**Limarí River Basin Study Phase I – Current conditions, history and plans**

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## *Introduction*

For the SERIDAS project, the semiarid Central Chilean region was selected as its water bodies are highly modified to irrigate intensive agriculture and water resources availability is expected to decrease due to climate change triggered temperature rise and seasonal precipitation shifts. The drought prone agricultural areas are supplied with water from mountainous headwater catchments. Stream runoff in Central Chile mainly consists of snow melt, ablation of glaciers and rock glaciers and other melting permafrost and ground ice (Arenson&Jakob 2010) which are especially vulnerable to climatic changes (Barnet et al., 2005; Bates et al., 2008).

The following figure shows the Central Chilean semiarid catchments from Copiapo, Huasco, Elqui, Limarí, Choapa, Petorca-La Ligua, Aconcagua and Maipo and their snow cover after a wet winter year 2002 and a dry year 2006 respectively:

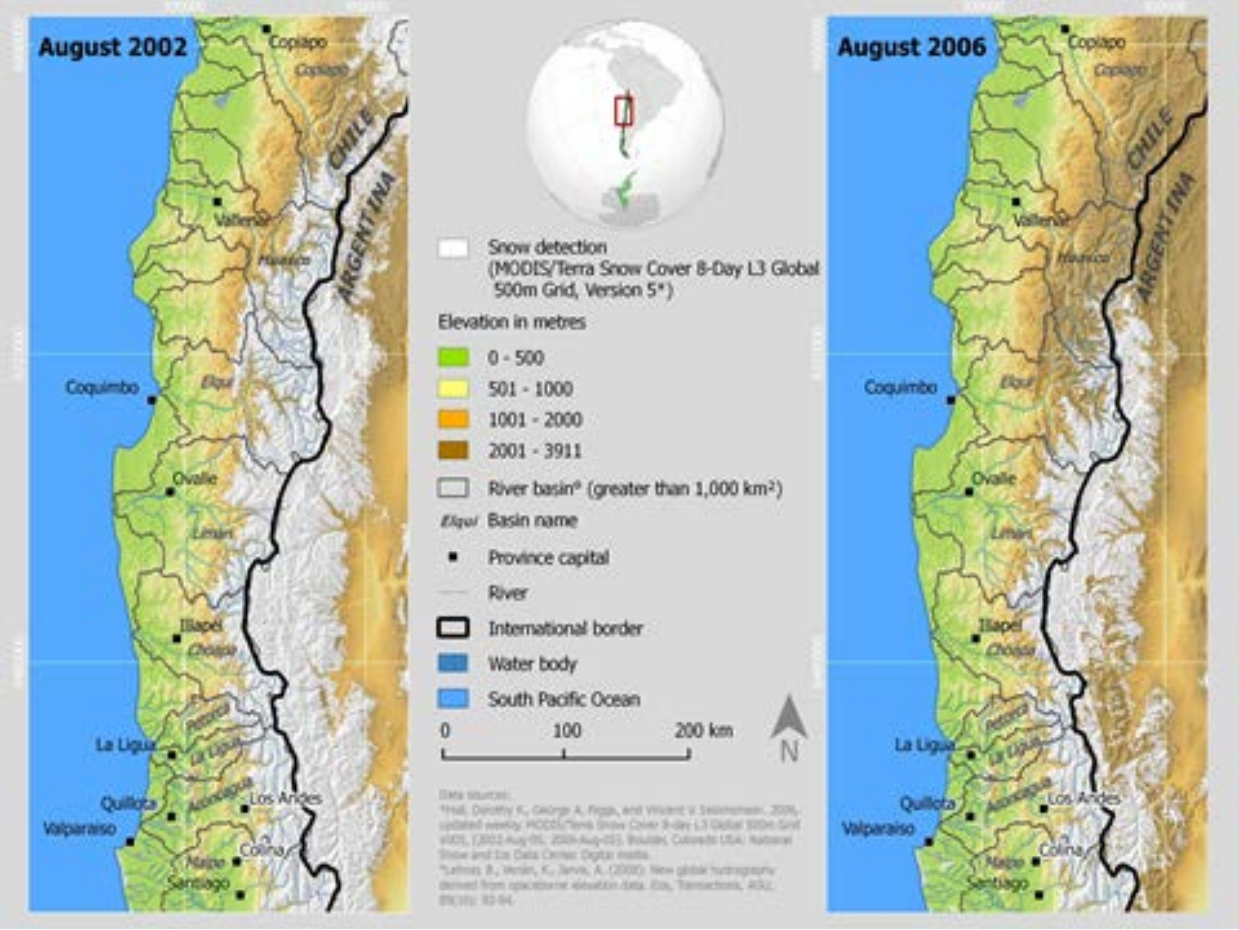


Figure 1: Snow cover in a dry and in a wet year in Central Chile

The Limarí River basin was selected as an example to describe the regional characteristics:

*1. Physical and human geography*

*1.1 River and tributaries*

The Limarí River is formed by the confluence of the Grande and Hurtado rivers. The Grande River drains the central parts of the basin (Commune of Monte Patria), whereas the Hurtado drains the northern part (Commune of Hurtado). Both rivers originate in the Andean Cordillera, with headwaters at 4,500 m.a.s.l., thus snowfall makes an important contribution to their discharge. The Hurtado River does not have any important tributaries, and its course is intercepted by the Recoleta dam. The Grande River presents some tributaries of relative importance, such as the Rapel, Mostazal and Guatulame rivers. The discharges of the latter are regulated by the Cogotí reservoir. The La Paloma dam is located at the confluence of the Guatulame and the Grande rivers. The Grande and Hurtado rivers merge about 4 km upstream from Ovalle, the catchment's main city. From this point, the river is called Limarí and runs 60 km until reaching the Pacific Ocean at Punta Limarí. Two tributaries of little importance in terms of discharge but of relevance in terms of water quality join the Limarí River between Ovalle and the river mouth: El Ingenio and Punitaqui creeks. Both of them originate in the Coastal Cordillera, mainly as a result of rainfall. Although their spatial and temporal variability is high, the average discharge of the Grande, Hurtado, and Limarí rivers is ca. 3.9, 1.2, and 2.3 m3/s, respectively (Kretschmer et al, 2012).

The following map shows the main river courses, reservoirs and the agricultural area:

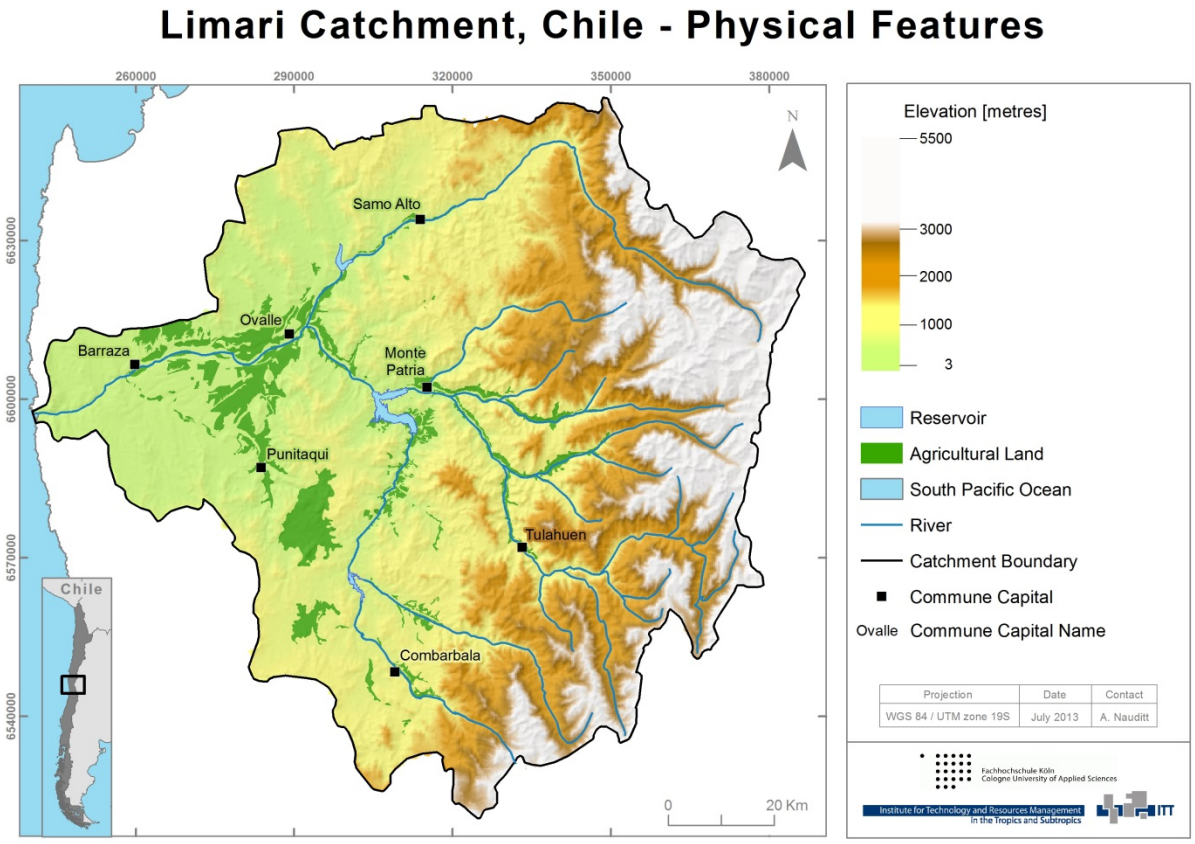


Figure 2: The Limarí river basin: hydrology, topography

*1.2 Aquifers*

Groundwater is present in a gravel-sand dominated aquifer formed by shallow sediments of the flood plains of valleys between Ovalle downstream along the Limarí and Punitaqui to the coast as well as other valleys further upstream along the rivers Hurtado, Mostazal and Huatulame. In general, the groundwater level in these shallow aquifers is below 10m (INIA, 2007). Groundwater pumping, illegal drilling of boreholes and resulting overexploitation for irrigation security is an increasing problem.

