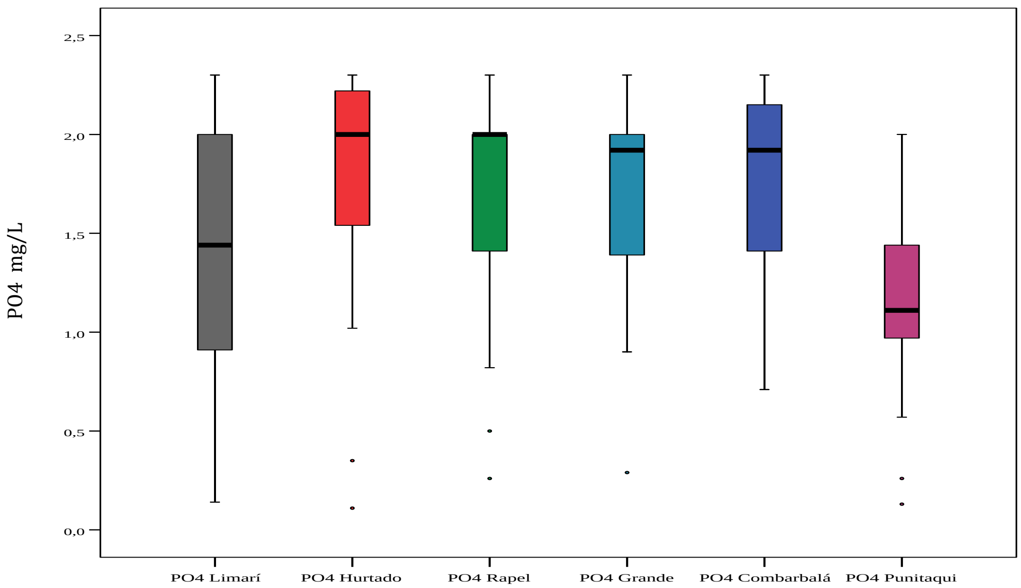


Figure 11. Box plot generated using SPSS for PO4 in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 15: Decadal averages and standard deviations for PO4 with information from the DGA for the period of 1970-2000.

PO4 mg/L	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1980s	0.024	0.035	0.005	0.001	0.007	0.004	0.008	0.003	0.015	0.019	-	-
1990s	0.194	0.292	0.091	0.193	0.137	0.274	0.130	0.302	0.152	0.433	0.353	0.542
2000s	0.025	0.028	0.147	0.904	0.067	0.301	0.014	0.011	0.014	0.012	0.070	0.059

Dissolved oxygen (DO). If the levels of dissolved oxygen in the water go below 5.0 mg/L, aquatic life is put under pressure. In addition dissolved oxygen is associated with a vast number of indicators, not only biochemical, but also aesthetic indicators, such as smell, clarity of the water, and flavor. In the Limarí River watershed, the highest values are in Punitaqui Stream and in the Limarí River, the latter with average values of 17.64 to 16.31 mg/L over the last 20 years. In Chile, regulation NCh 1333 has a reference value of a minimum of 5 mg/L for maintaining aquatic life, and in general the Limarí River watershed is above this minimum standard of dissolved oxygen Indeed, DO has stayed relatively constant since 1970 (INIA, 2009).

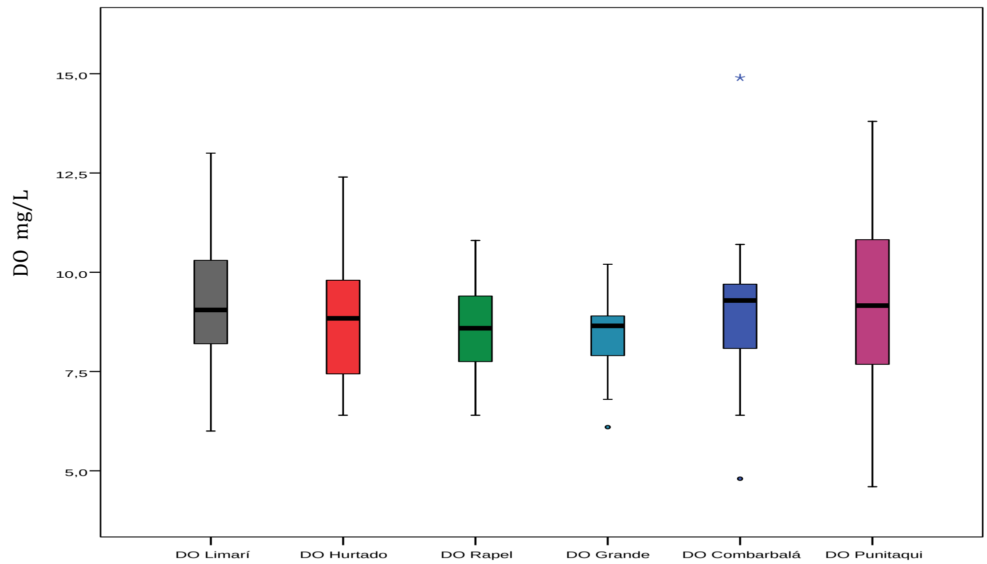


Figure 12. Box plot generated using SPSS for DO in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 16: Decadal averages and standard deviations for DO with information from the DGA for the period of 1970-2000.

DO mg/L	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1980s	-	-	9.53	0.59	9.07	0.64	8.13	2.05	9.30	0.80	-	-
1990s	17.64	13.59	8.65	1.32	8.71	1.32	8.44	0.86	8.78	1.05	9.87	3.32
2000s	16.31	11.65	8.37	1.60	8.73	1.09	8.70	1.09	8.97	1.05	8.96	1.49

Sulfates. The most common sulfates found in the system are $MgSO_4$ and Na_2SO_4. Sulfates of calcium and magnesium contribute to water hardness, constituting the permanent hardness found throughout the watershed. The NCh 1333 regulation fixes a limit of 250 mg/L of sulfates for waters of irrigation. Punitaqui Stream and the Limarí River register the highest values for sulfates.

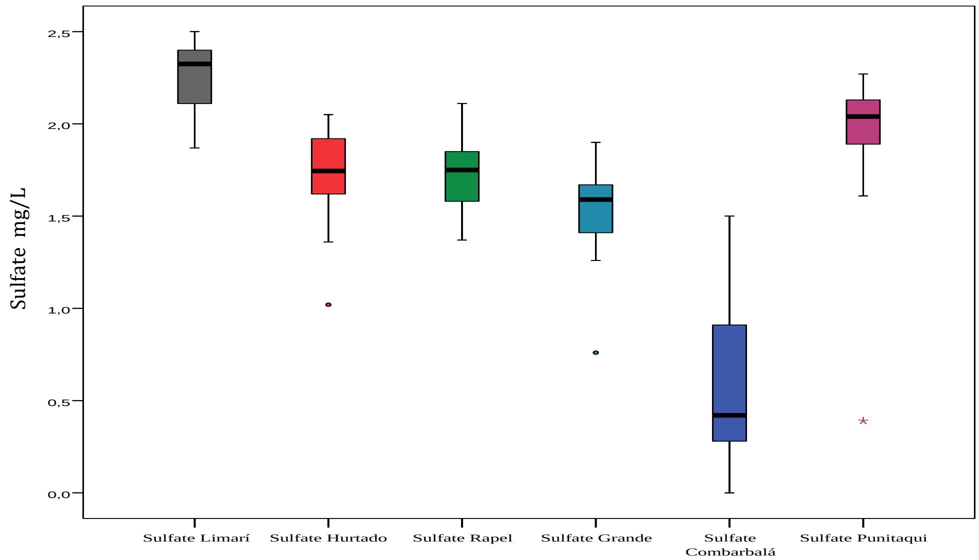


Figure 13. Box plot generated using SPSS for Sulfate in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 17: Decadal averages and standard deviations for Sulfate with information from the DGA for the period of 1970-2000.

Sulfate mg/L	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1970s	218.44	65.85	63.33	24.40	57.47	22.76	33.66	14.15	6.75	8.10	-	-
1980s	133.90	54.05	57.22	27.01	59.29	26.20	21.75	8.69	2.55	3.17	-	-
1990s	207.83	80.47	67.58	29.96	57.90	22.22	29.56	14.82	1.58	1.82	86.58	38.61
2000s	251.10	83.35	72.92	23.00	67.63	25.86	29.02	19.89	1.95	2.45	120.83	40.09

Chloride. In the upper regions of the basin, the values of chloride do not exceed 20 mg/L, save for in Punitaqui Stream, where the recorded values exceeded 50 mg/L. In contrast, during the last decade, the Limarí River has witnessed an increase in the concentration from 246.5 to 454.5 mg/L. During the eighties, the Limarí River registered lower concentrations of chlorine, but since 2000 this concentration has doubled.

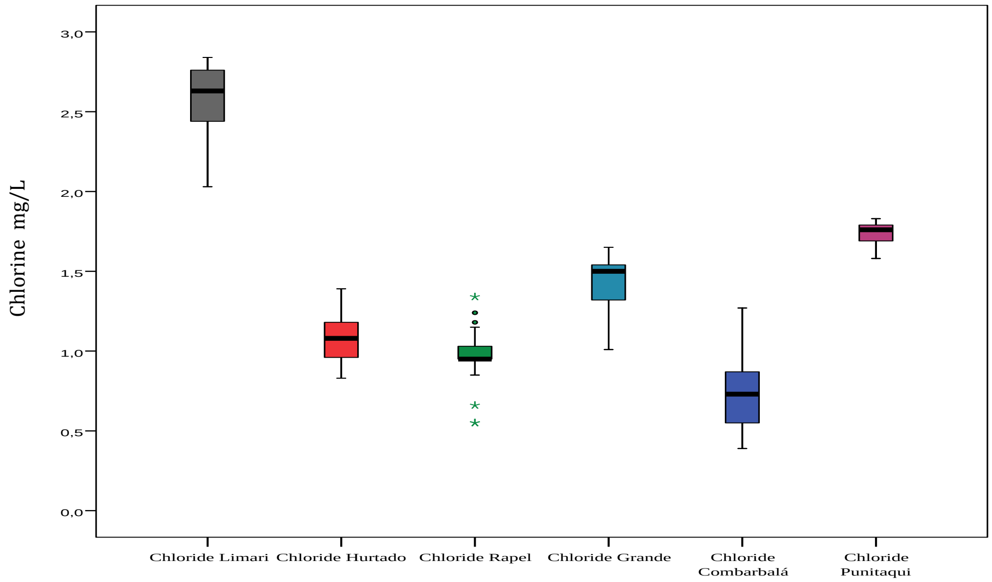


Figure 14. Box plot generated using SPSS for Chlorine in six monitoring stations with data of the DGA, for the period of 1970-2000.

Table 18: Decadal averages and standard deviations for Chlorine with information from the DGA for the period of 1970-2000.

Chloride mg/L	Limarí River in Panamericana		Hurtado river		Rapel river in Paloma		Grande river in Ramada		Combarbalá river in Ramadilla		Punitaqui Stream	
Decade	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV	Average	STDEV
1970s	420.17	158.39	13.36	4.88	10.33	4.10	27.35	7.71	7.82	4.96	-	-
1980s	246.52	119.24	8.92	3.29	6.66	1.60	16.79	4.93	4.54	1.85	-	-
1990s	363.94	176.78	8.16	3.88	5.90	3.18	15.05	8.64	4.40	2.98	53.78	10.85
2000s	454.51	185.83	6.01	2.30	5.27	1.67	12.89	4.92	2.28	1.20	55.87	7.68

5.3.3 Water quality spatial pattern

Punitaqui Stream and the Limarí River register the highest values for sulfates, with the Limarí River reporting values are over the Chilean regulation, and this concentration could be explained by contributions from natural sources from El Ingeniero stream (Astudillo, 2011). The increase of chlorides in the terminal portion of the Limarí River can be explained by its confluence with El Ingeniero Stream and Punitaqui Stream. The principal reason of the high concentration of chlorides is of natural origin, according to INIA (2009).

According to INIA (2009), the longitudinal pattern in the observed water qualitycan identify upstream water quality as being good in the Hurtado and Grande river, and for the Rapel and Combarbalá Rivers, water quality is establishedas regular. Downstream, in the Limarí River and Punitaqui Stream, water quality is deficient. The author suggests that the poor water quality is influenced by anthropogenic factors such as agriculture, mining activities and urban discharge in the rivers.

5.3.4 Relation between water quality, chemical and morphological parameters

In order to determine that the probabilities of the distribution of X^2 constitute a good approximation to the distribution of the X^2 statistic, it is necessary that some conditions are fulfilled, such asthe expected frequencies not being too small. If the expected frequency is less than 5, the quantity must be less than 20% of the total expected frequency. The Pearson statistic must be interpreted carefully (Díaz, 2009).

The analyzed variables that registered significance values higher than 0.05 were chloride, sulfate, valley slope, and land use, which suggest a high probability of assuming erroneous associations. In addition, these variables registered low values in the coefficient of correlation (*phi*). For these reasons is not possible to determine associations to be statistically significant between those variable and the water quality in the basin.

Table 19: Results of X^2 using SPSS for the combination of the water quality index, ICA (INIA, 2009), together with chemical and the morphological parameters.

		chi-square test			Symmetric measurements*	
		X^2 Pearson	df	Bilateral asymptotic significance	*phi*	Approximate significance
Chemical parameters	EC	6.00 a	2	0.05	1.00	0.05
	Chloride	2.40 b	2	0.30	0.63	0.30
	Sulfates	2.40b	2	0.30	0.63	0.30
Morphological parameters	Geology class	6.00a	2	0.05	1.00	0.05
	Slope valley	1.50 a	2	0.47	0.50	0.47
	Land use	2.40b	2	0.30	0.63	0.30
	Influence of big cities	6.00a	2	0.05	1.00	0.05

*****Assuming the alternative hypothesis and using the standard asymptotic error based on the null hypothesis.

a Six cells have a lower expected frequency than 5. The minimal expected frequency is 0.67.

b Six cells have a lower expected frequency than 5. The minimal expected frequency is 0.33.

Note: It was not possible to calculate some statistics for pH and dissolved oxygen, because the period 2000-2010 was constant.

For the variables of electrical conductivity (EC), geology class, and influence of big cities, the X^2 test determined there was a significance of 0.05, which implies an association between the above mentioned variables and the deficient water quality in the basin. In addition, this is reaffirmed by a high coefficient of correlation (*phi*=1), from these results in EC and influence of big cities, it is reasonable to think that the influence of anthropogenic activities worsen the water quality in this watershed. This fact agrees with the information described in section 5.2.1. However the geology class could be interpretedmore carefully as natural factor that negatively influences water quality. Astudillo (2011) make an exhaustive study of the river sediment and the chemical variation and he presented a relation between sediment types. In order to make a statement about how geology class could affect water quality requires the development of a future methodology to establish how geology affects water quality in this watershed.

With the application of the modified AQEM sheets, it was possible to completely visit the Limarí River watershed, and all the water ways upstream have less human intervened and are more clean that the ones in lowers portions of the watershed. Downstream, it was possible to see many human modifications to the flow, including bridges, channelizing, straigtening, the influence of big city and the intensification of agriculture.

The creation of the Table 14 was constructed using the limits of NCh 1333. Therefore, in this context, every parameter that registered a permissible concentration under the Chilean normative was in agreement with the quality standard established in Chile. In constrast to the single number of the water quality index (ICA), the values found in Table 19 provide a general idea of how major chemical parameters relate to morphological parameters.

For the WFD, the hydromorphological and chemical parameters are quality elements (among others) that support the biological elements, without the biological elements is impossible to establish the *Ecological Status*. This thesis work always contemplated the fact that there is not enough information to perform an analysis, such like that of the EU. However, one of the main goals was to see how different or related the Chilean and the European normative are, since Chile can benefit from the twelve years' experience in the EU about proper ecological assessment.

In terms of applicability of the EU's framework within Chile, Chile has as much variation in climate as found in Europe. Therefore, if the EU framework can accommodate European climatic and ecological variation, then it can possibly be of similar utility in Chile. This is yet another reason why continued studies into the feasibility of the European approach of the WFD in Chile is important.

6. Conclusions and recommendations

This work is far from complete with regard to chemical monitoring, and it is necessary to have more chemical data in order to develop better and more complete analyses. With regard to morphological information in Chile, an ongoing project is still young, but it provides adequate information, and a typology has been created for all the country so it would be possible to replicate this study in some other Chilean watersheds.

WFD and Chilean normative

In general, the Chilean regulation could be adjusted to the international establishment for chemical parameters regarding maximum allowed limits. However, according to the guidance of the WFD, in this thesis work identified the following conflicts: The first conflict is that the information registered in the water quality stations of the DGA is not sufficiently regular across the years, and as the samplings are normally conducted every two months, which means that it is possible for important information to get lost. It is recommended to do a study on the sufficiency of existing monitoring stations and the determination of the number of annual samplings, in order to generate detection of irregular incidents and illegal discharges.

This problem raises new challenges that leave opened news debates, such as: how to implement an automatic system of water quality monitoring, like those that have been implemented in Europe and the feasibility of implanting the concept of sustainability on top of economic growth in Chile.

The second conflict is that the chemical parameters analyzed in this work were chosen according to the available information. Not all the water quality stations possess a complete series of information or measure all the universal parameters used in water quality assessments. Some transverse chemical parameters must be defined by the DGA. For instance, the characterization of water bodies uses alkalinity and hardness, and these estimations are easy to calculate. However, the DGA does not publish this information that is very essential for industry and agriculture.

In addition, the information about the microbiological parameters (e.g., total and fecal coliforms) does not depend on the DGA, but on another agency, the National Cattle Service (SAG), and it was not possible to include this information in this thesis. However, having multiple government agencies in charge of measuring different parameters, with little information sharing between them, is inefficient. Therefore, assembling all the information related to the water quality in just one governmental institution would be optimal.

Finnaly, to these two conflicts, there are three additional points of recommendation that ought to be considered in moving forward with research into water quality: river flow in semi-arid regions, and extending the holistic approach.

Relation between water quality, chemical and morphological parameters

According to the ICA (INIA, 2009), in general the water quality for the upstream regions of the watershedrange from good to regular, whereas the downstream regions (e.g., the Limarí River and Punitaqui Stream) have deficienct water quality. In this semiarid Region, not only is the quality of the water a problem, but decreasesin the river flow is critical. During the course of conducting this thesis investigation, the water courses at two field stations were completely dry, and most of the remaining field stations did not have abundant river flows.

Furthermore, there is a lot of natural contribution of salts and minerals in this watershed that contribute to worsening the water quality for irrigation and affecting many fields in the area. Since the landscape can be a natural pollutant source, is recommended to create a standardization of the water for irrigation using filtration treatmentbefore their use, with this it could be guarantees an acceptable water quality for irrigation.

The analysis of the raw data provides a perspective on the behavior of the chemical parameters across the years, and with this information, plus the information extracted from the literature, is possible to generate a matrix to analyze contingency table information about chemical and morphological data. In this work it was possible to establish three important associations: where salinity, local geology and the influence of big cities are related with deficient water quality. While the number of chemical monitoring stations and the monitored parameters can be debated, this thesis represents the first step toward the combination of chemical and morphological parameters and applying a holistic approach in the Limarí River watershed.

Inspired by the European Union model of water managment that includes three fundamental supports (biological parameters, hydromorphological characteristics and physico-chemical parameters), this work seek to establish statistically significant relations between chemical and morphologic factors of the area, with this the first step towards the establishment of the ecological status in this basin.

Continuing to extend this work, both geographically, and parametrically will help provide a framework for assessing water quality from more than merely a chemical approach. Furthermore, it could be a method that can be used to reassess the priorities that Chile has toward managing its water resources as it moves into a future of uncertain water availability. Also, a customized metric for each region in the Chilean territory is needed in order to include all the different type of climate in the country, is possible to learn about the European experience related to how they consider all the different countries and different climate region with customize programs.

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Appendix A

Table 1: Biological quality elements (WFD, 2000/60/EC).

