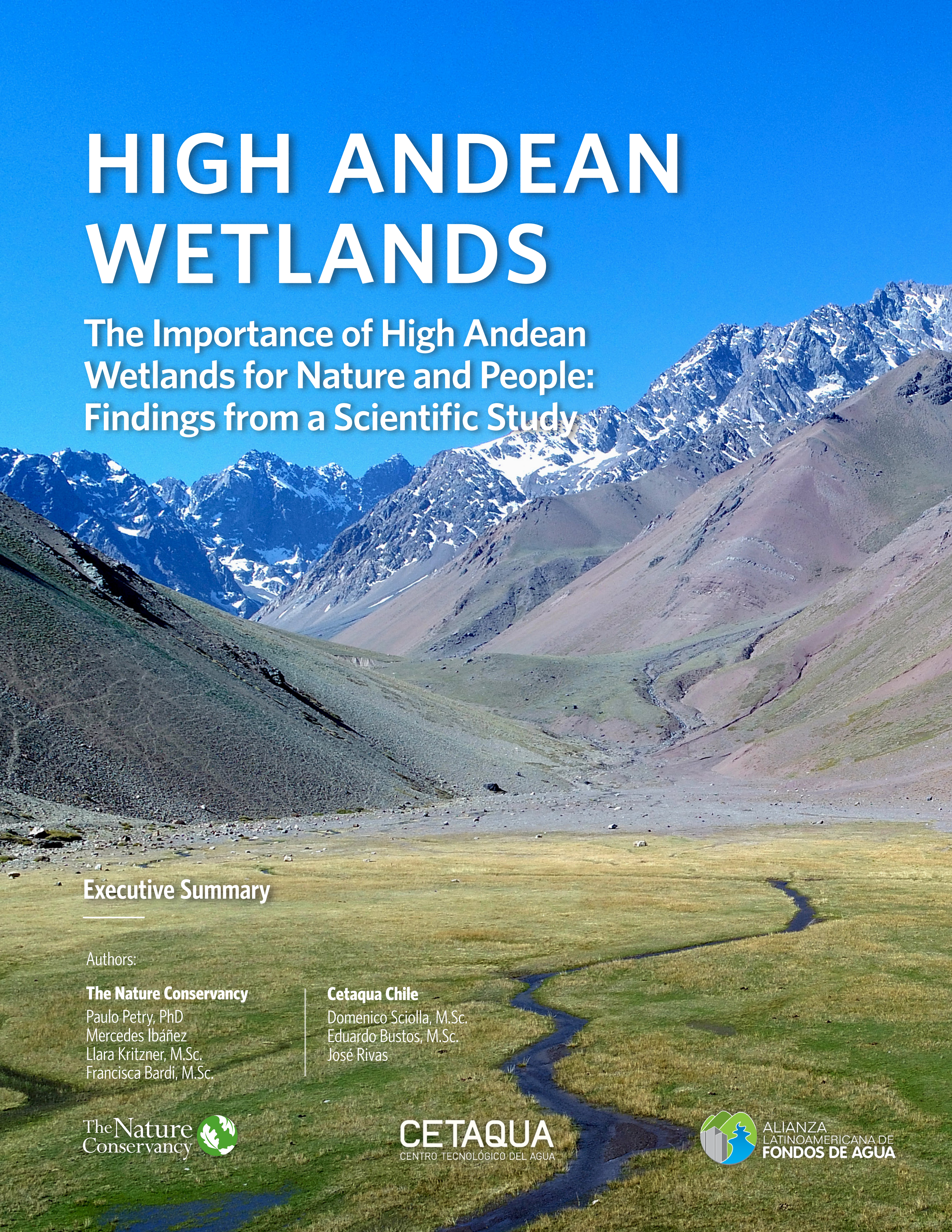

HIGH ANDEAN WETLANDS

The Importance of High Andean Wetlands for Nature and People: Findings from a Scientific Study

Executive Summary

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Valle El Yeso Wetland Park © TNC

Introduction

The Nature Conservancy (TNC) in Chile, together with leading national research teams, completed an eight-year study monitoring the behavior of the High Andean wetlands located in the Maipo River basin at approximately 70 kilometers from the capital city of Santiago, Chile. The study aimed to prove the importance of these ecosystems in the regulation, quantity and quality of water that is produced in the Andes Mountain range. A substantial part of this water is stored in the High Andean wetlands before it finally reaches the city of Santiago, with its more than seven million inhabitants.