*1.3 Population*

One pressure on the natural resources of the Limarí Basin, is related to its demographic dynamics. According to previous and actual data of INE, in the last 20 years the Limarí province has reached a population growth of 15.1% (CEAZA, 2005, updated with data census data of 2012), increasing from 140 to 163 thousand inhabitants. The tendency of population dynamics at the communal level keeps similar as analyzed in the previous stated study. There is an increase of population in the communes of Ovalle (23.7%), Monte Patria (5%) and Punitaqui (16.4%), while the communes of Hurtado and Combarbaláa show a decreasing population tendency (19.5% and 4.2% respectively).

The migratory displacements of the population, which are associated mainly to negative environmental situation, are developed fundamentally in the interior of the respective communes; dynamics that is decreasing if they consider displacements towards another commune of the province of Limarí, to another province of the Region of Coquimbo or to another region of the country (CEAZA, 2005).

Table 1: Comparison of the Census (including the preliminary results from the census of 2012)

| County (Commune) | Census 1992 | Census 2002 | Census 2012 (preliminary) | Variation between 1992/2002 | Variation between 2002/2012 | Variation between 1992/2012 |
|---|---|---|---|---|---|---|
| Ovalle | 84,787 | 98,368 | 104,855 | 16.0% | 6.6% | 23.7% |
| Combarbalá | 14,391 | 13,531 | 13,785 | -6.0% | 1.9% | -4.2% |
| Monte Patria | 28,549 | 30,247 | 29,983 | 5.9% | -0.9% | 5.0% |
| Punitaqui | 8,793 | 9,553 | 10,236 | 8.6% | 7.1% | 16.4% |
| Rio Hurtado | 5,133 | 4,770 | 4,132 | -7.1% | -13.4% | -19.5% |
| ***Limarí total*** | ***141,653*** | ***156,469*** | ***162,991*** | ***10.5%*** | ***4.2%*** | ***15.1%*** |

The distribution of population densities are illustrated in the following map:

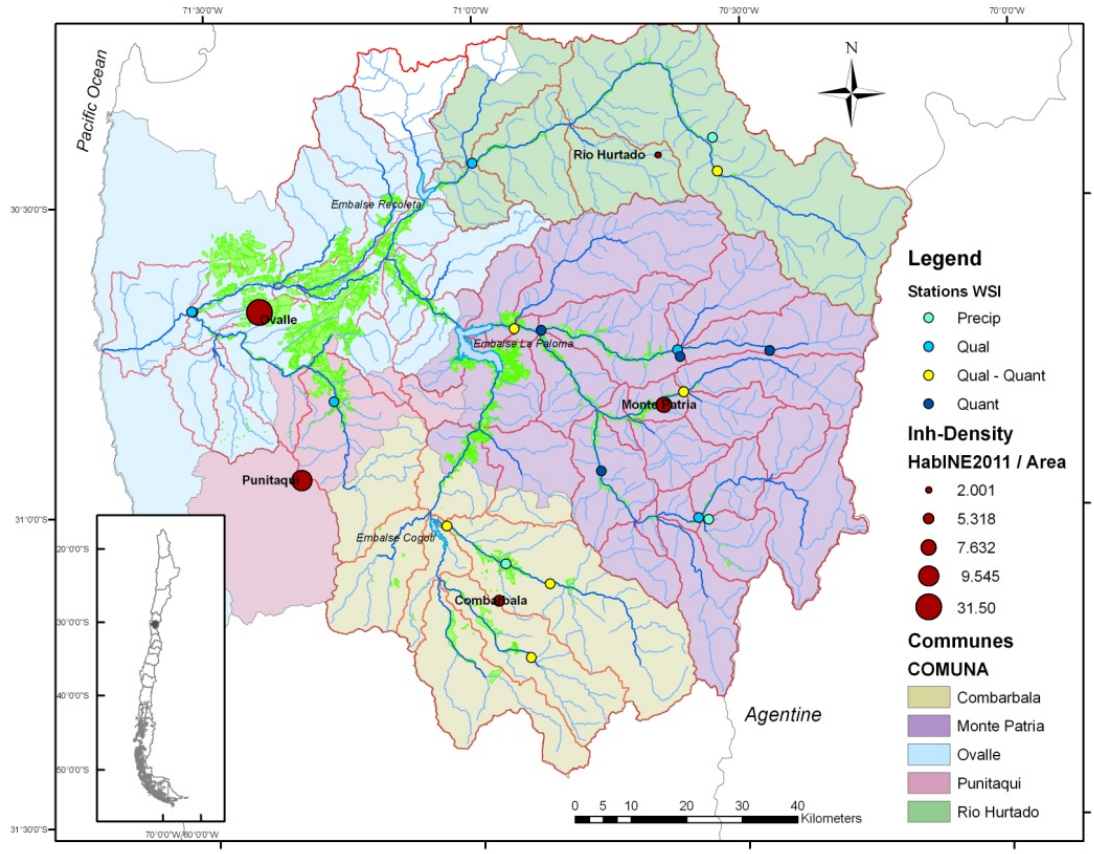


Figure 3: Location of the Limarí basin and its communes, population density and most important river gauging stations of each commune, as well as irrigated areas (Source: Kretschmer et al, 2012)

*1.4 Land Use*

The dominant vegetation is “Matorral”, dry steppe, mainly consisting of bushes of sparse distribution on bare ground. Agriculture is found mainly in the valleys and flood plains of the lower areas.

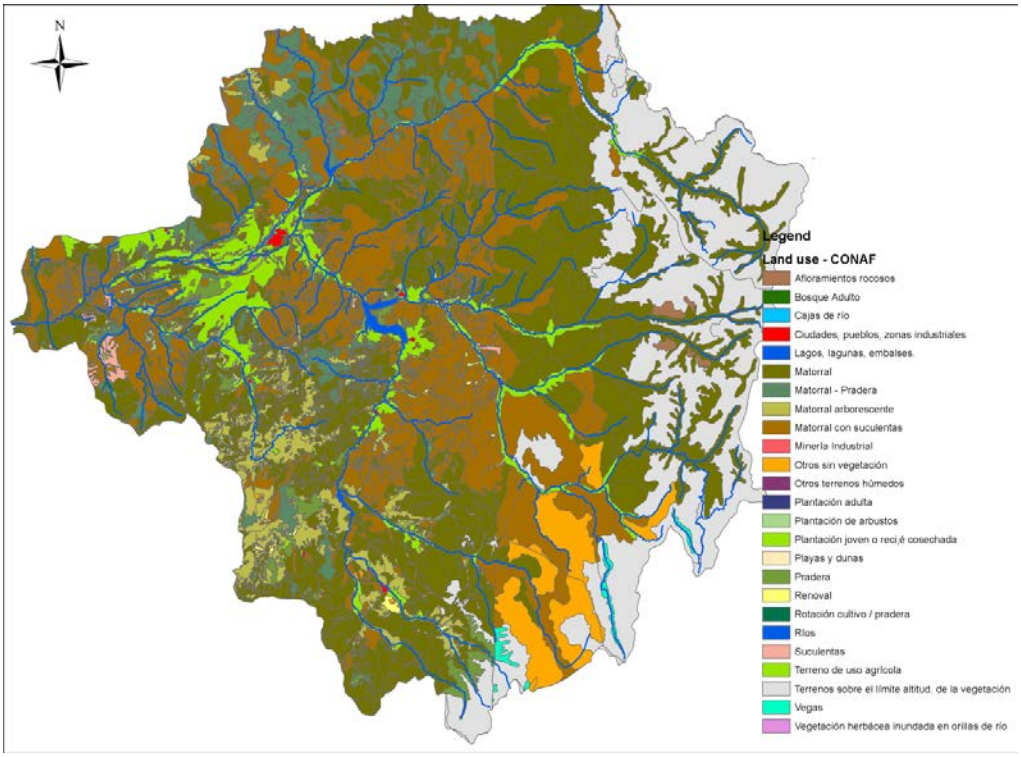


Figure 4: Land use (Source: elaborated out of digital data from CONAF for the region)

The brown surface is “Matorral con Suculentas”, a sparse shrub vegetation with cacti on bare ground, which can be referred to as steppe. The light green corresponds to agricultural land, the white is arid mountainous “Matorral”, sparse bush vegetation, while the grey surface corresponds to rocks without vegetation.

**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the different land uses in the river basin:

Table 2: Land cover in the Limarí basin according the Natural Forest inventory CONAF-CONAMA (Source: Oyarzún 2010)

| Limarí basin | Land cover | Surface in hectares | Land use in % |
|---|---|---|---|
| **1,176.000 hectares** **11,760 km²** | Grassland | 93 | 0.01 |
| | Agricultural land and irrigated area | 80,011 | 7 |
| | Forest plantations | 0 | 0 |
| | Urban and industrial area | 396 | 0.03 |
| | Industrial mining area | 156 | 0 |
| | Natural forest | 115 | 0,01 |
| | Other uses as steppe/matorral, shifting matorral/ water bodies | 883,777 | 75 |
| | Areas without vegetation | 215,608 | 18 |

*1.5 Economy*

Agriculture is of major economic importance in the Coquimbo Region. The region has about 75,700 ha of irrigated crops (INE, 2007). Within the Coquimbo Region, the Limarí basin is the most important agricultural area. The Limarí Basin represents 33 % of the surface of the Region of Coquimbo (about 1,3 million hectares), 42 % of the regional agricultural surface and 70 % of the regional exports. Analyzing the agricultural census of 2007, the irrigated area of the Limarí province results to be 41,760.44 ha.

In the province of the Limarí the industrial activity is of minor importance, and mainly associated with Pisco companies. The mining activity is disperse, and just the mining plant of Panulcillo due to its magnitude sticks out, but even here just with marginal production within the region.