Element	High status	Good status	Moderate status
Phytoplankton	The taxonomic composition of phytoplankton corresponds totally or nearly totally to undisturbed conditions. The average phytoplankton abundance is wholly consistent with the type-specific physico-chemical conditions and is not such as to significantly alter the type-specific transparency conditions.	There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water sediment.	The composition of planktonic taxa differs moderately Abundance is moderately disturbed and may be such as to produce a significant undesirable disturbance in the values of other biological and physico-chemical quality elements.
Macrophytes and phytobenthos	The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average macrophytic and the average phytobenthic abundance.	There are slight changes in the composition and abundance of macrophytic and phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity.	The composition of macrophytic and phytobenthic taxa differs moderately from the type-specific community and is significantly more distorted than at good status. Moderate changes in the average macrophytic and the average phytobenthic abundance are evident. The phytobenthic community may be interfered with and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities.
Benthic invertebrate fauna	The taxonomic composition and abundance correspond totally or nearly totally to undisturbed conditions. The ratio of disturbance sensitive taxa to insensitive taxa shows no signs of alteration from undisturbed levels. The level of diversity of invertebrate taxa shows no sign of alteration from undisturbed levels.	There are slight changes in the composition and abundance of invertebrate taxa from the type specific communities. The ratio of disturbance-sensitive taxa to insensitive taxa shows slight alteration from type-specific levels. The level of diversity of invertebrate taxa shows slight signs of alteration from type-specific levels.	The composition and abundance of invertebrate taxa differ moderately from the type-specific communities. Major taxonomic groups of the type-specific community are absent. The ratio of disturbance-sensitive taxa to insensitive taxa, and the level of diversity, are substantially lower than the type-specific level and significantly lower than for good status.
Fish fauna	Species composition and abundance correspond totally or nearly totally to undisturbed conditions. All the type-specific disturbance sensitive species are present. The age structures of the fish communities show little sign of anthropogenic disturbance and are not indicative of a failure in the reproduction or development of any particular species.	There are slight changes in species composition and abundance from the type-specific communities attributable to anthropogenic impacts on physico-chemical and hydromorphological quality elements. The age structures of the fish communities show signs of disturbance attributable to anthropo-genicimpacts on physico-chemical or hydromorphological quality elements, and, in a few instances, are indicative of a failure in the reproduction or development of a particular species, to the extent that some age classes may be missing.	The composition and abundance of fish species differ moderately from the type-specific communities attributable to anthropogenic impacts on physico-chemical or hydromorphological quality elements. The age structure of the fish communities shows major signs of anthropogenic disturbance, to the extent that a moderate proportion of the type specific species are absent or of very low abundance.

Table 2: Hydromorphological elements supporting the biological elements (WFD, 2000/60/EC).

Element	High status	Good status	Moderate status
Hydrological regime	The quantity and dynamics of flow, level, residence time, and the resultant connection to groundwaters, reflect totally or nearly totally undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Morphological conditions	conditions Lake depth variation, quantity and structure of the substrate, and both the structure and condition of the lake shore zone correspond totally or nearly totally to undisturbed conditions.	Conditions consistent with the achievement of the values specified above for the biological quality elements.	Conditions consistent with the achievement of the values specified above for the biological quality elements.

Table 3. Chemical and physicochemical elements supporting the biological elements (WFD, 2000/60/EC).

Element	High status	Good status	Moderate status
General conditions	The values of the physico-chemical elements correspond totally or nearly totally to undisturbed conditions. Nutrient concentrations remain within the range normally associated with undisturbed conditions.	Levels of salinity, pH, oxygen balance, acid neutralising capacity and temperature do not show signs of anthropogenic disturbance and remain within the range normally associated with undisturbed conditions.	Temperature, oxygen balance, pH, acid neutralising capacity and salinity do not reach levels outside the range established so as to ensure the functioning of the type specific ecosystem and the achievement of the values specified above for the biological quality elements. Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements. Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific synthetic pollutants	Concentrations close to zero and at least below the limits of detection of the most advanced analytical techniques in general use.	Concentrations not in excess of the standards set in accordance with the procedure detailed in the annex V section 1.2.6 without prejudice to Directive 91/414/EC and Directive 98/8/EC. (< EQS)	Conditions consistent with the achievement of the values specified above for the biological quality elements.
Specific non synthetic pollutants	Concentrations remain within the range normally associated with undisturbed conditions (background levels = bgl).	Concentrations not in excess of the standards set in accordance with the procedure detailed in section 1.2.6 [(1)] without prejudice to Directive 91/414/EC and Directive 98/8/EC. (< EQS)	Conditions consistent with the achievemen of the values specified above for the biological quality elements.

* bgl = background level, EQS = environmental quality standard.

(1) Application of the standards under this protocol shall not require reduction of pollutant concentrations below background levels: (EQS > bgl).

Appendix B

The AQEM system

According to AQEM Consortium (2003) biological monitoring programmes first errors can already occur within the process selecting of sampling sites. To minimize the errors associated with sampling site selection, the following guidelines should always be considered:

The main goal of a monitoring programme is not to assess local features of a stream but to gain understanding of the ecological quality of a larger stream stretch or a complete catchment. Therefore, the selected sampling site and any samples taken must reflect the nature of the entire stream or at least the stream reach, which is to be assessed.

Biological samples usually require different sites than those used for chemical analyses. Usually it is not suitable to sample macroinvertebrates near a bridge, where water samples are most frequently taken. The site for the biological sampling should reflect the physical and ecological features of a larger reach.

The sampling site is the spot where the biological sample is taken and should be representative for the stream reach to be assessed. The survey area might cover a section of several hundred meters stream length up to a complete catchment area of a small stream, this is the area to be monitored, and for which the sampling site should be representative. The length of the sampling site depends on the stream width and the variability of the habitats. As a general rule, it should not be shorter than 20m in length and must cover the whole width of the stream it must be representative for a minimum survey area of 500m stream length. It is necessary to know the follow characteristics (AQEM Consortium, 2003):

- *Stream morphology and habitat composition*: The site must reflect the habitat composition of the survey area. Examples: If the survey area is predominantly free of debris dams it should be avoided to sample the only accumulation of dead wood. If the stream channel is not channelised in most of its length the only channelised section is unsuitable for sampling.

- *Hydrology.* Short reaches of residual flow or affected by pulse releases should be avoided unless they are typical for the survey area.
- *Shoreline vegetation.* The site must accommodate the characteristic composition and density of shoreline vegetation and provide the typical shading within the survey area.
- *Riffle-pool sequences.* The sampling site must reflect the share of riffles and pools of the reach. If both pools and riffles are representative for the survey area, both must be sampled.
- *Artificial disturbances.* Places close upstream or downstream of bridges, fords or weirs should be avoided unless they are typical for the survey area.
- *Point source pollution.* e.g. a sewage overflow, affects only a short stream section within the survey area, the sampling site must not be located close to the outlet of the sewer. Instead, the sampling should be performed at a distance from the outlet where the mixing process of river water and sewage overflow is complete.
- *Disturbance.* The macroinvertebrate community of sampling sites, which are sampled very frequently within other monitoring programmes, may be affected and should not be selected.

A site protocol describes a sampling site, it contains both site and sample related information and it serves for the following purposes:

1. To give an impression of river and floodplain morphology, hydrology and vegetation
2. To ensure that the site can be precisely re-located in the field
3. To document the process of biological sampling (sample related information)

The site protocol specified here has been developed for practical fieldwork. It mainly serves the documentation of the biological sampling and provides some additional information, which can be easily quickly recorded in the field. The site protocol is not designed to replace detailed morphological studies for other purposes

The site protocol consists of four data sheets. The site name, sampling date, sample number and the name of the investigator must be recorded on the top of every page to avoid problems, in case individual sheets are separated or copied.

Basic and additional data

The site protocol contains 73 data fields, which should be recorded. 24 of these are basic and 49 are additional data. The basic data are essential for the documentation of the exact locality of the site and of the biological sampling (share of habitats and number of replicates taken from each habitat). The additional parameters provide detailed and easy-to-note information on the physical and chemical features of the sampling site. Therefore, they may help in analyzing the results of the biological assessment and provide valuable hints for water management action. They are named "additional" because they are not essential for the calculation process of the biological data. Data fields for documenting the results from water analyses are also offered.

Field and lab data

Most of the data must be recorded in the field. Only a few parameters on the first data sheet should be taken directly or indirectly from maps, usually topographic maps. Preferably, a (digital) map of the stream reach investigated should be used with a 1:50,000 scale. If not available, 1:25,000 scale is also possible; in any case, the scale must be mentioned. Some data have to be measured, e.g. distance to source, stream order, size class based on catchment area, slope of the valley floor. To obtain these data, maps of the whole catchment upstream of the sampling site are necessary. Some data may sometimes require specific maps, e.g. geological maps or maps on sub-ecoregions and distribution of stream types, which are in preparation in several European states. Those site protocol data, which require wading in the streambed, must be collected after the biological sampling in order to avoid disturbing the fauna. The site protocol form is given in Annex 2, and a detailed description of all parameters to be recorded is given in Annex 3 in (AQEM Consortium, 2002).

Appendix C

Table 1: Physical and biological parameters in the typology of the Limarí watershed according to Fuster and collaborates (2011).

N° Type	Name Type	Physics Parameters		Biology Parameters		
		Determinant	Dominant	Fishes	Macroinvertebrate	Other
6	Semiarid Andean	Altitude: >1500 m.a.s.l	Silica[1] geology NF: medium and low Thick grained.	Absent	Mainly: Diptera, Oligochaeta Minorly: Ephemerotera Trichoptera	Large fauna different since high mineral content
7	Semiarid Transitional	Altitude: < 1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	*Dyplomistes Cheirodon Basilichthys*	Associated to ritron (high slope) sectors.	Fauna stable during the year
8	Of river mouth semiarid	Altitude: < 800 m.a.s.l	Silica geology NF: medium Fine-grained	*Dyplomistes Cheirodon Basilichthys*	Associated to Potamon (slow flow) sites. More: Diptera Mollusca Crustacean	Low zone of small flow and moderate diversity
9	Semiarid of transition with calcareous dominance	Altitude: 100-1500 m.a.s.l	Calcareous [2] NF: medium and low	Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types
10	River mouth of semiarid with calcareous dominance	Altitude: < 800 m.a.s.l	Calcareous NF medium and low Fine-grained	Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types
24	Mediterranean nearest to the coast	Expert criteria	Altitude: <800 m.a.s.l Silicide NF <200m^3/s All kind of substrate	*Geotria, Percillia, Percichthys, Basilichthys, Trichomycterus*	Quick rotation. Due to the scanty length of these systems and a refill in the dominance on the dry and rainy stations	Difference in his fauna structure from Coastal Mountain Chain

NF: Natural flow

(1) Correspond to rocks that consist principally for minerals silicates, already be forming minerals of rock (quartz, feldspars and maphics minerals) constituent of igneous rocks (intruder or volcanic); or minerals of alteration (clays, clorita or silica, among others), that overlap and they modify the original mineralogy of the rock. The silica (SiO_2) and the silicates (in general) possess a major resistance to the dissolution and to the erosion.

(2) Correspond to sedimentary rocks composed principally by carbonate of calcium, the most common rocks are limestones formed. In this category they qualify in addition, the metamorphic units with marble.

Appendix D

1.1 ICAS indicator (DGA, 2004)

The ICAS (Spanish for superficial water quality index), is inspirited in international experiences, mostly from United States through the Water Quality Index (WQI), this indicator has been adapted to the national requirements related to water uses (DGA, 2004).

The normalization of scales of measurement to have percentage normalized scales, has considered to be a reference the system elaborated by the National Sanitation Foundation (NSF) in the construction of an index of water quality, which bases on curves that relate the physical values of the parameters to a percentage scale. The Curves of Standardization are obtained from the information in the Instructive 1 (Annex A1 in DGA, 2004) in that there are established the maximums and minimums allowed for every parameter in the corresponding class. To be able to realize a direct reading of the value of the quality of the parameter, the following standardization of the classes for *Qi*:

The ICAS is express as follows:

$$ICAS = \sum_{i=1}^{i=n} wi * Qi$$

Where:

n: is the number of parameters that will form the ICAS.

Qi: represent the value of the parameter, expressed in percentage

wi: is the pondered weight of the parameters, where the six obligatory parameters weight each one 11,67% given a total of 70%, so the relevant parameters weight in total 30%.

The ICAS considers the exceptions of those parameters that exceed this class of a natural way, for what only they change those parameters of anthropogenic origin.

The data of water quality comes from the DGA (2004) were classified in five levels.

a) Level 1. Data from systematic sampling, larger than four times per year and for a period superior to 3 years. The register must have at least 10 values for each parameter.
b) Level 2. Data from systematic sampling, but with a register 5 to 10 values for each parameter.
c) Level 3. Data from specific sampling. They included campaigns of 2 to 5 values for the same parameter.
d) Level 4. Data from the present study. Specific measuring, with unique measuring.
e) Level 5. Theoretical estimation of quality water from existing data.

1.2 ICA indicator (INIA, 2009)

In the report made by the INIA (2009) consider that the calculation of the ICA according to the different uses of water in the Chilean norm and on having included the regulation it generates the biggest difference regarding to the work done in 2004 by the DGA.

The Water Quality Index (WQI) is a dimensionless number obtained from a combination of some physicochemical parameters, measure in a water sample. From mathematic formulation that are value from linear equations, that can measure the influence from each one of this parameters in the total of the index, and the value can be between 0, contaminated water, and 100, clean water. An index between 50 and 0 involved the impossibility of utilize the water of any kind of use (Box 1).

Box 1: Classification in ranges of the index of quality of water according to INIA (2009).

Range	Quality
100-85	Excellent
85-75	Good
75-65	Regular
65-60	Deficient
<60	Bad

The index of quality of water is express as follows:

$$IQW = \frac{\left(\sum Ci * Pi\right)}{\sum Pi}$$

Where:

Ci: values assigned for each parameter, according to the Normalization Table (Table 2)

Pi: is the relative weight assigned to each parameter, taking account the importance in aquatic life (to a high importance is a high weight).

Table 2: Factors of normalizations of, C_i according to INIA (2009).

		Normalization Factor										
		100	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
Parameters	***Pi***	**Analytic Values**										
Ammoniac Nitrogen	3	<0,01	<0,05	<0,10	<0,20	<0,30	<0,40	<0,50	<0,75	<1	≤1,25	>1,25
BDO_5	3	<0,5	<2	<3	<4	<5	<6	<8	<10	<12	≤15	>15
Calcium	1	<10	<50	<100	<150	<200	<300	<500	<700	<1000	≤1500	>1500
Chloride	1	<25	<50	<100	<150	<200	<300	<500	<700	<1000	≤1500	>1500
Conductivity	2	<750	<1000	<1250	<1500	<2000	<2500	<3000	<5000	<8000	≤12000	>12000
COD	3	<5	<10	<20	<30	<40	<50	<60	<80	<100	≤150	>150
% of saturation of D.O	4	>84,2	>80,1	>77,2	>73,8	>63,5	>52,4	>47,2	>40,5	>29,9	≤15,8	>15,8
Magnesium	1	<10	<25	<50	<75	<100	<150	<200	<250	<300	≤500	>500
Nitrate	2	<0,5	<2	<4	<6	<8	<10	<15	<20	<50	≤100	>100
Nitrite	2	<0,005	<0,01	<0,03	<0,05	<0,10	<0,15	<0,20	<0,25	<0,50	≤1,00	>1,00
Oil & fat	2	<0,005	<0,02	<0,04	<0,08	<0,15	<0,30	<0,60	<1,00	<2,00	≤3,00	>3,00
pH	1	7	7-8	7-8,5	7-9	6,5	5-9,5	5-10	4-11	3-12	2-13	1-14
Orthophosphate	1	<0,16	<1,6	<3,2	<6,4	<9,6	<16	<32	<64	<96	≤160	>160
Dissolved Solids totals	2	<100	<500	<750	<1000	<1500	<2000	<3000	<5000	<10000	≤20000	>20000
Total Solids	4	<250	<750	<1000	<1500	<2000	<3000	<5000	<8000	<12000	≤20000	>20000
Sulfate	2	<25	<50	<75	<100	<150	<250	<400	<600	<1000	≤1500	>1500
Temperature	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/-2	40/-4	45/-6	>45/-6
ΔT	1	5	7	10	14	18	25	32	38	44	51	>51
Total Coliform	3	<0,5	<2	<3	<4	<5	<6	<8	<10	<12	≤15	>15
Fecal Coliform	4	<0,5	<2	<3	<4	<5	<6	<8	<10	<12	≤16	>16
Turbidity	2	<5	<10	<15	<20	<25	<30	<40	<60	<80	≤100	>100

Appendix E

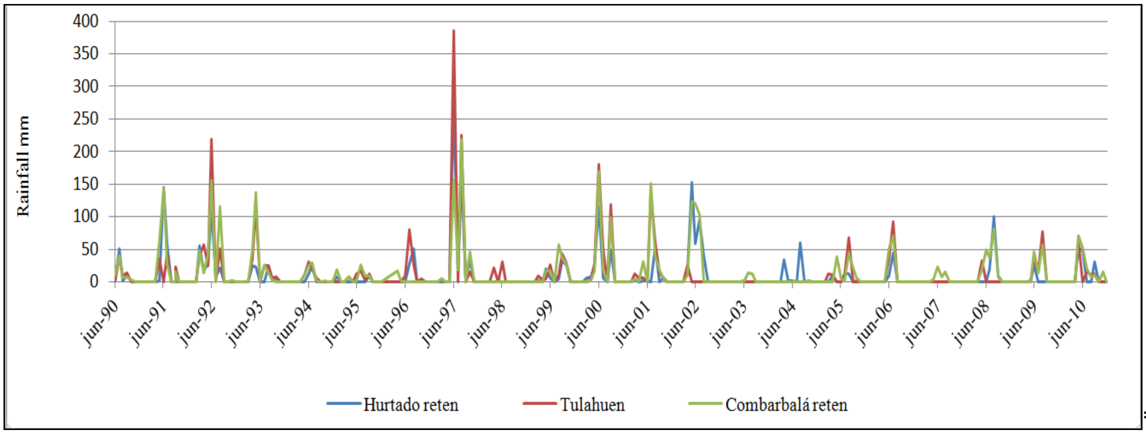
1. Biophysical environment

1.1 Climate

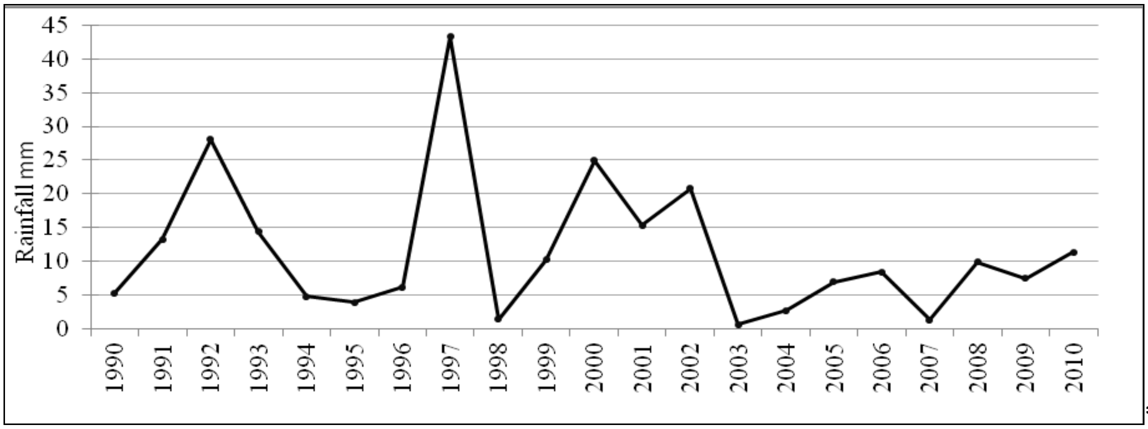
The Limarí basin has three climatic types, the semi-arid with abundant cloudiness, temperate semi-arid climate with winter rainfall and cold semi-arid also with rainfall in winter (It begins with the winter solstice in June) (DGA, 2004). **(**a) *Semi-arid climate* with abundant cloudiness: it presents throughout the coast. Its influence reaches inside until 40 km through the valleys transverse, very cloudy, humidity and moderate temperatures, with an average rainfall of 130 mm per year with a dry period of 8 to 9 months. **(**b) *Temperate semi-arid climate* with winter rainfalls: located in the valley of Limarí basin and posses a dry climate with evaporation rates superior to the precipitation. Their Average annual temperatures are below 18˚C. **(**c) *Cold semi-arid climate* with winter rainfalls: located in the Andes mountains (3000m ASL) posses high rainfall, low temperatures, permanent snow and provide a significant amount of water into the rivers in the summer by melting.

