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Article

A Conceptual Model Considering Multiple Agents for Water Management

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Abstract: In Chile, as in many other areas of the world, water supplies have been poorly managed and water availability is decreasing. In order to manage water resources more sustainably and equitably, it is necessary to understand and predict their supply and use considering the characteristics of a particular zone. This study aimed to develop a conceptual model for water management in the Libertador Bernardo O'Higgins Region in Chile. The model considers the water needs of industries with production activities, human consumption, and the ecological flow of each sub-basin in the area. The results show that the proposed model contributes to the understanding of the critical variables, their agents, and the interaction between the hydric demands, which enables the prioritization of human consumption and the ecological flow. Furthermore, the cross-analysis between the offer and demand indicates that current and predicted consumption levels will only be sustainable up to the year 2031. The findings may be of use to decision-makers seeking to improve water management plans in this area and elsewhere, and to others interested in modeling water management in different areas.

Keywords: water management; model based on agents; water balance; sub-basins; water availability; water balance model

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1. Introduction

Over the past decades, climate change has had an impact on the availability of different resources but especially water [1]. The data show that temperatures are increasing around the world: 2017 registered a global temperature increase of 1.0 °C in comparison to the preindustrial period (1850–1900), and a yearly temperature rise of between 0.1 and 0.3 °C is projected to result in a 1.5 °C increase (above preindustrial temperatures) at some point between 2032 and 2052 [2]. At higher temperatures, evapotranspiration rates increase [3,4], which reduces the amount of water available and is one of the most relevant parameters in terms of the effects of phenomena related to climate change in a region [5]. Furthermore, worldwide, the population is expected to increase by 26% by 2050 [6], energy consumption by 71% by 2040 (compared to 2013) [7], and food production by 60% by 2050 [5]. Given the predicted decrease in water availability and increase in demand for it, it is imperative that the management of this resource is improved.

1.1. The Management of Water Resources in Chile

Table 1 shows the main areas of Chile and its water sources and distribution. According to the General Water Directorate, Chile has 101 hydrographic basins, 467 hydrographic sub-basins, 1251 rivers, and 12,748 lakes and lagoons. The total demand for water in the country is marginal when compared to its abundant availability. However, there are considerable regional differences in supply and demand. In the desertic northern macrozone, for example, the runoff offer is not sufficient to supply the demand of all its regions, but in the southern macrozone, there is an excess of water offer that exceeds the demand.

Table 1. General water balance of Chile by macrozones (based on DGA data [8]).

Macrozones	Northern	Central	Southern	Far Southern
Regions	Arica and Parinacota, Tarapacá, Antofagasta, Atacama, and Coquimbo	Valparaíso, Metropolitan, Libertador General Bernardo O'Higgins, and Maule	Biobío, Ñuble, La Araucanía, Los Ríos, and Los Lagos	Aysén and Magallanes
Rainfall (average, mm/year)	87.0	943.0	2420.0	2963.0
Water flow (m^3/s)	36.9	1116.0	7834.0	20,258.0
Water Demand (m^3/s)	71.7	451.7	110.8	11.3

It is worth noting that there are two types of water use: consumptive use, which refers to extracted water that does not return to the environment; and non-consumptive use, which is extracted water that will be returned after it has been used [8]. Regarding the distribution of the demand for the resource's consumptive use, 82% is used by the farming sector (526.72 m^3/s), 8% is for drinking water and household use (54.84 m^3/s), 7% is used by the manufacturing industry (43.85 m^3/s), and the remaining 5% is used by the mining sector (19.99 m^3/s) [8]. The demand is expected to have grown by 4.5% by 2030, and 2040 will see an increase of 9.7% at the national level.

With regard to the resource's availability, the past years have registered a drop of between 20% and 50%, a trend that is predicted to continue for the coming 30 years. The central zone (from the Coquimbo Region to the Maule Region) will be one of the most affected areas because it will see a reduction in rainfall of between 6% and 10%, which represents around 50 to 200 mm of the annual average precipitation [9].

As [10] notes, adequate, efficient government determines the context in which hydric management operates. In Chile, hydric resources have been managed by centralized governments using a top-down approach that focused on increasing the supply of water but not on managing the demands for it. The lack of understanding of the interactions between the human, hydric, and socioecological systems; the lack of research funding; and the lack of interaction between science, politics, and management have given rise to several problems: erroneous concepts about the socio-hydrological dynamics, indiscriminate water use, undue appropriation of the resource, and institutions that do not adequately respond to these challenges [11,12].

In response to these problems, the National Council for the Implementation of the 2030 Agenda was created in 2016; however, meeting SDG 6 (Sustainable Development Goal 6) is considered difficult as Chile has not been able to implement IWRM (integrated water resources management). With regard to management of its hydric resources, the country has developed a National Policy (2015), a National Strategy (2012–2025), and an Administration Council for the National Water Policy (2020), all of which seek to face the increased demand for water by prioritizing the efficient and sustained management of the resource, social improvement and equality, and informed citizenship. The proposed objectives have not yet been met though and lack a focus on integrated management. The OECD (2015) has developed 12 Principles for the Good Governance of Water, grouped into 3 key dimensions: effectiveness, efficiency, and trust and commitment [13], which are found in SDG 6.5.1 [14,15]. Underpinning our research is the need for a model that allows us to meet Principle 5, which refers to “Data & Information”, and Principle 12, which refers to “Monitoring & Evaluation”.

