

ECONOMIC VALUE OF WATER IN THE ACONCAGUA RIVER BASIN, A COMPARISON BETWEEN AGRICULTURE AND MINING SECTORS

E. Figueroa San Martin*, N. McIntyre**, Jim Smart***

* Angloamerican Chile, Copper Business Unit, Los Bronces Site, Santiago, Chile,
E-mail: eric.figueroa@angloamerican.com

** Sustainable Minerals Institute, The University of Queensland, Brisbane, St. Lucia, Queensland,
Australia, E-mail: n.mcintyre@uq.edu.au

*** Griffith School of Environment, Griffith University, Nathan Campus, Brisbane, Queensland,
Australia, E-mail: j.smart@griffith.edu.au

Abstract: In the Aconcagua River Basin (ARB), social and economic development has been undermined, mainly due to a decreasing water supply, increasing water consumption, and limitations of the water market for fostering competition fairly. Also, the lack of knowledge about the value of water is an obstacle for understanding and communicating the impact of these factors. This paper evaluates the behaviour of the water market in ARB through the Ecosystem Services Approach and the Total Economic Value concept. The main results show the range of willingness to pay and to buy by water users, and main drivers.

Keywords: Water Value, Trade-market, Water Economics, Water Management

1 INTRODUCTION

The Aconcagua River Basin (ARB) is one of the most important rivers of the central zone in Chile, supporting agricultural, industrial and mining activities and supplying water to approximately to 550,000 people. The ARB is located 130 km to the north of Santiago, and it covers a surface of roughly 7,300 km².

During the last five years, in the ARB, social and economic development has been undermined, mainly due to a decreasing water supply (drought and climate change), increasing water consumption (population growth and new water requirements from mining and agriculture sectors), low-efficiency irrigation systems, and limitations of the water market for managing water and fostering competition fairly.

Likewise, the lack of knowledge about the value of water (social, environmental and economic values) is an obstacle for understanding and communicating the impact of these issues and how they may be managed by new approaches for allocating water.

By all above, this study is conducted to support an Ecosystem Services Approach, specifically through the Total Economic Value concept, to quantify the value of water in the ARB and comparable basins in Chile. While ultimately the Total Economic Value approach would include social value assessments (equity), environmental requirements and economics benefits, under an Integrated Water Resources Management (IWRM) perspective, this project focusses on understanding the economics of water use in the ARB.

Also, the following specific objectives have been developed:

- Analyse the water trading data to understand the economic value of water for different user groups, and which factors control the value of water.
- Estimate water supply and demand curves for the main water users.
- Conclude on the applicability of TEV in ARB and recommendations for further work.

2 DESCRIPTION OF ACONCAGUA RIVER BASIN

2.1 Overview

The Aconcagua River begins in the Andes Mountains (a glacier source) at 5,400 masl, where the Juncal River joins with the Blanco River, then it flows through the central valley up to its final discharge in the Pacific Ocean.

The ARB has been separated into five administrative divisions. Four of them cover the Aconcagua River, and the fifth one covers the Putaendo River (see Figure 1).

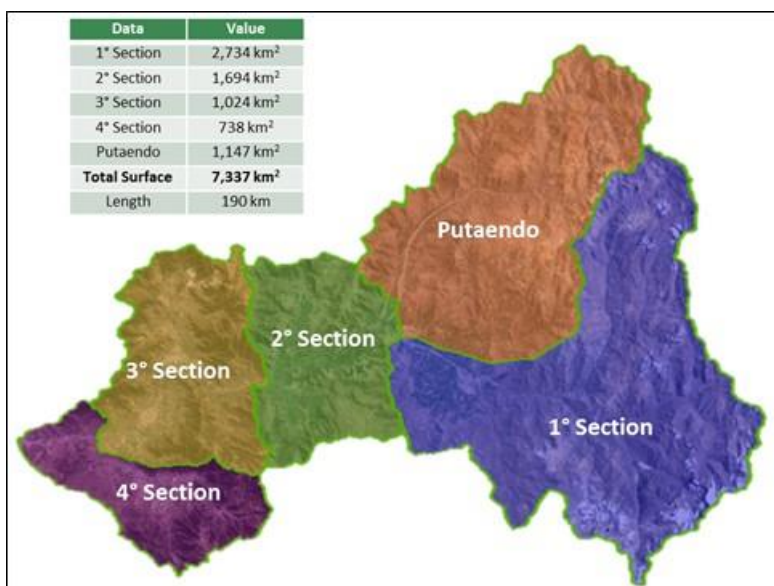


Figure 1. Aconcagua River Basin – Administrative Divisions (Figueroa San Martin, 2016).