The precipitation is mostly produced by the passage of extra tropical cold fronts during austral winter months, with more than 80% of the annual total precipitation between May and August, the inter annual variability is high and strongly linked to ENSO (El Niño Southern Oscillation), whose warm phase is generally associated with higher-than-average precipitation (Aceituno 1988; Rutllant and Fuenzalida 1991 mentioned in Vicuña *et al.*, 2010). The thermal variation that characterize the zone, limited the verticals movements of air generated an arid regimen with few precipitation with a mediterranean rainfall patron, that has an accumulation of rainfall over 60% in winter months and almost null in summer (Oyarzun, 2010) (Figure 1 a, b).

Some climatic studies have revealed trends towards the desertification, in agreement to described by Gwynne and Meneses (1994 mentioned in Ferrando, 2001) it mentions that the annual variation of the rain is major of 48 %; also that the droughts happen, at least, one per decade and last between 3 to 6 years and that the annual rainfall decreased near 30% in the twentieth century (Ferrando, 2001).



*a



*b

Figure 1. a: rainfall in three localities in the Limarí river basin; b: show the rainfall average in the tree localities mentioned above. Data extract from the Meteorological Anuary[6]. Own production

The mean annual precipitation exhibits strong spatial variations ranging from about 100 mm at the coastal side to about 300 mm at the top of the Andes and a marked decline from south to north (Vincent *et al.*, 2008 mentioned in Vicuña *et al.*, 2010). In the eighties the mean annual precipitation have been between 40% and 50% lowers that in the twenties, adding to the lack of rainfalls this region registers high daily temperatures in summer particularly in the interior valley (Ferrando, 2001).

Along the subtropical Andes at the end of twenty first century indicated a model based climate projections of substantial warming (increase of 3 to 4°C) and droughts (reductions of 15 to 35% of precipitations values) (UDEC 2009).

[6]*Dirección general de aeronáutica civil, Dirección meteorológica de chile, Subdirección climatología y metodología aplicada, Anuario Meteorológico*, from 1990 to 2010.

Actually, the warming observed in the temperature of the sea, of agreement with the forecasts tends to be kept, which means that during the winter a neutral phase will be reached. In these conditions the most probable thing is that the season of rainfalls of 2012 is superior to the last winters, which is equivalent to say that it is improbable that it repeats the conditions of drought of last two years (DGA, 2012).

1.2 Hydrology and water uses

Chile is a country favored with water resources, due to the fact that the total average of runoff for 2010 corresponds to 53000 m^3/person per year. A high enough value, thinking that the world average reaches 6600 m^3/person per year and very superior to the 2000 m^3/person per year (Banco Mundial, 2011). Nevertheless, some region of the country have arid and semiarid condition like those to the north of the Metropolitan region where the average of water availability is below the 800 m^3/person per year, in contrast, at the south the availability overcomes the 10000 m^3/person for year (Banco Mundial, 2011). In Chile the natural waters are categorized according to the chemical composition; the waters of the Big North (Norte Grande) (territory between I and II region in Chile) are characterized by high saline waters. In addition, in the high Andean plateau is possible to observe places contained high amount of arsenic associated with the quaternary volcano activities. The waters of the Small North (Norte Chico) (territory between the III to the IV region), the saline content is minor than in the Big North, but the water use is also restricted. In the central zone (territory between the regions V, the metropolitan capital, VI, VII and the north part of the VIII region), the quality of the water in relation to the salinity improves, though regarding to heavy metals copper continues been detected in the rivers Aconcagua, Maipo and Rapel (CONAMA, 2007 mentioned in MMA, 2011).In the south zone the quality of the water presents suitable values, with some exceptions in the rivers Biobío, Damas and Rahue. In the austral zone, the quality of the waters is catalogued like very good (CONAMA, 2007 mentioned in MMA, 2011).

The study of Vicuña and collaborates (2010) show a reduction of the mean annual stream flow and mention a change in the hydrography with a decreased (increased) stream flow fraction occurring during spring/summer (winter). About the fractional reduction in annual stream flow is larger than its rainfall, because a warmer condition increases the process of evapotranspiration (Vicuña *et al.,* 2010). In relation to the flows in the region of Coquimbo the rivers practically maintain their flows approaching historical minimums. In general, during 2010 the quantity of water retained in the national reservoirs is lower than 10% respect of the year 2011.

In the highest part of the hydrographic basin of Limarí river the permeability is low because there are plutonic rocks, in the middle section predominate the volcano rocks. The rocks impermeability characteristics originate that the aquifers runoff parallel of water curses. There are three visibly runoffs: one in southwest direction that runoff parallel to Hurtado river with phreatic depths of 2,0 to 3,6 m until Ovalle city. In northwest direction runoff from Grande river until the confluence of Hurtado river, with phreatic levels of 1,7 to 4,5 m and south north direction runoff the last aquifer parallel to Combarbalá river until the La Paloma reservoir, for a layer of impermeable volcanic rocks with phreatic depths of 3,0 to 1,5 m (DGA, 2004).

The length of the Limarí river from the locality of Peñones to the sea is 64 km, of which the first ones 43 km pass in a wide open area of two or more kilometers of width where it develops numerous meanders, flanked by extensive fluvial plains. Towards the mountain chain of the Andes it is narrowing, presenting hillsides with very abrupt slopes as product of the erosive work of the glacier action and the water friction (DGA, 2004).

In Coquimbo the hydrographic system of Limarí river and its affluent are the most important in the agriculture activities, sustaining almost 70000 ha (Osorio, 2009). The enormous pressure for water stock, make that in 1928, started the construction of two reservoirs, Recoleta, being the oldest one, and it is located between the confluence of the rivers Higuerilla and Hurtado, at 18 km northeast of Ovalle city, this reservoir has a capacity of 100 million m^3; the walls was made of gravel and shelter of concrete of 910 m of length for 80 m tall, this reservoir it started with an irrigation capacity of the 85%, for 18500 ha and present a historical monthly average of 60 million m^3 (Osorio, 2010; DGA 2012). The necessity of cover the totally it made necessary increase the capacity building a complex system that contemplate (Osorio, 2009). In the other hand Cogotí reservoir was built in the confluence of the rivers Pama and Cogotí, and regulated the resources of the rivers Cogotí, Pama and Combarbalá, this reservoir has 82,7 m of high with a maximum length of 160 m. Cover a surface of 850 ha and has a capacity of 150 million m^3 and present a historical monthly average of 68 million m^3 (Osorio, 2010; DGA, 2012). Finally a third reservoir was started to build in the confluence of the rivers Grande and Rapel, and is called La Paloma, is the biggest of the three, and the walls was made principally of concrete with gravel cover has 910m of length and 80m tall, with 750 million m^3 and present a historical monthly average of 384 million m^3 (Osorio, 2010; DGA, 2012). The set of the three reservoirs form the "Paloma system" and allow benefit principal to the agriculture activity and can irrigate a surface of 51325 ha. Also the volume store allows a seasonal and annual regulation. This system has a physic system of water distribution based in sluice gate and channels that allow interconnect the different irrigate sites (Figure 2). This is the biggest irrigate system in Chile with an irrigation security of four years (DGA, 2004; Matus *et al.,* 2004; León, 2008; Oyarzun, 2010).

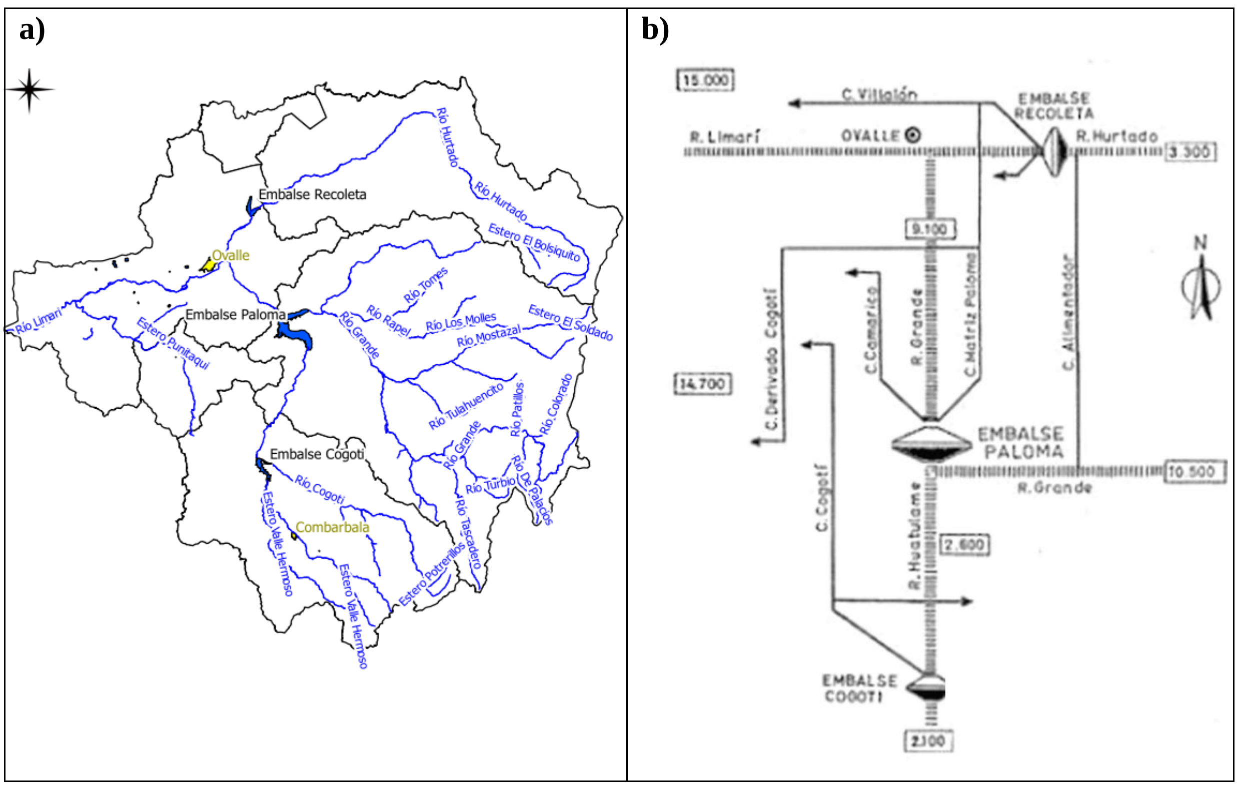


Figure 2. a) Scheme of system La Paloma. Map mounted from the information of Fuster *et al.*, 2011. b) Graph of La Paloma System and his respective actions. The system indicates the interconnections and the irrigated surfaces in every zone (León, 2009).

During the winter of 2010, the catchment in the country maintained their historical values, but the stream accumulation was lower than 2009, in the case of the La Paloma system, Cogoti and Recoleta they registered 375 million m^3 in 2010 in comparison of 560 million m^3 in 2009. This situation makes the resource insufficient to provide enough amounts for the irrigation season (Nazarala *et al.*, 2010).

The energy generation is represented by the central Los Molles, this hydroelectric plant use the waters from Los Molles river who possess a flow rate of 1,86m^3/s. The water demand for industrial activity, principally the production of the alcoholic drink pisco, reaches 31 L/s at 1996 (DGA, 1996). Regarding to the mining activity it uses around the 3% from superficial water resources and it is associated to Punitaqui stream and Mostazal river (DGA, 2004). In view of the foregoing it’s clear that the Limarí river is an imperative source of water for the diverse uses, supporting all these different kinds of activities, where the husbandry is the main activity in the valley and the (second economic activity in the region of Coquimbo) (Osorio, 2009).

Another dramatic change in the hydrological regime of the Limarí basin is the modification of the seasonal cycle of streamflow. These changes are greatly determined by the sub-basin elevation. The highest sub-basin, Hurtado at San Agustin (mean elevation of 3720 m), with a climate purely snow-dominated regime remains unchanged, the second highest basin, Grande at Las Ramadas (2998 m), is also purely snow-dominated under current conditions (late October) but clearly shifts to a mixed regime with peak stream flows during winter months associated with the rainy season. The lowest sub-basin, Cogotí in Fraguita (2594 m), currently shows a rain-snow dominated regime and the projected future change in timing is less dramatic as already the peak flow occurs in late winter (Vicuña *et al.*, 2010).

1.3 Vegetation

In Coquimbo region more than the half of the vascular plants are in some categories of conservation around 587 species of these, 207 are in category of “in danger” or “vulnerably”, representing 14% of the regional flora. At the local level in Ovalle, the scene is similar, since the percentage of species in category of conservation reaches 31% and the species in category “in danger” or “vulnerably” to 19% (Squeo *et al.,* 2001). Squeo and others (2001), established 14 priority sites for the conservation of the native flora in the region of Coquimbo (Figure 3).

In Limarí basin is important for the biodiversity in the zone, in which Limarí river have two main areas in the National System of Protected Area of the State (SNASPE). The first one is the natural monument of Pichasca an important archeology and paleontology zone, where it is possible find fossils and vegetables rest, and it was an antique ground settlement of the Inca culture, and the second one is the Fray Jorge National Park, which presents a natural phenomenon, a Valdivian Forest in a costal dessert zone, other sites in protection are El Durazno, El Quillay, Valle Hermoso and Cuesta el Espino (DGA, 2004). To the east of Combarbalá Is located El Durazno, El Quillay and Valle Hermoso, in these localities have registered 9 species with problems: one in danger *Kageneckiaangustifolia* and eight species vulnerable, *Eriosyceaurata, Haplopappusbezanillanus, Maytenusboaria, Porlieriachilensis, Quillajasaponaria, Seneciojilesii*y *Trevoaquinquenervia* (Table 1).

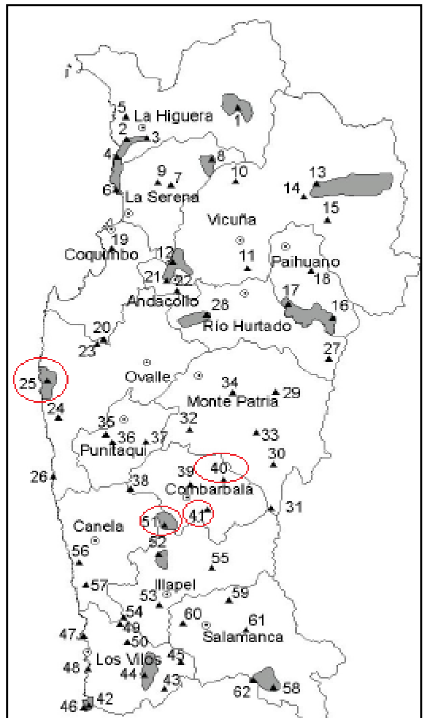


Figure 3. Map of Coquimbo region determinate its priority sites by Squeo*et al.,* 2001.

*Area:25 Fray Jorge; 40 The Durazno, 41 Quillay-valle Hermoso, 51 Cuesta espino

Table 1: It shows some species representatives of the flora in the region of Coquimbo and their distribution in the area.

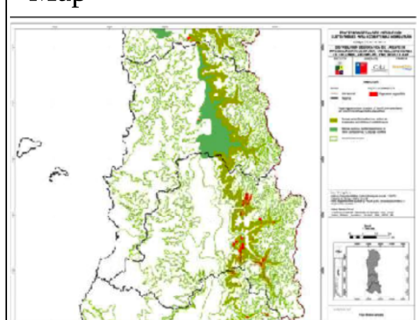
Specie	Description	Distribution in the IV region
Eriosyce aurata[4] 	Chilean endemic cactus in Habits in arid areas. It is found between the III to Metropolitan Region[4]. Status: Vulnerable[3]	Map [5] 
Eriosyce curvispina[5] 	It grows naturally from the region of Coquimbo (Combarbalá) to the north of the region of the Maule in the south[5]. His habitat is composed from the low part of the mountain chain up to coastal hills, always in arid sectors, frequently in rocky systems[5].	Map [5] 
Kageneckia angustifolia[1] 	Endemic specie. Habits in the Andine zone from the IV to VII región[3]. Status: Danger[3]	Map [2] 
Tecophilaea violaeflora[5] 	Geophyte plant that grows in the regions of Coquimbo, Valparaiso and Metropolitan[5]. Status: Out of Danger[6].	Map [5] 

Table 1: It shows some species representatives of the flora in the region of Coquimbo and their distribution in the area. Continuation.

Specie	Description	Distribution in the IV region
Lapageria rosea[4] 	Specie considered as the Chilean national Flower. Principally its distribution is from Valparaíso to Araucania Region. In Coquimbo Region it is found in the national park Fray Jorge[3]. Status: Danger[3].	Map [5] 
Myrceugenia correifolia[6] 	Small tree present in the coast of the small north and Central Chile habitually associated with the relic olivillo forests (*Aextoxiconpunctatum*)[7]. Status: Rare[6].	Map [5] 
Tessaria absinthioides[7] 	Shrub from 1 to 1,5 m of height, always green. Leaves lengthened with irregularly toothed edges. Flowers in pink arranged in clusters. It lives in the river beds and in the edges of ways and channels, from Tarapacá up to Arauco. Also in humid sites of the coast[7].	Map [5] 

1 http://www.florachilena.cl

2 http://www.mma.gob.cl

3 Squeo*et al.*, 2001.

4 http://www.chileflora.com

5 http://www.chilebosque.cl/

6 http://www.biouls.cl

7http://www.asociacionparquecordillera.cl

*Own production

1.4 Land uses

In the Limarí river basin is possible to find different types of soil as consequence of the location and geological origins of the region. In the central part of the Limarí Province, the brown calcaric soils predominate with pH neutral or lightly alkaline. In the valleys and in the bordering terraces the soils posses a salinity level that does not restrict the agricultural activity. They predominate over the slimes and recent sediments in contraposition to the soils of the upper terraces that are more clayey (Oyarzun, 2010).

The soils that they have formed in the lowest terraces are less evolved with little depth and are slightly fertile since they possess low quantities of nitrogen. The soils formed of ancient warehouses in the high terraces are more evolved and present a high contained of clay that they make them denser, these soils possess variable depths that change from 30 to 70 cm (Oyarzun, 2010). Figure 4 shows the classification of the land uses in the Limarí river basin. The land uses in the Limarí river basin concentrates 48% of the agricultural surface of the Coquimbo region. Table 2 shows information about land uses in this basin and the Table 3 shows the crops distribution according to the land use.