The Maipo River basin was selected for this research since it provides 70% of the water consumed by the Santiago Metropolitan Region and 90% of the water used to irrigate agricultural production in the area, which accounts for 3.5% of Chile's GDP and almost 10% of its workforce.

The study's systematic monitoring of wetland ecosystems included measurement of water flow, soil quality and climatic factors in selected sites. A wetland inventory was compiled and an analysis of their current state of degradation was carried out. This data provided scientific evidence to understand the role of wetlands as part of a green infrastructure that is crucial for a sustainable water supply.

Science has shown that wetlands and forests help regulate natural flows and provide more water in the dry summer seasons. When healthy, wetlands can more effectively accomplish their ecosystem function, which is basically regulating waterflows and guaranteeing water supply in times of drought.

Wetlands have an enormous potential for mitigating climate change through their capacity to adapt and regulate the ecosystem services they provide. Chile formally acknowledged the ecological importance of these wetlands in its 2020 Nationally Determined Contributions (NDC), a first step towards official protection. This study seeks to promote the development of public policies that protect these ecosystems.

The need for improved management of natural water systems is urgent in the face of climate change. In the case of the Maipo River basin, climate change has intensified the high natural variability of high mountain rainfall, altering its water flows. The resulting water deficit has caused the degradation of high conservation value natural systems and worsened water quality. All this has increased the pressure on this water resource from different users.

The Faculty of Agronomic Sciences of the University of Chile, the General Directorate of Water of the Ministry of Public Works and the Center for Climate Science and Resilience were crucial in the task of data collection, and Cetaqua Chile and the UC Global Change Center served as key collaborators in the data analysis.

The High Andean Wetlands

Wetlands are among the most productive ecosystems in the world. They host significant biological biodiversity and play a critical role regulating the water system. They provide numerous ecosystem services such as carbon sequestration, water quality protection, flood protection, water level regulation in aquifers and soil, regulation of peak flows, and support for biodiversity.

However, wetlands are also very fragile ecosystems and can be affected by natural events and conditions such as extreme droughts, strong winds, high radiation and large thermal amplitudes. They are also sensitive to anthropogenic factors such as overgrazing, water extraction for agriculture, mining, human consumption, and modifications of water courses. Hence the importance of measuring and monitoring the hydrology, climate, and soils of the wetlands to quantify their capacity to respond to environmental fluctuations and climate change. Understanding how this capacity can be increased is crucial for human communities and for maintaining the biodiversity of the wild species that inhabit them.