2.2 Hydrology

About surface water, although rainfall in upper ARB occurs principally in the winter season (June-August), the peak of water flows happens during the summer season (November-February), due to water flow depending on snow and glaciers melting. Higher temperatures mean higher water flows. Average annual flows in the Aconcagua River are higher in upstream than downstream, mainly because there are a series of water canals in downstream, that use the water principally in agricultural activities.

The aquifer (groundwater) in ARB is directly linked with surface water, and it moves in the same direction of the Aconcagua river. The depth of water table is between 5.0 m-15.0 m on average (DGA, 2015).

2.3 Water Users

Main water users in ARB are represented by agriculture activities, sanitary sector (human consumption), industrial and mining activities. The agriculture sector is the most important water user, reaching the 80% of the total water requirements. On the other hand, mining activity uses roughly the 4% of the total water requirements (see Figure 2).

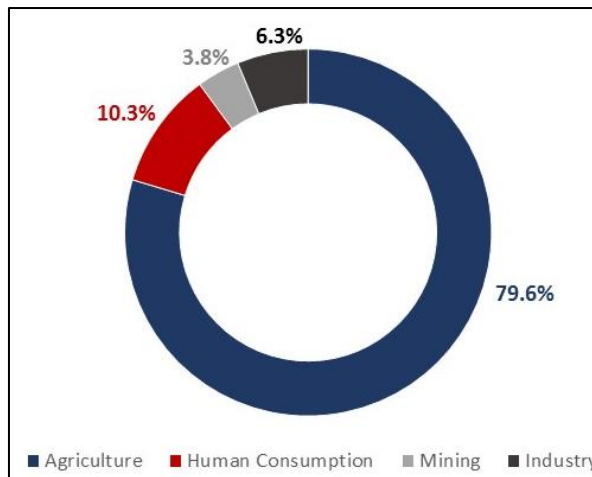


Figure 2. Distribution of Water Consumption by Sector (Cade Idepe Consultores, 2004)

2.4 Water Governance

The Water Code (WC) of 1981 is the main regulatory policy that regulates water allocation in Chile; it was developed under a strong neoliberal period. The WC establishes that water resources are a “national property for public use,” but grants permanent, transferable water use rights to individuals to reach an efficient allocation of the resource through market transactions of water user rights (Donoso, 2011). Thus, water rights are traded, inherited, and subject to the same rules of real estate (Bitrán *et al*, 2011). This allocation mechanism is known as Water Market.

The main public body that manages the Water Code is the Directorate General of Water (DGA). It is part of the Ministry of Public Works of Chile, and it is responsible for monitoring and enforcing the water user rights. Nevertheless, the DGA has maintained a limited role, imposed by the paradigm of limited state interference.

2.5 Key Challenges and Water Issues on Aconcagua river basin

During the last five years, social and economic development has been undermined, mainly due to a decreasing water supply (drought and climate change), increasing water consumption (population growth and new water requirements from mining and agriculture sectors), low efficiency irrigation systems, poor water quality, and limitations of the water market for managing water and fostering competition fairly. Main issues in ARB related to these effects are:

- Interruption of copper production in the mining sector (water scarcity)
- Decline of crops farming in the agriculture sector (water scarcity, low efficiency irrigation systems)
- Increase of algae concentration in Aconcagua river (poor water quality)
- Water shortage in rural villages (water scarcity and water competition)
- High tension between water users (water competition)

3 THEORETICAL FRAMEWORKS

The theoretical frameworks used to develop the methodology were:

- Integrated Water Resources Management
- Water Allocation Systems
- Ecosystems Services Approach
- Total Economic Value

3.1 Integrated Water Resources Management (IWRM)

Global Water Partnership (GWP) describes IWRM as a process to promote a coordinated development and management of water, land, and its related resources, with the aim of maximizing the economic and social welfare, by an equitable manner assuring the sustainability of vital ecosystems (GWP, 2000).

3.2 Water Allocation Mechanisms / Water Market

To understand how to implement IWRM principles, it is necessary to know where these principles will be applied. The water market allocation mechanism is referred to as an exchange of the water-use rights of a given quantity of water between users (Dinar *et al*, 1997). Water market mechanism plays a preponderant role in allocating water between users, distributing water to where it is most valued, and fostering an efficient use of water (Department of Environment, 2016). As mentioned before, in Chile is established a water market mechanism.