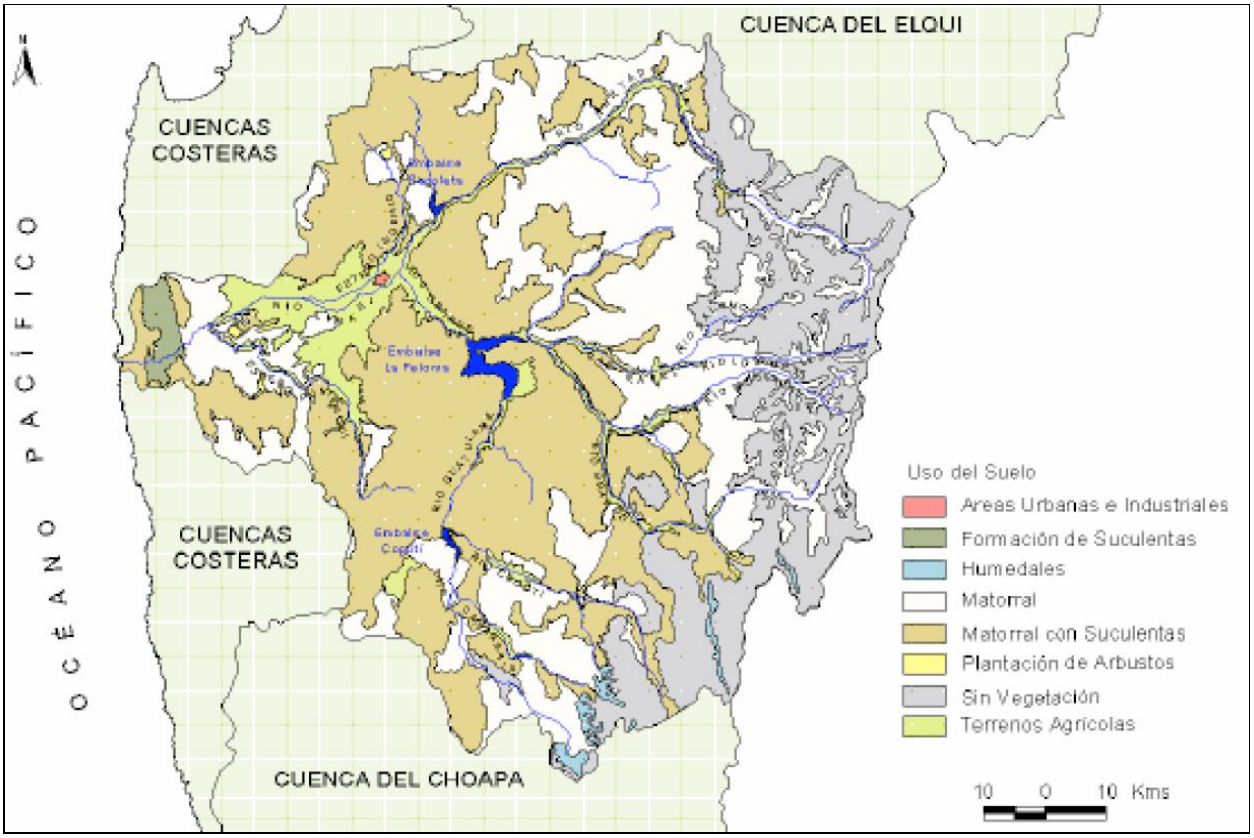


Figure 4. Clasification of the land uses in the Limarí river basin, source DGA mentioned in Oyarzún (2010).

Table 2: Land uses in the Limarí river basin. Source CONAF, CONAMA land registry of native forest mentioned in Oyarzún (2010).

Limarí riverbasin	Land uses	Surface in ha	% of land use
1180000 ha	Prairie	93	0,01
	Agricultural areas and agriculture with irrigation	80011	7
	Forestplantations	0	0
	Urban and industrial areas	396	0,03
	Industrial mining	156	0
	Native forest and mixed forest	115	0,01
	Other uses (*)	883777	75
	Areaswithoutvegetation	215608	18

(*) Related to the following uses: bushes, bushes-prairie, rotation culture- prairie, areas not recognized, water bodies, snow glaciers and wetlands

Table 3: Areas of types of cultivation according to the land use in the Limarí river basin and his communes.

	Surface (ha)				
Type of crops	Limarí river	Combarbalá	Monte Patria	Punitaqui	% of cultivation
Crops	2125,4	53,7	22,2	38,3	3
Leguminous and tuber	442,4	5,4	33,5	51,2	1
Industrial crops	13,6	0	0,6	1	0
Vegetables	4753,04	41,87	348,63	78,21	8
Flowers	361,97	1,79	0	5,41	1
Pastures	25455,74	755,34	796,34	899,1	41
Fruits	20151,46	1848,81	7387,37	1054,8	33
Winery and vineyard	8353,04	100,92	1182,42	946,1	13
Indoorcultivation	42	0,3	1	1,2	0
Seedbeds	82,7	2,5	9,2	6,5	0
Total	61781,35	2810,63	9781,26	3081,82	100

The use of urban land in the Limarí river basin reaches 396 ha equivalent to 0,03% of total surface. Where the urban population is mostly concentrated in Ovalle city, the inhabitant in the basin is of 96239 persons according to CENSO 2002(INE, 2002). In 1997 the use for potable water collecting reached 163,4 L/s gross demand and 114,8 L/s for net demand. In terms of location it has been detected two sources of superficial potable water, one in the Combarbalá River and the other one in the high zone of the Limarí River (DGA, 2004).

1.5 Socioeconomic aspects

The agriculture in the zone of the Limarí was strongly stimulated after the decadence of the copper mining (from the second half of the 18th century) because of the crisis of the regional mining industry the agriculture returns to be the principal economic activity of the Limarí watershed, this time orientated to the satisfaction of a market in the Big North immediately after the exploitation of the saltpeter. To supply the demand of wheat, cereals and meat, the regional authorities include more than 10000 ha across the construction of channels of irrigation, such as that of Talhuén, Tamelcura, Camarico and others[7].

After the economic crisis of 1929-1930 in the saltpeter, this zone of the Limarí was included into the government plans of that time designed to absorb the unemployment, such

[7] www.municipalidaddeovalle.cl

as the exploitation of golden washers, the construction of roads, channels, and reservoirs that will allow to cultivate new lands. Cogotí and Recoleta reservoir arise in this period. From 1960 new lands was included due to the construction of the reservoir of La Paloma, this allowed to develop the viniculture, principally the production of pisco (similar to grappa) trough the creation of industrial plants and cooperative. After the Chilean Agrarian Reform (1967-1973) the expropriated lands was sold to persons with purchasing power like professionals, businessmen and to the national and transnational companies. In 1980 to the fruit-growing crops, start to sell their products to Europa, USA and Asia begins the principal product the grape[8].

According to the new technologies at 2017, the water demand would be expected to be 677601000 m^3/year and the irrigation system would keep its actual rate. In the region of Coquimbo the irrigation system is represented by the gravitational (most important) and pressurized, the last one includes methods for spray, pivot, drip and microjet systems (UDEC, 2011). Also in this region it can be found dry land agriculture system, which is based only in the use of water directly from rain, without any system of irrigation, this methods is used for agriculture with low water demand, this method named “secano” use the available water from rainfall captured with a special net (FIA, 2009).

In 2007 over US$ 2.6 million were spent during a severe drought to support affected families and farmers, repair damages, recover degraded soils, and increase irrigation programs in the Coquimbo region. Despite this effort to avoid the negatives effects of the drought, more than 75% indicated suffering a lack of sufficient water for irrigation and domestic use (Verbist*et al.*, 2010). Enclosed some studies conclude that already there has been reached the maximum capacity of the water resource, even in spite of the system introduction of irrigation that they allow a better utilization of the water (Ferrando, 2001).

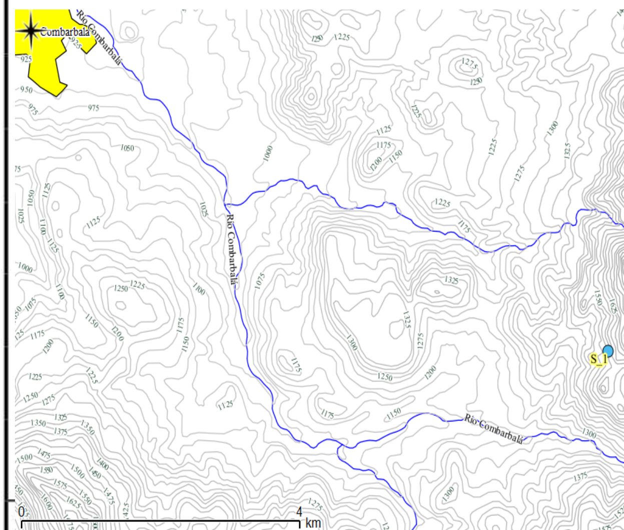
[8]www.municipalidaddeovalle.cl

Appendix F

site name	date	sample no.	investigator
Limarí Watershed	22-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



1´

2 stream name
No name

3 stream system (river flowing into the sea)
Limarí river

4 country
Chile

5 federal state
Coquimbo region

6 map no.
1

7 longitude (degree, min, sec)
70°55.610’ W

8 latitude (degree, min, sec)
31°13.378’ S

9 distance to source [km]
24.8 Km

11 slope of the valley floor [%]
Low (<2%)

12 subregion (if applicable)
-

13 ecoregion and ecoregion no.
Mediterranean

14 altitude of sampling site [m a. s. l.]
1272 m. a. s. l

15 altitude class
Average

16 catchment area [km²] at sampling site
-

17 size class based on catchment area
Class 2: 5 -50 m^3/s

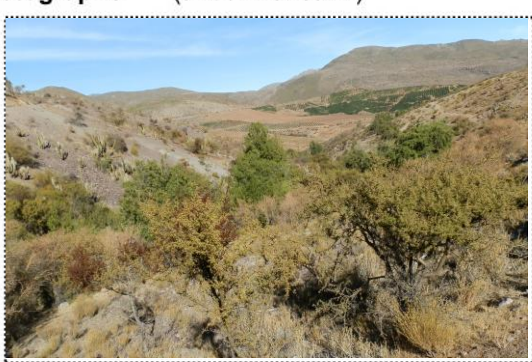
18 Geology (dominant type)
Substrate Gravel

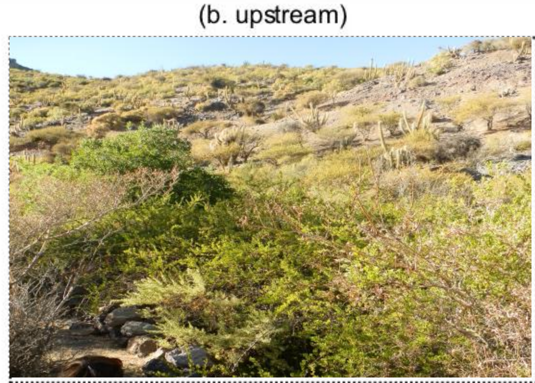
19 geology class
Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Andean semiarid

21 photographs (a. downstream) (b. upstream)





22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: <1500 m.a.s.l	Silica geology NF: medium and low Thick grained	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

Type N° 7, Semiarid (Fuster *et al.*, 2011)

This station is located in the most nearby zone of the origin of the river that was possible to accede in car, nevertheless the vegetation covers completely the course of the river, it is necessary to fix the station of monitoring downstream or to use tools to make way between the dense vegetation.
The areas downstream are a private property dedicated to the cultivate of fruits. Is observed a structure of stones, used probably to give course to the river.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☒ meander valley

☐ U-shaped valley

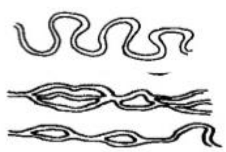
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

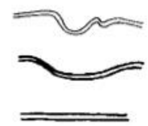
☐ anabranching



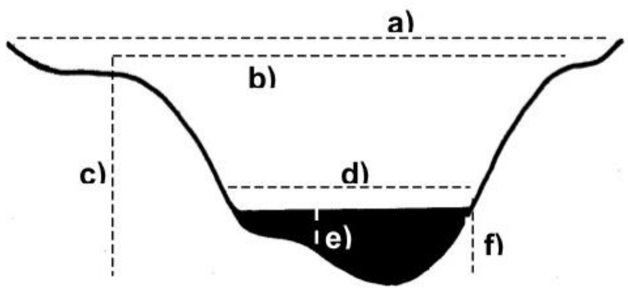
☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m] _______

b) flood prone area width [m] _______

c) entrenchment depth [m] _______

d) average stream width [m] _______

e) mean depth water body [m] _______

f) maximum depth water body [m] _______

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

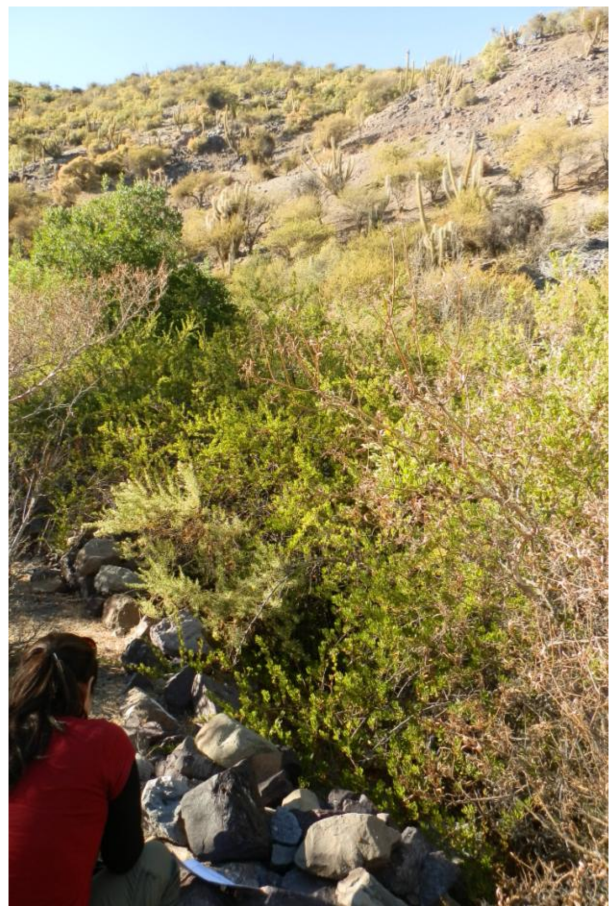
32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☐ yes ☒ no ☐ ?	**34 pulse releases** ☐ yes ☒ no ☐ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☐ no ☒ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others** Garbage	

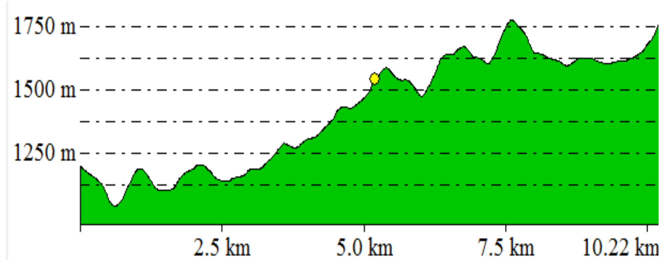
Additional data

Station 1:
Near Combarbalá stream

Aditional information
This station was chosen since it hast an easy access because upstream it is between mountains and it is not possible to go up to the river.

The site was visited in dry winter, the water is transparent and without smell. In this a sector of the river there are is some kind of modification.



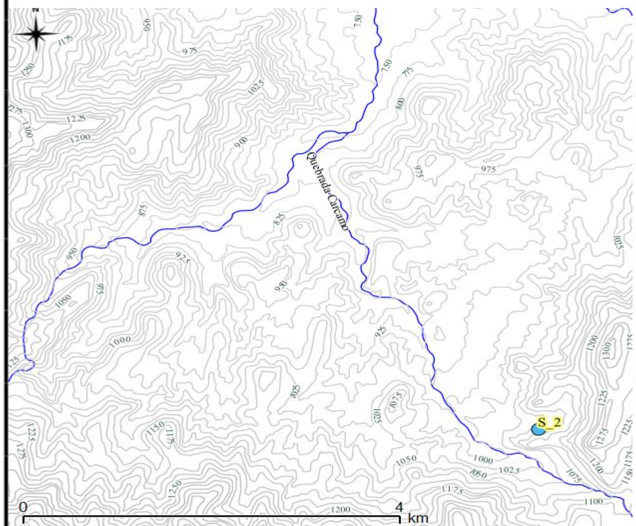


Profile of the station 1: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	22-06-2012		Carolina Aguirre

Site related information: Site description

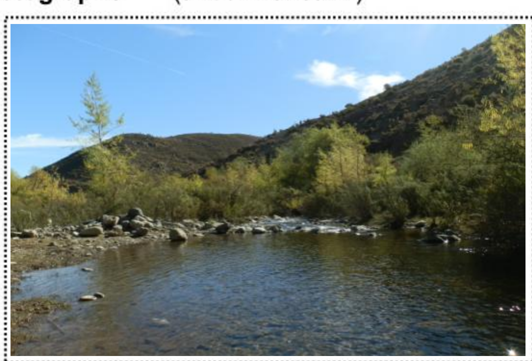
1 map (No., scale) (No. 1,50000)	**2 stream name** Near Quebrada Carcamo
	3 stream system (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo region
	6 map no. 2
	7 longitude (degree, min, sec) 70°54.424’ W
	8 latitude (degree, min, sec) 31°06.313’ S
	9 distance to source [km] -
10 stream order (Strahler system) 1´	**11 slope of the valley floor** [%] Not classified
12 subregion (if applicable) -	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 950.2 m. a. s. l.	**15 altitude class** Not classified
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Not classified
18 Geology (dominant type) Not classified	**19 geology class** Not classified

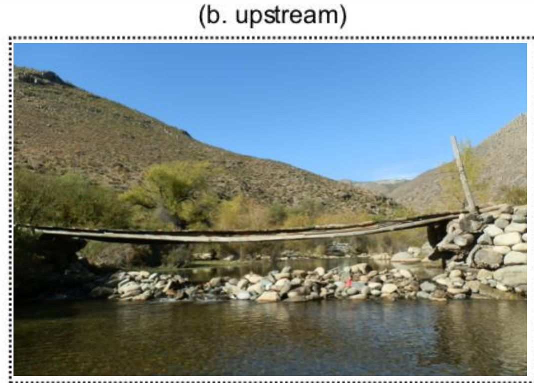


WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Not classified

21 photographs (a. downstream) (b. upstream)





22 short description

Presents a small dam made of stones, the stream hast a low speed and there is footbridge for the local people.

Type is not determined (Fuster *et al.*, 2011)

Basic data

site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

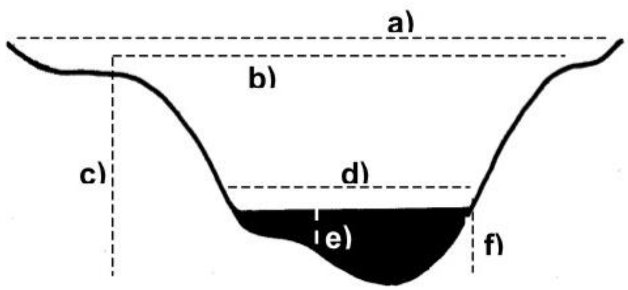
25 valley form ☝

☐ canyon
☒ V-shaped valley
☐ trough
☐ meander valley
☐ U-shaped valley
☐ plain floodplain

26 channel form ☝

☐ meandering
☐ braided
☐ anabranching
☒ sinuate
☐ constrained (natural)
☐ constrained (artificial)

27 cross section



a) width of floodplain [m]	17.56
b) flood prone area width [m]	11.06
c) entrenchment depth [m]	-
d) average stream width [m]	10.10
e) mean depth water body [m]	0.45
f) maximum depth water body [m]	0.80

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

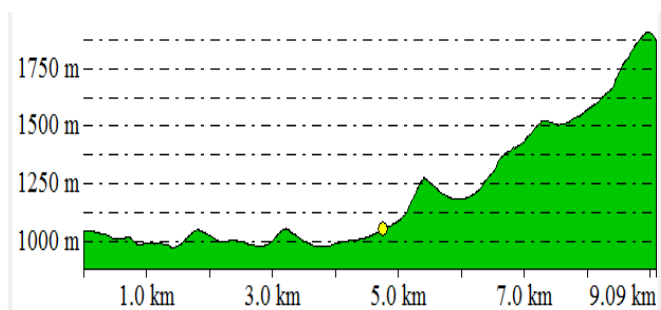
31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ____________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☐ yes ☒ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Station 2:
Near Carcamo gully

Aditional information
This station was chosen since it hast an easy access
The water is transparent and without smell.
In general it is a sector of the river moderately modified with a small transverse structure.

