Integrated Water Resources Modeling to Estimate the Risk of Groundwater Depletion in Semi-arid Basins in a Context of Climate Change

Kiara Tesen[1], Sebastian Vicuña[1], Jorge Gironás[1], Francisco Suarez[1], and Eduardo Bustos[2]

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November 21, 2022

Abstract

The increase in world population, added to socioeconomic development and climate change, have highlighted one of the biggest problems worldwide: the depletion of water resources. The La Ligua and Petorca river basins, in central Chile, are an example of this problem, as rainfall has decreased in recent years, while socio-economic activities, mainly agriculture have increase. This situation has led to a severe water stress, and the need for integrated and sustainable river basin management, aimed at understanding the behavior of basins, aquifers, and the exchange of flows between them. Therefore, the main objective of this research is to quantify the impacts of climate change, in terms of groundwater scarcity, in semi-arid basins using integrated modeling of water resources. For this purpose, groundwater/surface waters integrated models of La Ligua and Petorca basins were developed using WEAP and MODFLOW. Both basins present different hydrological, social, and geographical characteristics. Different scenarios were evaluated to quantify groundwater depletion. These scenarios depend on climatic forcings, such as precipitation and temperature, which were obtained from the Phase 6 of the Coupled Model Intercomparison Project (CMIP6). Results forecast that annual precipitation will decrease, whereas average annual temperature will increase in these semi-arid regions. As a consequence, the aquifer's recovery rate will reduce, decreasing the number of wells that provide drinking water in rural and agricultural areas. In conclusion, the coupling of hydrological and hydrogeological models is a tool that allows researchers and stakeholders to make opportune and appropriate decisions on the management of basins and aquifers, which is even more important in basins that are expected to be or are already under severe water stress.

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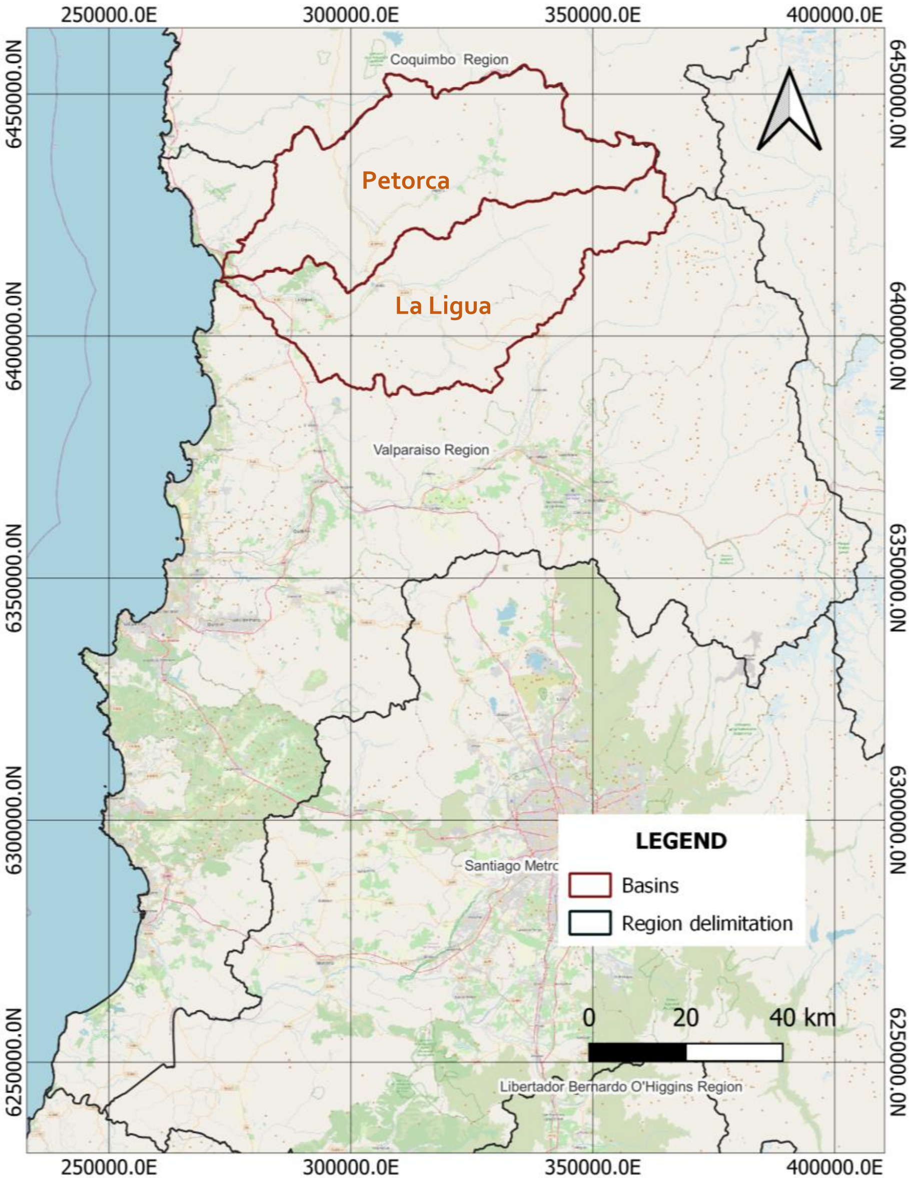


Figure: Pilot basins.

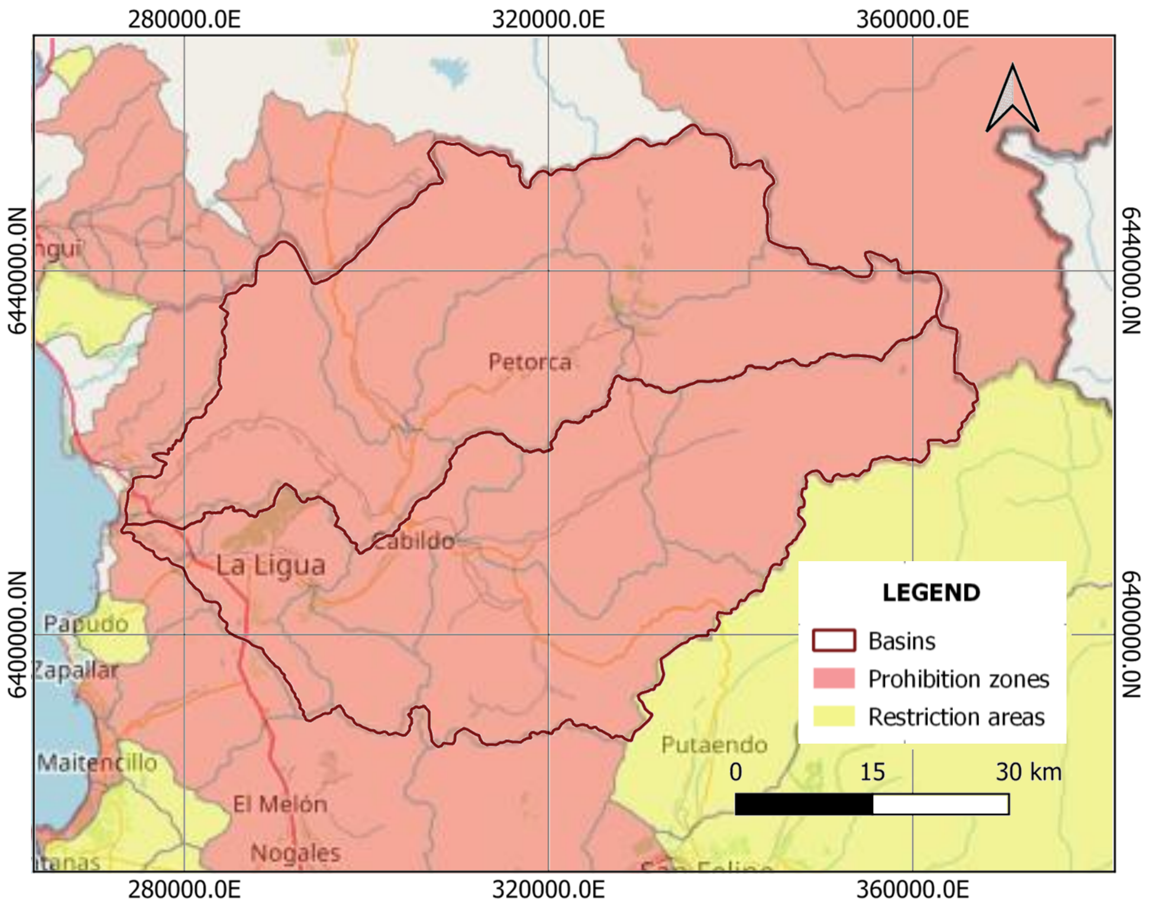


Figure: Current state of the awarding of rights to use groundwater.