## 2. Hydrology

*2.1 Groundwater*

Groundwater is present in a gravel-sand dominated aquifer formed by shallow sediments of the flood plains of valleys between Ovalle downstream along the Limarí and Punitaqui to the coast as well as other valleys further upstream along the rivers Hurtado, Mostazal and Huatulame. In general, the groundwater level in these shallow aquifers is below 10m (INIA, 2007).

Further groundwater is found in fractured rock aquifers corresponding to both granitic batholiths and volcanic and sedimentary beds especially upstream in the cordillera (Strauch et al., 2009). The contribution of these rock aquifers to the surface runoff is difficult to quantify which represents a major challenge to hydrological modelling.

Strauch et. al. (2009) analyzed $^{2}H$-$^{18}O$ relations of river water and groundwater of the Limarí catchment to investigate the behavior and origin of river waters. They found that the groundwater from several production wells in the lower parts of the Limarí is related to the surrounding river water but it can be differentiated. They implemented an isotope mixing model to estimate the interaction between surface and subsurface flows and river flow (Strauch et al., 2009).

They found that the isotopic signature of the groundwater in Ovalle has a similar isotopic composition to the lake water of the dams. Therefore, they suggest that groundwater is a mixture of base flow from the corresponding rivers and of bank filtrate from the reservoirs (Strauch et al., 2009).

*2.2 Engineering projects*

The Limarí basin is the most engineered in Chile by the "La Paloma Irrigation System". This technical and social system of water allocation is in operation since 1972. It is composed by three reservoirs, storing together 1,000 MCM, and the associated channel network, which sums up to about 700km.

The three reservoirs in the Limarí are: La Paloma (capacity of 750 MCM), Recoleta (100 MCM) and Cogotí (150 MCM) (compare Figure 2). The system was designed originally to increase irrigation security for up to three years.

All three reservoirs of the La Paloma system were built as single purpose irrigation reservoir, just for irrigation purpose and thus for consumptive use.

The following figure shows the reservoir volume decrease of the last 5 years. Until 2013, the storage could cover the water demand of the permanent crops. In 2014, however, there is no more water available.

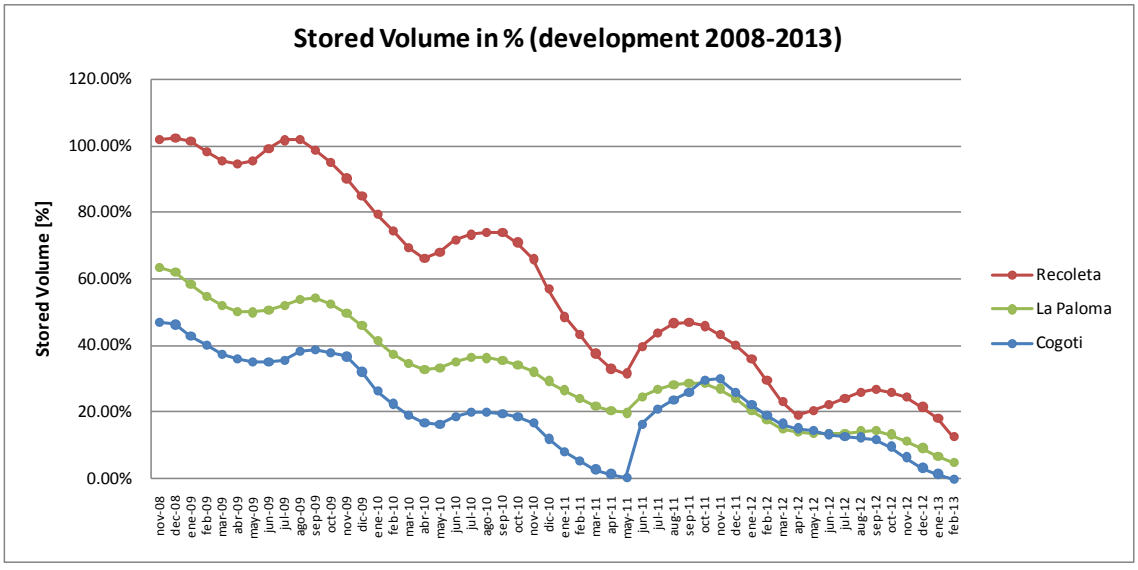


Figure 5: Decreasing water volume (in%) storage in the three main reservoirs of the system since 2008 (Kretschmer, 2013, source DGA)

*2.3 Planned projects*

There is a high demand for new irrigation reservoirs. They are seen as the solution to develop poorer areas as well as to mitigate the water scarce years. In 2012, the Ministry of Agriculture signed the contract with an association of farmers in the commune of Combarbalá, for one reservoir to get built: the reservoir "*Valle Hermoso*", in the Pama river catchment (http://www.minagri.gov.cl/minagri-mop-y-regantes-del-rio-pama-firman-acuerdo-para-construccion-de-embalse-valle-hermoso/).

The volume is planned with 20 MCM and the main objective is to augment the actual 110ha to 1.500 ha with 85% irrigation security, and additionally to secure the rural potable water supply of 17 APR (**A**gua **p**otable **r**ural). They are serving around 2670 people (information Ministry of Agriculture).

Furthermore, there are various studies concerning new reservoirs in different stages in the upper part of the basin. One is the catchment of the Combarbala river with the reservoir "*Murallas Viejas*" (planned so far with 50 MCM) and the reservoir "*La Tranca*" in the Cogotí river (planned so far with 50 MMC).

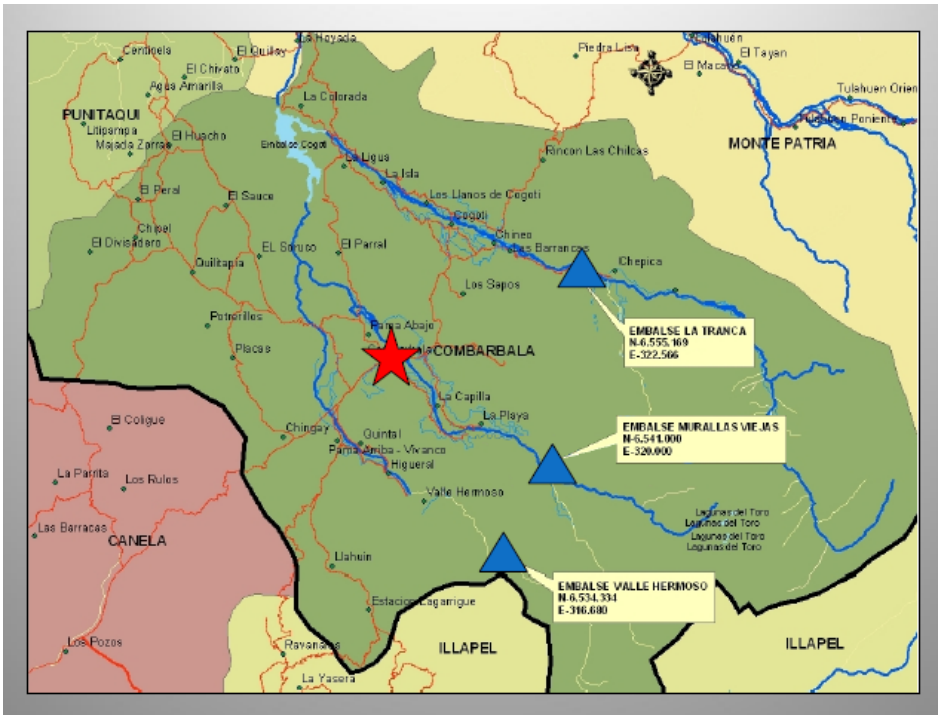


Figure 6: Location of the planned reservoir in the Commune of Combarbalá (unpublished report of MV).

Besides, there are discussions and preliminary studies for a reservoir in the Rapel river.

## 3 Water supply and demand

*3.1 Agriculture, cities and industry*

Water supply and demand is mainly driven by agriculture; the irrigation period starts in September and ends in general at the end of April, the demands are highest in the summer months when evaporation is highest, too. Depending on the crop and location this can be between November and January.

Most recent demand data were obtained from the DGA and are illustrated in the following figure. Looking at the diagram one can see that the agricultural use (depicted in light green) prevails in the IVth region and is furthermore the highest compared to whole Chile.

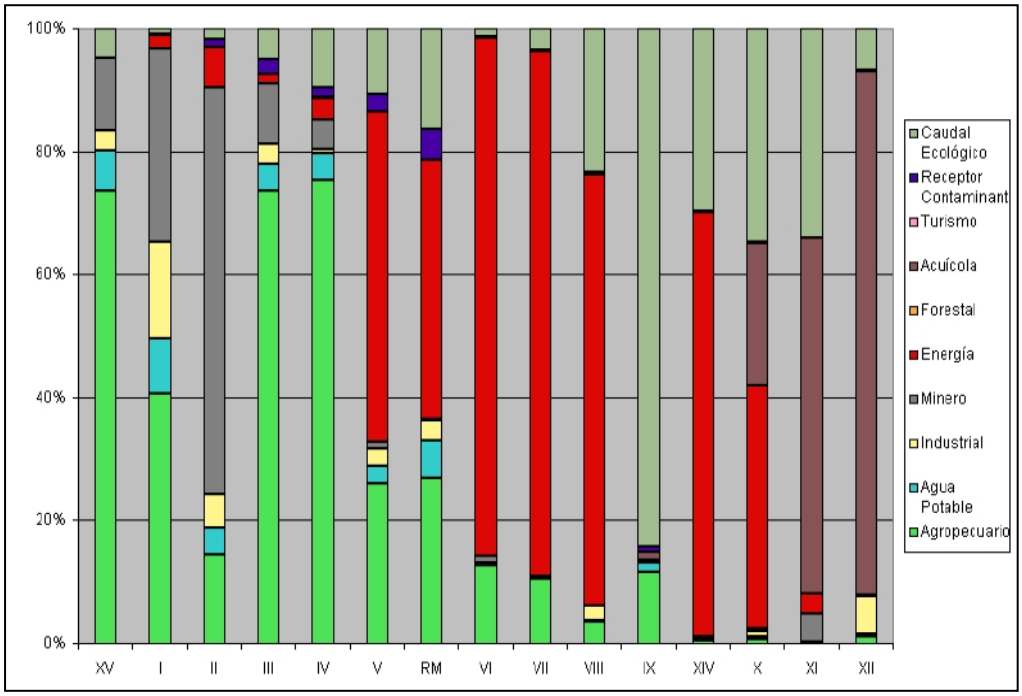


Figure 7: Distribution of water demand of the different regions of Chile; Limarí is in the IVth region (Source: DGA, 2011)

Furthermore, it can be seen that in general industrial demand is very low, potable and mining demand (here separated from other industrial need) are almost the same with around 5% and about 76% is required for agricultural use.