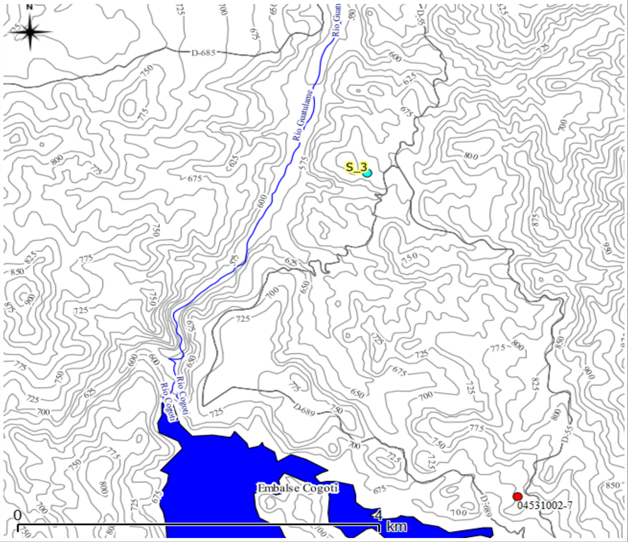


Profile of the station 2: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	22-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name	Guatulme river
3 stream system (river flowing into the sea)	Limarí river
4 country	Chile
5 federal state	Coquimbo region
6 map no.	3
7 longitude (degree, min, sec)	71°04.720' W
8 latitude (degree, min, sec)	30°59.100' S
9 distance to source [km]	4.55 Km
10 stream order (Strahler system)	2´
11 slope of the valley floor [%]	Low (<2%)
12 subregion (if applicable)	-
13 ecoregion and ecoregion no.	Mediterranean
14 altitude of sampling site [m a. s. l.]	559.6 m. a. s. l.
15 altitude class	Low
16 catchment area [km²] at sampling site	-
17 size class based on catchment area	Class 2: 5 -50 m^3/s
18 Geology (dominant type)	Substrate Gravel
19 geology class	Calcareous

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

Type N° 10 (Fuster *et al.*, 2011)

The water course is one of the biggest found in this work, there is a small dam made of wood, this station is located in the exit of the Cogotí reservoir, to visit this structure is necessary to have a permission of the local authority.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

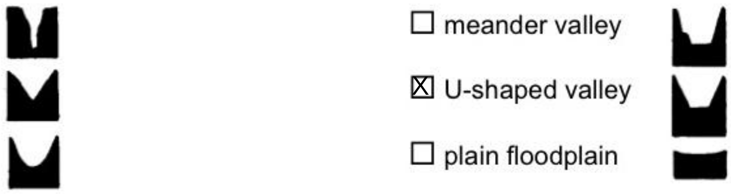
☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

☐ plain floodplain



26 channel form ☝

☐ meandering

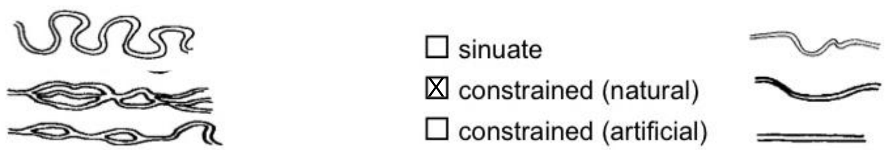
☐ braided

☐ anabranching

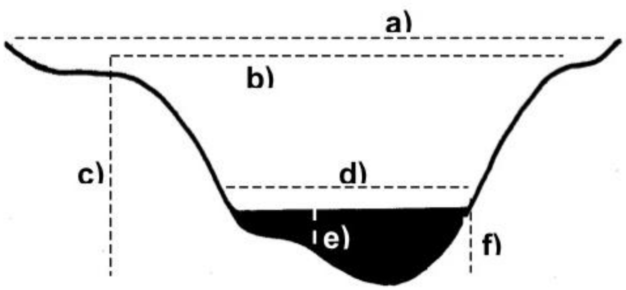
☐ sinuate

☒ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	30.50
b) flood prone area width [m]	25.00
c) entrenchment depth [m]	-
d) average stream width [m]	18.50
e) mean depth water body [m]	0.75
f) maximum depth water body [m]	1.50

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☐ none ☒ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

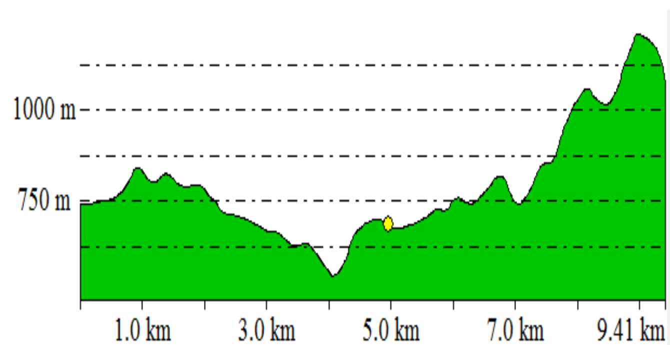
31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☒	☒
wood	☐	☒	☐
trees	☐	☐	☐
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☒ yes ☐ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☒ yes ☐ no ☐ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☐ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☒ no [m] ☐ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others** Cogotí reservoir up stream	

Station 3:
Guatulme river

Aditional information
The water is transparent and without smell but in the bottom there is lot of silt. In the surroundings it is possible to find cattle and cultivated fields.

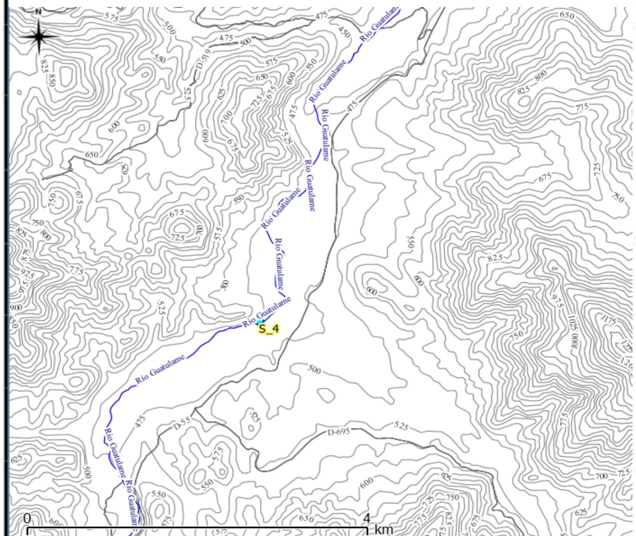


Profile of the station 3: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	22-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name Guatulme river

3 stream system (river flowing into the sea) Limarí river

4 country Chile

5 federal state Coquimbo Region

6 map no. 4

7 longitude (degree, min, sec) 71°01.127' W

8 latitude (degree, min, sec) 30°52.952' S

9 distance to source [km] 22.2 Km

10 stream order (Strahler system) 2´

11 slope of the valley floor [%] Low

12 subregion (if applicable) -

13 ecoregion and ecoregion no. Mediterranean

14 altitude of sampling site [m a. s. l.] 479,3 m.a.s.l

15 altitude class Very low

16 catchment area [km²] at sampling site -

17 size class based on catchment area Class 2: 5 -50 m^3/s

18 Geology (dominant type) Substrate Sand

19 geology class Calcareous

WFD Categories

20 stream type (mark system and fill in name)

☐ System A ☐ System B Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

Type N° 10 (Fuster *et al.*, 2011)

This station is near the locality of Chañaral alto, the stream it is dry, however during this time of winter should be with water on it. There is a great trunk of tree that the local people use as bridge.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

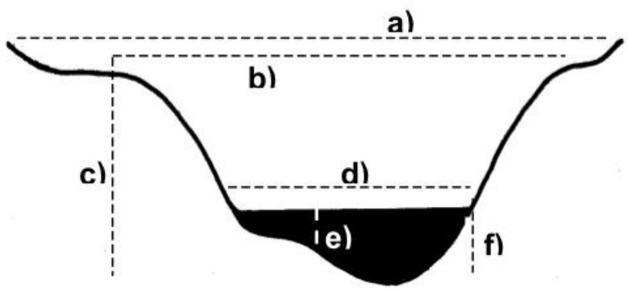
25 valley form ☝

☐ canyon
☐ V-shaped valley
☐ trough
☐ meander valley
☒ U-shaped valley
☐ plain floodplain

26 channel form ☝

☐ meandering
☐ braided
☐ anabranching
☒ sinuate
☐ constrained (natural)
☐ constrained (artificial)

27 cross section



a) width of floodplain [m]	22.50
b) flood prone area width [m]	7.50
c) entrenchment depth [m]	-
d) average stream width [m]	15.8
e) mean depth water body [m]	0.05
f) maximum depth water body [m]	0.10

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

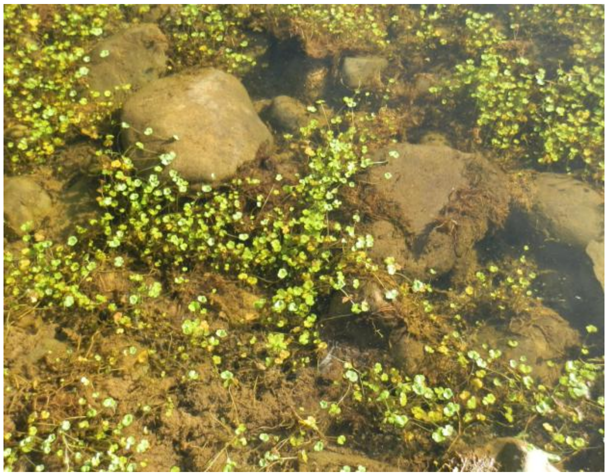
31 bank and bed fixation ✋

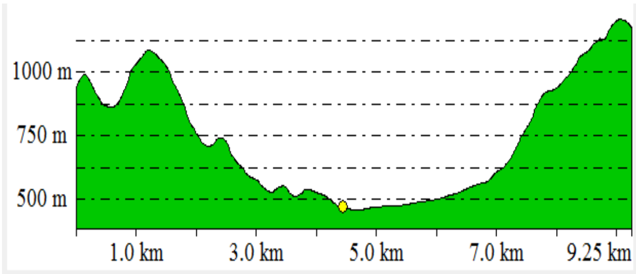
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☒	☐
wood	☒	☐	☒
trees	☐	☐	☐
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ______________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☐ no ☒ ?
36 stagnation ☒ yes ☐ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☒ no [m] ☐ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others**	

Station 4:
Guatulme river

Aditional information
The river is dry, there are puddles isolated with stagnant water where the water ist transparent and without smell.
Seemingly this river was bringing great amount of water since is possible to see a river bed of approximately 80 m.



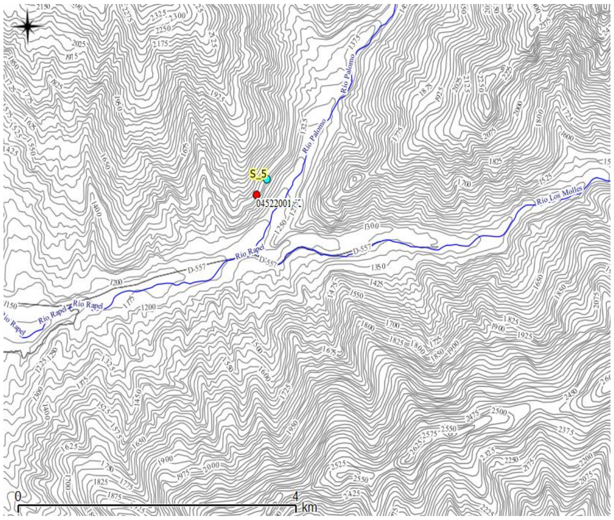


Profile of the station 4: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	23-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name
Palomo river

3 stream system (river flowing into the sea)
Limarí river

4 country
Chile

5 federal state
Coquimbo Region

6 map no.
5

7 longitude (degree, min, sec)
70°37.186’ W

8 latitude (degree, min, sec)
30°44.635’ S

9 distance to source [km]
11.10 Km

10 stream order (Strahler system)
2´

11 slope of the valley floor [%]
Average

12 subregion (if applicable)
-

13 ecoregion and ecoregion no.
Mediterranean

14 altitude of sampling site [m a. s. l.]
1195 m.a.s.l

15 altitude class
High

16 catchment area [km²] at sampling site
-

17 size class based on catchment area
Class 2: 5-50m^3/s

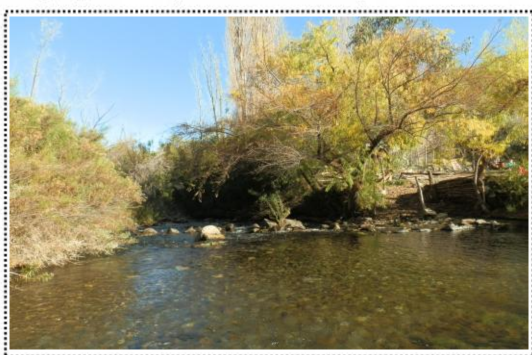
18 Geology (dominant type)
Substrate Gravel

19 geology class
Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B
Andean semiarid

21 photographs (a. downstream) (b. upstream)



22 short description

Biology Parameters		
Fishes	Macroinvertebrate	Other
Absent	Mainly: Diptera, Oligochaeta Minorly: Ephemerotera Trichoptera	Large fauna different since high mineral content

This station is located closely to the hydroelectric “Los Molles”. Near the course of the river there are people and they cultivate grape for the production of the alcoholic drink Pisco.

Type N^o 6 (Fuster *et al.*, 2011)

Basic data

site name	date	sample no.	investigator
Limarí Watershed	23/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

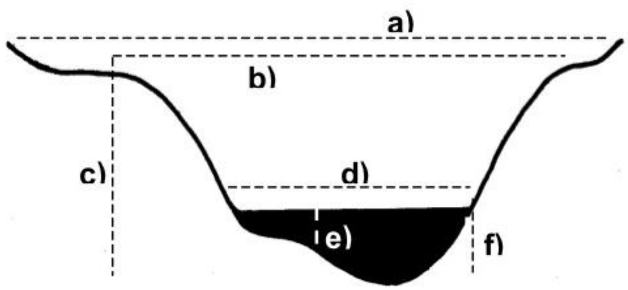
☐ anabranching

☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)

27 cross section



a) width of floodplain [m]	33.10
b) flood prone area width [m]	32.10
c) entrenchment depth [m]	-
d) average stream width [m]	21.55
e) mean depth water body [m]	0.30
f) maximum depth water body [m]	0.60

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

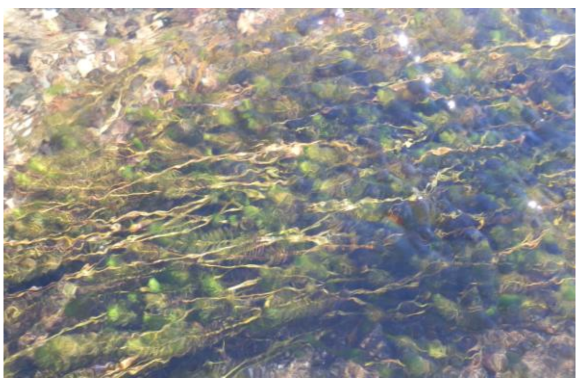
31 bank and bed fixation ✋

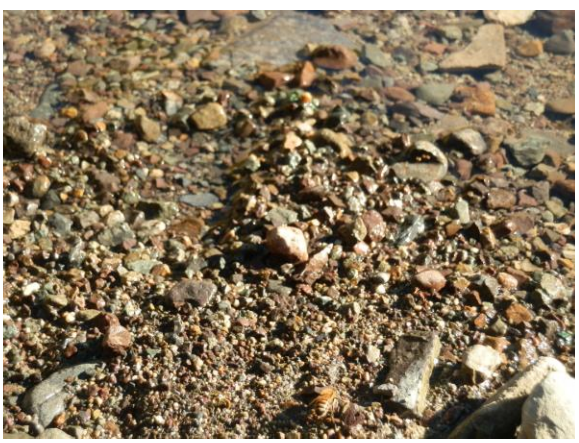
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☒	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ____________	☐	☐	☐
no bank fixation	☐	☐	☐

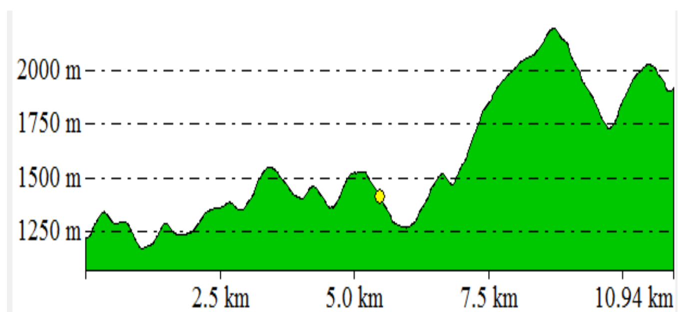
32 dams ☒ yes ☐ no ☐ ?	**33 oth. transv. structures** ☐ yes ☐ no ☒ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☒ yes ☐ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☒ no [m] ☐ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Station 5:
Palomo river

Aditional information
The water runs with speed, is transparent and very cold.
In the nearby area there are cultivated fields and farms with beekeeper and it is possible to see some bees near the river.



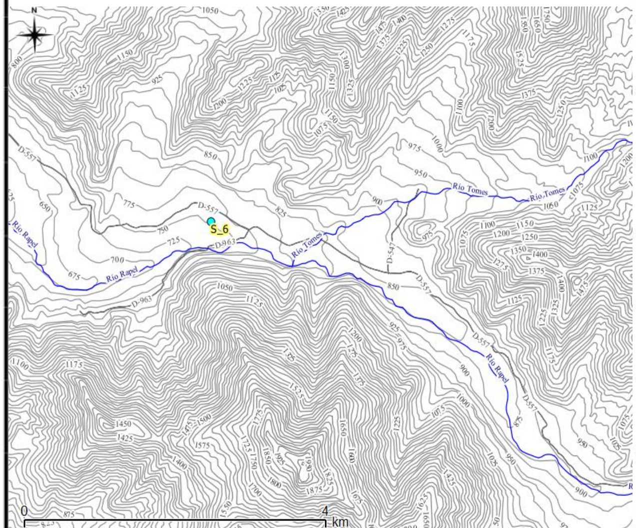




Profile of the station 5: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	23-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)	**2 stream name** Low Rapel river
	**3 stream system** (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo Region
	6 map no. 6
	7 longitude (degree, min, sec) 70°48.090’ W
	8 latitude (degree, min, sec) 30°43.231’ S
	9 distance to source [km] 25.06 Km
10 stream order (Strahler system) 3´	**11 slope of the valley floor** [%] Low (<2%)
12 subregion (if applicable)	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 751,3 m.a.s.l	**15 altitude class** Average
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Class 2: 5-50m^3/s
18 Geology (dominant type) Substrate Sand	**19 geology class** Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B — Andean semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: < 1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

Type N^o 7 (Fuster *et al.*, 2011)

This station is in the lower part of the Rapel river, is completely covered by trees and dense vegetation. This station is near a bridge and is full of garbage.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	23/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

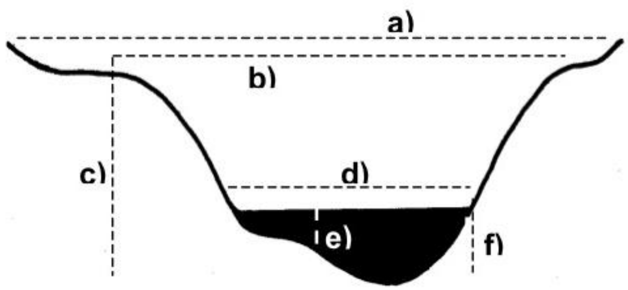
25 valley form ☝

☐ canyon	☒ meander valley
☐ V-shaped valley	☐ U-shaped valley
☐ trough	☐ plain floodplain

26 channel form ☝

☐ meandering	☐ sinuate
☐ braided	☒ constrained (natural)
☐ anabranching	☐ constrained (artificial)

27 cross section



a) width of floodplain [m]	-
b) flood prone area width [m]	-
c) entrenchment depth [m]	-
d) average stream width [m]	-
e) mean depth water body [m]	-
f) maximum depth water body [m]	-

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

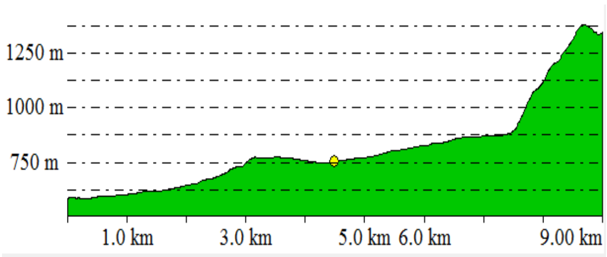
31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☐	☐
wood	☐	☐	☐
trees	☒	☒	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ____________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others** Garbage	

Station 6: Rapel river

Aditional information
Between the dense vegetation it is possible to see the course of the river, but it is not possible to go down and to do the necessary measurements, nevertheless the water seems transparent and with an average speed.
Of all the places visited in this work, this station have a higher quantity of garbage.