Description		La Ligua	Petorca
Aquifer reality	Declared restricted areas	DGA Resolution No. 204 (May 14, 2004)	DGA Resolution No. 216 (April 15, 1997)
	Declared prohibition zones	DGA Resolution No. 19 (July 25, 2018)	DGA Resolution No. 19 (July 25, 2018)

Objective

Quantify the impacts of climate change, in terms of groundwater scarcity, in semi-arid basins using integrad modelling of water resources.

Part I - Integrated model of water resources

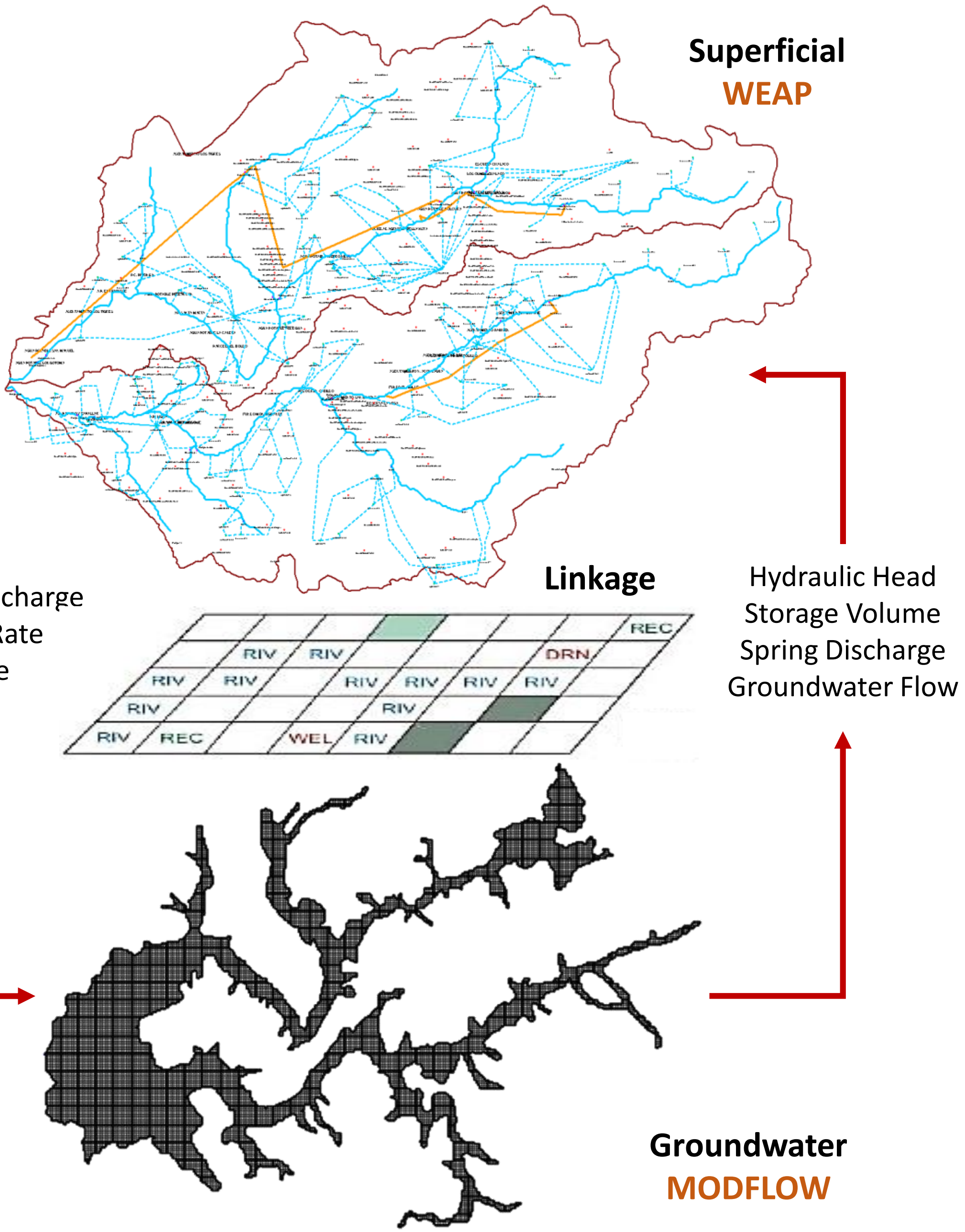


Figure: Schematic configuration of the integrated model of WEAP-MODFLOW.