3.3 Ecosystem Services Approach

The ecosystem service approach is defined as a strategy for the integrated management of land, water, and living resources that encourage the conservation and the sustainable use in an equitable way (Convention on Biological Diversity, 2016).

The ecosystem services approach links underlying science to environmental valuation and policy development, aiming to account for the full range of ecosystem service types (provisioning, regulating, cultural, and supporting) in policy appraisal and the decision-making process. This approach is appropriate for defining the links between different socioeconomic values and changes in the ecosystem, such as river hydrology (Pascual and Muradian, 2010).

3.4 Total Economic Value (TEV)

Total economic value is intended to estimate the use (direct contact or encounter with water resources) and non-use (no direct contact or encounter with water resources) value of water. Total economic value refers to the total gain in wellbeing from a policy/program/project measured by the net sum of social willingness to pay or the willingness to accept that policy/program/project. Thus, it is possible to estimate the costs and benefits of using, protecting, or developing water resources depending on social, economic, and environmental requirements (Defra 2007). The TEV concept is presented in Figure 3.

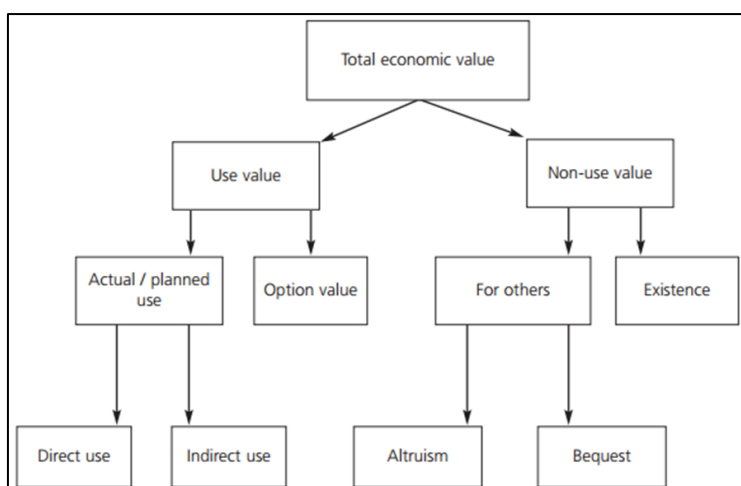


Figure 3. Total Economic Value Approach (Defra, 2007)

4 RESEARCH METHODOLOGY

The research methodology was divided into three analysis:

- i. Water price analysis
- ii. Market Prices Method
- iii. Drivers analysis

4.1 Water Price Analysis

Considering the public data of water transactions in ARB, the econometrics assessment was developed through a spatial (prices of water volume by administrative sections) and water user analysis (buyer and seller prices paid or accepted by each water user).

4.2 Market Price Method

To estimate the demand and supply curves, it is necessary to gather the results of the water price analysis by water user, and by sellers and buyers.

4.3 Drivers Analysis

A regression model analysis was developed to determine the most important drivers of water price. Through a panel data regressions, it is possible to deal with time effects and cross-sectional effects. In this case, a fixed effects regression analysis was developed.

Fixed-effects regression analyses the relationship between predictor and outcome variables within an entity. It assumes that the entity and its variables may or may not influence the predictor variables (Torres-Reyna, 2007).

5 DATA ANALYSIS AND RESULTS

5.1 Data Management

In order to organize the data by administrative divisions (sections), the following codification is presented:

Table 1. Administrative Divisions – Section Codification

ID Code	Division Name
S1	First Section
S2	Second Section
S3	Third Section
S4	Fourth Section
S5	Putando Section

In relation to water analysis the following measurements will be used:

- UF: Indexation Unit (Chile). 1UF = 40.64 US dollars (15/01/2017)
- LS: litters per second (water volume). 1 LS = 0.032 GL/year = 86.4 m³/day
- UF/LS: water price in water market. 1 UFLS = 1,280 US/GL/year = 0.47 US/m³/day

5.2 Water Price Analysis Results

From the results of the economic analysis, the average price of water in ARB during 2005-2014 was about 125 UF/LS (approximately 160,000 US dollars per Gigalitres in a year). The value of the water differs by section, going from 75 UF/LS in the Third Section to 260 UF/LS in the Fourth Section (see Table 2).