Aparejo Creek © TNC

Study Areas

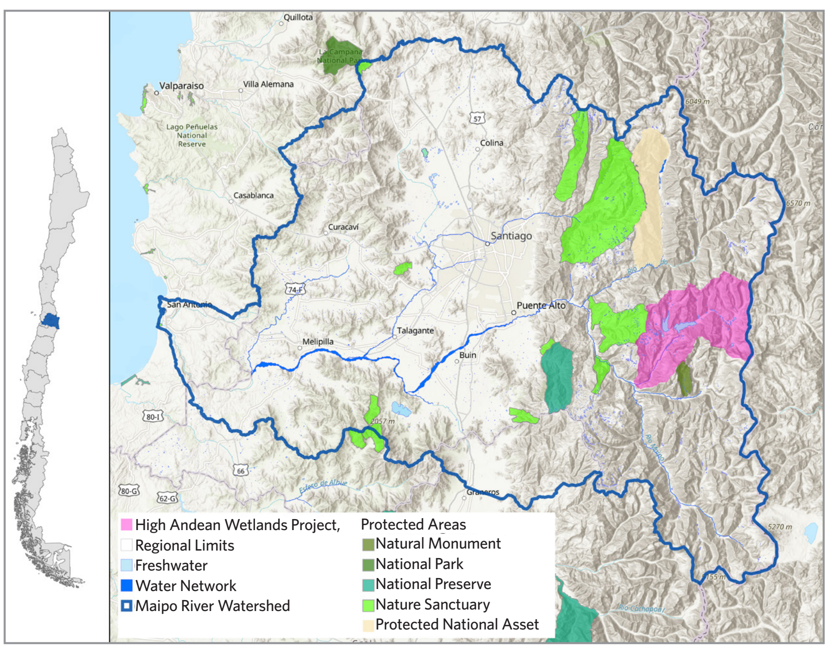


FIGURE 1: Maipo River Basin, Yeso River Sub-Basin, and protected areas

The hydrological monitoring network implemented by TNC consists of a series of monitoring points in the sub-basin of the El Yeso River, a tributary of the Maipo River, more than 2,500 meters above sea level. The points are distributed in four sites: Casa Piedra Wetland Site, Mining Camp Wetland Site, El Yeso Valley Park Wetland Site and Aparejo Creek Site.

The El Yeso River sub-basin has been affected by climate change conditions with average reduction rates close to 10 mm of rainfall per year from 1990 to 2020. Since 2010, this area has experienced extreme drought, with water deficits of 83% and 78% in 2019 and 2021, respectively, compared to the average for the period 1990-2020. As of September 2022, this deficit reached 68% compared to a normal year (1991-2020), with severe drought persistent for at least the last 48 months.

A better understanding of the functioning and hydrological role of the High Andean wetlands and their contribution to the water security of systems dependent on Andean basins, can promote the use of wetlands as green infrastructure and as a natural solution for water provision. It also provides a better insight into how the wetland can maintain the quality and regulation of water flows, and how this, in turn, can contribute to urban, agricultural, and other uses, especially during periods of drought that will continue to intensify due to climate change.

To measure the impact of native vegetation on wetland behavior, TNC chose two micro- basins in the El Yeso River sub-basin: the Casa Piedra and Aparejo micro-basins. These two micro-basins display very similar physical conditions and one fundamental difference: one has a wetland while the other does not.

Both are micro-basins of similar size that drain parallel to the south, with similar geology and slopes and are geographically contiguous. Both form an alluvial fan, containing alluvial deposits formed in fans composed of a mixture of rock, boulders, gravel and fine soil derived from the slopes of nearby mountains. Casa Piedra contains a wetland of approximately 18 hectares (ha) in an alluvial fan of 40 ha. Aparejo is an alluvial fan of 10.5 ha with a small wet area close to 0.1 ha. Both micro-basins contain glacial formations, Casa Piedra holds 340 ha of glaciers, and Aparejo 48 ha. Both have elevations ranging from approximately 2,500 to 4,600 meters above sea level.

The Casa Piedra wetland is located in the lower half of the micro-basin, and spreads across 18 ha. Its vegetation is characteristic of this type of wetland, composed mainly of sedges, grasses, perennial grasses and other species present in soils saturated with peat, an organic material rich in carbon. Historically, this wetland has been under high anthropic pressure due to livestock activities and unregulated tourism, causing loss of vegetation and soil compaction.

The Aparejo micro-basin flows through an alluvial fan similar to that of Casa Piedra, with the notable difference that it has no wetland, and its surface is devoid of vegetation. The terrain is mainly gravel and boulders, with a braided stream flowing through it, and vegetation is limited to the margins of the main course of the stream, at the basin's exit. The only source of water is surface flow caused by mountain snow and melting ice.