Part I - Integrated model of water resources

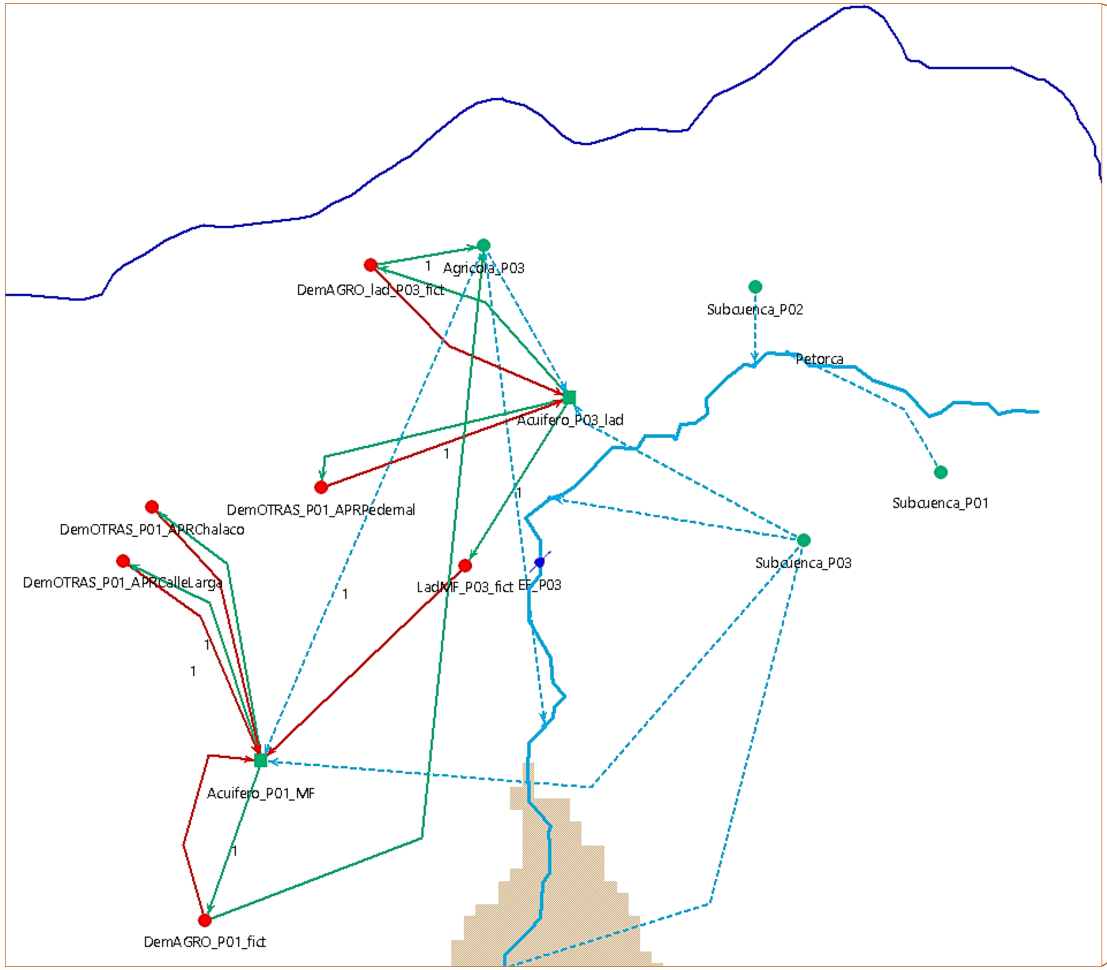
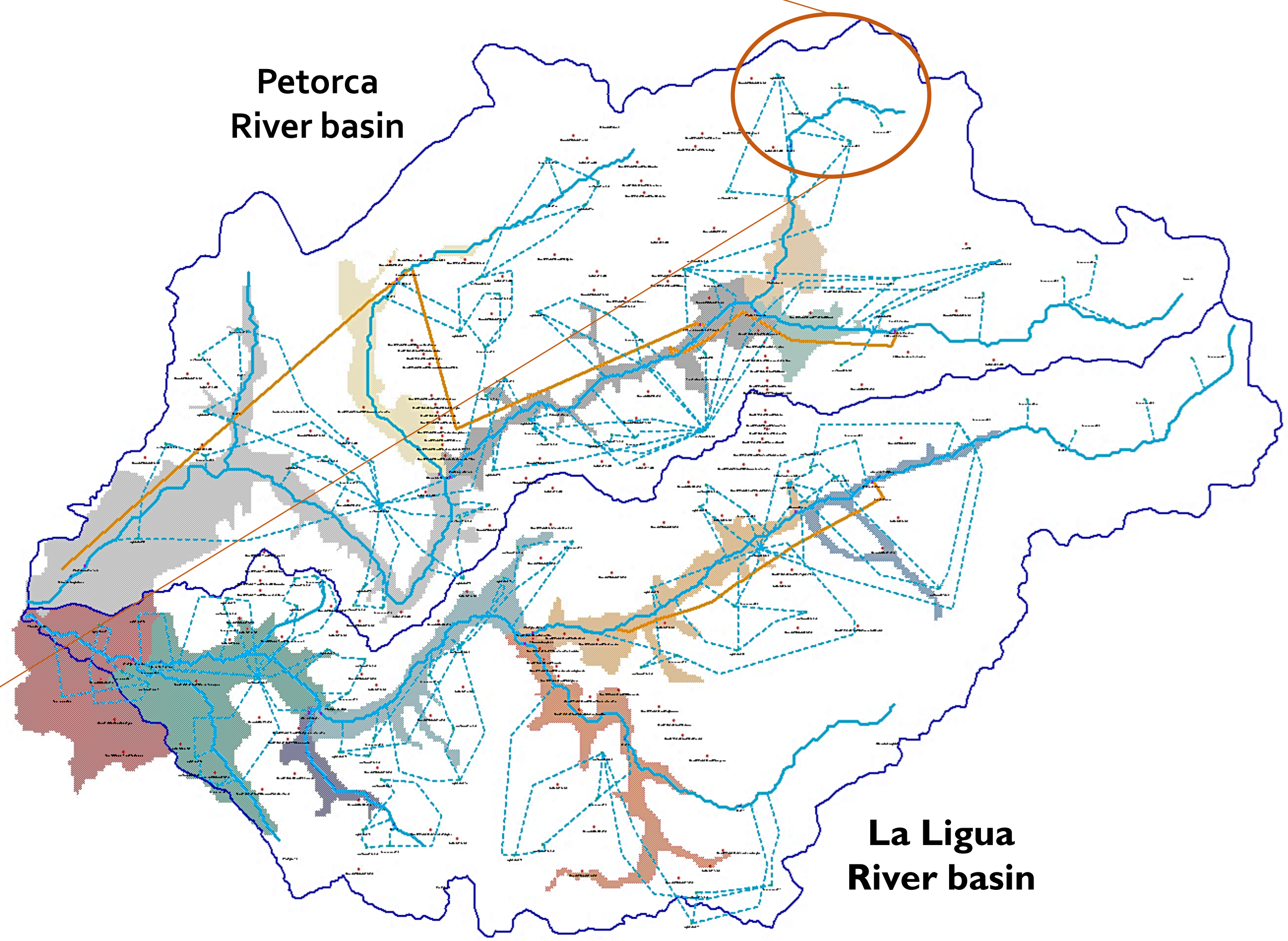


Figure: Zoom of the schematic configuration of the WEAP model.



Part II - The uncertainty associated with climate change through the use of General Circulation Models (GCMs) that participate in the CMIP6 phase

Obtaining future climatic series

GCM → **CMIP6** → SSP1-2.6, SSP2-4.5, SSP5-8.5 → **Precipitation Temperature**

Use of downscaling techniques

- Spatial disaggregation
- Temporal disaggregation

Transformation on a local and daily scale

Historical data:

- Local meteorological stations
- CR2met

To evaluate

- Variation of Precipitation and Temperature.
- Impacts of climate change on groundwater resources.

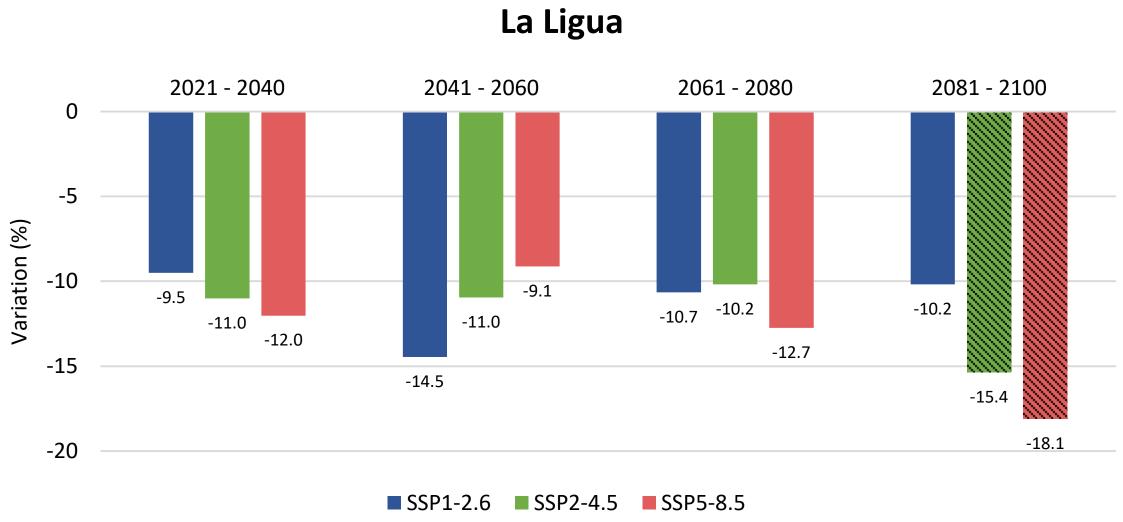
Three-time thresholds:

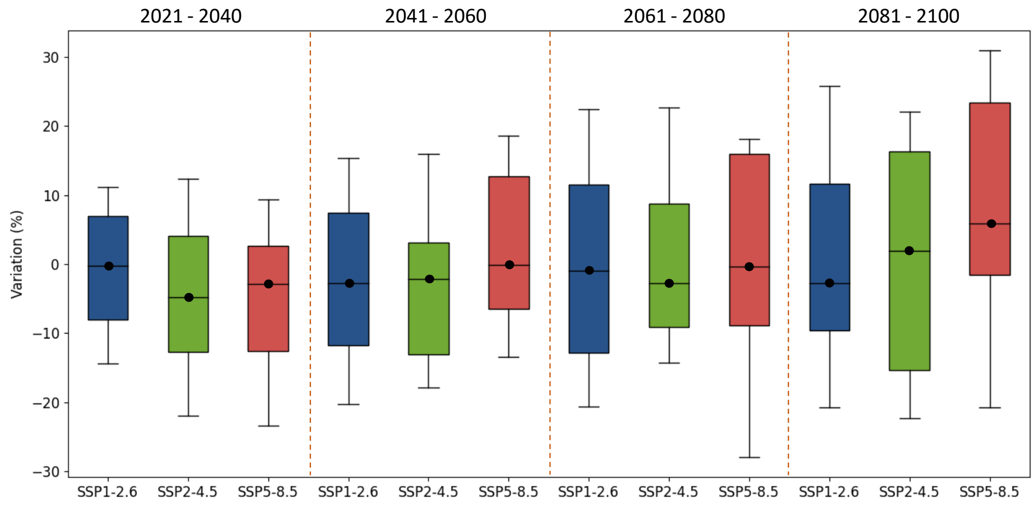
- Short-term → 2021 – 2040
- Medium-term → 2041 – 2060
  → 2061 - 2080
- Long-term → 2081 – 2100

Considerations:

- Agricultural surfaces do not vary from 2018.
- Population growth according to censuses.

Future projection of climatic forcing - Precipitation





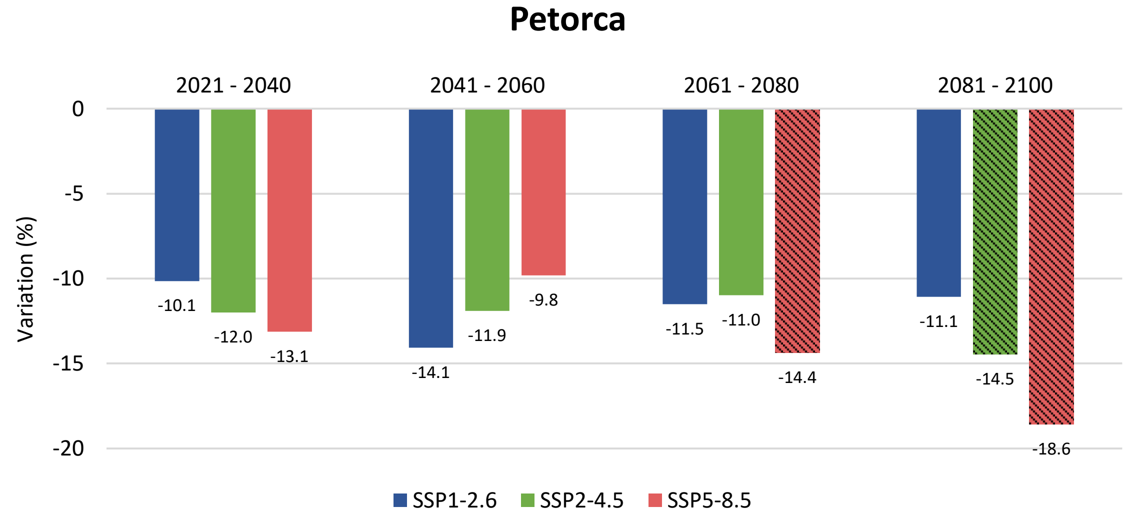


Figure: Variation in total annual precipitation (%) for the CMIP6 scenarios in La Ligua and Petorca river basins.
Note: Shaded areas represent areas with higher uncertainty.

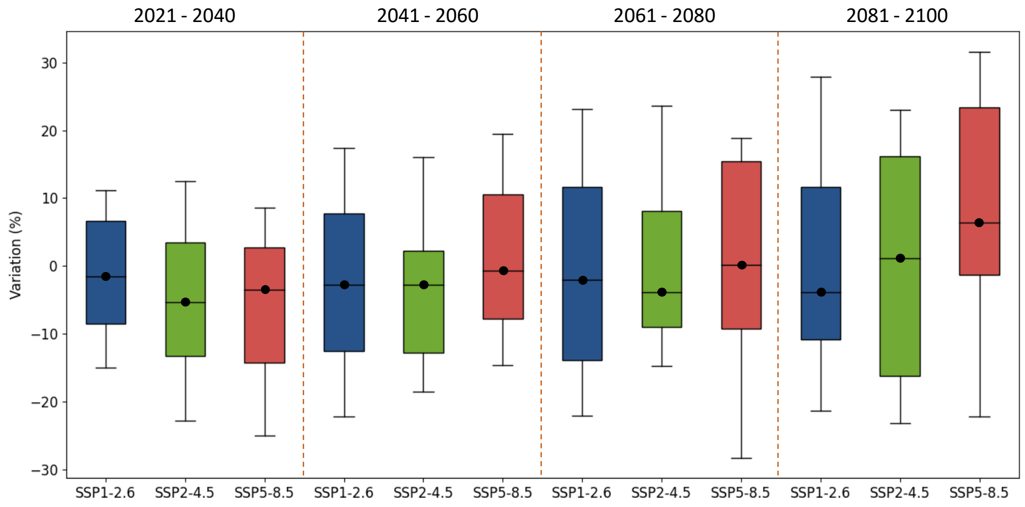


Figure: Variation in total annual precipitation (%) for the CMIP6 scenarios.
Note: The colored rectangles show the 25th and 75th percentiles, the bars the 5th and 90th percentiles, and the circle the 50th percentile.