1.2. Hydrological Models for Integral Analysis

Around the world, water is used by a variety of industries and agents for their production activities. In any given zone, it is not surprising to find more than one agent extracting water. Due to this, several models have been developed to gather information in order to understand a zone’s water dynamics based on a study of more than one industry. These models include the WEF (Water-Energy-Food) models used to analyze the water consumption inherent to each of these industries. Examples of these models being applied are found in the formulations of [16], showing the behavior of industries in Phoenix, Arizona, by means of the WEAP (Water Evaluation and Planning System) platform and which was calibrated on the basis of historical water consumption and available data from 1985 to 2009, and projections built on these values for the period of 2010–2069. The results show better water use thanks to modifications in the farming and food industries, due to a decrease expected for the areas destined to farming work as a result of the population growth during the past years. In the energy industry, greater water savings came from enhancing the use of renewable energy instead of conventional energy, which would lead to 2% water savings.

The WEF models were applied in Chile by [17], who conducted a conceptual study of the main water-demanding agents in four basins: Antofagasta, Copiapó, Maipo, and Maule. A modification of the classical WEF models was implemented, adjusting and including the most important industries in each basin.

In parallel, a breakdown was made of each of the agents, including the type of origin of the water that was used in each of the basins under study, to understand the region’s water dynamics and the possible compensations that take place, for current and future scenarios. Mention is made of the benefit of adjusting a WEF model to the reality of a particular region because the results vary considerably according to the definition of the problem being modeled and the considerations taken. With regard to the different regions, the study showed that the Maipo basin is very sensitive to climate change and that it is important to take urban water use into account because of its significance in the area; the Atacama basin is highly significant for the mining industry, specifically for copper extraction and, therefore, desalination will play an important role in the area; the Copiapó basin showed intensive groundwater use and is, therefore, under water stress; and in the Maule basin, the WEF model illustrated the importance of the water in the area, in which surface water represents the main source of supply for the demand for hydropower generation and agriculture.

The work proposed in [18] provides an encouraging study of multiple industries in Chile based on an integral analysis and shows how water scarceness had affected the mining and farming industries in the Atacama Region, and the interactions that emerge when a finite quantity of the resource is shared in the same area. First, the water demands of each agent were quantified and then a series of strategies were assessed to reduce water consumption. The results show that applying such strategies in the mining industry, which represents the highest demand in the area (64%), would reduce the WSI (Water Scarcity Indicator) by up to 48%. For agriculture, an improvement in irrigation efficiency would lead to reducing scarceness in irrigation areas by 19%, which, when applying an integral study focus, leads to good results in the search to reduce water consumption in the region.

Therefore, this research should be applied in adjacent areas to understand the benefits of reducing water consumption. One of the most complex aspects of carrying out this kind of study is the quality of the information about water resources since it is often not up to date.

1.3. Water Balance

Water balances represent the application of a mass balance for water, which results in the quantity of water present in an area. The proposition of [19] results in the water balance equation, which is used to verify water conservation in a hydrological year for one area:

$$P_a = R_{sa} + R_{ga} + E_{ta} + \triangle S_{sa} + \triangle S_{ga} \tag{1}$$

Where P_a represents the annual rainfall, R_{sa} is the annual surface water runoff, R_{ga} is the annual groundwater runoff, E_{ta} is the annual evapotranspiration, $\triangle S_{sa}$ is the surface water storage difference, and $\triangle S_{ga}$ represents the stored groundwater difference, measured in cm/year, to analyze the mass conservation in yearly periods.

The study proposed in [4] mentions a simplification of the water balance to update the national water balance in Chile, applied to certain basins in the central zone in Chile (Regions IV, V, Metropolitan, and VII). It is based on a mass balance, which does not consider the physical processes of the hydrological cycle, and, therefore, when considering periods of time for a water year, only considers the average rainfall $\overline{P}$, the average evapotranspiration $\overline{E}$, the average flow $\overline{Q}$, and an error factor η, measured in mm/year, simplifying Equation (1). The following Equation (2) describes the balance used in the study:

$$\overline{P} - \overline{Q} = \overline{E} + \eta \tag{2}$$

This comes about because, when considering a hydrological year as the balance analysis period, R_{ga} tends to be zero because it is assumed that the groundwater movement velocity is very low and can, therefore, be disregarded in the equation. As for the surface water and groundwater storage variations, $\triangle S_{sa}$ and $\triangle S_{ga}$, it is assumed that since an annual period of time should not show significant variations in the storage level from one year to the other when taking the same starting point for their measurements, they are considered zero in the equation. Given Equation (2), in case of a possible lack of data on $\overline{E}$, [6] proposed a formula to calculate the reference evapotranspiration (loss of water by evaporation of the surface and transpiration of vegetation) considering the average temperature t_{med} (°C) and the average incident solar radiation R_s in mm/day, by means of the following equation:

$$ET_0 = 0.00135 \cdot (t_{med} + 17.78) \cdot R_s \tag{3}$$

Years later, the work in [20] proposed a simplification considering the maximum temperatures t_{max}, average temperatures t_{med}, and minimum temperatures t_{min}, measured in degrees Celsius (°C) and including established extraterrestrial solar radiation values R_0, measured in mm/day of water evaporated per day, according to a tabulation proposed by [21] given the area's latitude and hemisphere. The following equation represents this simplification:

$$ET_0 = 0.0023 \cdot (t_{med} + 17.78) \cdot R_0 \cdot (t_{max} - t_{min})^{0.5} \tag{4}$$

