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RESEARCH AND OBSERVATORY CATCHMENTS: THE LEGACY AND THE FUTURE

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Forestal Arauco experimental research catchments; daily rainfall-runoff for 10 catchments with different forest types in Central-Southern Chile

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Abstract

Forestal Arauco (FA), a global manufacturer of forest products, manages more than 1 million ha of forest plantations and oversees the conservation of more than half a million hectares of native forest and vegetation in Brazil, Argentina and Chile. In 2008, FA responded to local concerns about the effect of plantations on water resources and commenced streamflow monitoring in catchments in the coastal range of central-southern Chile between 35° and 39° of latitude south. This data note presents an overview of daily streamflow and rainfall records for 10 small catchments (18–112 ha) from 2008 to 2018. The catchments are covered by three different forest types, namely native forest (2), pine plantations of different ages (6) and eucalypt plantations (2). All of these catchments share similar metamorphic geology. A 90° V notch weir was built at each catchment outlet and data collected at 5 min interval using a pressure transducer that was calibrated monthly. The dataset is part of a research programme aiming to improve our understanding about the role of forest plantations on water balance at a stand and catchment level. It also includes the rainfall data from these catchments estimated using a combination of local rain gauges and data from the longer term records of the Chilean Directorate of Water. This dataset can be used in hydrological modelling and in a wide range of research questions and water management issues regarding forest plantations in a Mediterranean climate.

KEYWORDS

Chilean native forest, Mediterranean climate, plantations, south-Central Chile

1 | DATASET NAME

Forestal Arauco research catchments streamflow-rainfall data, Central-Southern Chile.

2 | INTRODUCTION

The effect of forests and their management on water resources is a globally important natural resource management issue. In recent decades there has been a strong focus on the effect of wood production plantations, particularly of *Eucalyptus*, on streamflow and water quality. This research has underpinned policy and forest management all over the world but particularly in South Africa (Albaugh et al., 2013), Australia (Greenwood, 2013), southern Europe (Pereira de Almeida & Riekerk, 1990) and South America (Almeida et al., 2007). Some studies have found annual streamflow increases (e.g., Jones et al., 2009) after harvesting while others have shown no difference after 100% removal of forest cover (e.g., Brown, 1971) or even a decreasing trend in summer flows in the years after harvesting