Future projection of climatic forcing - Temperature

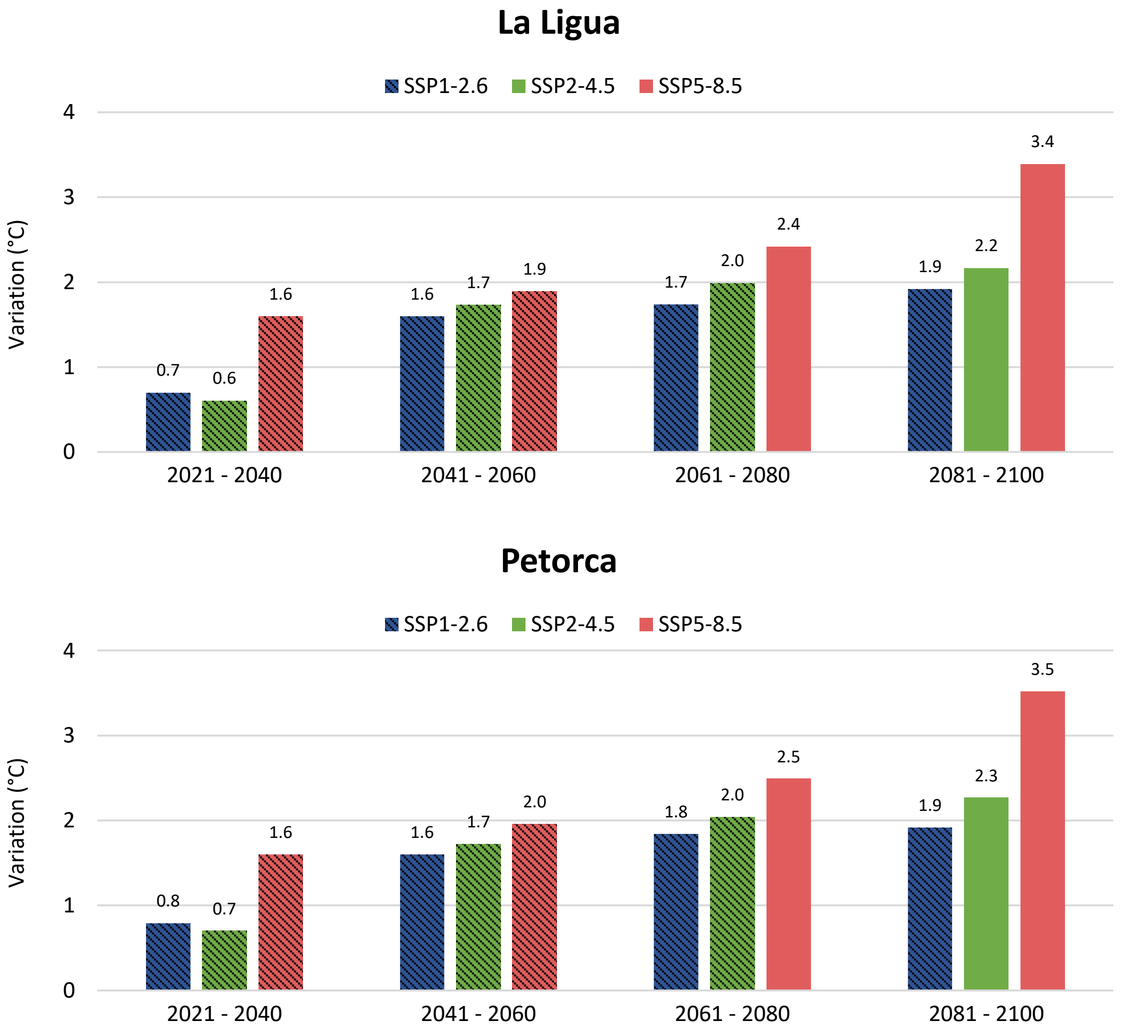


Figure: Variation in average annual temperature (°C) for the CMIP6 scenarios in La Ligua and Petorca river basins.
Note: Shaded areas represent areas with higher uncertainty.

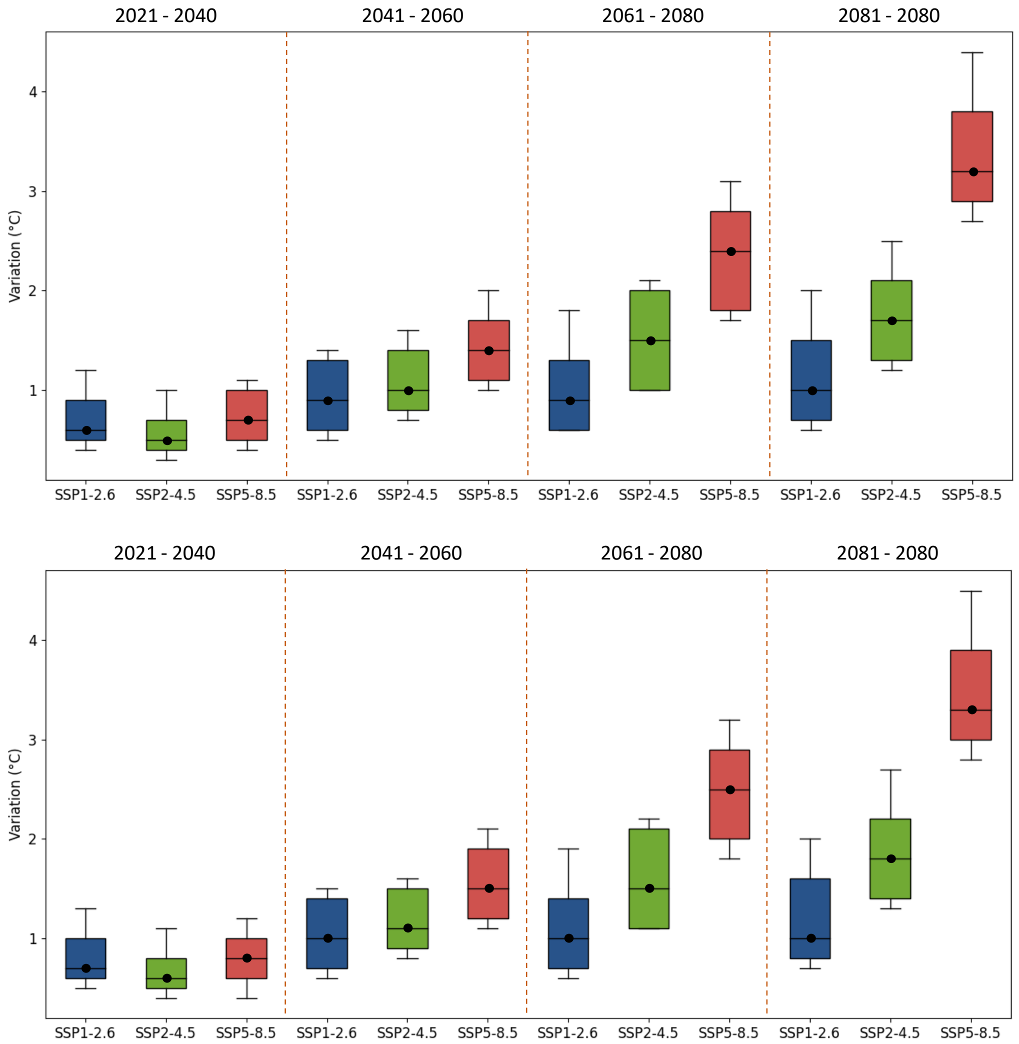
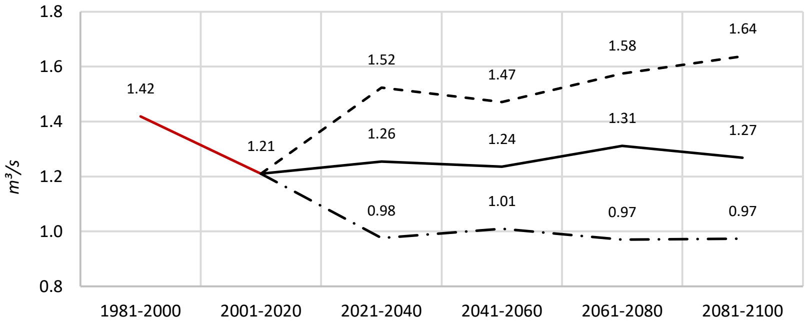


Figure: Variation in average annual temperature (°C) for the CMIP6 scenarios.
Note: The colored rectangles show the 25th and 75th percentiles, the bars the 5th and 90th percentiles, and the circle the 50th percentile.

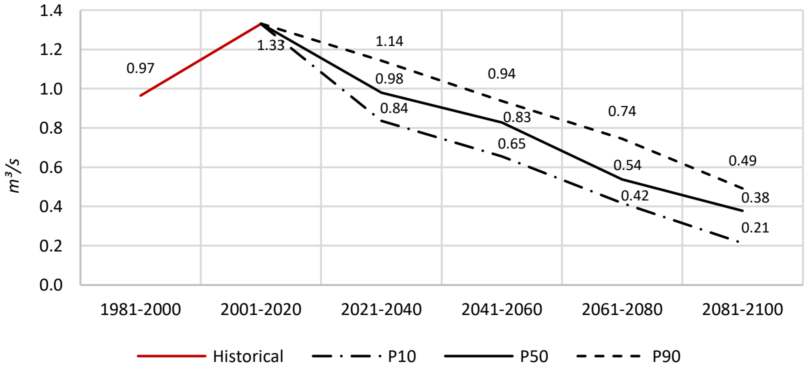
Recharge / Groundwater storage – La Ligua