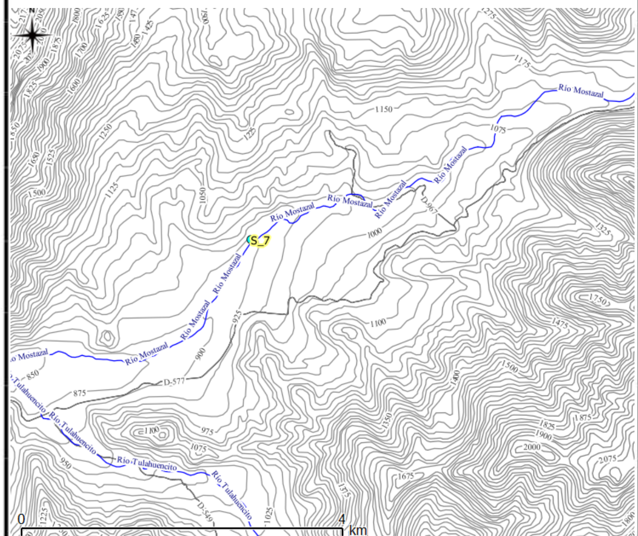


Profile of the station 6: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	23-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name
Mostazal river

3 stream system (river flowing into the sea)
Limarí river

4 country
Chile

5 federal state
Coquimbo Region

6 map no.
7

7 longitude (degree, min, sec)
70°41.668’ W

8 latitude (degree, min, sec)
30°50.878’ S

9 distance to source [km]
47.76 Km

10 stream order (Strahler system)
2´

11 slope of the valley floor [%]
Low (<2%)

12 subregion (if applicable)
-

13 ecoregion and ecoregion no.
Mediterranean

14 altitude of sampling site [m a. s. l.]
888,6 m.a.s.l

15 altitude class
Average

16 catchment area [km²] at sampling site
-

17 size class based on catchment area
Class 2: 5-50m^3/s

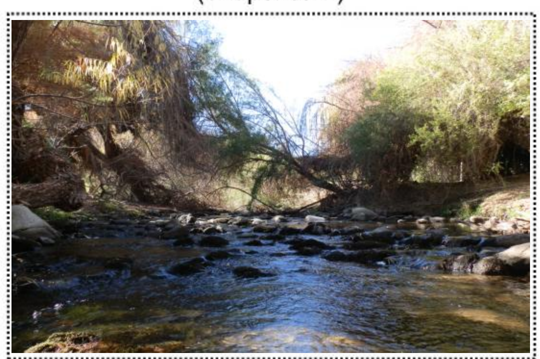
18 Geology (dominant type)
Substrate Sand

19 geology class
Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B
Andean semiarid

21 photographs (a. downstream) (b. upstream)



22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: <1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

This is a small river near to the local way, there are around many fields with grape cultivation and numerous irrigation projects stimulated by the national government.
The hills are seen cutlery of cactus and small bushes.

Type N^o 7 (Fuster *et al.*, 2011)

B a s i c d a t a

site name	date	sample no.	investigator
Limarí Watershed	23/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☒ V-shaped valley

☐ trough

☐ meander valley

☐ U-shaped valley

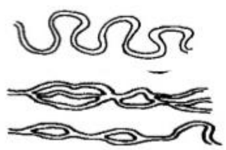
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

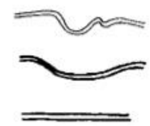
☐ anabranching



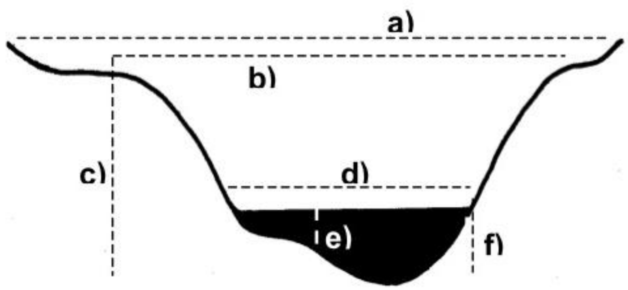
☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	17.0
b) flood prone area width [m]	8.0
c) entrenchment depth [m]	-
d) average stream width [m]	5.5
e) mean depth water body [m]	0.30
f) maximum depth water body [m]	0.60

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation ✋

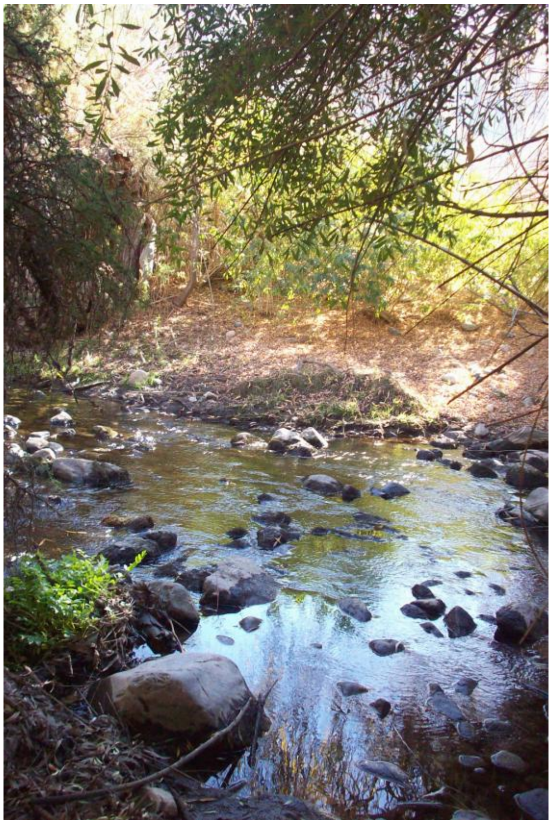
	left shoreline	**bed**	**right shoreline**
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☒	☐	☒
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

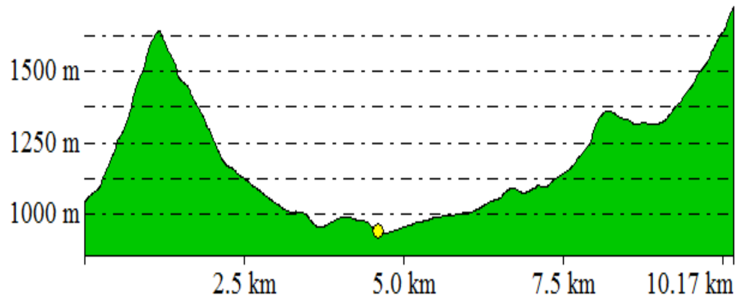
32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☐ yes ☒ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Additional data

Station 7:
Mostazal river

Aditional information
The stones of the bottom of the river are covers of slime, there are many remains of dead wood in the shore. The water is transparent and the speed of the river is average.



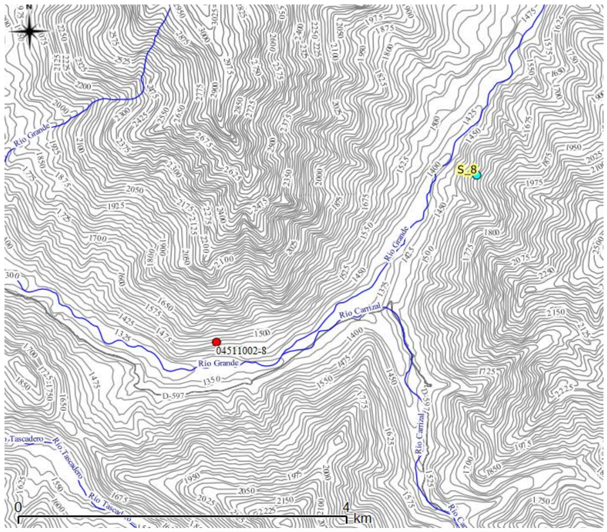


Profile of the station 7: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	23-06-2012		Carolina Aguirre

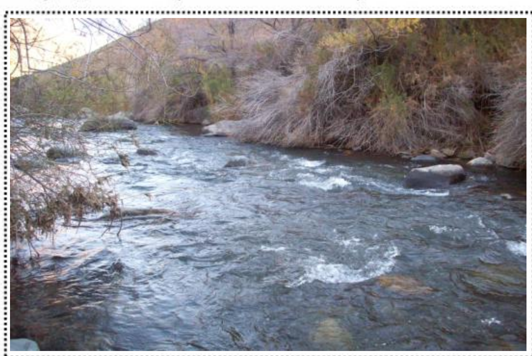
Site related information: Site description

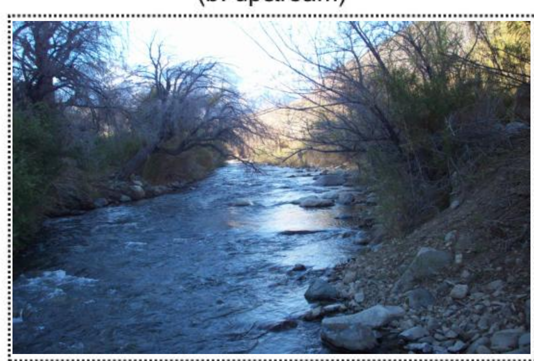
1 map (No., scale) (No. 1,50000)	**2 stream name** Grande river
	3 stream system (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo Region
	6 map no. 8
	7 longitude (degree, min, sec) 70°34.661' W
	8 latitude (degree, min, sec) 30°00.567' S
	9 distance to source [km] 51.58 Km
10 stream order (Strahler system) 2´	**11 slope of the valley floor** [%] Average (2%-4%)
12 subregion (if applicable) -	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 1379 m.a.s.l	**15 altitude class** High
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Class 2: 5-50m^3/s
18 Geology (dominant type) Substrate Gravel	**19 geology class** Silica



20 stream type (mark system and fill in name)
☐ System A ☐ System B Andean semiarid

21 photographs (a. downstream) (b. upstream)





22 short description

Biology Parameters		
Fishes	Macroinvertebrate	Other
Absent	Mainly: Diptera, Oligochaeta Minorly: Ephemerotera Trichoptera	Large fauna different since high mineral content

Type N° 6 (Fuster *et al.*, 2011)

This station is the nearest to the high mountains, and is close to the local way, there are people who lives in the edge of the river and uses of for activities like washing clothes, there are some horses in the river.

WFD Categories

Basic data

site name	date	sample no.	investigator
Limarí Watershed	23/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☒ V-shaped valley

☐ trough

☐ meander valley

☐ U-shaped valley

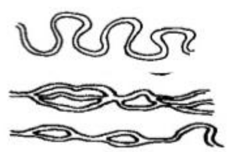
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

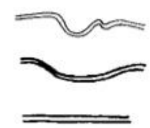
☐ anabranching



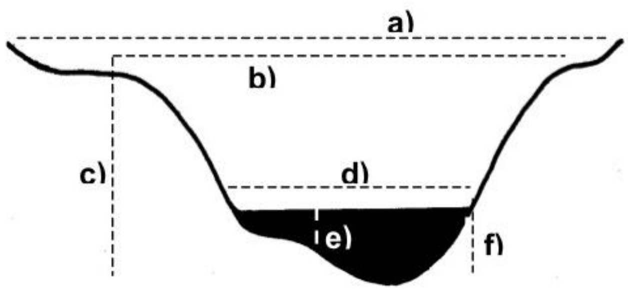
☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	10.24
b) flood prone area width [m]	9.24
c) entrenchment depth [m]	-
d) average stream width [m]	5.00
e) mean depth water body [m]	0.70
f) maximum depth water body [m]	0.6

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

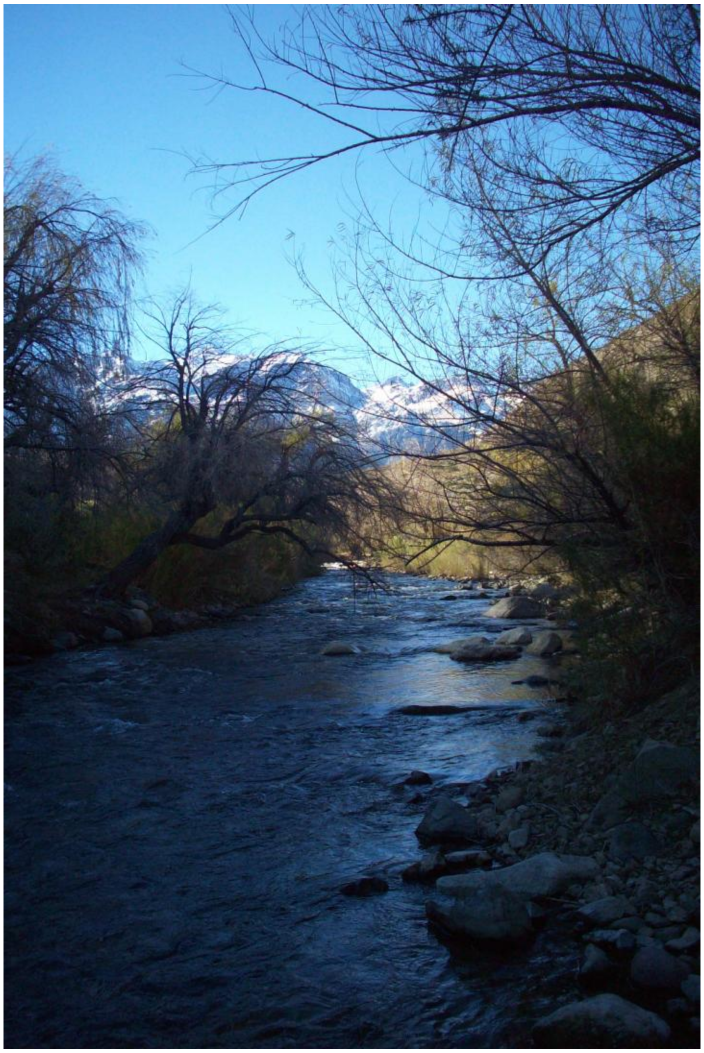
31 bank and bed fixation ✋

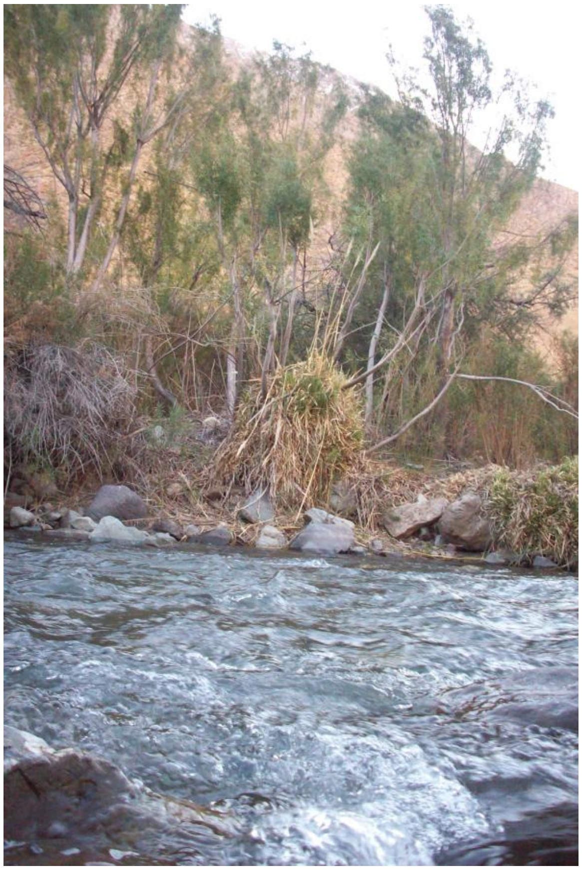
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ___________________	☐	☐	☐
no bank fixation	☐	☐	☐

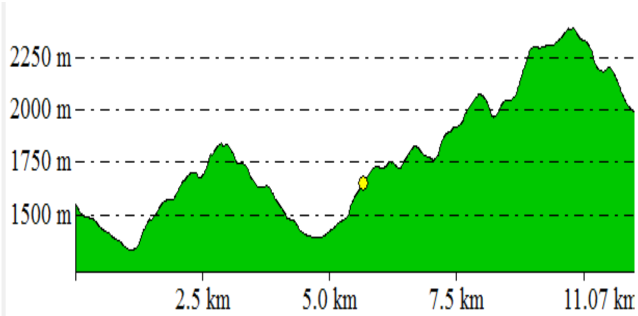
32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☐ yes ☒ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Station 8:
Hurtado river

Aditional information
The water is transparent, very cold and the water runs fast. There are lots of rocks and also many vegetation.





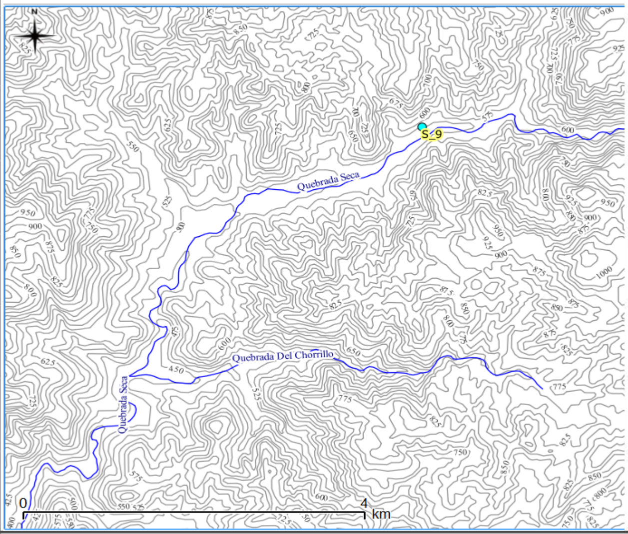


Profile of the station 8: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	23-06-2012		Carolina Aguirre

Site related information: Site description

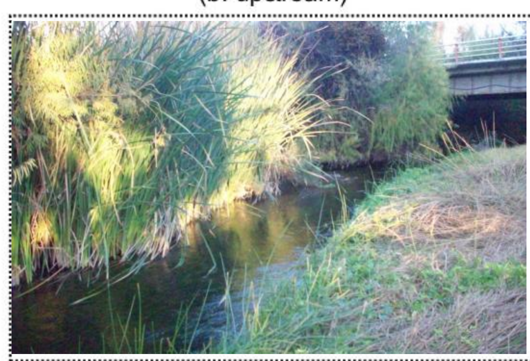
1 map (No., scale) (No. 1,50000)	**2 stream name** Quebrada seca
	3 stream system (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo Region
	6 map no. 9
	7 longitude (degree, min, sec) 71°08.859' W
	8 latitude (degree, min, sec) 30°35.771' S
	9 distance to source [km] -
10 stream order (Strahler system) 2´	**11 slope of the valley floor** [%] Low (<2%)
12 subregion (if applicable) -	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 232,1 m.a.s.l	**15 altitude class** Very low
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Class 2: 5-50m^3/s
18 Geology (dominant type) Substrate Sand	**19 geology class** Silica



WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B
Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)



22 short description

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

This station is in the way to the Ovalle city, the access to the river was done near to a bridge, close to this sampling site is located a camping place.