1.4. Conceptual Models and Their Use in Water Management

Conceptual models are used to represent the interactions of a problem or situation in many areas. In the work by [22], an application of conceptual models to the modeling of water problems can be seen that facilitates comprehension, based on the simplification of a series of details that are not incorporated by a mathematical or theoretical model. The study by [22] analyzed 59 articles with conceptual models for hydrology, highlighting the importance of the model's goals and purposes matching the final result, thus contributing to the correction of the variability in the possible results to be obtained in a computer reflection. With this kind of model for water management, the data and considerations used can be made visible, which increases the confidence in the final results.

The authors of [23] performed a study on water resource management in Chile, and proposed a conceptual model for understanding the offer and demand for the Maipo River

Basin in the Metropolitan Region in Chile. It considers municipal-industrial, farming, power generation, flow transport relations, and output balance consumption. This model sheds light on the different interactions that take place across the basin, so that, by means of a holistic model, its water resources can be economically optimized. The conceptual model shows that the greatest water flow is the result of melting snow, which the farming lands of the higher sectors benefit from easily, but this situation causes water stress in the farming lands in the lower area of the basin.

The modeling of the interactions by the agents and industries is explained by [24] in a theoretical focus illustrating the development of the dynamics and interactions between the energy industry, tourism, farming, and human consumption, representing the case by a model built on agents for water resource management. Even though no geographical zone is assigned, the agents participating in water extractions are divided between three fictitious towns/villages, which are supplied by the offer of two rivers that flow there. Figure 1 provides a graphical representation of the distributions of agents considering the villages, sources of water offer, participating industries, and the respective extractions that each of them performs in the conceptual model for the theoretical case. It shows how water regulation between the demands of the villages located upstream and downstream arises when studying the dynamics between the villages. This happens in different annual periods of time in the simulation, which is an implementation in NetLogo. It shows how in villages where there is a water surplus, in the following period, there is a reduction, and, therefore, an increase in the offer is made possible for those villages that showed a lack of water. This creates an autoregulation of the industries in case of excessive consumption in certain periods, which, with the support of conceptual modeling, allows us to better understand the outcomes and the water problem.

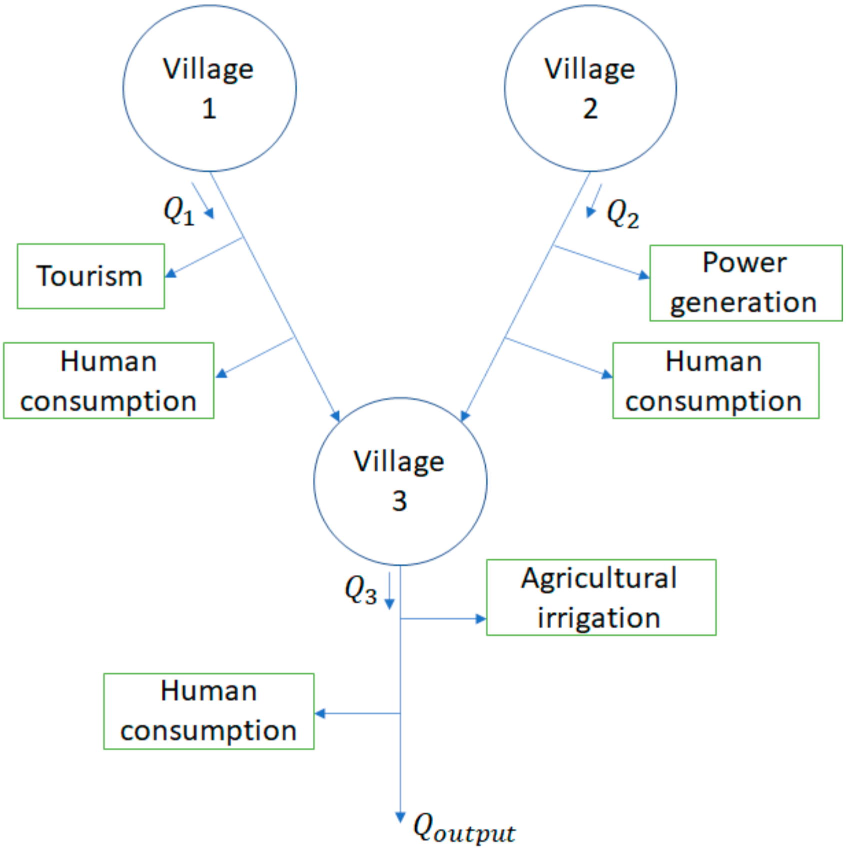

Figure 1. Conceptual model of the study case when implementing the modeling based on NetLogo agents (adapted from [24]).