The demand for hydroelectric energy is a bit less than 5%. Here the main part is used in the Limarí basin (but this is non-consumptive use), from two small hydro power plants.

Water uses as being shown are mainly for agriculture purposes; it is allocated according to water rights.

The net demand which is allocated in the basin (corresponding to 1997) is 724 MCM/year, where it is estimated to assign in average for one water right 1l/sec per ha for a farmer. Taking into consideration that in the future the irrigation efficiency in the most productive areas (orchards and pisco grapes) increases it can be estimated for 2017 that the demand reaches about 747 MCM / year (DGA 2005; Espinosa et al. 2011).

*3.1.1 Water uses in the Mining Industry*

The following table summarizes the details of the different sites. Out of 23 mining sites in the region of Coquimbo, six are located in the Limarí Province, where three are copper sites and one iron (metallic minerals), furthermore there are rocks and industrial minerals; here: Lapis lazuli (temporary closed) and Calcium Carbonate.

Table 3: Description of principle sites in exploitation in the Limari province (Source: Sernagenomin, 2012]

| ID | Name of the company, Comune | Name of the installation (plant) | Material exploited | UTM North | UTM East |
|---|---|---|---|---|---|
| 9 | Minerales del Sur S.A., *Punitaqui* | Mina los Mantos | Copper | 6.584.200 | 286.950 |
| 10 | Cia. Explotadora de Minas Cemin, *Monte Patria* | Mina Los Pingos | Copper | 6.581.500 | 350.100 |
| 11 | Cia. Mra. Domino Trucco, *Punitaqui* | La Poderosa | Calcium Carbonate | 6.565.000 | 265.000 |
| 13 | Flor de Los Andes S.A., *Monte Patria* | Flor de Los Andes | Lapiz lazuli | 6.542.200 | 354.100 |
| 22 | Minera Altos de Punitaqui, *Punitaqui* | Cinabrio | Copper | 6.588.735 | 288.540 |
| 22 | Cia. Minerial Tierra Del Fuego, *Ovalle* | El Dorado | Iron | 6.617.500 | 286.500 |

Besides this recent information of 2012, there are new mining projects on the way, information had been gotten out of press information of the region (see links in Literature chapter).

Furthermore, there is an important mining plant to mention, since it has still an influence on the management, especially on water quality, the *Panulcillo plant*, also known as *"La cocinera"*. It has been property of ENAMI (state-owned mining company) since 1982, which means that it was minimum 28 years in function. It processed minerals which were bought from small and medium mines. Its location was just before entering at the city Ovalle and next to the Ingenio creek and therefore contamination there and further downstream in the Limarí River are being still detected. The plant was closed in 2010, and replaced with the new opening of the Delta plant of ENAMI (ENAMI, Planta Delta), which is also located in Ovalle province but more or less 10 km before reaching Ovalle coming from La Serena. Due to ENAMI the plant provoked for years environmental problems for the city of Ovalle (ENAMI, 2009). The Delta plant benefits today about 328 mining producers in the area (Mineria chilena, 2012).

*3.1.1 Drinking Water*

Potable water provider can be distinguished in urban and rural areas. The private company *Agua del Valle*, provides the region with potable water in the urban or semi-urban areas, whereas the so called APRs (Agua Potable Rural) have been emerged out of the habitants of the rural area, to provide their sectors with potable water supply. The more recent information which could be received in time was the number of APR and their location with date of Nov. 2012. The details about water rights (l/sec) have to be consulted by the DOH or DGA, until the end of the report these information could not be accessed.

The information which was provided summed up to 73 APR in the basin, from which for 63 locations UTM coordinates were given and are shown in the following Figure 14. Since most of the locations are the locations of the wells which provide them with groundwater, they are almost all next to the rivers, since the aquifers in the basin in general have an interaction with the rivers.

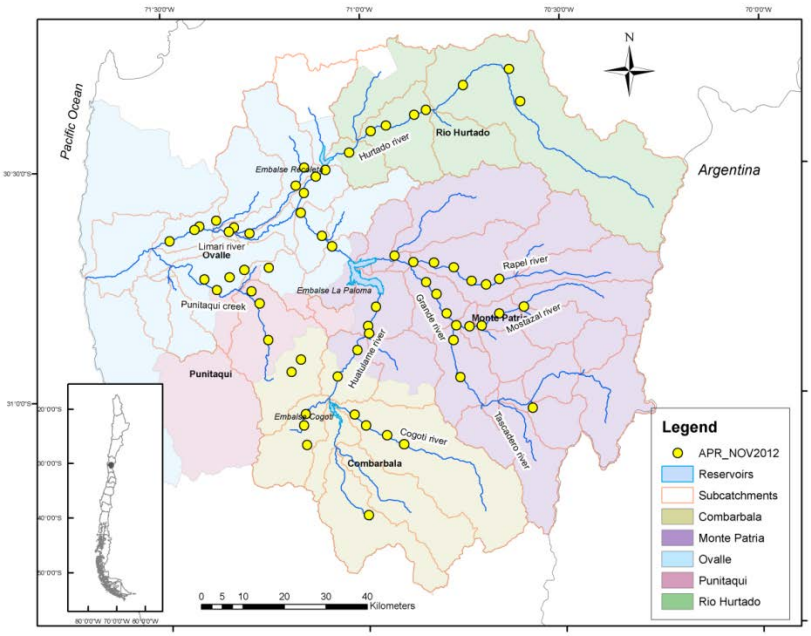


Figure 8: Location of the rural potable water provider (APR: Agua potable rural) in the Limarí basin (Source: elaborated out of data acquired from DOH, 2012)

Even though the spatial distribution looks already quite good not all areas until now are covered because for example sometimes one APR serves just 50 families. The areas which are not covered are served by the regional company "*Aguas del Valle"* through water delivery by trucks. During the last month of the drought period (end of 2012/ beginning of 2013) especially the Commune of Combarbalá started suffering water shortage in potable water supply, which was getting on a peak of getting less than 50% of the normal water allocation in Februray 2013, here especially through water delivery by trucks (Semanario el Tiempo: Feb. 2013).

*3.2 Environment*

Two conservation areas are located in the Limarí province, one national park and one natural monument. The national park "Bosques de Fray Jorge" is situated in the commune of Ovalle in the lower part of the basin. It has a surface of 9,959 ha and is being conserved since 1941. The natural monument "San Pedro de Pichasca" located in the commune of Río Hurtado, with a surface of 128 ha, is being conserved since 1972.

Both sides are also the only ones which are named in a more recently published book defining priority sides for conservation (Squeo et al, 2001). In this study two more sites are mentioned " El Durazno", in Combarbalá and "Cuesta El Espino", without providing detailed information. Compare Fig 7 for the location of these areas.

3.3 Hydropower

In the main Paloma reservoir in July 2010 a small hydro power plant was constructed, run-of-river installation, but with storage. There is no conflict with irrigation as only the water which is released for irrigation purposes is used beforehand. The plant consists of two turbines and an installation capacity of 4.5 MW, with a designed discharge of 12 m3/s and an average energy production of 19.000.000 Kw/h. Currently it is not operating due to water scarcity.

Furthermore, there is a small hydropower plant in the river Los Molles, which is in place since 1952 (Central Los Molles, 1952) with a capacity of 16.000 kW. Thus, it is categorized as small hydropower plant (100kW-30MW).

## 4. Governance

*4.1 Water Policies*

In 1999, the DGA elaborated a National Water Resources Policy (*Política Nacional de Recursos Hídricos*) which included the following general objectives: (a) To ensure an adequate water supply to meet the basic needs of the population; (b) To improve water use efficiency at the watershed level within a framework of economic feasibility, considering that water is a scarce good in a large part of the country; (c) To focus delivery of the water resource on those demands that present the greatest economic, social and environmental benefit for the country; (d) To maximise the contribution of water resources to the country's growth through the development of unused sources and reuse; (e) To decrease the impact of hydrological variability on the country's activities; (f) To recover the existing environmental liability and to ensure the development of water resources without incurring environmental deterioration; (g) To minimise the level of water-related conflicts and thus to contribute to social peace.

One of the most important advances that have been introduced with the Law of Associations of "*Canalistas*" of 1908 was to grant juridical personality to the water communities and to establish a practical way of linkage between the water rights of every associate. Thus they gave birth to the *"irrigator (Regador)"* like unit of measurement corresponding to the water quantity that a worker could handle to carry out the irrigation. In turn the law of Associations of *"Canalistas"* determined that *Irrigator* would correspond to aliquot parts of the water of the aqueduct, being another measurement unit able to be specified in the statute (Alvarez P, 2005 in Oyarzun R. et al, 2011).

Later the Code of 1951 added other forms of organization named like water Communities (Comunidades de Agua) and Associations of Rivers (Juntas de Vigilanica), institutions that still persist in the current Code. In any case it is important to mention that the current Code allows the persons who possibly could constitute a users' organization to be able to organize themselves like a Society of any type (Alvarez P, 2005 in Oyarzun R. et al, 2011).