Type N^o 10 (Fuster *et al.*, 2011)

Basic data

site name	date	sample no.	investigator
Limarí Watershed	23/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

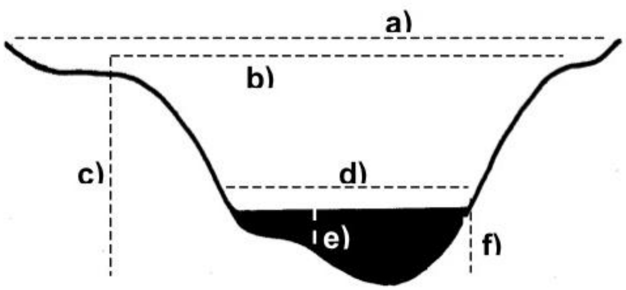
☐ anabranching

☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)

27 cross section



a) width of floodplain [m]	0.10
b) flood prone area width [m]	5.20
c) entrenchment depth [m]	
d) average stream width [m]	3.00
e) mean depth water body [m]	0.30
f) maximum depth water body [m]	0.60

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

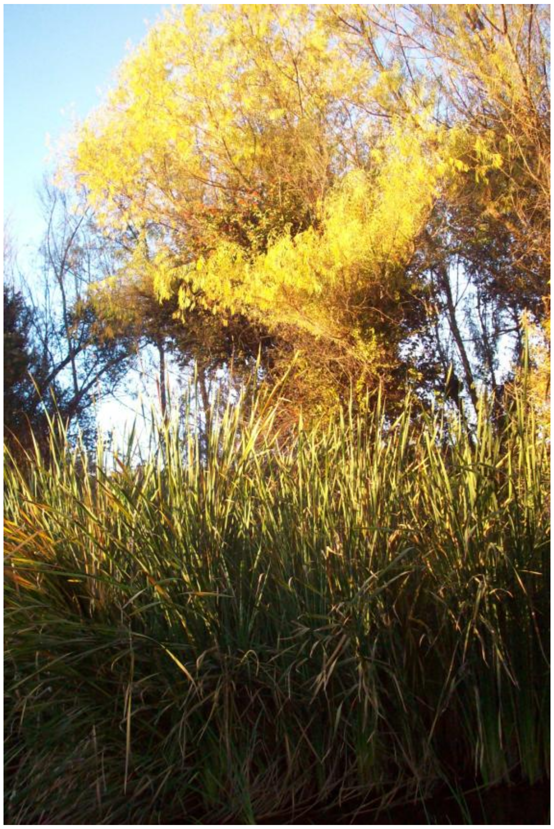
31 bank and bed fixation ✋

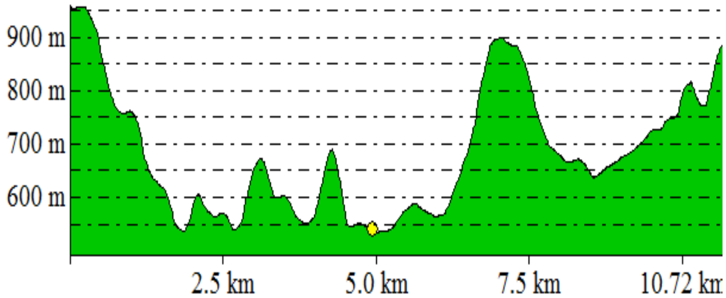
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☐	☐
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials Grass	☒	☒	☒
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Station 9:
Quebrada seca

Aditional information
It is a very narrow course of water because there is a thick vegetation, principally of pasture and this one is also in the bottom of the river bed. The water is transparent and with an average speed.



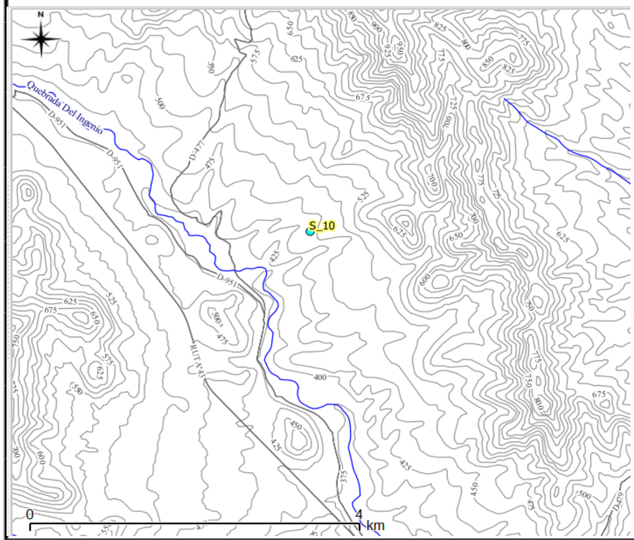


Profile of the station 9: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	24-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name Ingeniero

3 stream system (river flowing into the sea) Limarí river

4 country Chile

5 federal state Coquimbo Region

6 map no. 10

7 longitude (degree, min, sec) 71°11.668' W

8 latitude (degree, min, sec) 30°24.309' S

9 distance to source [km] -

10 stream order (Strahler system) 1´

11 slope of the valley floor [%] Low (<2%)

12 subregion (if applicable) -

13 ecoregion and ecoregion no. Mediterranean

14 altitude of sampling site [m a. s. l.] 426,9 m.a.s.l

15 altitude class Very low

16 catchment area [km²] at sampling site -

17 size class based on catchment area Small

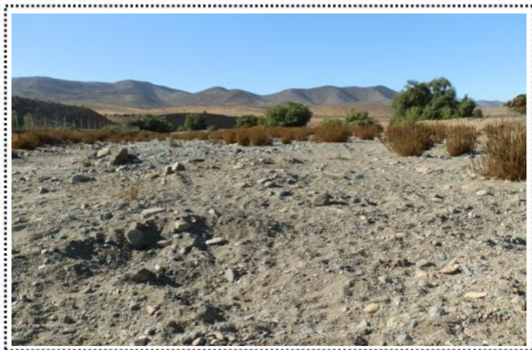
18 Geology (dominant type) Substrate Sand

19 geology class Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B
On transition

21 photographs (a. downstream) (b. upstream)



22 short description

This station is in the northern part of the watershed, the course of the river this one completely dry, the local people assure that at the same date but in last winter there was water in the river.

Type N° 8 (Fuster *et al.*, 2011)

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: < 800 m.a.s.l	Silica geology NF: medium Fine-grained	Dyplomistes Cheirodon Basilichthys	Associated to Potamon (slow flow) sites. More: Diptera Mollusca Crustacean	Low zone of small flow and moderate diversity

Basic data

site name	date	sample no.	investigator
Limarí Watershed	22/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

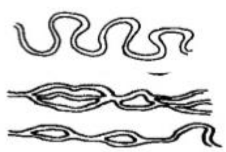
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

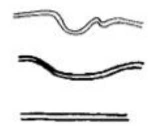
☐ anabranching



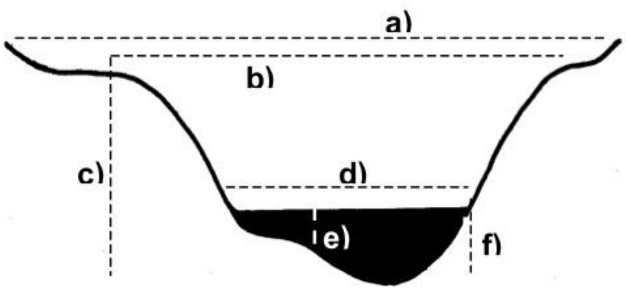
☒ sinuate

☐ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m] ______-

b) flood prone area width [m] ______-

c) entrenchment depth [m] ______-

d) average stream width [m] ______-

e) mean depth water body [m] ______-

f) maximum depth water body [m] ______-

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

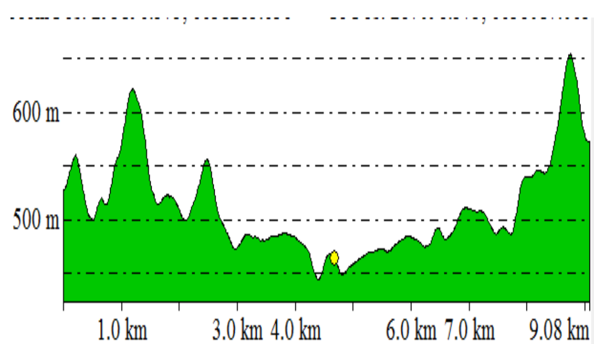
31 bank and bed fixation ✋

	left shoreline	**bed**	**right shoreline**
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☐	☐
wood	☐	☐	☐
trees	☐	☐	☐
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☐ no ☐ ?	**33 oth. transv. structures** ☐ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☐ ?	**35 water abstract.** ☐ yes ☐ no ☐ ?
36 stagnation ☐ yes ☐ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☐ no ☐ ?	**39 straightening** ☐ yes ☐ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☐ ?	**41 cut-off meanders** ☐ yes ☐ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☐ ?	**43 culverting** ☐ yes ☐ no ☐ ?
44 fire incident ☐ yes ☐ no ☐ ?	**45 waste** ☐ yes ☐ no	**46 others** Dry stream	

Station 10:
Ingeniero

Aditional information
As the river it is dry, the people use ground water to support small cultivation of subsistence.

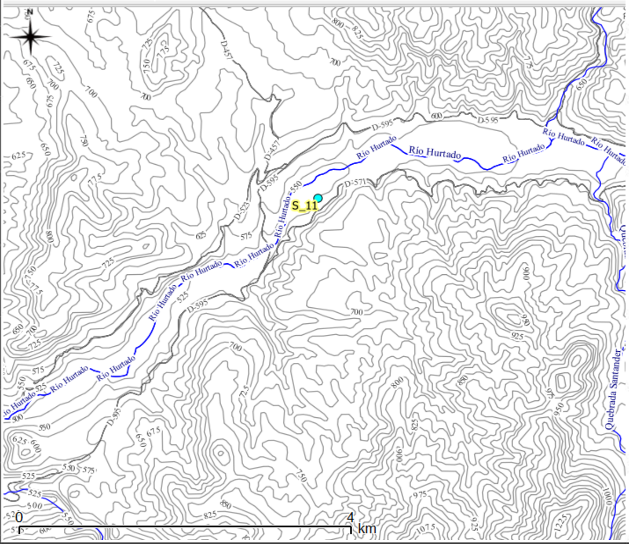


Profile of the station 10: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	24-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name Hurtado river

3 stream system (river flowing into the sea) Limarí river

4 country Chile

5 federal state Coquimbo Region

6 map no. 11

7 longitude (degree, min, sec) 70°58.448’ W

8 latitude (degree, min, sec) 30°25.370’ S

9 distance to source [km] 115.18 Km

10 stream order (Strahler system) 3´

11 slope of the valley floor [%] Low (<2%)

12 subregion (if applicable) -

13 ecoregion and ecoregion no. Mediterranean

14 altitude of sampling site [m a. s. l.] 426,9 m.a.s.l

15 altitude class Average

16 catchment area [km²] at sampling site -

17 size class based on catchment area Class 2: 5-50m^3/s

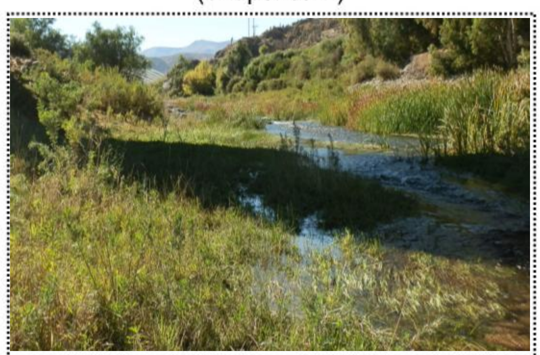
18 Geology (dominant type) Substrate Sand

19 geology class Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Andes semiarid

21 photographs (a. downstream) (b. upstream)



22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: <1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

Type N^o 7 (Fuster *et al.*, 2011)

To have access to this part of the river was necessary to do it near a bridge, one of the props it modifies the natural course of the river.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	24/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

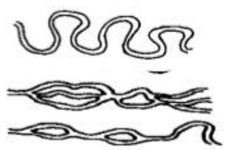
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

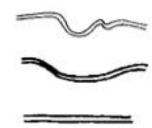
☒ anabranching



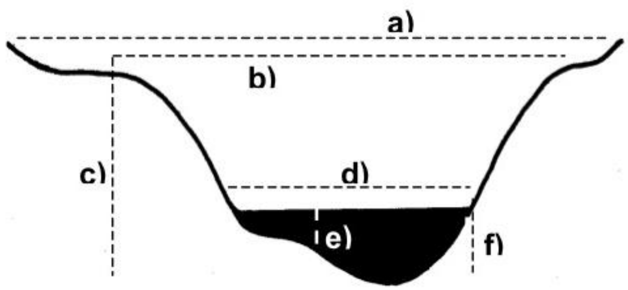
☐ sinuate

☐ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	45.00
b) flood prone area width [m]	25.00
c) entrenchment depth [m]	-
d) average stream width [m]	16.50
e) mean depth water body [m]	0.30
f) maximum depth water body [m]	0.50

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

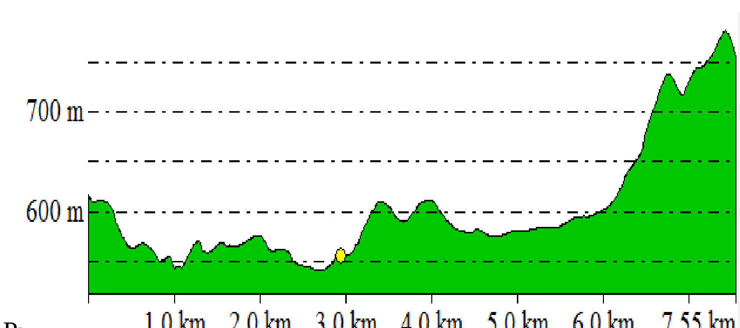
31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☒	☐
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials Grass	☒	☒	☒
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others**	

Station 11:
Hurtado river

Aditional information
The small vegetation covered the river bed and there is a few trees, there is garbage and a lot of mud in the shore. The course of the river has a anabranching form that not been observed on the previous stations.

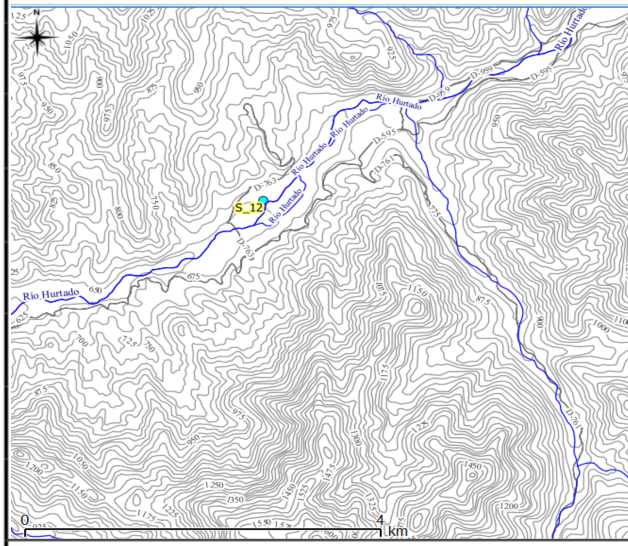


Pr
(Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	24-06-2012		Carolina Aguirre

Site related information: Site description

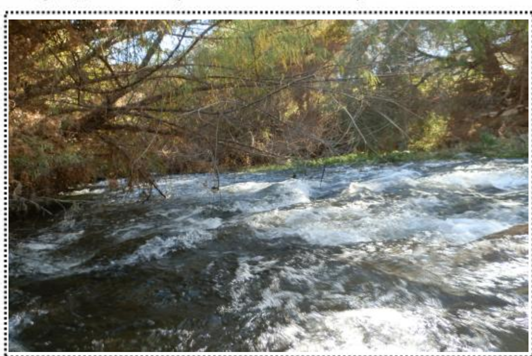
1 map (No., scale) (No. 1,50000)	**2 stream name** Hurtado river
	3 stream system (river flowing into the sea) Limarí river
	4 country Chile
	5 federal state Coquimbo Region
	6 map no. 12
	7 longitude (degree, min, sec) 70°53.198’ W
	8 latitude (degree, min, sec) 30°24.252’ S
	9 distance to source [km] 104.44 Km
10 stream order (Strahler system) 3´	**11 slope of the valley floor** [%] Low (<2%)
12 subregion (if applicable) Mediterranean	**13 ecoregion and ecoregion no.** Mediterranean
14 altitude of sampling site [m a. s. l.] 539 m.a.s.l	**15 altitude class** Average
16 catchment area [km²] at sampling site -	**17 size class based on catchment area** Class 2: 5-50m^3/s
18 Geology (dominant type) Substrate Sand	**19 geology class** Silica

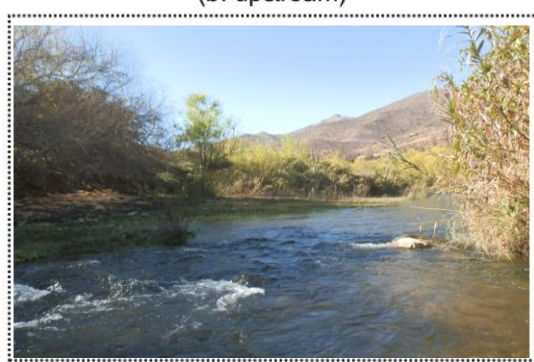


WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Andean semiarid

21 photographs (a. downstream) (b. upstream)





22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: < 1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

Type N^o 7 (Fuster, 2011)

This station is located near to a bridge, the size of the river is medium and there is a zone of camping near to the shore.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	24/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

25 valley form ☝

☐ canyon

☐ V-shaped valley

☐ trough

☐ meander valley

☒ U-shaped valley

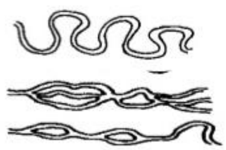
☐ plain floodplain

26 channel form ☝

☐ meandering

☐ braided

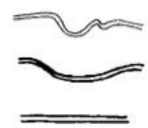
☐ anabranching



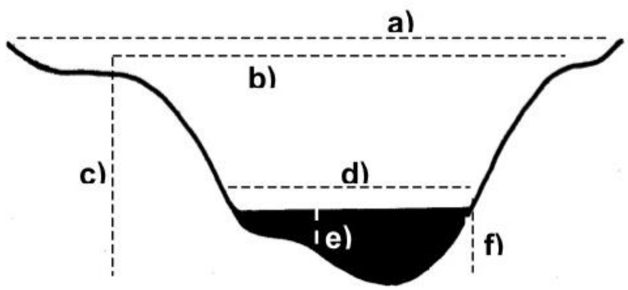
☐ sinuate

☒ constrained (natural)

☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	37.00
b) flood prone area width [m]	32.00
c) entrenchment depth [m]	-
d) average stream width [m]	22.00
e) mean depth water body [m]	0.45
f) maximum depth water body [m]	0.80

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site

☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site

☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation ✋

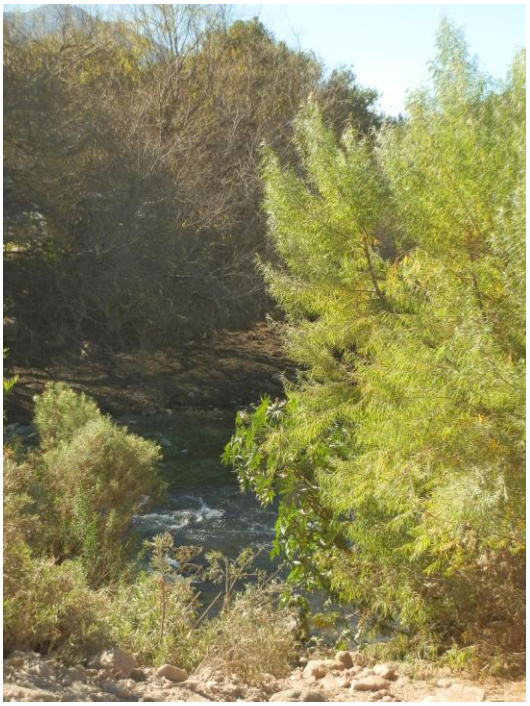
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☐	☒	☐
wood	☐	☒	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ____________________	☐	☐	☐
no bank fixation	☐	☐	☐

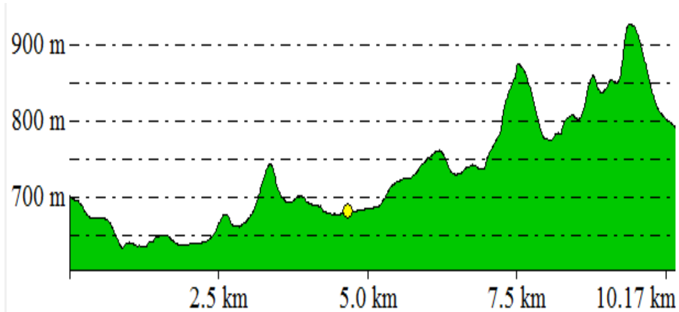
32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Additional data

Station 12:
Hurtado river

Aditional information
The water is transparent, the current of the river is very fast. This river presents higher depths than rivers seen in previous stations.
There are many rocks in differents sizes in the river bed.