1.5. Use of the Water Resource and the Ecological Flow

In order to develop sustainable water use, it is important to consider the preservation of the sources that supply the water and the ecosystems that contain them, thus reaching an equilibrium between the extractions and the quantity of water that is kept in circulation. In Chile, the so-called 'ecological flow' is stipulated in article 7 of the Water Code, which describes the methodology used to estimate the quantity of the water resource that is to remain in circulation. There are case studies analyzing how sustainable the use of the resource is based on the propositions established in [25], which prove the sensitivity of the water rights allocation system and analyzes the natural variability of the data in the long term, based on a reconstruction of tree rings of 400 years of runoff and historical information of the Quella Basin in the Maule Region. In addition, an assessment was made of the performance of the current legislative model in historical and future scenarios. The real flow that can be supplied as water rights was estimated and then contrasted with the quantity allocated for extraction. The calculations of the available flow consider the ecological flow. This represents a certain percentage of the circulating flow that remains for the preservation of the ecosystems. Finally, the research showed that the study region has an overdraft of allocated water rights, which, for the performed projections, is a situation that will only worsen over the years. It also mentions the quality and quantity of the available information on water rights, which is a factor to consider in terms of how far the results obtained are from the real water situation.

1.6. The Purpose of the Current Study

The bibliographical analysis presented demonstrates the importance of developing models for understanding how different agents interact and how water can be adequately managed to meet the human and production needs while maintaining the ecological flow, given the characteristics of a specific region. This paper develops such a model for the Libertador Bernardo O'Higgins Region in the central zone of Chile, since, to the best of our knowledge, one does not exist for this region; moreover, it is an area with a substantial population and a number of industries that are likely to be affected by the predicted decrease in water availability and increase in water demands from diverse agents.

The objective of this work is, therefore, to propose a conceptual model for the Libertador Bernardo O'Higgins Region to facilitate an understanding of the interactions between the diverse agents, such as the mining, agricultural, energy, and manufacturing sectors, and human consumption, and the allocation of the water offer, based on a focus that prioritizes and guarantees human consumption and the ecological flow for the region, and, at the same time, fulfills the water demand for the different production activities.

2. Materials and Methods

The objective was met using quantitative methodology with an integral analysis of the set of industries and human consumption in the area. To this end, the following information was considered:

Study area: The Libertador Bernardo O'Higgins Region is formed by 3 provinces (Cardenal Caro, Colchagua, and Cachapoal), which in total contain 33 communes. The main rivers are the Tinguiririca and the Cachapoal, which both flow into the Rapel River (Figure 2). There are 2 hydrographical basins, the Rapel and Costeras Rapel–Estero Nilahue, which consist of 6 and 5 sub-basins, respectively [26], geographically distributed as shown in Figure 2. The region has a Mediterranean climate and geography that spans the coast in the east, a relatively low coastal mountain range, a central valley, and then the higher Andes Mountains in the west. As for water demand, in 2015, the region was the third highest consumer of water in the country (60.11 m^3/s), and the area's agricultural industry (54.65 m^3/s) was second only to the mining industry for the consumption of continental water in the whole of Chile [27]. Under Chilean legislation, the Water Code [28,29] establishes the regulations for water rights, one of the main points being article 129 bis 1, which explicitly defines and estimates the minimum ecological flow in the function of the flow circulating in the different water sources, which vary across the region.