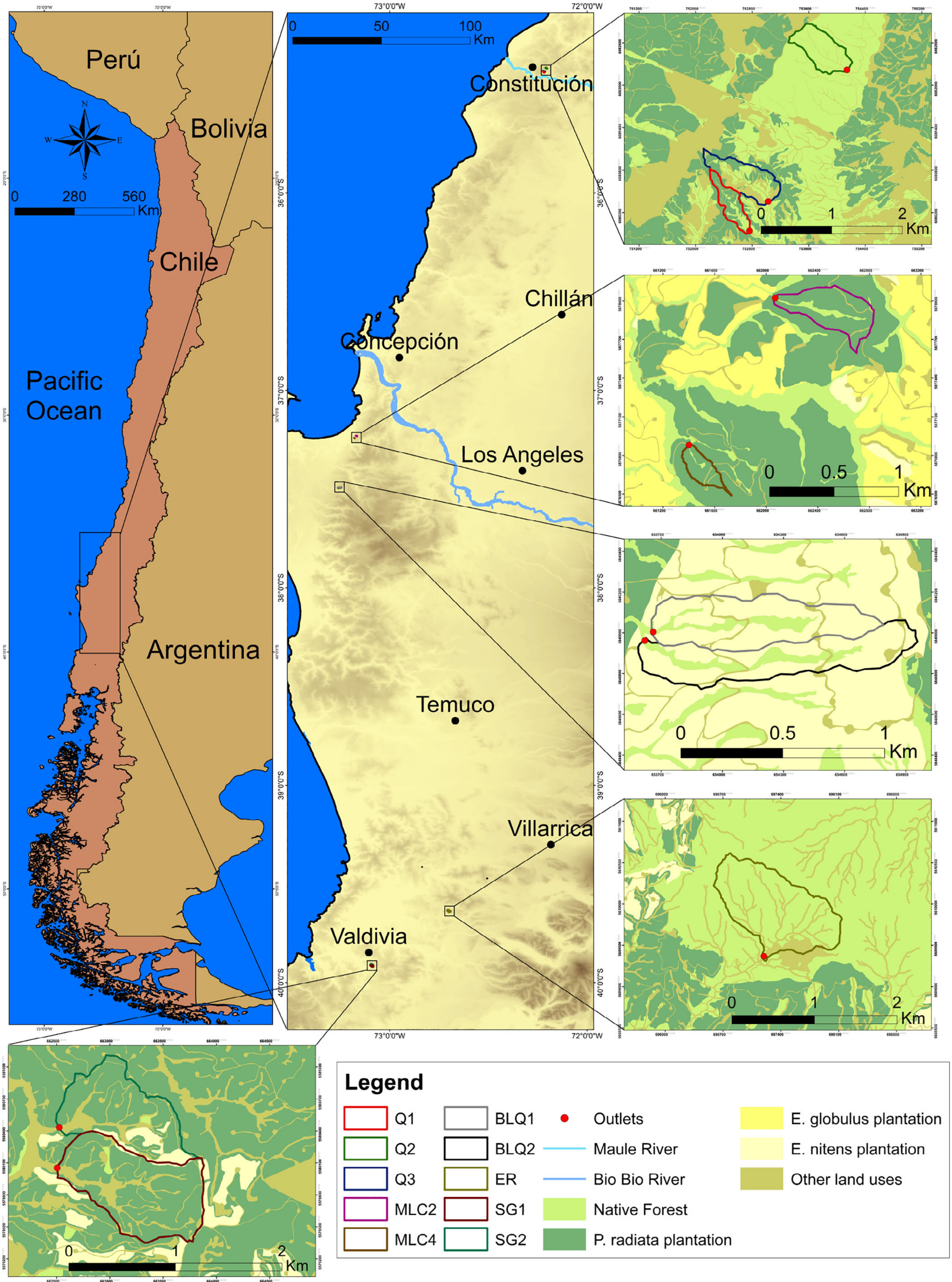

FIGURE 1 Maps showing the location of the catchments in South America and Central Chile

and planting (Segura et al., 2020). Thus, local data are important and will become increasingly so in coming decades if the projected changes in temperature and rainfall distribution occur and as governments struggle with the need to balance carbon sequestration in forests for global warming mitigation and water consumption by plantations (Batelis & Nalbantis, 2014; Ellison et al., 2012).

The limited availability of data from small catchments in South America (Jones et al., 2017) means that sharing these data is especially important. A Special Issue of Hydrological Processes titled 'Hydrological Processes on South American hydrology' (edited by Boutt & Iroume, 2018) emphasized the value of sharing local data. The papers in the special issue provide useful insights for the region into important areas of knowledge such as the 'two water worlds' hypotheses applied in a wet environment (Hervé-Fernández et al., 2016). Nonetheless, there is still limited availability of data and most of these papers relied on public data from catchments with an area of more than 25 km^2.

Streamflow is a fundamental component of hydrology that has been used for more than 80 years to analyse the effect of human activity on hydrological processes (Incoll, 1936; Wicht, 1939). However, while studies in catchments larger than 1,000 km^2 are common (Burn, 2008; Do et al., 2017; Rientjes et al., 2011; Yan et al., 2013), especially in the northern hemisphere, datasets from smaller catchments (<1 km^2) are rarer (Bosch & Hewlett, 1982; Chen et al., 2001; Stahl et al., 2010). In Chile, the effect of management of plantations on streams in the coastal mountains is an important water resources issue that is not well served by existing publicly available data such as that provided by the Chilean Directorate of water (Dirección General de Aguas, DGA). The DGA stations are located with an emphasis on the central valley between the Andes and the coastal range (e.g., the CAMELS dataset from DGA stations in Alvarez-Garreton et al., 2018).