The title III raises that "if two or more people have the water rights of the same channel or reservoir […] they will be able to regulate the community resulting out of this, be constituted in association of "*canalistas"* or any type of society, in order to take the waters of the main channel and distribute it between the water right holders […]. In case of natural river beds they will be able to organize themselves as, *"Junta de Vigilancia*". Afterwards it is stated that as soon as they are registered in the

records of the DGA (Water agency in Chile) they are accepted as organized. After the register holds the statute of the above mentioned community it can be inscribed (Alvarez 2005 in Oyarzun R. et al, 2011).

The water management in Chile and its effects represent an extreme case of management of a scarce natural resource in an economic context and a neo-liberal political framework. The water code of 1981 (Codigo de agua) stipulates that water is a national resource for private use and allows private transferable property rights for water use (Alvarez et al, 2006).

In more detail the article I of the water law of 1981 divides the terrestrial waters in superficial and groundwater. It is important to comprehend that the intention of the water law to separate conceptual surface and groundwater in order to create later different kind of water rights for each of them. In general, the owners of groundwater rights operate individually as mentioned before, while those of surface water form users' associations (Alvarez y Oyarún, 2006).

Article VII establishes that the enrolled water rights can independently be mortgaged from the land area to which his owner will have them assigned to. This means that once obtained, the location of a water right can be managed separately to the property of land initially assigned, according to different arbitrary criteria (Alvarez et al, 2006).

With regard to ownership and use of the water, the article II of the water law establishes clearly that "the water is national good of public use and the right of use is granted to the individuals; after the surface water enters a channel, its character changes from a national good of public use to a temporary property of the owners of the right using the channel systems. During this time they are able to retain it.

The water code was modified and advanced constantly. A large modification of the "Código de Aguas" took place in 2005 through the law Nº 20.017, which affected mainly the rights of exploitation[1]. In 2006 it was modified again by the law Nº 20.099 which extended the deadline for regulating the right of exploitation of groundwater by one year and introduced other modifications to the law Nº 20.017. In 2008 another modification through the law Nº 20.304 was introduces; it's about the operation of the reservoirs in the case of alerts and floodwater-emergencies and other risk indicators. The last up to date modification took place in 2010 by the law Nº 20.417 and implicated the creation of the ministry of environment, the environment evaluation service and the environment supervisory authority (Internal report: Kretschmer/Wendt 2011).

1 Law Nº 20.411 of 2009 prohibits the constitution of rights of water exploitation in certain zones or areas by virtue of Art. 4° transitional of law N° 20.017 of 2005.

*4.2 Institutions*

In the following table the stakeholder apart of the private farmer organizations are listed, which also represent the institutional capacity concerning IWRM in the basin.

Table 4: Institutional capacity concerning IWRM (Source: elaborated out of different sources: Kretschmer/Wendt, 2011, Internet Sources)

| Institution | Mission/ Idea[2] | Function |
|---|---|---|
| DGA (General Water Directorate) | State organization encouraged to advance the sustainable management and administration of the water resources, as a public interest and a efficient allocation; publish and care for the information generated through its hydrometric net and the data content in the public water cadastre, with the aim to contribute the competitiveness of the country and improve life quality of the persons | - Arrange the development of the water resources in the natural sources, with the goal to formulate recommendations for its exploitation.<br>- Constitute rights of water exploitation<br>- investigate and measure the resources<br>- maintains and operates the national hydrometric service, obtain and publish the corresponding information.<br>- control the compliance of police and supervising laboratory of water in the natural riverbeds under public use and prohibit construction in the riverbed which are built without permission of the authority<br>- Supervises the operation of the river and canal associations (Juntas de Vigilancia), in accordance to the device in the "Código de Aguas". |
| SISS (supervisory of sanitary services) | Participates in the establishment of norms and standards in its sphere of competence, and attends to the spread of information about the market referring to the national sanitary sector. | - regulation of the tariffs for the service of potable water and canalization of sewage water, which are provided by the sanitary companies<br>- the authorization of concessions for sanitary services<br>- supervising of the sanitary companies, partly referring to the quality of the provided service<br>- Supervision of the industrial establishments which generate industrial liquid residues. |
| Aguas del Valle (private) | Sanitary company of the region of Coquimbo | - has the concession to distribute potable water and recollect the served water in the concession area (the whole Limarí basin, except the commune of Río Hurtado) |
| APR Comités de Agua Potable Rural | Private organisations in the rural areas which are providing access to potable water | - rural sectors organize themselves to form an APR and get capacitation of the provinal gpvernment to manage the water in their sectors, which includes construct an dmaintain the necessary structures, and administration of all users; as source they use normally groundwater |
| CNR (Comisión Nacional de Riego) | Creation of the National Commission of Irrigation (CNR) in 1975, in order to constitute a public entity entrusted to coordinate the efforts and to supervise the investments in irrigation in the country. Additionally, in the year 1985 the administration of the Law 18.450[3] (last version of 2009) was incorporated inside its functions: Promotion of Investment to small Irrigation and Drainage works. | - They are in charge to coordinate, implement and evaluate permanent the National Politics of Irrigtaion by means of plans and programs that allow to improve and increase the surface of irrigation of the country, across initiatives of investment that optimize the use of the water resource in the agriculture.<br>- One of the main functions of the CNR is to strengthen the management of the organizations of farmers, with the objective, to promote the water market and the efficient use of the water resource [4] |
| DOH (Dirección | State division for water Works (part of the Ministry for public | - Responsible for studies, future projection, construction, reparations and the development of hydraulic works that are |

[2] Information found on www.dga.cl, www.siss.cl and www.aguasdelvalle.cl.
3 More: http://www3.cnr.cl/opensite_20041126124214.aspx
4 http://www.minagri.gov.cl/institucion/servicios-del-agro/cnr/

| | | |
|---|---|---|
| de Obras Hidráulicas) | construction: Ministeri de Obras Publicas) | realized by public funds (works of irrigation and certain channels in urban areas, drainage and water collection structures, works of sanitation and recovery of areas).<br>- Responsible also for the development of the Master Plans, which define systems of evacuation of rainwater in urban centers. |
| SAG (Servicio Agrícola y Ganadero: Service for Agro(forestry) and pecuario) | Its objective is to develop the industry in Chile by means of the protection of its productive resources. | - Responsible of the control of contamination by the industrial and mining activities and the discharge of the treatment plants.<br>- Pursuit of the agricultural practices since the companies that commercialize phytosanitary products must declare to them their sales (but this isn't applied to the fertilizers).<br>- It has a network of control of the water quality to evaluate the impact of human activities (mining, industry, treatment plants). The SAG can control for exceeding the norms, but the totals of the fines are too low to be effective. |
| INIA<br>INDAP | Instituto de Investigación Agropecuarias<br>Instituto de Desarrollo Agropecuario | - Organization of capacitating measures to farmers and they are<br>- entrusted of research programs and/or transference of technologies with regard to the irrigation. |

*4.3 Key decisions*

**Environmental guidelines:**

Two types of environmental guidelines (standards) exist in Chile: the primary Guideline of water quality and the secondary guideline of water quality. The first mentioned one has as a target to protect the health of the population and is being applied in the whole country equally. The second seeks to protect the natural resources and others such like cultivation, ecosystems, and species of flora or fauna, national monuments or places with archaeological value. The environmental quality norms are the following ones:

- DS 145/02 or primary guideline of environmental quality to protect uses in continental waters, takes as a target to protect the health of the population and it will be applied in the whole country equally (still in elaboration: Bernardin (2009), no actualization found in 2013).
- Secondary environmental quality guideline for superficial and marine continental waters. Targets of specific background qualities to the catchments of the country are defined to protect the water resources and aquatic medium. The program started in December, 2004, when the Guideline of CONAMA (CONAMA, 2004) with the same name was published. This guideline had the objective to serve as a technical background, for the elaboration and homogenization of the secondary norms of water quality for all the basins in the country. Four classes of environmental quality are defined:
  - *Exceptional*: It indicates a water of better quality than the Class 1, which for its extraordinary purity and scarcity, forms part of the environmental patrimony of the Republic. This quality is adapted also for the conservation of the aquatic communities and other defined uses which quality requests are lower than this Class.
  - *Class 1*: Very good quality. It indicates adequate water for the protection and conservation of the aquatic communities, for the irrigation without restriction and for the uses defined in the Classes 2 and 3.
  - *Class 2*: Good quality. It indicates adequate water for the development of aquaculture, of sports and recreational fishing, and for the uses understood in the Class 3.

- *Class 3*: Regular quality. It indicates adequate water for animals and for restricted irrigation.

If the water is classified as one of the before mentioned four quality classes it is appropriate for potable water supply after possible treatment (depending on the class).

Water, that exceeds the limits established for the Class 3, will indicate a water of bad quality (Class 4), in general not adapted for the conservation of the aquatic communities and only for potable water supply if necessary treatment is carried out (CONAMA, 2004).

**Main Chilean guidelines concerning water quality:**

- The "**Norma Chilena NCh 1.333"** with requisites of water quality for different uses of 1978, modified in 1987. It specifies extreme values of several parameters for water destined for potable water and for animals (references to the Chilean Guideline NCh 409 of drinking water), for irrigation purposes, water for aquatic life, water for recreational use with or without direct contact, and for the esthetic value.

  It is the guideline of reference to irrigation water, and the guideline which is used to analyze the quality of the water in a catchment.

- The **guidelines of emission** (supreme decrees) that regulate the discharges of liquid effluent to water bodies.

  a) The DS 90/2001 for the regulation of pollutants associated with the discharges of liquid residues in superficial marine and continental waters;
  b) The DS 601/2004 and DS 3592/2000 that modify the DS 609/98 MOP for the regulation of pollutants associated with the discharges of liquid industrial residues to sewerage systems;
  c) The DS 46/2003 on the emission of liquid residues to groundwater.

The compliance with that decree should be controlled by the SISS. Additionally a decree Nº 143 of the year 2009 was introduced, which sets up norms for prime quality of continental surface water that is adapted for recreation activities with direct contact.
Further, the transparency regarding the operative model for water allocation and distribution, considering the rights to be served and the available water stored, should go beyond the organization and reach the individual water right users and owners. This will require the establishment and development of an integrated protocol for the system.