Table 2: Water Price by Section - Analysis Data, Figueroa San Martín (2016)

Administrative Section	No of water trades	Average Water Price [UF/LS]
S1	183	195
S2	421	108
S3	480	75
S4	27	260
S5	735	146
Total	1,846	125

The results of the data analysed by sellers and buyers of each water users are presented in the tables below.

Table 3. Average Price by Seller Users in each section [2005-2014] [UF/LS], Figueroa San Martín (2016)

Seller Users	No. of transactions	Section 1	Section 2	Section 3	Section 4	Section 5	Total
Agriculture	187	166	94	81	-	70	97
Bank	15	69	107	120	-	-	111
Real State	40	49	113	37	250	80	59
Investment	28	8	312	32	163	108	157
Mining	5	-	-	-	-	17	17
Other	50	62	58	103	-	52	71
Private Individuals	1,528	208	106	76	265	151	132
Sanitary	2	-	-	20	-	-	20
Total	1,855	195	108	75	260	144	125

Table 4. Average Price by Buyer Users in each section [2005-2014] [UF/LS], Figueroa San Martín (2016)

Buyer Users	No. of transactions	Section 1	Section 2	Section 3	Section 4	Section 5	Total
Agriculture	244	158	92	106	3	131	114
Bank	13	28	152	133	-	55	88
Hydroelectric	2	-	33	-	-	-	33
Real State	42	193	86	25	-	279	101
Investment	78	332	83	25	318	147	115
Mining	21	-	159	-	-	312	261
Other	63	436	133	64	109	144	149
Private Individuals	1,391	189	112	72	249	141	125
Sanitary	1	-	68	-	-	-	68
Total	1,855	195	108	75	260	144	125

From the above tables emerged the following conclusions:

- Agriculture sector prefers to buy water on S1, S2 and S5 sections (Upper Basin), but they are not interested in section S4.
- The mining sector is willing to pay more than any other sector per one unit of water volume.

- All water users are interested in buy water rights in section S2, but they are not interested in section S4.

5.3 Market Price Method Results

The results of demand and supply curves are presented in Figure 4.

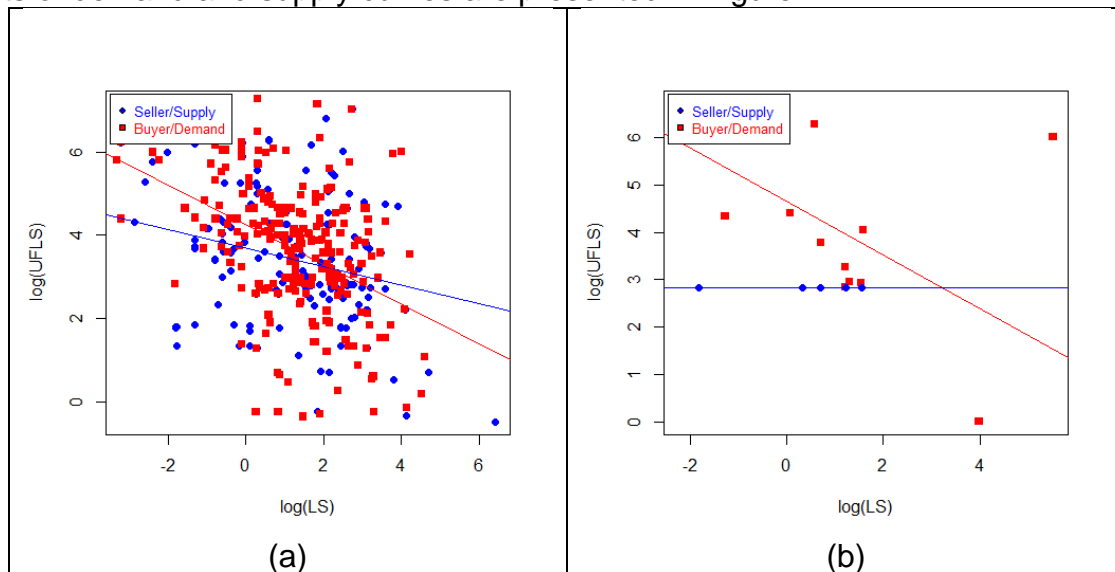


Figure 4. Demand and Supply curves in ARB in Log-scale – (a) Agriculture Sector - (b) Mining Sector,
Figueroa San Martín (2016)

5.3.1 Regression Model Results (Driver Analysis)

The regression model has been implemented in Agriculture sector because it was the only one sector that met the necessary amount of data to run the model.