Here, we present data from a set of 10 experimental catchments in southern Central Chile within the coastal range of Chile. These catchments are covered by the three main land covers of the region, namely plantations of *Pinus radiata* and *Eucalyptus* spp. and Chilean native forest. Pine and Eucalyptus catchments are in a paired-catchment design while the native species catchments are nearby (see section catchment descriptions). The plantations were planted between 1990 and 2011. Streamflow has been monitored in some catchments since 2008. This data note provides a description of this experimental infrastructure and access to this valuable dataset.

3 | CATCHMENT DESCRIPTIONS

The study sites include 10 small catchments located between 35°S and 39°S (Figure 1) in the coastal range in Central-Southern Chile. The geology of this part of the coastal range is dominated by a

TABLE 1 Catchment area, land cover, location, annual rainfall, soils and pressure transducer sensor

	Quivolgo 1 (Q1)[a]	Quivolgo 2 (Q2)[a]	Quivolgo 3 (Q3)[a]	María las Cruces 2 (MLC2)	María las Cruces 4 (MLC4)	Bajo las Quemas 1 (BLQ1)	Bajo las Quemas 2 (BLQ2)	San Gabriel 1 (SG1)	San Gabriel 2 (SG2)[b]	Entre Ríos (ER)
Data first available	2009	2009	2013	2009	2013	2010	2010	2012	2012	2013
Main land cover[c]	*P. radiata*	Native forest	*P. radiata*	*P. radiata*	*P. radiata*	*E. nitens*	*E. nitens*	*P. radiata*	*P. radiata*	Native forest
Plantation year	2003	NA	*2001*	*1994*	*1994*	*2011*	*2011*	*1990*	NA	NA
Annual precipitation (mm)		966		1200		1800		1900		1800
Area (km^2)	0.1895	0.3302	0.4014	0.1912	0.0572	0.2263	0.2221	0.8909	0.6989	11 225
Outlet latitude (°S)	35.37778	35.35692	35.37396	37.21539	37.22578	37.47853	37.47854	39.89811	73.09910	39.62698
Outlet longitude (°O)	72.21757	72.20312	72.21479	73.17342	73.18070	73.26213	73.26260	39.89469	73.09898	72.70242
Type of climate	Temperate semi-oceanic							Rainy temperate		
Average clay content (%)	33	35	33	37	40	36	36	19	19	16
Average sand content (%)	30	28	29	28	30	29	30	41	39	45
Average silt content (%)	37	37	38	35	30	35	34	40	42	39
Pressure transducer brand[d]	KPSI OTT (Aug-14)	KPSI	OTT KPSI (Jan-14)	KPSI OTT (Aug-16)	OTT	OTT	OTT	KPSI	KPSI	OTT

[a]These catchments were completely burned by the megafires of 2017 (Balocchi, Flores, et al., 2020).
[b]SG2 was harvested between 2013 and 2015. Land use changes in this catchment in the repository at http://www.hydroshare.org/resource/4b517deaa07243aa8c46a58646dd4281.
[c]A resume for the 2016 inventory for all land uses per catchment can be found in Table 2.
[d]First line refers to first installed pressure transducer sensor and second line refers to a sensor change and date when it was changed. KPSI: KPSI 550 pressure transducer sensor and OTT: OTT Orpheus Mini pressure transducer.

metamorphic rock complex (Mordojovich, 1974) with rock ages from the Silurian-Carboniferous in the northern and central area to Palaeozoic-Triassic in the southern part of the study site (Servicio Nacional de Geología y Minería, 2003). The soils that are derived from this metamorphic rock are in the clay loam (Q1, Q2, Q3, MLC2, MLC4, BLQ1 and BLQ2), clay (MLC1) or loam (SG, ER) texture classes (Table 1). The soils in Q1, Q2, Q3, MLC1 and MLC2 are less than 1 m deep and include a high percentage of stone. The soils in BLQ1, BLQ2, SG and ER are generally deeper than 1 m.