Livestock activity in wetlands © TNC

Hydrological Monitoring of the High Andean Wetlands

Both sites underwent hydrological monitoring (which included measurement of surface flow, groundwater levels, and soil temperature); climate characterization (seasonal and annual trends in precipitation, snow cover and temperature); soil characterization and, finally, an estimate of water storage based on the evidence collected.

The most complete monitoring was carried out in the Casa Piedra wetland, with measurements of surface flows and groundwater levels. Surface flows were measured at three sites. The groundwater was monitored by seven test wells. Because of the absence of wetlands in the Aparejo micro-basin, only the outflow of surface runoff derived from the melting of ice and snow from the mountains was monitored. This outflow does not filter into the ground but reaches the Aparejo Creek by moving on the surface of the land due to the force of gravity.

To measure surface and groundwater levels pressure sensors registered the levels every 15 minutes on the flow sensors and every three hours on the wells. Field visits were made two to four times a year, to collect data, carry out maintenance and cleaning of wells and take atmospheric pressure measurements to complement the analysis of water level data. In each field visit, the water flow in the outlet streams was measured, with a current meter and a topographic characterization of cross sections of the measured currents. Two measurement points were installed in the Casa Piedra wetland and one point in the Aparejo Creek, next to the surface runoff level sensors. This enabled the collection of water flow data every 15 minutes throughout the monitoring period at each measurement point, providing valuable information to for analyzing how surface waters in micro-basins of mountain systems respond to climate variability.

In collaboration with the Faculty of Agronomic Sciences of the University of Chile, two test wells were established in the Casa Piedra wetland. Data collected from these wells helped to determine soil infiltration capacity and groundwater depth. A vertical profile was also installed using a soil temperature sensor at Casa Piedra, where temperatures were measured at seven ground depth intervals (down to -1.5 m) and on the ground surface at three-hour intervals, from April 2015 to February 2019.

Three camera traps synchronized with the sensor network were installed in the Casa Piedra wetland and one in the Aparejo alluvial fan. Camera traps help to understand anomalies observed in the data and document the dynamics of environmental conditions and their temporal variation with a series of images. Unfortunately, this monitoring only lasted a few months as most of the equipment was stolen.