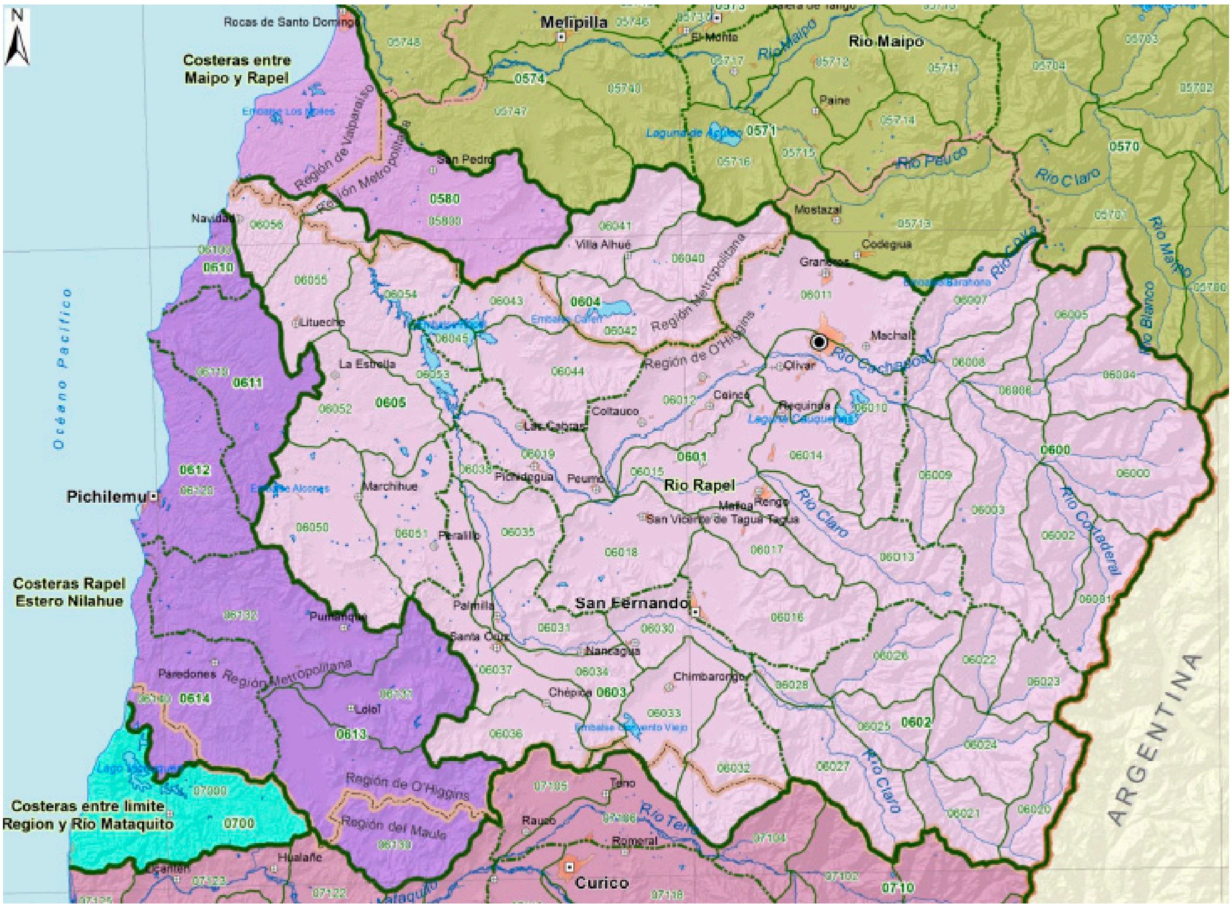

Figure 2. Division per basin, sub-basin, and sub-sub-basin in the Libertador Bernardo O'Higgins Region (based on DGA data [8], available online: https://dga.mop.gob.cl/administracionrecursoshidricos/inventario_cuencas_lagos/Paginas/default.aspx, accessed on 9 June 2022).

The region has a GDP (Gross Domestic Product) of 6.613 billion CLP (Chilean pesos), which represents 4.5% of the total Chilean GDP (145.364 billion CLP). The region's main economic activities represent 58% of the region's GDP [28], and include the mining sector, which produces 1.422 billion CLP (22%); the livestock-forestry sector, which produces 809 million CLP (12.5%); personal services, which produce 791 million CLP (12.1%); and the manufacturing industry, which produces (11.1%).

Date source: To analyze the demands, the mining industry, the manufacturing sector, farming, livestock, power generation, and human consumption were considered given their use of urban and rural drinking water, whether consumptive or non-consumptive. In terms of the offer, the measurement stations distributed in the study area were considered to quantify the water offer in the region based on data on its flows, rainfall, and evapotranspiration. Of a total of 21 measurement stations, 18 were selected because of the validity of the dates of the measurements performed; those that had not been operating in the past years were excluded.

The water offer was obtained from the CAMELS-CR2 [30] database of the CR2 meteorological explorer, which contains referential information on flows, rainfall, and evapotranspiration in accordance with the methodology in [3], as measured in daily and monthly values for the different stations distributed in the region. These data were submitted to a trend analysis to illustrate the circulating flow, given a certain quantity of precipitation fallen, and, at the same time, given the quantity of this precipitation that is not available for consumption in the form of evapotranspiration or infiltration. Considering a hydrological year as the time interval between one period and the other, it was assumed that the variation in the storages and groundwaters in each one of the sub-basins is insignificant. This way, the so-called unavailable flow can be considered as effective evapotranspiration. Then, the flow/precipitation conversion percentage was assigned, according to the division of sub-sub-basins in the "Inventory of basins, sub-basins, and sub-sub-basins in Chile" [26], which contains the regional divisions in the basin units mentioned. Figure 1 shows its graphical representation. In parallel, an analysis was performed of the trend per commune and the data on in-between rainfall were completed based on a database of the communal climate in Chile, which supplies the average rainfall projections in yearly periods of time for the region per commune, considering the historical average (1980–2010) and predictions up to 2050 [31]. After that, the area was divided per sub-sub-basin and the data were cross-referenced between the communes that are part of each sub-sub-basin to obtain the annual average rainfall for each. The conversion rate obtained from the analysis of the CAMELS database was applied to each sub-sub-basin, thus achieving their annual runoff. Finally, the conversion was made from mm/year to m^3/s, in consideration of the area of each sub-sub-basin in km^2, and then groups were made according to sub-basins, basins, and the complete region to apply the model, contrasting offer and demand, measured in m^3/s.

Model development: The conceptual model presented illustrates the region's interactions of offer and demand at the sub-basin level, based on the flow circulation characterization by the respective sub-basins and the water needs of the mining, farming, manufacturing, power generation, and livestock industries and human consumption of rural and urban drinking water, and which defines the extracted resource's type of use according to the industry as consumptive (not returning to the environment) or non-consumptive (returning to the environment). To understand the area's demand, data were used from the report "Estimations of today's demand, future projections and characterization of the water resources in Chile" [27], which presents future estimations (2016–2040) and current data (2015) on the demands of each one of the region's industries in yearly periods of time. For the data analysis, a characterization was made of the region's hydrographical basins and sub-basins to understand the distribution of the offer, the limits, and the main landmarks present in each. Afterwards, the information on the demands was analyzed to understand their geographical distribution and the type of consumption in the area's sub-basins. Finally, a graphical contrast was made, based on the water balance, to help prepare and articulate the different offers and demands by the respective sub-basins of the studied region.