The Fixed-Effects equation is presented in Eq [1], where has been incorporated the most important variables that may affect the water price.

$$\begin{aligned}
 WPA_{it} = & \alpha_1 NWT_{1,it} + \alpha_2 PP_{it} + \alpha_3 Q_{it} + \alpha_4 ET_{it} + \alpha_5 AS_{it} + \alpha_6 AI_{it} & [1] \\
 & + \alpha_7 LAG1 WPA_{it} + \alpha_8 LAG1 PP_{it} + \alpha_9 LAG1 Q_{it} + \gamma_1 SE_1 \\
 & + \gamma_2 SE_2 + \gamma_3 SE_3 + \gamma_5 SE_5
 \end{aligned}$$

where,

WPA: Water price in Agriculture Sector

NWT: Number of Transactions [N]

PP: Rainfall [mm/six-months]

Q: Water Volume in Aconcagua River [LS]

ET: Evapotranspiration [mm/six-months]

AS: Agriculture Land Surface [acres]

AI: Agriculture Incomes [UF]

LAG1 WPA: Lag(1 period) Water Price [UF/LS]

LAG1 PP: Lag(1 period) Rainfall [mm/six-months]

LAG1 Q: Lag(1 period) Water Volume in Aconcagua River [LS]

α k: is the coefficient for the drivers

γ m: is the coefficient for the binary regressors (sections in ARB)

The results are presented in tables below.

The results are presented in Table 5.

Table 5. Water Price Variables Equation / Fixed Effects, Figueroa San Martín (2016)

Variable	Agriculture Sector Sellers				Agriculture Sector Buyers			
	Coefficient	SE	t-stat	P-val	Coefficient	SE	t-stat	P-val
Linear Panel Data Model								
Number of Transactions [N]	2.476	4.220	0.58	0.560	-4.837	7.160	-0.676	0.502
Rainfall [mm/six-months]	-0.136	0.202	-	0.505	-0.151	0.393	-0.383	0.703
Water Volume [LS]	-0.167	0.114	-	0.150	-0.097	0.219	-0.444	0.659
Evapotranspiration [mm/six-months]	-0.210	0.111	-	0.064	0.098	0.193	0.506	0.615
Agri. Surface [acres]	0.045	0.037	1.23	0.224	-0.027	0.062	-0.436	0.665
Agri. Incomes [UF]	0.000	0.000	0.23	0.812	0.000	0.000	1.907	0.062
Lag(1) Water Price [UF/LS]	0.042	0.133	0.31	0.752	0.470	0.233	2.019	0.048
Lag(1) Rainfall [mm/six-months]	0.330	0.247	1.33	0.189	-0.056	0.445	-0.126	0.900
Lag(1) Water Volume [LS]	-0.101	0.093	-	0.283	0.222	0.178	1.251	0.216
S1	-88.210	324.28	-	0.786	-52.320	502.9	-0.104	0.917
S2	-180.040	386.77	-	0.642	43.097	585.6	0.074	0.941
S3	-514.660	569.20	-	0.366	102.408	874.7	0.117	0.907
S5	-216.500	390.29	-	0.579	-19.005	602.3	-0.032	0.975
R-Squared	0.141				0.174			
Adjusted R-Squared	0.110				0.141			
F-statistic	0.856				1.287			
p-value	0.570				0.265			
Non-linear Panel Data Model - Log-scale								
Number of Transactions [N]	0.385	0.219	1.75	0.086	0.076	0.194	0.394	0.695
Rainfall [mm/six-months]	-0.210	0.116	-	0.077	0.022	0.113	0.195	0.846
Water Volume [LS]	-0.194	0.250	-	0.441	-0.274	0.250	-1.095	0.278
Evapotranspiration [mm/six-months]	-1.371	0.766	-	0.080	0.141	0.683	0.206	0.837
Agri. Surface [acres]	12.564	6.017	2.08	0.042	1.167	5.424	0.215	0.830
Agri. Incomes [UF]	-0.480	1.229	-	0.698	1.440	1.107	1.301	0.199
Lag(1) Water Price [UF/LS]	0.094	0.136	0.68	0.495	0.296	0.138	2.137	0.037
Lag(1) Rainfall [mm/six-months]	0.052	0.138	0.37	0.711	0.166	0.123	1.348	0.183
Lag(1) Water Volume [LS]	-0.581	0.290	-	0.051	0.378	0.295	1.281	0.206
S1	-89.076	52.841	-	0.092	-30.354	48.09	-0.631	0.528
S2	-92.168	53.920	-	0.087	-30.351	48.97	-0.620	0.536
S3	-97.618	56.175	-	0.082	-31.238	51.06	-0.612	0.541
S5	-92.301	54.013	-	0.087	-30.121	49.13	-0.613	0.540
R-Squared	0.239				0.162			
Adjusted R-Squared	0.187				0.131			
F-statistic	1.636				1.179			
p-value	0.133				0.327			