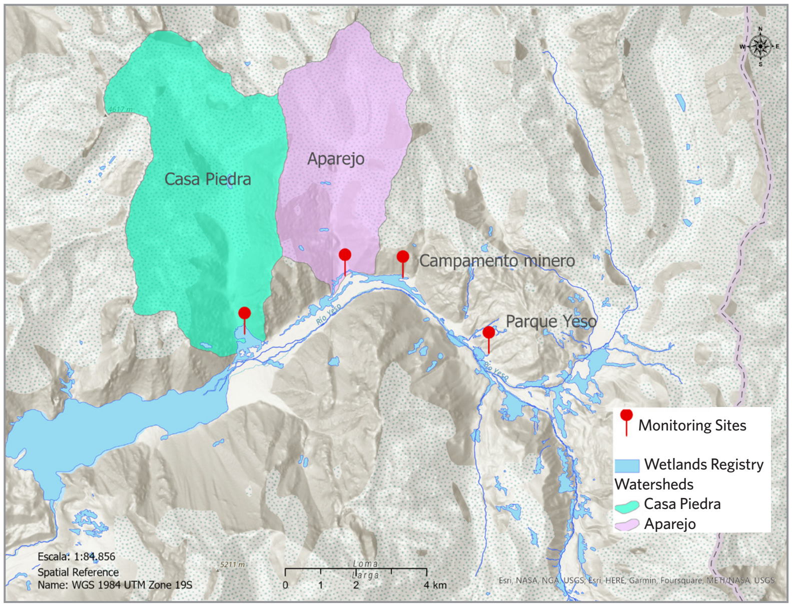


FIGURE 2: Yeso River Sub-Basin with monitoring sites

TNC team reviewing monitoring instruments in Valle El Yeso Wetland Park © TNC

Discharge measurement transect in Aparejo Creek © TNC

Results

How the High Andean Wetlands Regulate Waterflow

The average specific flows in both basins are very similar. However, records from the Aparejo sector show the occurrence of numerous flood events, in contrast to Casa Piedra, where maximum flows generated were considerably reduced, producing a more constant runoff due to its aquifer-wetland system. In addition, the base flows increase with the summer thaw, which is characteristic of the flows of the upper part of the Maipo basin.

The specific flows for the hydrological year 2019/20 show more clearly the effect of the aquifer-wetland system on the maximum specific flows. Flooding was monitored at both sites. The Casa Piedra aquifer-wetland system avoided, on average, 1.4 floods per year. Hence, the aquifer-wetland system of Casa Piedra provides an ecosystem service of water regulation and flood control, additionally reducing sediment drag due to the control of maximum flows.

In the Aparejo sector there is no important aquifer-wetland system at the point of exit of the basin. Hence, the flows in Aparejo show a greater correlation with rainfall and a lower regulatory effect on the water flow since there is no ecological structure to retain water.

The regulatory effect of the aquifer-wetland system of Casa Piedra is evidenced in higher base flows during the years with lower rainfall, than those registered in Aparejo. This effect can be very beneficial for creating a significant supply for downstream users and ecosystems.

Flow analysis shows that the average specific production of the micro-basins is similar. This could indicate that hydrological evaporation processes are similar in both micro-basins. Despite the above, the Aparejo basin presents several specific episodes of flooding, which are not observed in the dynamics of the Casa Piedra flows.

In Casa Piedra, due to the regulatory effect of the wetland system, the maximum flows turn out to be an order of magnitude lower than those recorded in Aparejo. Hence, maximum instantaneous discharges are attenuated by the presence of the wetland.

Hence, the aquifer-wetland system in Casa Piedra reduces flooding, since it moderates the maximum flows. This allows the preservation of the banks and the hydraulic works located downstream. In addition, it significantly reduces sediment entrainment.

Wetlands not only have an important regulating effect on flows, but also regulate the base flow. Proof of this is the data showing that the base flow of Casa Piedra is greater than that of Aparejo. Casa Piedra's water regulation ecosystem service provided by the wetland can be very beneficial during dry years, since it allows for higher minimum flows during winter and summer.

The volume of flow in the Casa Piedra wetland has significant seasonal variations between winter and summer. In the winter season, the volumetric flow is 43,200 cubic meters per day and can meet the water supply needs of 216,000 people per day. In summer (December to March in Chile) the flow can supply 500,000 people per day, with a volumetric flow of 103,680 cubic meters per day.

Groundwater Storage

Groundwater storage could only be measured in the Casa Piedra wetland. Groundwater in the Aparejo sector could not be measured due to challenges in installing the equipment.

Groundwater levels in Casa Piedra's alluvial fan (from the surface to an eight-meter depth) follow a seasonal monotonous pattern, which combines with precipitation weather patterns.

The lowest levels are observed from late August to mid-September, while maximum groundwater levels occur from late January to mid-February, in all installed test wells.