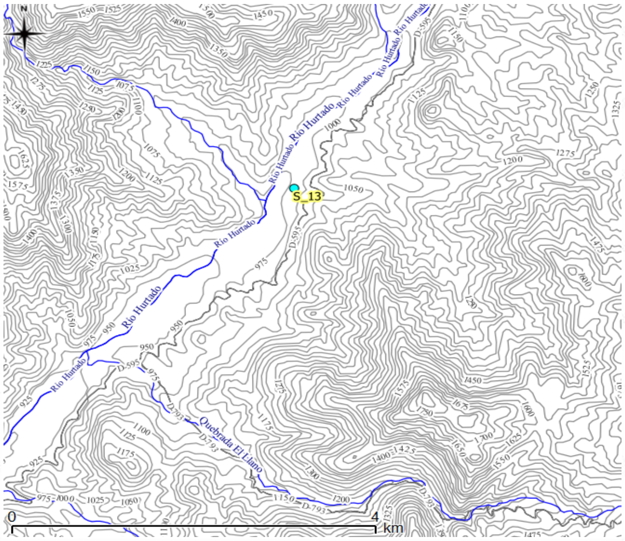


Profile of the station 12: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	24-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



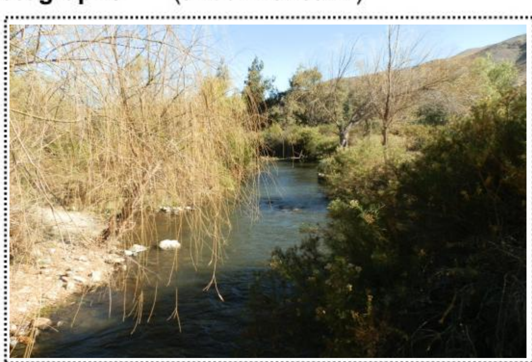
2 stream name	Hurtado river
3 stream system (river flowing into the sea)	Limarí river
4 country	Chile
5 federal state	Coquimbo Region
6 map no.	13
7 longitude (degree, min, sec)	70°44.792' W
8 latitude (degree, min, sec)	30°19.637' S
9 distance to source [km]	83.25 Km

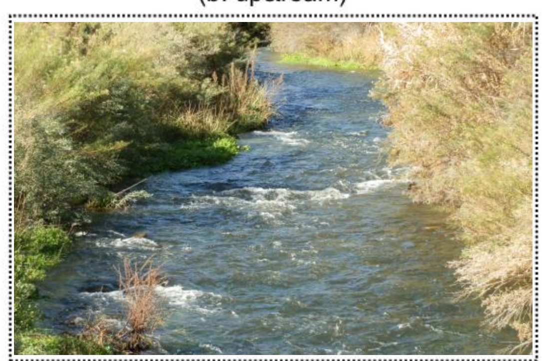
10 stream order (Strahler system)	2´	**11 slope of the valley floor** [%]	Low (<2%)
12 subregion (if applicable)	-	**13 ecoregion and ecoregion no.**	Mediterranean
14 altitude of sampling site [m a. s. l.]	682,8 m.a.s.l	**15 altitude class**	Average
16 catchment area [km²] at sampling site		**17 size class based on catchment area**	Class 2: 5-50m^3/s
18 Geology (dominant type)	Substrate Sand	**19 geology class**	Silica

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Andean semiarid

21 photographs (a. downstream) (b. upstream)





22 short description

Physics Parameters		Biology Parameters		
Determinant	Dominant	Fishes	Macroinvertebrate	Other
Altitude: < 1500 m.a.s.l	Silica geology NF: medium and low Thick grained.	Dyplomistes Cheirodon Basilichthys	Associated to ritron (high slope) sectors.	Fauna stable during the year

Type N^o 7 (Fuster *et al.*, 2011)

This station is located in the middle of cultivated fields with grape.
This site is near to a bridge and it looks like this zone is used for aquatic activities by locals.

Basic data

site name	date	sample no.	investigator
Limarí Watershed	24/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

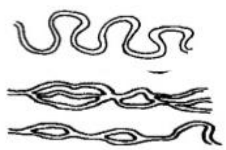
25 valley form ☝

☐ canyon
☐ V-shaped valley
☐ trough

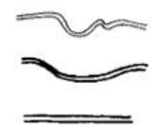
☐ meander valley
☒ U-shaped valley
☐ plain floodplain

26 channel form ☝

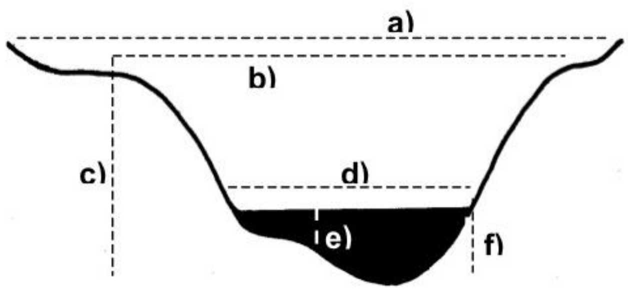
☐ meandering
☐ braided
☐ anabranching



☒ sinuate
☐ constrained (natural)
☐ constrained (artificial)



27 cross section



a) width of floodplain [m]	0
b) flood prone area width [m]	8.20
c) entrenchment depth [m]	-
d) average stream width [m]	5.6
e) mean depth water body [m]	0.80
f) maximum depth water body [m]	1.50

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

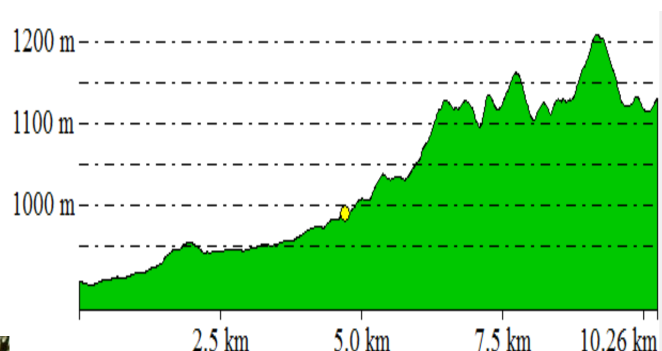
31 bank and bed fixation ✋

	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☐	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☐ yes ☒ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☐ yes ☒ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☐ yes ☒ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☐ yes ☒ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☐ yes ☒ no	**46 others**	

Station 13:
Hurtado river

Aditional information
The water is transparent and the speed is average, there are is some kind of a swimming pool. There are trees and pastures in the shore with the remains of dead wood and branches.

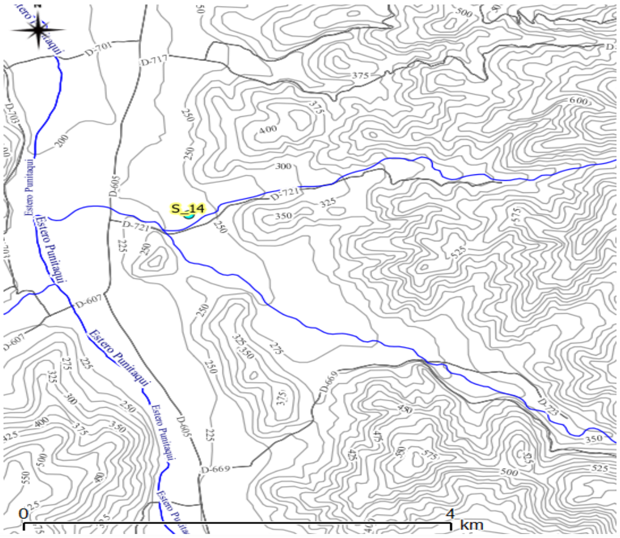


(Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	24-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name Punitaqui

3 stream system (river flowing into the sea) Limarí river

4 country Chile

5 federal state Coquimbo Region

6 map no. 14

7 longitude (degree, min, sec) 71°15.814’ W

8 latitude (degree, min, sec) 30°49.823’ S

9 distance to source [km] 20.18 Km

10 stream order (Strahler system) 2´

11 slope of the valley floor [%] Low (<2%)

12 subregion (if applicable)

13 ecoregion and ecoregion no. Mediterranean

14 altitude of sampling site [m a. s. l.] 202,1 m.a.s.l

15 altitude class Very low

16 catchment area [km²] at sampling site -

17 size class based on catchment area Class 2: 5-50m^3/s

18 Geology (dominant type) Substrate Sand

19 geology class Calcareous

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

This station the course of the river is completely dry, it is crossed by bridges that communicate the city of Punitaqui.

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

Type N^o 10 (Fuster *et al.*, 2010)

Basic data

site name	date	sample no.	investigator
Limarí Watershed	24/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

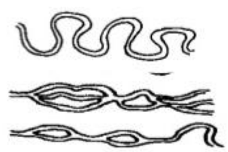
25 valley form ☝

☐ canyon
☐ V-shaped valley
☐ trough

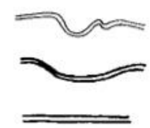
☐ meander valley
☒ U-shaped valley
☐ plain floodplain

26 channel form ☝

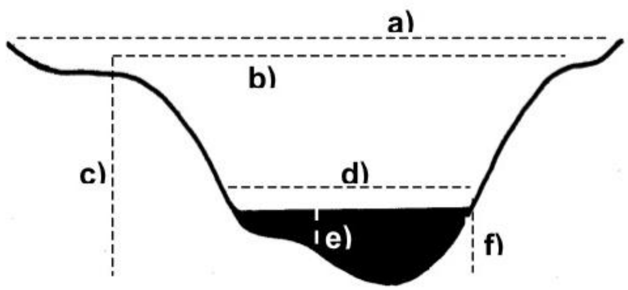
☐ meandering
☐ braided
☐ anabranching



☐ sinuate
☒ constrained (natural)
☐ constrained (artificial)



27 cross section



a) width of floodplain [m] ______ -

b) flood prone area width [m] ______ -

c) entrenchment depth [m] ______ -

d) average stream width [m] ______ -

e) mean depth water body [m] ______ -

f) maximum depth water body [m] ______ -

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation ✋

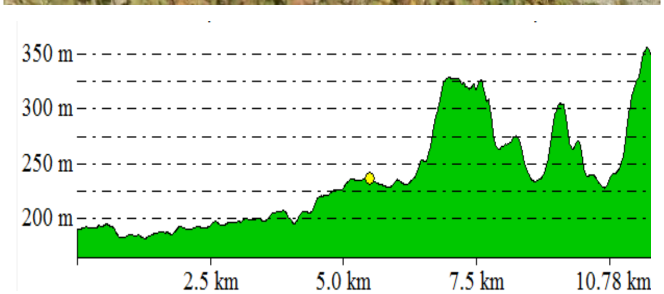
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☒	☐
trees	☒	☐	☒
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☐ no ☐ ?	**33 oth. transv. structures** ☐ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☐ ?	**35 water abstract.** ☐ yes ☐ no ☐ ?
36 stagnation ☐ yes ☐ no ☐ ?	**37 torrent modification** ☐ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☐ no ☐ ?	**39 straightening** ☐ yes ☐ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☐ ?	**41 cut-off meanders** ☐ yes ☐ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☐ ?	**43 culverting** ☐ yes ☐ no ☐ ?
44 fire incident ☐ yes ☐ no ☐ ?	**45 waste** ☐ yes ☐ no	**46 others**	

Station 14: Punitaqui

Aditional information

Across the river bed it is big bridge, however this stream is completely dry, there are old trees in the shores. At the bottom of the river it is possible to see small rocks and dry mud.

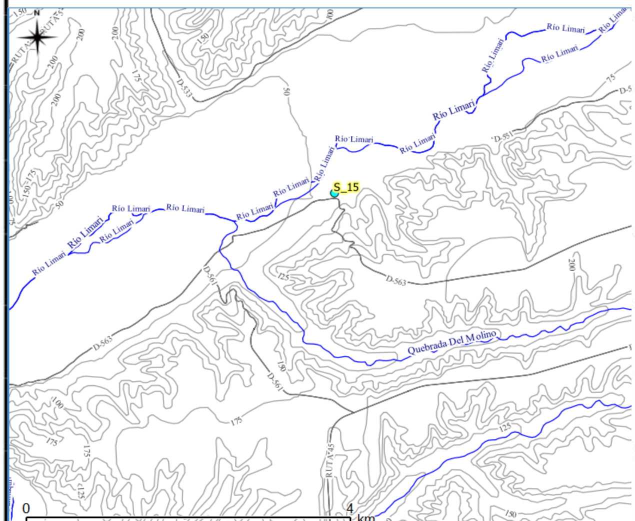


Profile of the station 14: in the yellow spot is the location (Global mapper v13.2).

site name	date	sample no.	investigator
Limarí Watershed	25-06-2012		Carolina Aguirre

Site related information: Site description

1 map (No., scale) (No. 1,50000)



2 stream name	Limarí river
3 stream system (river flowing into the sea)	Limarí river
4 country	Chile
5 federal state	Coquimbo Region
6 map no.	15
7 longitude (degree, min, sec)	71°28.972’ W
8 latitude (degree, min, sec)	30°39.222’ S
9 distance to source [km]	199.83 Km

10 stream order (Strahler system)	3´	**11 slope of the valley floor** [%]	Low (<2%)
12 subregion (if applicable)	-	**13 ecoregion and ecoregion no.**	Mediterranean
14 altitude of sampling site [m a. s. l.]	48,3 m.a.s.l	**15 altitude class**	Very low
16 catchment area [km²] at sampling site	-	**17 size class based on catchment area**	Class 2: 5-50m^3/s
18 Geology (dominant type)	Substrate Sand	**19 geology class**	Calcareous

WFD Categories

20 stream type (mark system and fill in name)
☐ System A ☐ System B Of river mouth of semiarid

21 photographs (a. downstream) (b. upstream)

22 short description

This station is crossed by a bridge done by a wall of soil that cuts the natural flow of the water; one of the arms of the river connects for an underground pipe.

Biology Parameters		
Fishes	Macroinvertebrate	Other
Similar to silica types	Similar to silica types	Is important to assess difference in biocenosis in calcareous and silica types..

Type N^o 10 (Fuster *et al.*, 2011)

Basic data

site name	date	sample no.	investigator
Limarí Watershed	25/06/2012		Carolina Aguirre

Sample related information, to be recorded just once

Stream morphology and hydrology at sampling site (☝ = one mark, ✋ = more than one mark possible)

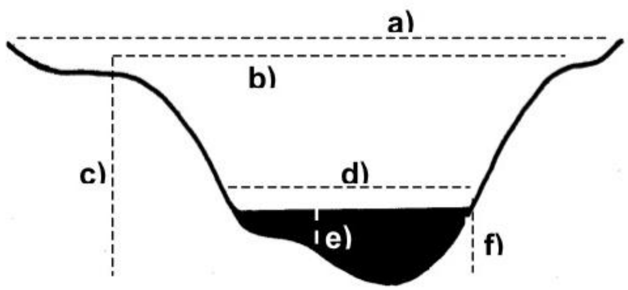
25 valley form ☝

☐ canyon
☐ V-shaped valley
☐ trough
☐ meander valley
☒ U-shaped valley
☐ plain floodplain

26 channel form ☝

☐ meandering
☐ braided
☒ anabranching
☐ sinuate
☐ constrained (natural)
☐ constrained (artificial)

27 cross section



a) width of floodplain [m] 21.50
b) flood prone area width [m] 13.00
c) entrenchment depth [m] -
d) average stream width [m] 8.00
e) mean depth water body [m] 1.00
f) maximum depth water body [m] 2.00

28 relation riffles/pools [share of pools%] estimated for a stretch 20 x av. stream width or 100 m, whichever is longer

29 debris dams ☝ (POM accumul. >0.3 m³) at sampling site
☒ none ☐ few ☐ several ☐ many

30 logs ☝ (>10 cm Ø) at sampling site
☐ none ☐ few ☐ several ☐ many

31 bank and bed fixation ✋

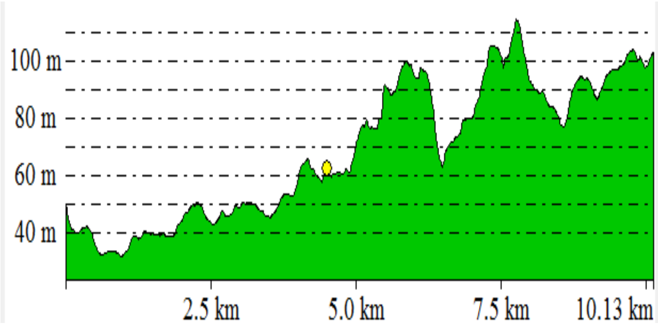
	left shoreline	bed	right shoreline
concrete without seams	☐	☐	☐
concrete with seams	☐	☐	☐
stones	☒	☒	☒
wood	☐	☐	☐
trees	☒	☐	☐
stone plastering with interstices	☐	☐	☐
stone plastering without interstices	☐	☐	☐
other materials ________________	☐	☐	☐
no bank fixation	☐	☐	☐

32 dams ☐ yes ☒ no ☐ ?	**33 oth. transv. structures** ☒ yes ☐ no ☐ ?	**34 pulse releases** ☐ yes ☐ no ☒ ?	**35 water abstract.** ☐ yes ☒ no ☐ ?
36 stagnation ☒ yes ☐ no ☐ ?	**37 torrent modification** ☒ yes ☐ no ☐ ?	**38 channelg. for navigation** ☐ yes ☒ no ☐ ?	**39 straightening** ☒ yes ☐ no ☐ ?
40 removal of CWD ☐ yes ☐ no ☒ ?	**41 cut-off meanders** ☒ yes ☐ no ☐ ?	**42 scouring** [m bel. surface] ☐ yes ☐ no [m] ☒ ?	**43 culverting** ☒ yes ☐ no ☐ ?
44 fire incident ☐ yes ☒ no ☐ ?	**45 waste** ☒ yes ☐ no	**46 others**	

Additional data

Station 15:
Limarí river

Aditional information
This river has a anabranching form, one of the arms has stagnant water and other one flows towards the sea, the water is transparent and is possible to observe for the first time in this work juvenile species of fish. There is presence of horses. The water moves with slow speed and is observed a medium size vegetation.



Profile of the station 15: in the yellow spot is the location (Global mapper v13.2).

Fachhochschule Köln
Cologne University of Applied Sciences

UNIVERSIDAD AUTÓNOMA
DE SAN LUIS POTOSÍ

THESIS TO OBTAIN THE DEGREE OF

MASTER OF SCIENCE

“TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

FOCUS AREA “ENVIRONMENTAL AND RESOURCES MANAGEMENT”

Student:

CAROLINA AGUIRRE MUÑOZ