## 5. Problems/challenges

*5.1 Water quality and bio diversity*

The growth of the area conjugates to challenges of environmental, economic and social nature. Environmentally, the sector of Agroforestry (*Spanish: silvoagropecuario*) of the province is strongly influenced by the vine monoculture, using inputs that are absorbed from the environment temporary and/or permanently. In this way, the biodiversity of flora and fauna is diminished by agriculture in a direct way and simultaneously threatened by the presence of agricultural residues in the physical environment (DGA, 2009).

The historical tendencies of the quality parameters demonstrate tendencies in increase in the low part of the basin where the problems of salinity are observed. The levels of the parameters of salinity in the lower part are deteriorating since 1985. An increase of the pH was observed also in almost the whole

basin (Meza F., 2009). Unfortunately, rarely historical and also actual information exist on the quantities of insecticides used in the area, but the measurements in the surface waters did not demonstrate presence of pesticides, except Methamidophos in very low concentrations (SAG, 2007).

*5.2 Climate change predictions*

It is widely recognized that anthropogenic $CO_2$ emissions will bring major changes to the world´s climate system as described in the last IPCC report in 2007. Christensen et al. (2007) report a temperature increase for Southern South America between 1.7 and 3.9 °C, with a median value of 2.5°C compared to the 1980-1990 baseline and significant precipitation decrease (Christensen et al., 2007). Also regarding future flow estimations, projections of Atmosphere-Ocean General Circulation Model (AOGCM) ensembles suggest reduced flow regimes in Chile over the next 50-100 years under climate change forcing (Milly et al., 2005). These changes in flow regimes might have a severe impact on the local population in the whole arid and semiarid zones of South America (Sivakumar et al., 2005).

The dependency on the Andean cryosphere and melting water in springtime for irrigation water supply makes Central Chile and its population extremely vulnerable to Climate Change impacts (Barnett et al., 2005).

Souvignet et al (2010) point out that enhanced snow and glacier melt due to increasing temperatures in the short term will accelerate runoff in spring time. This means that during the next decade significant water amounts are expected to fill the reservoirs and hence be available for irrigation. In the long run, however, reduced precipitation and snow cover on the one hand and increasing temperatures on the other are expected to make glaciers and rock glaciers melt away completely, produce significantly less runoff and hence provide less water for irrigation (Souvignet et al., 2010; Vicuña et al., 2010). These changes in flow regimes would severely affect the agricultural productivity, reduce socioeconomic development and lead to increased drought events in the region. Young et al. (2010) also suggest that soil sealing during extremely dry periods will increase the flood risk caused by higher precipitation events in winter (Young et al., 2010).

# 1 References


Adam, J.C.; Hamlet, A. and Lettenmaier, D.P., 2009, Implications of global climate change for snowmelt hydrology in the twenty-first century, Hydrological Processes, 23, 962–972 (2009), DOI: 10.1002/hyp.7201.

Alvarez, P., 2005, Un estudio del viaje del agua: un enfoque agronómico y geográfico de la situación del manejo del riego en una zona árida de Chile (en francés). Tesis Doctoral, Universidad de Orleans, Francia. 298 pp.

Alvarez, P., Oyarzún, R., 2006, Interacción río-acuífero en zonas áridas: contexto legal y análisis de casos. VIII Congreso Latino Americano de hidrología subterránea (ALSHUD). Asunción, Paraguay.

Álvarez, P., Kretschmer, N., Oyarzun, R., 2006, "Water Management for Irrigation in Chile: Causes and Consequences, Technology, Resource Management and Development" paper presented at the international water fair "Wasser Berlin 2006".

Arenson, L.U. & Jakob, M., 2010, The Significance of Rock Glaciers in the Dry Andes - A Discussion of Azocar and Brenning (2010) and Brenning and Azocar (2010), Permafrost and Periglacial Processes, vol. 21, no. 3, pp. 282-285.

Azócar, G.F. & Brenning, A., 2010, "Hydrological and geomorphological significance of rock glaciers in the dry Andes, Chile (27°/33°S)", Permafrost and Periglacial Processes, vol. 21, no. 1, pp. 42-53.

Barnett, T. P.; Adam, J. C. and Lettenmaier, D. P., 2005, Potential impacts of a warming climate on water availability in snow-dominated regions, Nature 438, 303-309, doi:10.1038/nature04141.

Barsch, D., 1996, Rockglaciers. Book in Springer-Verlag, Berlin. 331 p.

Bates, B.C.; Kundzewicz, Z.W.; Wu, S. and Palutikov, J.P.; 2008, Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, Geneva, IPCC Secretariat.

Bernardin, F.,2009, Informe de Practicas: Diagnostico de la calidad de las aguas superficiales en la cuenca del Limarí (IV Región – Chile), CEAZA/INIA/ INRA-UMR LISAH.

Bocchiola, D., Diolaiuti, G., Soncini, A., Mihalcea, C., D'Agata, C., Mayer, C., Lambrecht, A., Rosso, R. & Smiraglia, C., 2011, Prediction of future hydrological regimes in poorly gauged high altitude basins: the case study of the upper Indus, Pakistan, Hydrology and Earth System Sciences, vol. 15, no. 7, pp. 2059-2075.

Bocchiola, D. & Groppelli, B., 2010, Spatial estimation of snow water equivalent at different dates within the Adamello Park of Italy, Cold Regions Science and Technology, vol. 63, no. 3, pp. 97-109.

Bodin, X., Rojas, F. & Brenning, A., 2010, Status and evolution of the cryosphere in the Andes of Santiago (Chile, 33.5 degrees S.) RID E-6022-2011, Geomorphology, vol. 118, no. 3-4, pp. 453-464.

Boucharel, J., Dewitte, D; du Penhoat P., Garel, B.;Yeh, S.-W; Kug, J.-S., 2011, ENSO nonlinearity in a warming climate, Climate Dynamics (2011) 37:2045–2065, DOI 10.1007/s00382-011-1119-9.

Brenning, A., 2010, The Significance of Rock Glaciers in the Dry Andes - Reply to L. Arenson and M. Jakob, Permafrost and Periglacial Processes, vol. 21, no. 3, pp. 286-288.

Brenning A., 2005, Geomorphological, hydrological and climatic significance of rock glaciers in the Andes of Central Chile (33–35-S). Permafrost and Periglacial Processes 16: 231–240. DOI: 10.1002/ppp.528.

Chauvin, G.M., Flerchinger, G.N., Link, T.E., Marks, D., Winstral, A.H. & Seyfried, M.S., 2011, Long-term water balance and conceptual model of a semi-arid mountainous catchment, Journal of Hydrology, vol. 400, no. 1-2, pp. 133-143.

CEAMA, 2007, MÓDULO DE CÁLCULO, Hidrodem: Grupo de Ríos y Embalses (UGR - CEAMA) http://www.riosyembalses.com.

CEAZA, 2005, Levantamiento de situación base para el Programa Territorial Integrado (PTI) Cuenca Limarí. Informe Final. 122 p. y Anexos.

Central los Molles, 1952, Endesa, Empresa Nacional de Electricidad S.A., Chile.

Chaves, H.; Alipaz, S., 2007, An Integrated Indicator Based on Basin Hydrology, Environment, Life, and Policy: The Watershed Sustainability Index, Water Resources Management (2007) 21: 883–895, page 889.

CIREN, 1994, Estudio Agrológico de los valles de Choapa, Illapel y Limarí, Centro de Información de Recursos Naturales.

CIREN, 2011, Catastro frutícola, Principales Resultados, IV. Región de Coquimbo, Julio 2011, CIREN ,ODEPA (noch webseite anfügen).

CIREN, 2012, Describciones de suelos, Materiales y Simbolos, Publicación CIREN no. 129, Propiedad Intelectual N°151.231, ISBN956-7153-65-5, , Esta edición complementa la cartografía digital de suelos, actualizada

sobre 215 ortoimágenes satelitales año 2010-2011 en escala de salida 1:10.000 (the map in the annex shows the area of study).

Christensen J.H., Hewiston B., Busuioc A., Chen A., Gao X, Held I, Jones RG, Kolli RK, Kwon W-T, Laprise R, Magana Rueda VO, Mearns LO, Menedez CG, Räisänen J, Rinke A, Sarr A, Whetton P, 2007, Regional Climate Projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK, p. 848-926.

Collins, M.; Chandler, R.E.; Cox, P.M.; Huthnance, J.M.; Rougier, J.; Stephenson D.B., 2012, Quantifying future climate change, Nature Climate Change, 403–409, doi:10.1038/nclimate1414.

Comunidades de Aguas Subterráneas, 2011, Ficha Technica 4, Centro del Agua para la Agricultura, en pdf (source: http://www.centrodelagua.cl/documentos/difusion-documentos/ficha4%20Aguas%20Subterraneas.pdf).

CONAMA, 2004, Guía CONAMA para el establecimiento de las normas secundarias de calidad ambiental para aguas continentales superficiales y marinas.

DGA, 2004, Diagnostico y clasificación de los cursos y cuerpos de agua según objetivo de calidad, Cuenca del Limarí, Ministerio de Obras Públicas, Gobierno de Chile 2004, http://www.sinia.cl/1292/articles-31018_Limari.pdf, accessed in November 2011.

DGA, 2004, Diagnóstico y Clasificación de los Cursos y Cuerpos de Agua según Objetivos de Calidad. Cuenca del Río Limarí. Elaborado por CADE-IDEPE Consultores en Ingeniería.

DGA, 2008, Evaluación de los recursos hídricos subterráneos de la cuenca del río Limarí; Informe Tecnico, S.D.T N° 268, Dirección General de Aguas, Departamento de Administracion de Recursos Hidricos,Santiago.