Catchment Q2 is covered by the winter deciduous *Nothofagus glauca* (Hualo) as the dominant species. A complete description of the forest structure in Q2 can be found in White et al. (2020). Catchment Q3 is a mixed catchment covered by *Pinus radiata* planted in 2001 (62%), and native forest with *N. glauca* as the main species (34%). The *P. radiata* plantations on Q1 and Q3 were established at 1,250 tress ha^{-1} and were thinned at age six to 700 trees ha^{-1} and at age eight to 450 trees ha^{-1}. Trees were pruned to a height of 2.1 m and to 3.9 m respectively at the first and second thinning.

In MLC2 and MLC4, the initial stand density was 1,250 trees ha^{-1}. In MLC2, 920 trees ha^{-1} were pruned at age six to a height of 1.9 m, and 560 of these trees were pruned again at age 9 years to a height of 3.9 m. In MLC4 620 trees ha^{-1} were pruned at age six to a height of 2.1 m and at age 9590 trees ha^{-1} were pruned to a height of 3.7 m. Neither MLC2 nor MLC4 were thinned at any time.

In BLQ1 and BLQ2, the initial stock density was 1666 tress ha^{-1} and in these catchments no more forest management will be performed until harvesting. Within SG1 and SG2, the initial stock density was 1250 trees ha^{-1} in the *P. radiata* plantations, and they were thinned at age six to 700 tress ha^{-1} and at age eight to 450 trees ha^{-1}. Trees were pruned at age 10 to a height of 2 m, at age 11 to a height of 3.5 m and at age 12 to a height of 4.6 m. Within the Eucalyptus in SG1-2, the initial stock density was 1,666 tress ha^{-1} and no more forest activities in these catchments will be performed until harvesting. Q2 and ER have no management as they are native forest, aside from the manual removal *P. radiata* seedlings by Forestal Arauco. A list of land cover attributes by catchments can be found in Table 2 and the full detail of land cover changes within the repository in Balocchi, White, et al. (2020).

4 | DATA ACQUISITION

In all catchments, a McPherson thin wall 90° V notch weir was built at the catchment outlet (Figure 1). All weirs were instrumented with a pressure transducer to measure water height (Table 1 for sensor deployment and date of installation). These sensors are a KPSI 550 (Pressure Systems, Inc., VA) and an OTT Orpheus Mini (OTT Hydromet GmbH, Germany). KPSI 550 pressure transducer accuracy is ±0.05% Full Scale (FS). OTT Orpheus Mini pressure transducer accuracy is ±0.05% FS and resolution is 0.01% FS. Streamflow is determined using the theoretical rating curve. Depth of the water in the weir was measured at 5-min intervals and these data were used to estimate streamflow (Eli, 1986). Height data for streamflow calculation are corrected monthly to readings of a staff gauge installed each weir. The streamflow measurement can be downloaded as daily values (Figure 2 as streamflow and rainfall example for Q2-MLC2-BLQ2-ER).

Rainfall in Q1, Q2 and Q3 was measured at the top of the Q2 catchment in a clearing using an RG12 tipping bucket rain gauge (Environdata Weather Stations Pty Ltd, Australia. Resolution 0.2 mm per tip, accuracy of ±2% at low rainfall rates and ±5% at rainfall rates above 300 mm/h). This rain gauge is calibrated once a year. The measurements of rainfall commenced in August 2016 for these three catchments. For the period between 2010 and August 2016 (when streamflow data is available), daily rainfall was sourced from the nearby meteorological site (Forel station, Direccion General de Aguas, DGA) which is about 5 km south-east of the catchment. There was a strong linear relationship (R^2 of .84) between rain recorded at our gauge and the DGA gauge in Forel. This relationship was used to fill any gaps in the data. Periods of missing data from the Forel station prior to August 2016 were filled using data from the next nearest

TABLE 2 Catchment land cover area attributes (hectares) resume for Q1, Q2, Q3, MLC2, MLC4, BLQ1, BLQ2, SG1, SG2 and ER, inventory 2016 (pre-fire 2017)