3. Results and Discussion

Based on the characterization of the region's offer and demand, a contrast was made between them to observe whether the current and projected consumption levels are sustainable in the long term for the studied region. Table 2 shows the evolution in the joint water offer and demand in the time interval selected for the study (2009–2040), which makes it evident that, as of 2031, a negative balance will be produced because the estimated offer will not suffice to supply the needs of the different agents for their production activities. The conceptual model, which is built on the application of the water balance, as mentioned before, considers a series of factors, explained in a flow chart illustrating the multiple interactions that take place in the region.

Table 2. Contrasting offer and demand (2009–2040) for the Libertador Bernardo O'Higgins Region (forecast was performed based on data from the Chilean Ministry of Environment, the Chilean Ministry of Public Works, and [30]).

Year	Offer (m^3/s)	Demand (m^3/s)	Balance (m^3/s)
2009	225.42	200.11	25.31
2010	224.57	200.35	24.22
2011	223.72	200.59	23.13
2012	222.87	200.83	22.04
2013	222.02	201.06	20.96
2014	221.17	201.30	19.87
2015	220.32	201.54	18.78
2016	219.47	201.78	17.69
2017	218.62	202.30	16.32
2018	217.77	202.61	15.16
2019	216.93	202.81	14.12
2020	216.08	203.06	13.01
2021	215.23	203.30	11.92
2022	214.38	203.72	10.66
2023	213.53	204.08	9.44
2024	212.68	204.42	8.26
2025	211.83	204.88	6.95
2026	210.98	205.21	5.77
2027	210.13	205.55	4.58
2028	209.28	205.86	3.42
2029	208.43	206.08	2.35
2030	207.58	206.66	0.92
2031	206.73	207.58	−0.85
2032	205.88	208.28	−2.39
2033	205.04	209.02	−3.99
2034	204.19	209.75	−5.56
2035	203.34	210.63	−7.30
2036	202.49	211.43	−8.94
2037	201.64	212.19	−10.55
2038	200.79	213.03	−12.24
2039	199.94	213.86	−13.92
2040	199.09	214.65	−15.56

The flowchart in Figure 3 presents the theoretical considerations behind the results presented above and shows that precipitation can become a flow, evapotranspiration, surface water, or groundwater, but because time intervals between one period and the next are one hydrological year, there are no significant variations in terms of the storage of surface water and groundwater, which simplifies the application of the water balance. Moreover, it shows the functioning of the inputs, outputs, and reinput of used water in production activities, and environmental aspects across the region, which represent the area's water movements and dynamics.

It can be observed how the input and output of the resource, in the form of rainfall, enters the system (sub-basin) and moves in the form of flow across the region or leaves by evapotranspiration, which is influenced by temperature, according to the methodology [3]. The resource is extracted by the industries and for human consumption, prioritizing and assuring the satisfaction of human consumption, and there is a perpetual output given the consumptive use of the resource or water reinput due to non-consumptive use. As for flow permanence, the ecological flow is that which remains in the ecosystem and the sources that supply the resource, thus safeguarding 10% of the annual flow for any period of time. Because of this, part of the total offer may never be extracted from the system and, therefore, a total of 90% must remain for distribution among the different agents.

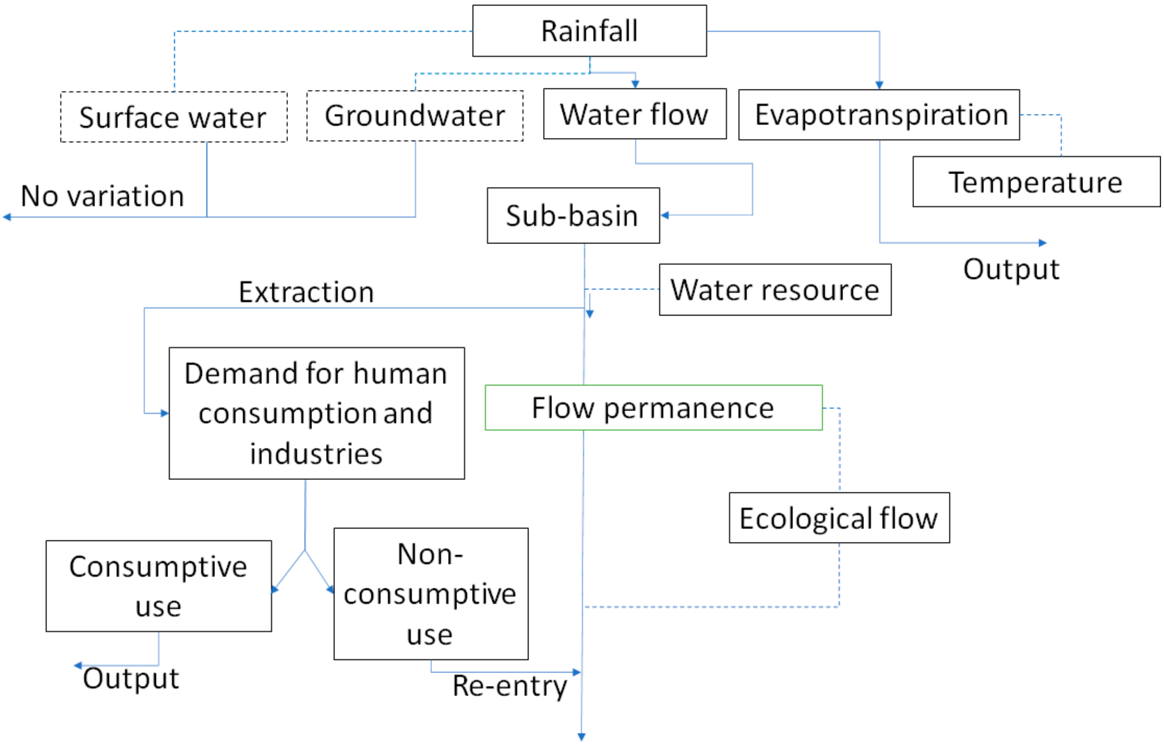

Figure 3. Flowchart contrasting offer and demand in the region.