DGA, 2009, Antecedentes para el análisis general del impacto económico y social de la norma de calidad secundaria de aguas continentales superficiales en la cuenca del Limarí. Anexo: caracterización de la cuenca del Limarí, realizado por la Universidad Católica del Norte, S.I.T. N° 197, Santiago, Diciembre 2009.

DGA, 2011, Escenario Hidrico 2012-2020 de la Region de Coquimbo, Lanzamiento de Mesa de Sustantablidad Minero, 06 Diciembre 2011 (Presentation).

ENAMI, 2009, Empresa nacional de Mineria, Memoria 2009 (http://www.enami.cl/memorias.html).

ENAMI, Planta Delta: http://www.enami.cl/nuestra-labor/produccion/plantas-de-beneficios/planta-delta.html.

Espinoza, M. C., 2005, "Vulnerabilidad de los Acuíferos en los Ríos Limarí y Maule Mediante las Metodologías GOD y BGR". Universidad de Chile. Facultad de Ciencias Físicas y Matemáticas. Departamento de Geología.

FAO, 2002, Digital Soil Map of the World and derived soil properties. Land and Water Digital Media Series #1 rev 1. FAO, Rome.

FAO–UNESCO, 1970–1981, Soil map of the world 1:5 000 000. Vol. 2–9. Paris.

FAO–UNESCO, 1988, Soil map of the world. Revised legend. World Soil Resources Report No. 60. Rome.

Favier, V., Falvey, M., Rabatel, A., Praderio, E. and D. López, 2009, Interpreting discrepancies between discharge and precipitation in high-altitude area of Chile's Norte Chico region (26–32°S), Water Resources Research, 45, W02424, doi:10.1029/2008WR006802.

Fernandez, B. L., Pizarro G. P., 1996, Statistical estimation of runoff characteristics of watersheds in central Chile, Hydrological Sciences 41(5): 735-749.

Garreaud, R.D., Vuille, M., Compagnucci, R. & Marengo, J., 2009, Present-day South American climate. Palaeogeography, Palaeoclimatology, Palaeoecology 281(3-4): 180-195.

Hadjigeorgalis, E. & Lillywhite, J., 2004, The impact of institutional constraints on the Limari River Valley water market. – Water Resources Research 40, 5, W05501.

Hearne, R. & Easter, K., 1995, Water Allocation and Water Markets. An Analysis of Gains -from -Trade in Ch
Bank – Papers. – Policy Research Working Papers.

INE, 2007, Censo Agropecuario, 2007, www.inecoquimbo.cl; accessed on the 18.04.2012.

INIA, 2009, Tierra adentro, frutales y viñas, Valle del Limarí, un aporte a la fruticultura chilena, http://www.inia.cl/link.cgi/; accessed on the 12th of March 2012.

INIA-CEAZA (2009). Instituto de investigaciones agropecuarias Inia-Intihuasi en colaboración con el centro de estudios avanzados en zonas áridas Ceaza (2009) II Informe Técnico: desarrollo de un modelo de gestión integral para el resguardo de la calidad de las aguas en los valles de Huasco, Limarí y Choapa.

Jorge Espinosa, Hamil Uribe, José Arumí, Diego Rivera, Alejandra Stehr, 2011, Vulnerabilidad del recurso hídrico respecto a actividades agrícolas en diferentes subcuencas del Rio Limarí, sociedad chilena de ingeniería hidráulica XX Congreso Chileno de Hidraulica, 2011.

Kalthoff, N., Fiebig-Wittmaack, M., Meißner, C., Kohler, M., Uriarte, M., Bischoff-Gauß, I. & Gonzales, E., 2006, The energy balance, evapo-transpiration and nocturnal dew deposition of an arid valley in the Andes, Journal of Arid Environments, vol. 65, no. 3, pp. 420-443.

Klein, A.G., Seltzer, G.O. & Isacks, B.L., 1999, Modern and last local glacial maximum snowlines in the Central Andes of Peru, Bolivia, and Northern Chile, Quaternary Science Reviews, vol. 18, no. 1, pp. 63-84.

Kretschmer, N., Wendt, A., Oyarzún, R., 2012, Watershed management: Its scope, a general analysis of its situation in Chile, and one approach to deal with it integrating environmental, political and social issues, in: Chile: Environmental, Political and Social Issues, page 69 -90, e-book, Novapublisher 2012 (https://www.novapublishers.com/catalog/product_info.php?products_id=34763).

Kretschmer, N., Wendt, A., Oyarzún, R., Henrique, C., 2011, El índice de Sostenibilidad de Cuencas en la cuenca del Río Limarí en Chile, Memorias del Segundo Simposio Internacional: Construyendo Caminos de Conocimiento para un Futuro con Sostenibilidad Hïdrica (p.318-325), Programa Hidrológico Internacional, Hidrología para el Ambiente, la Vida y las Políticas –HELP, Panamá 21-24 noviembre 2011.

Kretschmer, N., Wendt, A., Oyarzún, R., Henrique, C., 2011, The Watershed Sustainability Index in the Limarí River Basin, Chile, Journal of Hydrological Environment, UNESCO IHP HELP Programme; Special Edition, Vol. 7, No.1, December 2011.

Kull, C., Grosjean, M. and Veit, H., 2002, Modeling modern and late Pleistocene Glacio-climatological conditions in the north Chilean Andes (29– 30_S), Climatic Change, 52, 359– 381.

La Paloma, 2008, En histórico acto regantes de Limarí firmaron convenio que les entrega la administración del embalse La Paloma para riego más grande de Chile y el segundo de América del Sur.

La Paloma, 2010, Hydro electric power plant (http://antiguo.minenergia.cl/minwww/opencms/02_Noticias/index/noticia_detalle.jsp?noticia=/02_Noticias/10.0.1.6.noticias_anteriores/f_noticia_08_07_2010-2.html&nom=; http://www.elobservatodo.cl/admin/render/noticia/17575

La Tercera, 2012, Gobierno decreta zona de catástrofe a diez comunas de Región de Coquimbo por situación hídrica, http://www.latercera.com/noticia/nacional/2012/08/680-476613-9-gobierno-decreta-zona-de-catastrofe-a-diez-comunas-de-region-de-coquimbo-por.shtml, accessed on 7th of August 2012.

León, A., Montana, E. & Fuster, R., 2002, Riego y pobreza rural: dos estudios de caso en la región semiárida de Chile y Argentina: la comparación de dos cuencas hidrográficas en Chile y Argentina. – Eval. Usos del Agua en Tierras Secas de Iberoamérica 12, 65–92.

León, A. & Garay-Flühmann, R., 2005, Public policy as a means to increase human security in agriculture in a drought-prone area of northern Chile, Department of Environmental Sciences and Renewable Natural Resources, Faculty of Agricultural Sciences, University of Chile, Human Security and Climate Change, An International Workshop, Holmen Fjord Hotel, Asker, near Oslo, 22–23 June 2005.

Le Quesne, C., Acuña, C., Boninsegna, J.A., Rivera, A. & Barichivich, J., 2009, Long-term glacier variations in the Central Andes of Argentina and Chile, inferred from historical records and tree-ring reconstructed precipitation, Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 281, no. 3-4, pp. 334-344.

Mardones, M., Gonzalez, L., King, R. & Campos, E., 2011, Holocene glacial variations in Central Patagonia, Aisen, Chile: geomorphological evidences, Andean Geology, vol. 38, no. 2, pp. 371-392.

Mayewski, P.A., Meredith, M.P., Summerhayes, C.P., Turner, J., Worby, A., Barrett, P.J., Casassa, G., Bertler, N.A.N., Bracegirdle, T., Garabato, A.C.N., Bromwich, D., Campbell, H., Hamilton, G.S., Lyons, W.B., Maasch, K.A., Aoki, S., Xiao, C. and van Ommen, T., 2009, State of the Antarctic and Southern Ocean climate system, Reviews of Geophysics, vol. 47, RG1003, doi: 10.1029/2007RG000231.

Mc Avaney, B.J. et al., 2001, Model Evaluation. In: J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J.v.d. Linden, X. Dai, K. Maskell and C.A. Johnson (Editors), Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, UK, pp. 471–524.

Mc Phaden, M. J., Zebiak, S.E., Glantz, M. H., 2006, ENSO as an Integrating Concept in Earth Science, Science 15 December 2006: 314 (5806), 1740-1745. [DOI:10.1126/science.1132588].

Milly, P.C.D., Dunne, K.A. and Vecchia, A.V., 2005, Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate, Nature, 438: 347 - 350

Minetti, J.L., Vargas, W.M., Poblete A.G., Acuña L.R., Casagrande, G., 2003, Non-linear trends and low frequency oscillations in annual precipitation over Argentina and Chile, 1931–1999, Atmosfera 16:119–135.

Mineria Chilena, 2012, http://www.mch.cl/noticias/index_neo.php?id=37448 [source: Ministry of Mining].

Nauditt, A., Gaese, H. & Ribbe, L., 2000, Wasserressourcenmanagement in Chile, http://www.tt.fhkoeln.de/d/itt/publications/subject_bundles.htm#2002Vol2.

Oyarzún R, Arumí JL, Alvarez P, Rivera D, 2008, Water use in the Chilean agriculture: current situation and areas for research development. In: Sorensen ML (ed) Agricultural water management trends. Nova Publishers, New York, pp 213-236.

Oyarzun, R., 2010, Estudio de caso: Cuenca del Limarí, Región de Coquimbo, Chile, Compilación Resumida de Antecedentes, Centro de Estudios Avanzados en Zonas Aridas- Universidad de la Serena (CEAZA-ULS).

Oyarzún R, P. Alvarez ,N. Kretschmer, M. Muñoz F. Meza, G. Soto, M. Soto, J. Núñez, 2011, Monografia Limari (unpublished, prepared in the context of a thematic network: Aquiferural (Metodologías de análisis y aplicación de tecnologías para el manejo sostenible de acuíferos en zonas rurales).

Oyarzún, J., Oyarzún, R, 2011, Sustainable development, threaths, inter-sector conflicts, and environmental policy requirements in the arid, mining rich, northern Chile territory; Sustainable Development, 19(4): 263-274.