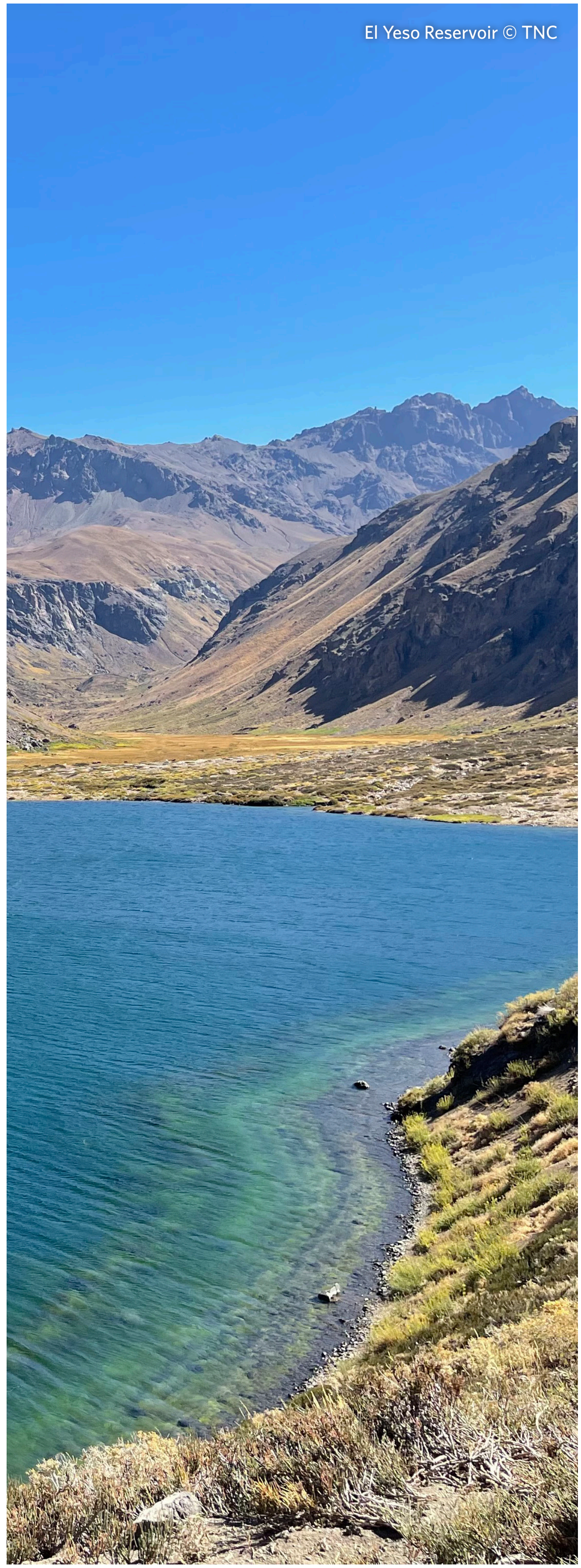
Recharge rates are highest from late October to mid-December after the winter thaw, and discharge rates are highest from late January to mid-April. Alluvial fan recharge starts at lower elevations in mid-September, while the alluvial fan top only starts recharging in mid-October, showing a two- to three-week delay in recharge response. This phenomenon is possibly associated with the presence of soils from the fertile plain, with a deposit of very fine texture containing a lot of organic matter that produces the retention of new water, contributing to the thaw in low areas of the fan. This effect produces an accumulation of water that fills the alluvial fan from the lower areas to the top.

Maximum storage occurred in early summer, between late December and mid-January, which was reflected in the highest surface flows of the same period, showing a synchrony between variations in groundwater storage and surface flows observed in the discharge zone of the micro-basin.