SE: standard error, t-stat: t-statistic, P-val: P-value

-: not applicable

From the panel model regression of fixed effects, the best fit was done with the Non-linear (log model) in the seller case (supply curve), and linear model in the buyer case (demand curve). The most important drivers that define the supply curve are evapotranspiration, rainfall and land surface. In the demand curve the drivers are the water price (lag-1) and the incomes of agriculture activities.

6 CONCLUSIONS AND RECOMMENDATIONS

The Ecosystem service approach links underlying science to environmental valuation to policy development, aiming to account for the full range of ecosystem service types (provisioning, regulating, cultural and supporting) in policy appraisal and decision-making process. This approach is appropriate for defining the links between different socio-economic values and changes in the ecosystem functioning such as river hydrology. Specifically, in this study, the Total Economic Value concept has been used for producing an estimate the change in socio-economic value associated with a change water delivery (Pascual and Muradian 2010).

Complemented with IWRM principles, principally defining water as a finite and vulnerable resource and water as an economic good, the Ecosystem Service Approach and the TEV meet the

requirements of maximizing the economic and social welfare, by an equitable manner assuring the sustainability of vital ecosystems (GWP 2000).

In this study, the feasibility of assessing water price and comprehending water issues in Aconcagua river basin through the Ecosystem Service Approach, the Total Economic Value concept, and Market Price methodology, is fully developed.

The most important results are the average of water price in the transactions in Aconcagua river basin, which reaches a price of 125 UF/LS (160,000 US dollars per Gigalitres in a year). This study also includes the spatial behaviour of the water price and the drivers and factors that control the value of the water. These factors are principally the location, the type of water users (quantity, power, interests, and willingness to pay), the kind of water rights (permanents, conditional), the allocation mechanism and, in the case of the water market, the number of transactions between its users.

The Total Economic Value approach and the market price valuation is not merely an econometrics analysis. Moreover, it is considered as a mechanism that should promote the sustainability of water resources through the use of high values of water (Van der Zaag and Savenije, 2006).

Nevertheless, the applicability and implementation of the Ecosystem Service Approach and TEV valuation, in ARB and other comparable basins have to be designed as a complement for improving the water market allocation mechanism, providing key information to the stakeholders and the decision-makers.

REFERENCES

Bitrán, E, Rivera, P and Villena, M. (2011). *Water Management Problems in the Copiapó Basin Chile: Markets, Severe Scarcity and the Regulator*, Faculty of Engineering & Science, Universidad Adolfo Ibáñez, Santiago

Cade-Idepe Consultores (2004). *Diagnóstico y Clasificación de Los Cursos y Cuerpos de Agua Según Objetivos de Calidad - Cuenca del Río Aconcagua*, Dirección General de Aguas, Ministerio de Obras Públicas, Gobierno de Chile

Cochilco (2016). *Chilean Copper Production*, Comisión Chilena del Cobre, Gobierno de Chile, viewed 13 March 2016, <http://www.cochilco.cl:4040/boletin-web/pages/index/index.jsf>

Cochilco (2008). *Best Practices and Efficient Use Of Water In The Mining Industry*, http://www.cochilco.cl/descargas/english/research/research/best_practices_and_the_efficient_use_of_water.pdf

Convention on Biological Diversity (2016). *COP 5 Decision V/6*, viewed 10 May 2016, <https://www.cbd.int/decision/cop/?id=7148>

DGA (2004a). *Evaluación de los Recursos Hídricos Superficiales en la Cuenca del Río Aconcagua*, Dirección General de Aguas, Gobierno de Chile, viewed 22 April 2016, <http://documentos.dga.cl/SUP3099.pdf>