Oyarzún R, Jofré E., Morales P., Maturana H., Oyarzun J, Kretschmer N., Aguirre E., Gallardo P., Toro L.E., Muñoz J.F., Aravena R (*send 2013 for evaluation*), A hydrogeochemistry and isotopic approach for the assessment of surface water-groundwater dynamics in an arid basin: The Limarí watershed, North–Central Chile.

Parga, F., León A., Vargas, X., Fuster, R., 2005, El índice de pobreza hídrica aplicado a la cuenca del Río Limarí en Chile semiárido, volumen XI; El Agua en Iberoamérica en 2005. Assessed at http://www.cricyt.edu.ar/ladyot/publicaciones/cyted_libro_XII/articulos/093.pdf on the 15th of August 2011

Parga, F., A León, X. Vargas y R. Fuster., 2006, El índice de pobreza hídrica aplicado a la cuenca del río Limarí en Chile semiárido.. Eval. Usos del Agua en Tierras Secas de Iberoamérica, 12: 93-109.

Peel, M.C., Finlayson, B.L. and McMahon, T.A., 2007, Updated World Map of the Köppen - Geiger Climate Classification. Hydrology and Earth System Sciences, 11(5): 1633 - 1644

Pizarro-Tapia, R., Cabrera-Jofre, C., Morales-Calderon, C. & Pablo Flores-Villanelo, J., 2011, Temporal variations of rainfall and flows in the Maipo River Basin, central Chile, and the influence of glacier melting on water yield (1963-2006), Tecnologia y Ciencias Del Agua, vol. 2, no. 3, pp. 5-19.

Pomeroy, J. W., R.L.H. Essery, and B. Toth, 2004, Implications of spatial distributions of snow mass and melt rate for snow-cover depletion: observations in a subarctic mountain catchment. Annals of Glaciology, 38: 195–201.

Power, S.B. & Kociuba, G., 2011, The impact of global warming on the Southern Oscillation Index Climate Dynamics, 37:1745–1754, DOI 10.1007/s00382-010-0951-7.

RHODOS-CAZALAC-DGA, 2005, Aplicación de metodologías para determinar la eficiencia de uso del agua. Estudio de caso en la Región de Coquimbo. 540 p.

Rosegrant, M.W., Ringler, C. & Zhu, T.J., 2009, Water for Agriculture: Maintaining Food Security under Growing Scarcity, Annual Review of Environment and Resources, vol. 34, pp. 205-222.

SAG, 2007, Plaguicidas más utilizados en las cuencas de Huasco, Limarí y Choapa durante los años 2005 y 2006, Servicio Agrícola y Ganadero.

Semanario el Tiempo, Feb. 2013, http://www.semanariotiempo.cl/2013/02/05/costo-de-la-tuberia-para-mejorar-entrega-de-agua-en-combarbala-no-supera-los-4-millones-de-pesos/

Sernagenomin, 2012, Anuario de la Minerai de Chile 2011, Servicio nacional de Geologïa y Mineria, Santiago, Chile 2012, www.sernageomin.cl].

Souvignet, M., Oyarzún, R., Verbist, K., Heinrich, J. Gaese H. & Heinrich, J., 2012, Hydro-meteorological trends in semi-arid North-Central Chile (29-32º S): Water resources implications for a fragile Andean region, Hydrological Sciences Journal, 57:3, 479.

Souvignet, M., Gaese, H., Ribbe, L., Kretschmer, N. & Oyarzun, R., 2010, Statistical downscaling of precipitation and temperature in north-central Chile: an assessment of possible climate change impacts in an arid Andean watershed, Hydrological Sciences Journal, vol. 55, no. 1, pp. 41-57.

Squeo, Francisco, Lopéz David, Nonoa José, 2001, Listado y Antecedentes de los Sitios Prioritarios para la Conservación de la Flora Nativa con Problemas de Conservación de la Región de Coquimbo, Libro Rojo de la Flora Nativa y de los Sitios Prioritarios para su Conservación: Región de Coquimbo, (F.A. Squeo, G. Arancio y J.R. Gutiérrez, Eds.), Ediciones Universidad de La Serena, La Serena, Chile (2001) 12: 195-202 (also in digital format: http://www.biouls.cl/lrojo/capeta_htm/libro.htm).

Stehr, A., Debels, P., Luis Arumi, J., Romero, F. & Alcayaga, H., 2009, Combining the Soil and Water Assessment Tool (SWAT) and MODIS imagery to estimate monthly flows in a data-scarce Chilean Andean basin, Hydrological Sciences Journal-Journal Des Sciences Hydrologiques, vol. 54, no. 6, pp. 1053-1067.

Strauch, G., Oyarzún, R., Reinstorf, F., Oyarzún, J., Schirmer, M. and Knöller, K., 2009, Interaction of water components in the semi-arid Huasco and Limarí river basins, North Central Chile, Advances in Geosciences, 22, pp. 51–57.

Suelos en Chile: *capitulo 2: Suelos in: Estado de Medio Ambiente en Chile, source* http://www.centrogeo.org.mx/unep/documentos/Chile/CHILEsuelos.pdf

Tahir, P., Chevallier, Arnaud, Y. and Ahmad, B., 2011, Snow cover dynamics and hydrological regime of the Hunza River basin, Karakoram Range, Northern Pakistan, Hydrology and Earth System Sciences, 15, 2275–2290.

Tudhope, A.W., Chilcott, C. P., McCulloch, M.T., Cook, E.R., Chappell, J.; Ellam, R. M.; Lea, D.W.; Lough, J.M. and Shimmield, G.B., 2001, Variability in the El Niño Southern Oscillation Through a Glacial-Interglacial Cycle; Science, Vol. 291, 23.

Verbist, K., Robertson, A.W., Cornelis, W., Gabriels, D., 2010, Seasonal predictability of daily rainfall characteristics in central-northern Chile for dry-land management, Journal for Applied Meteorology and Climate, 49(9), 1938-1955.

Vicuña, S., Garreaud, R.D. & McPhee, J., 2010, "Climate change impacts on the hydrology of a snowmelt driven basin in semiarid Chile", Climatic Change, vol. 105, no. 3-4, pp. 469-488.

Vörösmarty, C.J.; Green P.; Salisbury J.; Lammers, R.B., 2000, Global water resources: vulnerability from climate change and population growth, Science 289: 284–288.

XU, C., 2002, Textbook of Hydrologic Models, Uppsala University, Department of Earth Sciences Hydrology, Uppsala, Sweden, 168 pp.

Young, G.; Zavala H.; Wandel, J., Smit B., Salas, S., Jimenez, E. , Fiebig, E., Espinoza, R., Diaz, H. and Cepeda, J., 2010, Vulnerability and adaptation in a dryland community of the Elqui Valley, Chile, Climatic Change (2010) 98:245–276, DOI 10.1007/s10584-009-9665-4.

VII Censo Nacional Agropecuario y Forestal (2007): http://www.censoagropecuario.cl/

## *Institutional websites:*

- Government of the Limari (http://www.gobernacionlimari.gov.cl/)
- Gobierno Regional de Coquimbo: GORE COQUIMBO: http://www.gorecoquimbo.gob.cl/, http://www.gorecoquimbo.gob.cl/gore_noticias_vista.php?id_not=2163&noticia=1
- INIA (LA Serena): http://www.inia.cl/centros-de-investigacion-regionales/inia-intihuasi/
- Seremi del Ministerio de medio ambiente: http://www.mma.gob.cl/1304/w3-propertyvalue-12819.html

## *Population/Agricultural Census*

- ESTADÍSTICAS DEMOGRÁFICAS COMPENDIO ESTADÍSTICO (2011): http://www.ine.cl/canales/menu/publicaciones/compendio_estadistico/pdf/2011/1.2demograficas.pdf
- RESULTADOS PRELIMINARES CENSO DE POBLACIÓN Y VIVIENDA 2012 http://www.censo.cl/2012/08/resultados_preliminares_censo_2012.pdf
- INE (2007). Instituto nacional de estadística, Censo Agropecuario. Disponible en www.censoagropecuario.cl, but just at commune level, since 9.April 2009

- I-CET Sistema de Consulta Estadistico Terretorial OPEDA, Minsterio de Agricultura, VII Censo Agropercuario 2007, data at district level; http://icet.odepa.cl/ consulted 13.04.2011

## *Webpages about mining in the Limari*

- Foto1: http://pendientedemigracion.ucm.es/info/crismine/Aguas_contaminacion_Chile/Contaminacion_aguas_Chile.htm
- http://www.ovallehoy.cl/index.php?option=com_content&view=article&id=7440:-produccion-de-planta-delta-en-ovalle-supera-el-millon-de-toneladas-procesadas&catid=42:regional&Itemid=1208 (Article about Planta Delta, Ovalle
- http://www.semanariotiempo.cl/2012/09/14/dos-nuevos-proyectos-binacionales-mineros-en-carpeta/ (Dos proyectos en carpeta: Monte Patria/Colmillos, Andrea, Illapel)
- http://www.semanariotiempo.cl/2011/11/04/altos-de-punitaqui-concreta-primer-envio-de-6-mil-toneladas-de-concentrado-de-cobre/ (altos de Punitaqui)
- http://www.ovallehoy.cl/index.php?option=com_content&view=article&id=9110:pequenos-mineros-de-la-provincia-de-limari-reciben-retroexcavadoras&catid=44:otras&Itemid=1212
- http://www.ovallehoy.cl/index.php?option=com_content&view=article&id=10404:aprueban-ampliacion-de-faena-minera-tambo-de-oro-en-punitaqui&catid=43:empresa&Itemid=1211

## *Information about the province (political)*

- http://www.gobernacionlimari.gov.cl/filesapp/MO_LIMARI__29-10-2012.pdf: MAPA DE OPORTUNIDADES, Provincia de Limarí
- http://reportescomunales.bcn.cl/PdfPrint.php/Ovalle