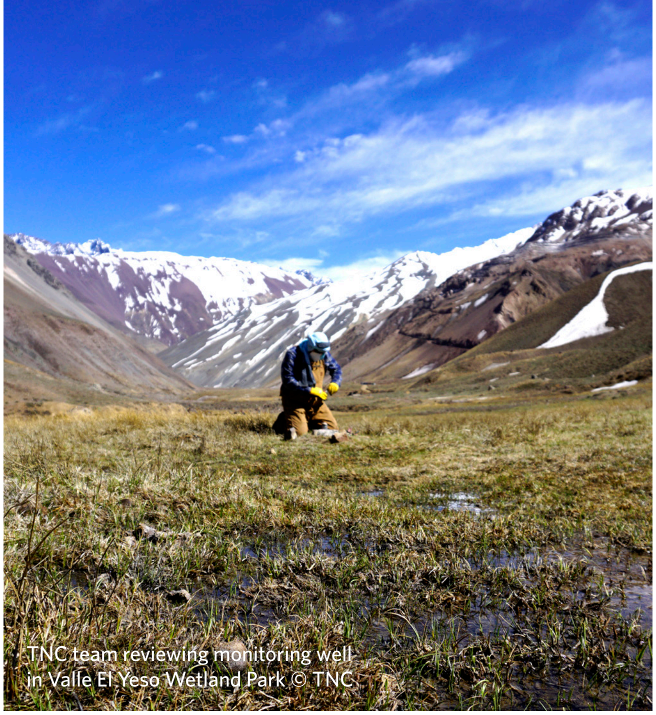
Temperatures below the surface fluctuate seasonally with shallow soil strata (down to -10 cm) varying according to daily surface variations. The deeper strata showed very little daily variation with smaller amplitudes of variation, between 1 and 18°C. The soil only froze below the surface for brief periods between June and August, from 2015 to 2018. None of the deeper layers of soil froze during this period, indicating that there is no hard freezing of the soil. This means that when snow melt occurs, meltwater will infiltrate the soil and initiate the groundwater recharge process.

The storage capacity range was estimated assuming an average soil porosity of 40%, based on data from typical alluvial deposits and the porosity measured from soil samples along the study transects. Estimating groundwater storage capacity more accurately would require additional data on sediment deposit characteristics or geophysical methods that quantify groundwater deposits in the subsurface.

With this information, the regulatory effect of a high- altitude wetland was quantified and it was shown that a basin with wetland vegetation experiences reduced maximum flood flows and increased minimum baseflow during dry seasons.



El Yeso Reservoir © TNC



TNC team reviewing monitoring well in Valle El Yeso Wetland Park © TNC

Casa Piedra Wetland. Vegetation regenerating with water from melting glaciers © TNC

Main Findings of the Study

The objective of this study was to collect long-term data on the surface and underground hydrology of high mountain micro-basins located in the Yeso River sub- basin in the upper Maipo River basin, central Chile. The information generated by the study is enabling a deeper understanding of the functioning and hydrological role of the High Andean wetlands and their contribution to the water security of systems dependent on Andean basins.

Below are the main findings and conclusions:

- Rainfall in Casa Piedra is estimated to be virtually identical to that of Aparejo. This, added to their similarity in land features and orientation, supports the hypothesis that the differences in water flows are due to the presence of an aquifer-wetland system in Casa Piedra.
- The groundwater storage data for the Casa Piedra aquifer provides evidence that the largest proportion of stored water is a retained volume that is independent of the increases and decreases recorded during the annual melting period. This volume would be the source of the base flow recorded during the winter months.
- The total volume of water stored in the Casa Piedra wetland would have a potential storage capacity of 648,000 m3, considering a soil porosity value of 40%. Considering a consumption per person of 200 liters per day, the water stored in the wetland would supply 3,140,000 people per day. This equates to a total of 81,000 people per hectare.
- The presence of the aquifer-wetland system in Casa Piedra reduces the severity of maximum instantaneous discharges. The capacity of wetlands to regulate maximum flows protects river banks, slows water flows which reduces erosion, and reduces risks to infrastructure located downstream.

The data and analysis presented here encompass the numerous benefits and services provided by the High Andean wetlands, especially those related to water supply and regulation. The findings affirm the urgent need for more robust protection for the wetlands as part of a green infrastructure to strengthen water security in Andean systems.

The ecosystem conservation and restoration actions carried out in these areas have tangible benefits, evidenced not only in the flourishing flora and fauna of the water basin, but also in the well-being of human populations enjoying greater water security. The challenge now is to extend the conservation and restoration of wetlands in water basins throughout central Chile to foment greater resilience in water supply and adaptation to climate change.

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