Catchment	Native forest	Stockyards	*E. nitens*	Forest roads	*P. radiata*	Afforestable	Buffer zone	Total
Q1	4.21	0.07	0	0.88	13.26	0	0.53	18.95
Q2	31.75	0	0	0.15	0	0.09	1.03	33.02
Q3	10.19	0	0	1.72	24.7	1.36	2.17	40.14
MLC2	1.92	0	0	0.65	16.56	0	0	19.12
MLC4	0.26	0	0	0.22	5.25	0	0	5.73
BLQ1	3.22	0	18.31	0.97	0	0.14	0	22.63
BLQ2	4.12	0	16.76	1.33	0	0	0	22.21
SG1	0.97	0.68	2.67	3.41	67.44	0.65	13.27	89.09
SG2	0.63	1.05	9.38	2.57	46.9	0.29	9.07	69.89
ERS	90.27	0	0	0.25	0	6.4	15.32	112.25

Note: Quivolgo catchments were completely burned by the megafires of 2017 (Balocchi, Flores, et al. 2020). For more information on catchment land cover changes refer to the repository at Balocchi, White, et al. (2020).

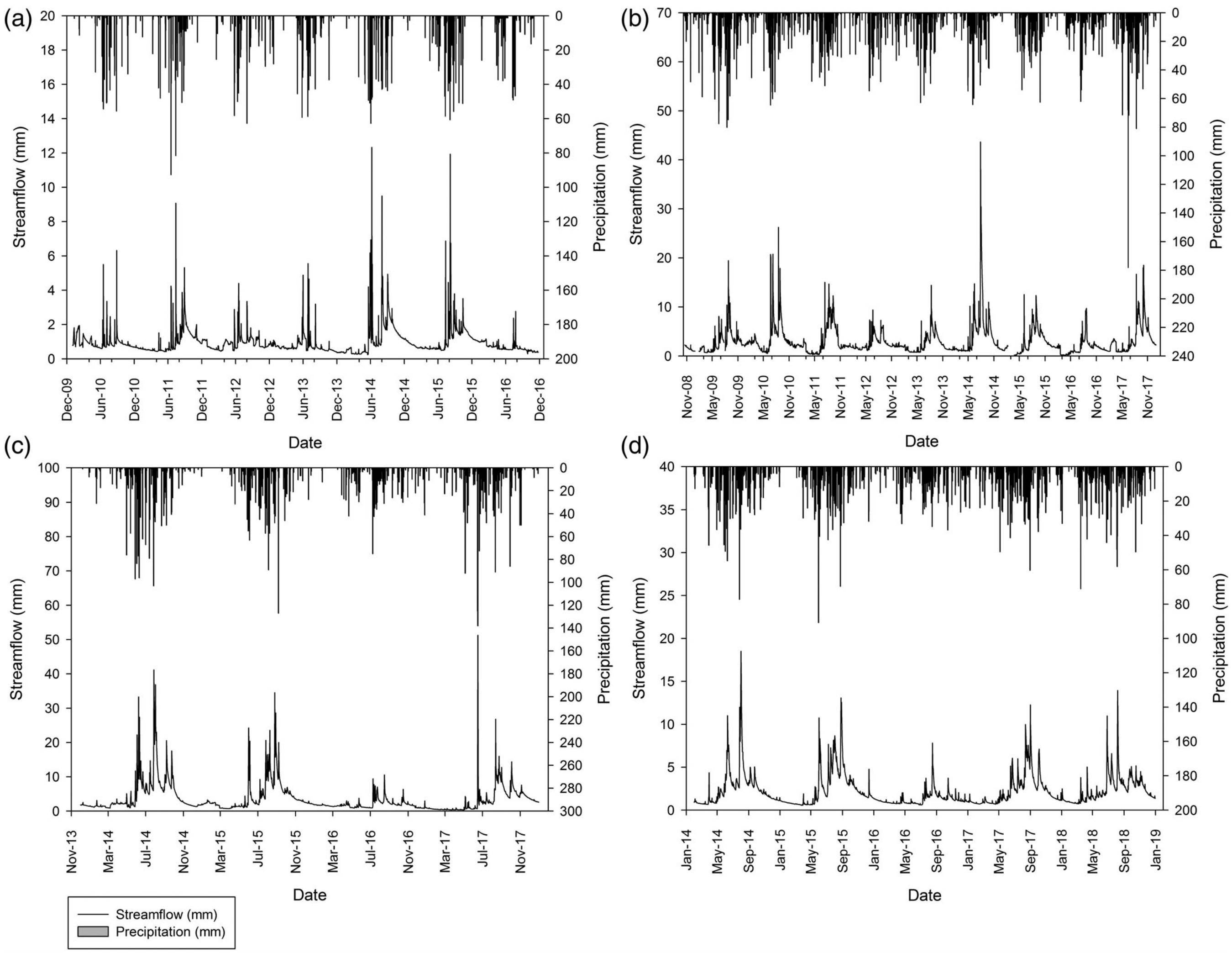

FIGURE 2 Rainfall and streamflow at (a) Q2, (b) MLC2, (c) BLQ2 and (d) ER

DGA station at Nirivilo, also using a linear regression (Balocchi, Flores, et al., 2020).

For the MLC zone, we have constructed the rain dataset using a RG12 automatic tipping-bucket raingauge (Environdata Weather Stations Pty Ltd., Australia) installed in 2016. We use these data to adjust the longer-term record at the closest Chilean Directorate of Water (DGA) station (Rio Carampangue in Carampangue). The RG12 rain gauge is calibrated once a year.

FA has a rain gauge station 11 km to the northwest of the BLQ catchments. This station records daily rainfall. For SG, the rainfall station for reference is the DGA station at Llancahue. There is no DGA station near ER and the CR2MET (Center for Climate and Resilience Research Meteorological dataset) rainfall product (5-km grid for continental Chile) was used (Boisier et al., 2018). The CR2MET product is partially based on a downscaling process from European Centre for Medium-Range Weather Forecasts reanalysis data interim version (ERA-Interim) reanalysis (Dee et al., 2011) and land rain gauges. Rain gauge locations are available within a kmz (Keyhole Markup Language Zipped) file inside the rainfall folder in the repository (Balocchi et al., 2020).