Regarding the conceptual model to contrast offer and demand, Figure 4 reflects the result from characterizing the water dynamics, which illustrates how production activities are carried out and where they are located in the Rapel and Coasts Rapel-Estero Nilahue basins. It specifies the industries located in the basins, the type of human consumption, and the classification of water use in each of the region's sub-basins.

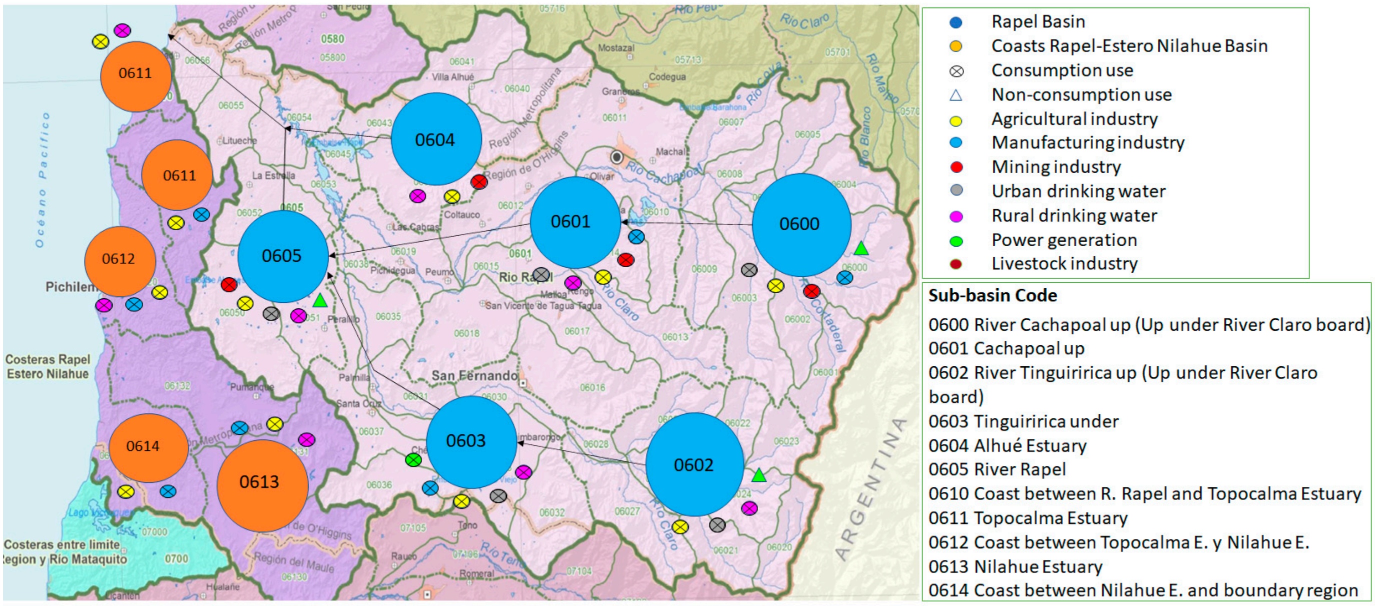

Figure 4. Conceptual model per sub-basin in the region (based on data from [8,9]).

The conceptual modeling enables an understanding of the region's water dynamics, and generically schematizes the phenomena that take place in any of the region's sub-basins. Thus, a series of phenomena inherent to water analysis at a regional scale can be interpreted, such as the origin of the water offer source, the agents that extract and use it for their production activities, and the region's dynamics in terms of the functioning and application of the Chilean legislative regulations. All of this information facilitates the understanding of the water movements that occur in the region.

Our model is somewhat similar to those in [16,24]; however, their works consider a smaller number of industries for water analysis and, moreover, do not define a specific study area and are restricted to giving a generic view for any case. The current proposal, however, is adjusted and takes into account the inherent criteria of the region. To cover the detected gap, it is proposed that the conceptual model should be based on the application of the water balance, which illustrates the scenario of water use for the area's current situation, with an integral focus on its agents, and considering all the main industries so as to have a more thorough understanding of the agents using the resource. Moreover, when considering offer and demand based on their flow (Figure 4), the interactions between the agents and their surroundings can be better understood when the geographical distribution of the industries in the region is taken into account. Thus, the study and analysis of the dependences and connections generated between the sub-basins can be addressed more profoundly and the possible results of applying mathematical models built on the proposed conceptual models can be more informed, in order to obtain future scenarios of contracting offer and demand through a water balance.