SSP1-2.6

Recharge

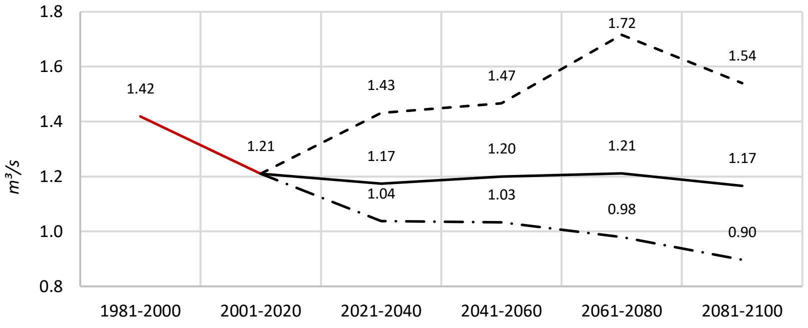


Groundwater storage

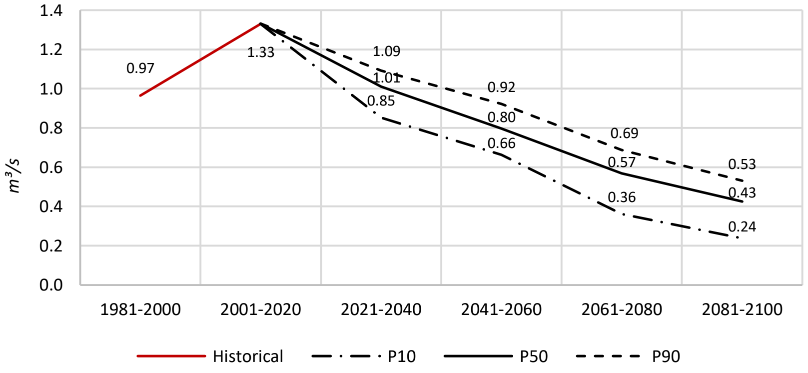


SSP2-4.5

Recharge

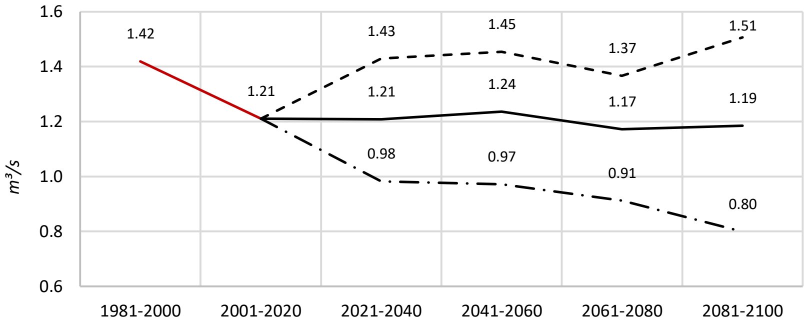


Groundwater storage

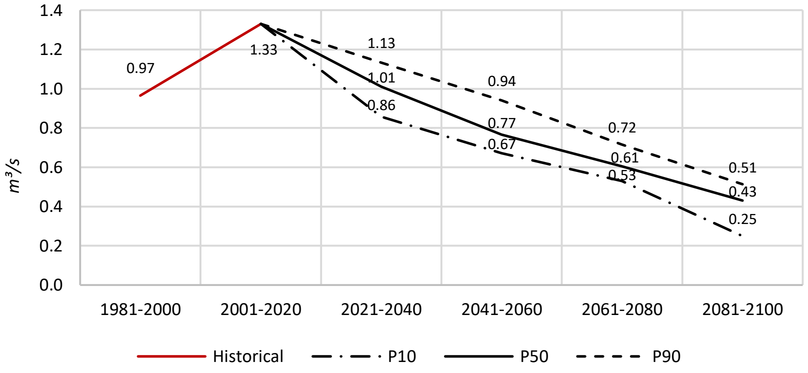


SSP5-8.5

Recharge



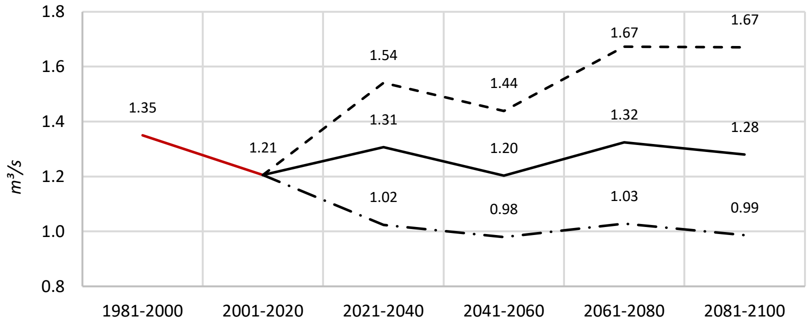
Groundwater storage



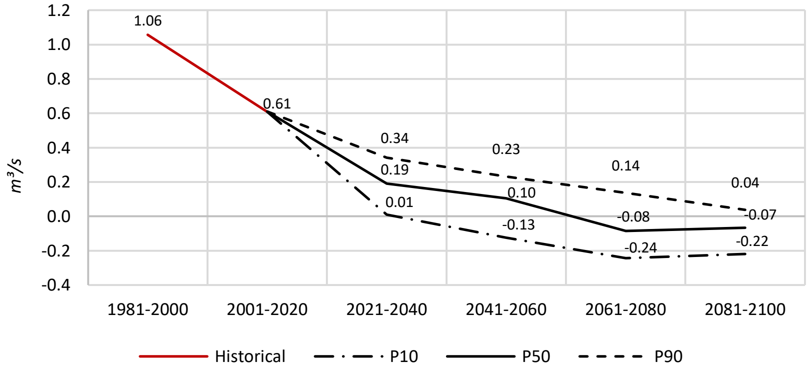
Recharge / Groundwater storage – Petorca