Some of these data have been published by Balocchi, Flores, et al. (2020) who have analysed, for the first time in Chile, the hydrologic balance pre- and post-fire within a High Conservation Value Hualo (*Nothofagus glauca* [Phil.] Krasser) forest in Central Chile. They found that annual peak flows and runoff coefficients decreased after fire, there was an average of 60% extra water not accounted for in the monitoring system after fire, and infiltration of rainfall was enhanced after fires. Also, Balocchi et al. 2021) have analysed the recession coefficients within eight catchments in south-central Chile. The differences in the recession coefficients were not statistically significant in winter but there were some statistical differences in summer and these differences were attributed to morphological characteristics between catchments and the effect of land cover (native forest and plantation) in the Q2 and Q3 catchments in the northern part of the study site.

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DATA AVAILABILITY STATEMENT

Streamflow and rainfall data are presented as daily values and they are available at Balocchi et al. (2020; http://www.hydroshare.org/resource/4b517deaa07243aa8c46a58646dd4281). The streamflow data is in the format of 'catchmentName_initialyear_endyear' inside the streamflow folder within the repository and the units are mm per day. Streamflow and rainfall data are available as .xlsx files. There are some gaps in the data due to weir maintenance or other issues. Both streamflow and rainfall data collection are ongoing as part of the continuing forest hydrology research programme at FA.

Rainfall data are also provided for all of the catchments (rainfall folder and a kmz file giving the location of each rain gauge) as well as a shapefile format (shp) file of the catchment outline and the Digital Elevation Model (DEM) at 5 x 5 m resolution. Streamflow and rainfall datasets are expected to be updated annually. All these data are owned and are being collected by Forestal Arauco.

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