Lastly, the results have shown that, as of 2031, the consumption level expected for the region is not sustainable, which puts the region, its water sources, its inhabitants, and the functioning of the different agents with production activities in the region at risk. These results are somewhat similar to those that [23] proposed because in that study, the contrast made for the Libertador Bernardo O'Higgins Region was restricted to a conceptual characterization only, which is just the first part. In [23], the number of industries considered is more limited and only one basin was considered. With respect to the proposal made by [4], the findings presented here are also somewhat similar because, even if the water balance mentioned is applied, the evapotranspiration considered in the proposed model corresponds to the Hargraves-Samani instead of the Pennmann-Monteith [3].

To improve our understanding of how water can best be managed in this area (and others), a mathematical optimization model should be applied to assess the existence of an optimum use of the resource for future scenarios, considering the agents, the surroundings, and the effects of climate change in it, according to the consumption model present today in the region.

Finally, considering human consumption and the ecological flow as the model's primary agents limits the specter of possible results that a view focused on general well-being might have and, therefore, water management strategies can be designed more easily. Moreover, with the characterization of multiple agents with water needs, the critical points to be analyzed to fulfil the purpose of prioritizing human consumption and the ecological flow can be identified more precisely, which, given the analysis's integral focus, ends up benefitting the entire region, because the goal is general well-being in terms of water matters, guaranteeing the resource for its inhabitants and an optimum status of the sub-basins' water offer sources. This is in partial agreement with the proposals made by [18], because, even though they share the interest of implementing management strategies for the water resource, [23] only considered two industries of a region, where the main motivation was to seek a reduction in water use, which went partially against the properties of the model. The prioritization of the resource is also in partial agreement with [32], who analyzed how sustainable water consumption is in a sector of the Libertador Bernardo O'Higgins Region, specifically for the farming industry, and considered the ecological flow for the preservation of the water sources. The differences with [32] lie in the larger coverage of the region, because their study included it entirely and contrasted the multiple industries with production activities, and, finally, prioritized the allocation of human consumption and the ecological flow. In order to cover the detected gap, it is proposed that scenarios should be contrasted by applying different water management strategies with variable criteria for the allocation of the water resource to be able to illustrate a consumption model in accordance with the region's water situation. In the scenarios, the water allocation priority will vary according to the following observation criteria: contribution to regional GDP, demanded quantity of water, restricted maximum demand for industries with higher consumption levels and a ponderation of the restriction scenario for the maximum demands and the distribution according to the economic contribution of each industry while permanently keeping consumption guaranteed for the agents with maximum priority (human consumption and ecological flow).

Finally, the findings of this study demonstrate the importance of considering water management in a region as a whole. In order to guarantee sustainable water supply systems, an understanding of water management must go beyond simply collecting and recording data and include social participation and public dialogue [33]. All the relevant sectors—government, private, and civil—must participate in decision-making and the development of a strategic plan in which they are all involved as an integral part of the solution [33,34]. In this manner, effective action can be taken when crises arise. To this end, a survey, for example, could be used to collect information about preferences, opinions, and choices from the target audience, as [33] has proposed. However, in Chile, the ability to respond to implement integrated water resources management (IWRM) is severely limited due to the lack of coordination between authorities and public institutions for managing water in basis and sub-basins. Moreover, private water rights usually refer to only a specific aquifer section. This fragmentation restricts our ability to consider the interactions between surface and subterranean water and ecological flow. Moreover, there need to be more instances of social participation [13,35] so that the different relevant sectors—government, private, and civil—can all be involved in decision making and the development of strategic planning according to IRWRM, so that change can take place on this basis, rather than simply in response to conflicts [36].

4. Conclusions

This work established the interaction of agents, production activities, and water management in the Libertador Bernardo O'Higgins Region in a conceptual model. Over the past decades, the offer of the water resource has dropped while the number of agents has grown in the region under study, and, with this, the demand of the resource. To understand the allocation phenomenon, different interactions of the agents were studied, considering the scarceness of the resource, the geographical dependence between sub-basins, and the dynamics that take place in each when articulating the water distribution. When considering the scenarios of ecological flow and human consumption, the model shows that the needs of the agents for their production use can be satisfied, even if priority is given to the environment and the first allocation priority is human consumption, up to the year 2031. After that, the projected consumption level becomes unsustainable, due to the estimated increase in water extractions and the clear decrease in its availability. Thus, the proposed conceptual representation allows us to understand not only the water dynamics but also the system's saturation, and to explain future results when using this as the base for a mathematical model. This work, therefore, contributes to understanding the critical variables in the model, the agents, and their interaction with the water resource demands in an area with a declining water offer. Decision-makers could use this model to develop a water management plan.

Finally, it is worth mentioning that, because of the advance of the effects of global warming and the droughts that have afflicted Chile and other countries over recent years, studies and their application in other areas are necessary. Such studies should be built on an integral observation focus for the different areas of the country, using a conceptual model to facilitate the understanding and characterization of the problems. It is proposed that the dynamics of a given area or region are first studied, thus allowing a better understanding of the diverse problems of water management. As for the needs of water management worldwide, the conceptual model is one of the tools that should be used to develop public policies, together with the discussion about measures to help and promote effective water management.

Another valuable route for extending this research would be to gather a set of qualitative data (via interviews or questionnaires) in order to obtain the perspectives and opinions of consumers and private companies with regard to the quality and level of service or water management in crisis situations. A pilot program that considers these opinions would complement the proposed model from this study and further develop the conclusions. A systematic map of the responses could be used to obtain a more detailed classification of the requirements of the sectors involved in water management.

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