SSP1-2.6

Recharge

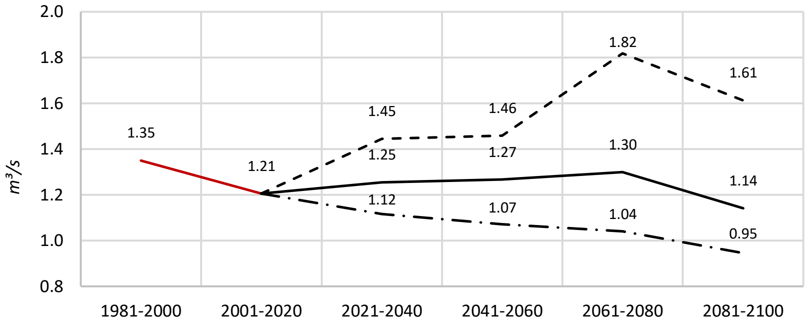


Groundwater storage

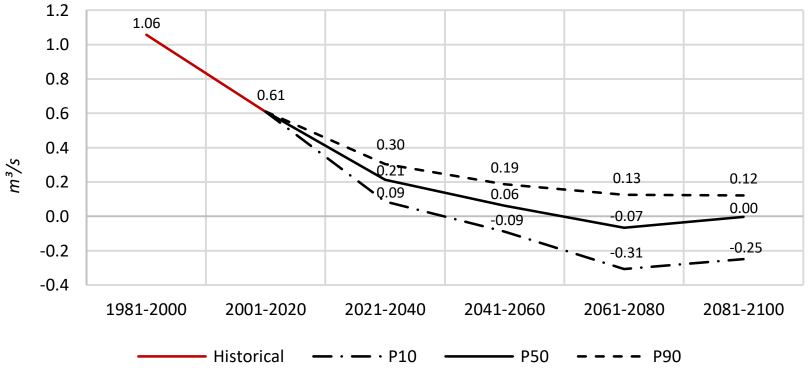


SSP2-4.5

Recharge

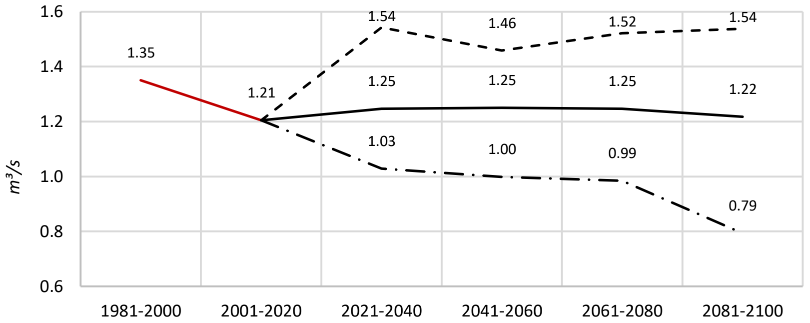


Groundwater storage

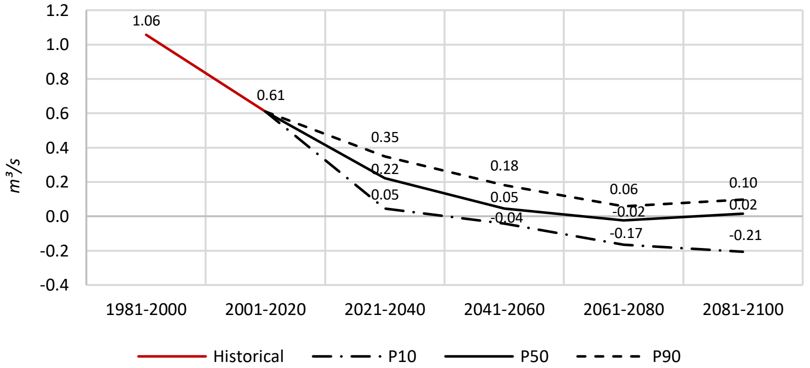


SSP5-8.5

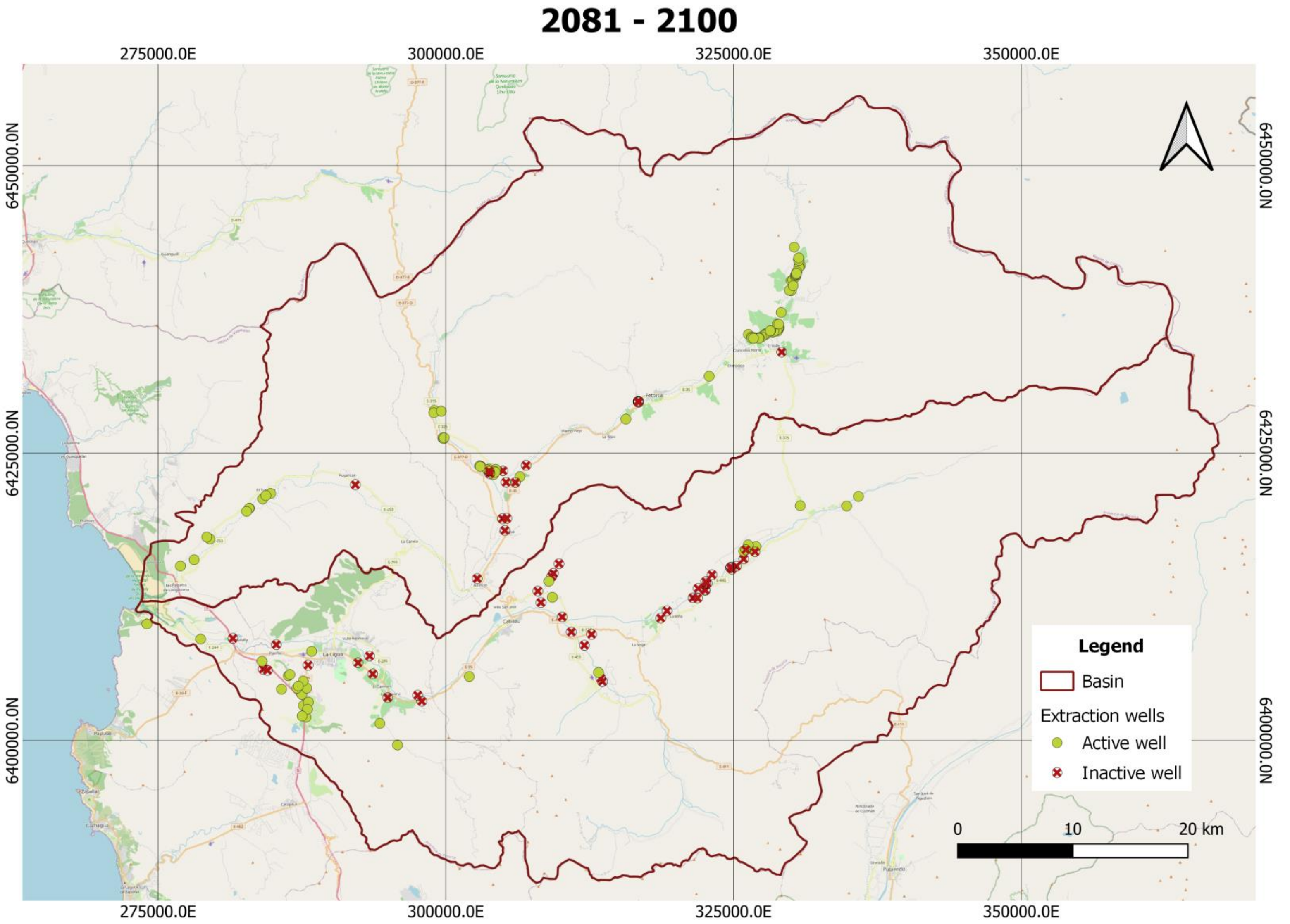
Recharge



Groundwater storage



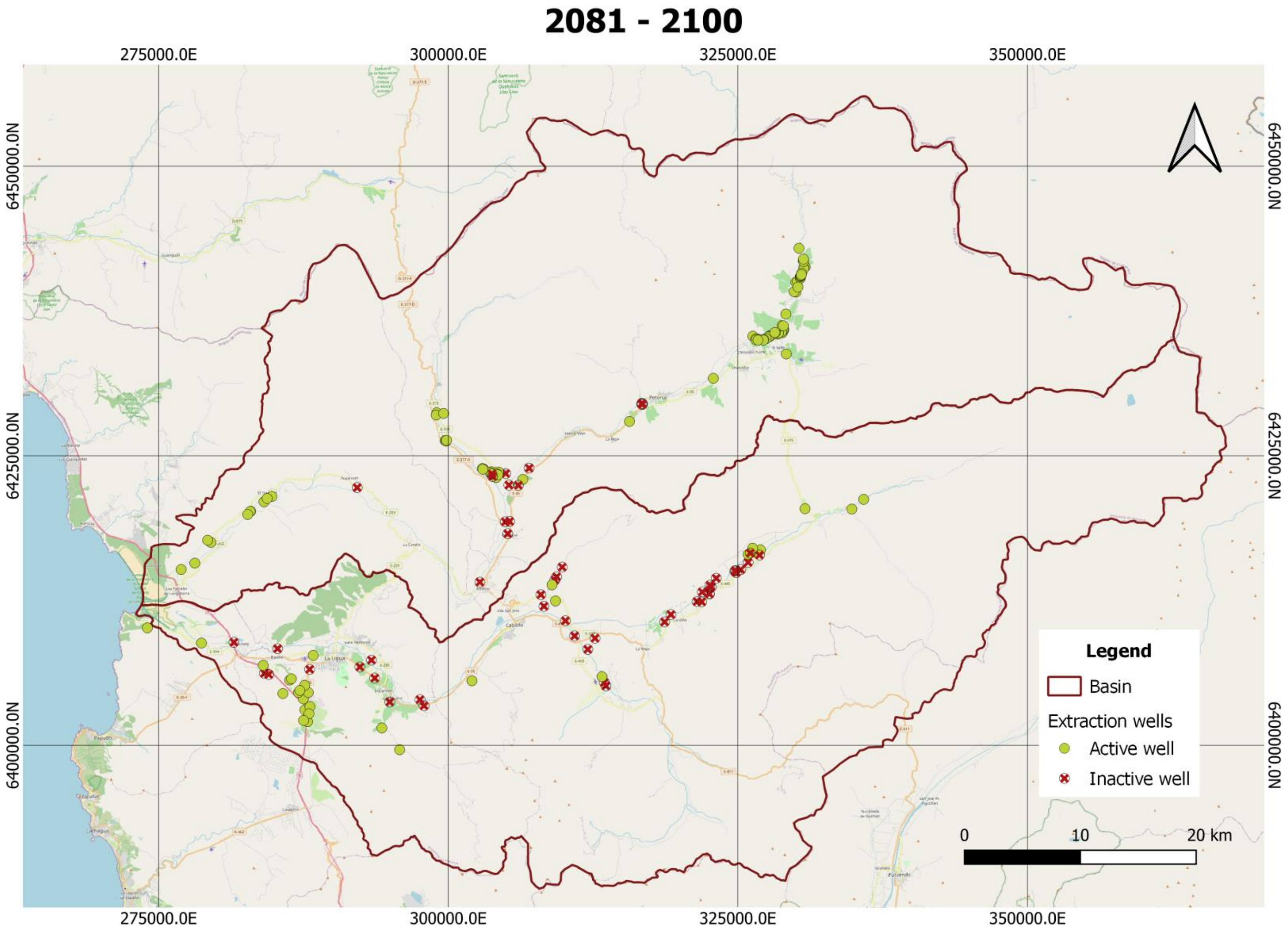
Extraction wells – SSP1-2.6



PETORCA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	7	15	16	17
Total number of wells	88			
Percentage	8.0%	17.0%	18.2%	19.3%