DGA (2004b). *Evaluación de los Recursos Subterráneos de la Cuenca del Río Aconcagua*, Dirección General de Aguas, Gobierno de Chile, viewed 22 April 2016, <http://documentos.dga.cl/SUB4201.pdf>

DGA (2015). *Determinación de la Disponibilidad de Aguas Subterráneas en el Valle del Río Aconcagua*, Dirección General de Aguas, Gobierno de Chile, viewed 20 April 2016,

http://www.dga.cl/administracionrecursoshidricos/informestecnicos/Series%20de%20Informes%20Tcnicos/InformeFinal_Aconcagua_SDT372.pdf

Defra (2007). *An introductory guide to valuing ecosystem services*, Department for Environment, Food and Rural Affairs, London, viewed 15 March 2016, <http://www.defra.gov.uk/publications/files/pb12852-eco-valuing-071205.pdf>

Department of the Environment (2016). *Water Markets and Water Trade*, viewed 25 April 2016, <http://www.environment.gov.au/water/market-trade>

Dinar, A, Rosengrant, M and Meinzen-Dick, R (1997). *Water Allocation Mechanisms Principles and Examples*, World Bank, viewed 9 March 2016, <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.203.2050&rep=rep1&type=pdf>

Donoso, G. (2015). *Chilean Water Rights Markets as a Water Allocation Mechanism. Use of Economic Instruments in Water Policy*. Springer.

Donoso, G, Cancino, J, Melo, O, Rodríguez, C and Contreras, H (2010). *Análisis del Mercado del Agua de Riego en Chile: Una Revisión Crítica a Través del Caso de la Región de Valparaíso*, Pontificia Universidad Católica de Chile, Santiago

Figueroa San Martín, E. (2016). *Understanding the Economic Value of Water in the Aconcagua River Basin, Chile*, Master of Integrated Water Management Research Dissertation, International Water Centre, Brisbane.

Global Water Partnership (GWP) (2000). *'Integrated water resources management'*, TAC Background Paper No 4, Stockholm: Global Water Partnership, viewed 27 February 2016. <http://www.gwp.org/Global/ToolBox/Publications/Background%20papers/04%20Integrated%20Water%20Resources%20Management%20%282000%29%20English.pdf>

Hamilton, K. (2013). *Biodiversity and National Accounting*, Policy Research Working Paper 6441, The World Bank Development Research Group, Environment and Energy Team, May 2013

Hearne, R. & Donoso, G. (2014). *Water Markets in Chile: Are They Meeting Needs?*, Water markets for the 21st century. Springer.

INE (2007a). *Censo Agropecuario 2007*, Instituto Nacional de Estadísticas, Gobierno de Chile, viewed 13 March 2016, http://www.ine.cl/canales/chile_estadistico/censos_agropecuarios/censo_agropecuario_07_comunas.php

INE (2007b), *División Político Administrativa Y Censal 2007*, Región de Valparaíso, Gobierno de Chile, viewed 10 March 2016, <http://www.inevalparaiso.cl/archivos%5Cfiles%5Cpdf%5CDivisionPoliticoAdministrativa%5Cvalparaiso.pdf>

King, D and Mazzota, M (2000). *Ecosystem Valuation*, viewed 22 March 2016, <http://www.ecosystemvaluation.org/index.html>

Mooney, H, Cooper, A and Reid, W (2005). *Confronting the human dilemma: How can ecosystems provide sustainable services to benefit society?*, Nature, vol. 434, pp.561–562.

ODEPA (2016). *Precios Frutas y Hortalizas – Series de Tiempo*, Oficina de Estudios y Políticas Agrarias, Ministerio de Agricultura, Gobierno de Chile, <http://www.odepa.cl/precios/series-de-tiempo/>

Pascual, U and Muradian, R. (2010). *The economics of valuing ecosystem services and biodiversity in D Simpson (ed)*, The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations, TEEB, Pushpam Kumar, London, pp. 183-256

Savenije, H and Van der Zaag, P (2002). *Water as an Economic Good and Demand Management: Paradigms with Pitfalls*, Water International, vol. 27, no. 1, pp. 98–104

Torres-Reyna, O (2007). *Panel Data Analysis Fixed and Random Effects using Stata (v. 4.2)*, Princeton University

Van der Zaag, P and Savenije, H (2006). *Water as an Economic Good: The Value of Pricing and the Failure of Markets*, Value of Water Research Report Series, Volume No. 19, UNESCO-IHE, Delft.