LA LIGUA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	21	33	39	39
Total number of wells	69			
Percentage	30.4%	47.8%	56.5%	56.5%

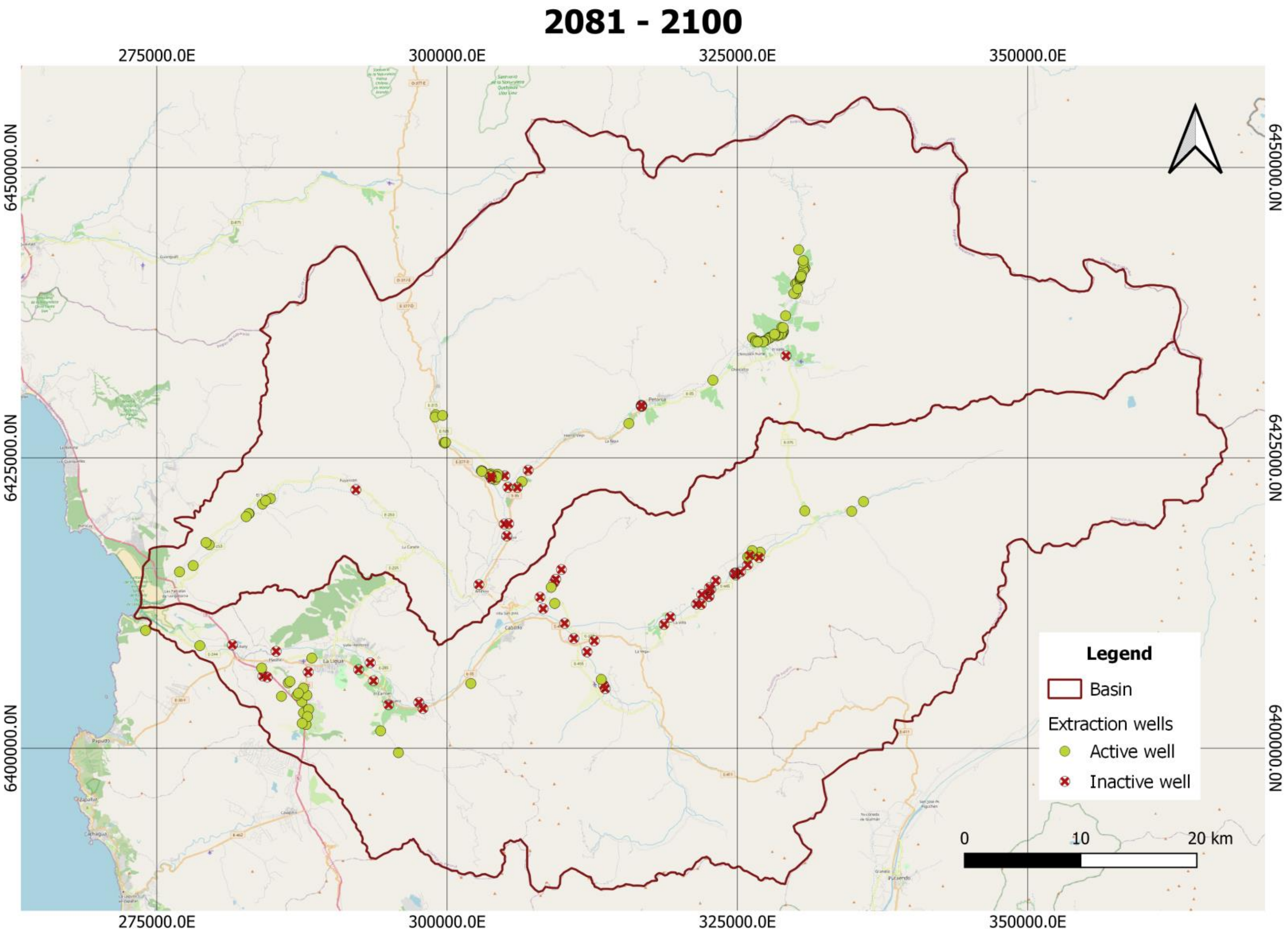
Extraction wells – SSP2-4.5



PETORCA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	7	16	16	16
Total number of wells	88			
Percentage	8.0%	18.2%	18.2%	18.2%

LA LIGUA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	21	34	39	39
Total number of wells	69			
Percentage	30.4%	49.3%	56.5%	56.5%

Extraction wells – SSP5-8.5



PETORCA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	7	16	16	17
Total number of wells	88			
Percentage	8.0%	18.2%	18.2%	19.3%

LA LIGUA	2021-2040	2041-2060	2061-2080	2081-2100
Inactive Wells	21	34	39	39
Total number of wells	69			
Percentage	30.4%	49.3%	56.5%	56.5%

Conclusions

- The coupling of hydrological and hydrogeological models is a tool that allows researchers and stakeholders to make opportune and appropriate decisions on the management of basins and aquifers, which is even more important in basins that are expected to be or are already under severe water stress.

Related to the results obtained for the basins:

- Annual precipitation will decrease, whereas average annual temperature will increase in these semi-arid basins.
- The aquifer's recovery rate will reduce, decreasing the number of wells that provide drinking water in rural and agricultural areas.
- It is necessary to implement actions that allow the sustainable development of the basins. For this, the **WEAP - MODFLOW models** can be used because they allow the simulation of actions in the future (e.g., apportionment of water use rights, construction of reservoirs or desalting plants, among others).

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Annex – GCMs obtained from CMIP6

Institution	Country	Model	SSP		
			1-2.6	2-4.5	5-8.5
Australian Community Climate and Earth System Simulator	Australian	ACCESS-CM2	x	x	x
		ACCESS-ESM1-5	x	x	x
Alfred Wegener Institute	Germany	AWI-CM-1-1-MR	x	x	x
Beijing Climate Center	China	BCC-CSM2-MR	x	x	x
Chinese Academy of Sciences	China	CAS-ESM2-0	x	x	x
Centro Euro-Mediterraneo sui Cambiamenti Climatici	Italy	CMCC-CM2-SR5	x	x	x
		CMCC-ESM2	x	x	x
Institute of Atmospheric Physics	China	FGOALS-f3-L	x	x	x
		FGOALS-g3	x	x	x
First Institute of Oceanography	China	FIO-ESM-2-0	x	x	x
		GFDL-ESM4	x	x	x
Russian Institute for Numerical Mathematics	Russia	INM-CM4-8	x	x	x
Centre for Environmental Data Analysis	United Kingdom	KACE-1-0-G	x	x	x
Korea Institute of Ocean Science and Technology	Korea	KIOST-ESM	x	x	x
Marine-Earth Science and Technology	Japan	MIROC6	x	x	x
Max-Planck-Institut für Meteorologie	Germany	MPI-ESM1-2-HR	x	x	x
		MPI-ESM1-2-LR	x	x	x
Meteorological Research Institute	Japan	MRI-ESM2-0	x	x	x
Nanjing University of Information Science and Technology	China	NESM3	x	x	x
Norwegian Climate Center Noruega	Norway	NorESM2-LM	x	x	x
		NorESM2-MM	x	x	x