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Climate data revisions and their impact on hydrological modelling

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Abstract: Hydrological and river system models are essential tools used by government agencies in Australia to inform water resources management and policymaking under changing climate. The performance of such models depends on the quality and availability of spatially adequate climate and flow data. The SILO database managed by the Queensland Government offers a consistent set of daily climate point data covering the period from 1889 to yesterday meaning that the database is continuously updated with the newest observations. Missing timeseries values are infilled using a specialised interpolation methodology. The dataset is further screened for erroneous values. This can occasionally lead to significant changes in timeseries, as for example the SILO update notes of 2020 and 2022 suggested. For hydrological modelling, this means that climate data are always up-to-date and tend towards the best possible estimate. Hydrological models calibrated before major data updates, however, might show unacceptable performance using the updated data. This may require reviewing and recalibration of existing models.

This case study of two coastal catchments in New South Wales (Manning and Richmond Valleys) aims at showing a possible approach how to assess the impacts on hydrological modelling due to SILO updates. This includes the magnitude of change in climate timeseries (percentage difference) and what the impacts are on rainfall-runoff and river system models calibrated prior to recent SILO updates (e.g. percentage bias of simulated flow compared to observed).

The Richmond River system model was developed and calibrated in 2018/19 (i.e. before major SILO updates) and the Manning River system model in 2021 (i.e. between major SILO updates). The comparison between the climate data used during model implementation and the updated data in 2024 showed significant differences. For the Richmond, differences in rainfall timeseries were between –16.5% and +0.6% and for potential evapotranspiration between –4.3% and +4.2%. For the Manning, the differences were smaller with –0.1% to +0.2% for rainfall and –1.0% to +0.3% for potential evapotranspiration. Using this updated climate data as input to the calibrated rainfall-runoff models lead to substantial streamflow biases. For the headwater catchments in the Richmond, the initial performance of –1.4% to +2.8% flow bias deteriorated to –12.0% to +5.7%. For the Manning, the original 0.0% flow bias deteriorated to –1.3% to +3.0% using the new data. These changes in flow bias show the impact of the SILO data updates on initially well-performing rainfall-runoff models. Other components of the river system model are affected by the updated SILO data too such as water user demands and storage balances. The long-term average net inflow into Rocky Creek Dam, the most important water supply storage in the Richmond River system, was significantly lower (–9.7%) when using the updated SILO climate data compared to before.

Whether a model must be recalibrated, needs to be decided on a case-by-case basis and highly depends on the purpose of their applications. This case study illustrates example impacts of the SILO updates and analysis methods to inform this decision. It is further recommended to define a common guideline that facilitates periodic assessments of changes to the climate inputs and model performance, prompting the need for recalibration. This should further include a more in-depth analysis of the impact on the entire water balance of the river system model and explore possible interim solutions, as recalibrating a whole river system model is extremely time-consuming.

Keywords: *SILO climate data analysis, Hydrological model performance, Coastal catchments*

1. INTRODUCTION

Hydrological models are widely used by government agencies to inform water resources management and policies, facing the challenges of ongoing climate change. To assure adequate performance of such models, good quality climate and flow data with a sufficient spatial coverage are needed.

For Australia, ready-to-use daily climate datasets at approximately 8,000 climate stations of the Bureau of Meteorology (BoM) are available through the SILO database (Scientific Information for Land Owners SILO, https://silo.longpaddock.qld.gov.au/, Jeffrey et al. 2001, Beesley et al. 2009). SILO consists of daily data from 1889 to present incorporating observations where available in acceptable quality and in-filled interpolated data where necessary. This is to ensure a complete dataset available for various applications such as hydrological modelling. The quality of these timeseries may vary from station to station depending on number of missing data and on the spatial variability of the climate variable. The New South Wales Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) Surface Water Modelling team uses SILO station data (e.g. rainfall and potential evapotranspiration) as inputs for their hydrological models, supporting the state's water management policies, strategies and planning.

As the SILO database is continuously updated, the timeseries are subject to change. While mostly changes are minor, some major updates and modifications were made in September 2019, July 2020, July 2022, and September 2023 (https://www.longpaddock.qld.gov.au/silo/about/data-updates/). These updates and modifications involve:

a. Correction of a software error affecting interpolations of data between 2017 and September 2019 (September 2019)
b. Data revisions and the removal of erroneous values used in the interpolation along whole period of 1889 to present (affects rainfall and calculated evapotranspiration) (July 2020 and 2022)
c. Change of solar radiation derived from cloud oktas/sunshine hours to BoM sourced satellite radiation after 1990 (affects calculated evapotranspiration) (September 2023)

A recent case study in the Lachlan catchment by Nguyen et al. (2023) revealed changes in rainfall of –2.5% to +0.7% and –3.5% to +4.1% for potential evapotranspiration after the major SILO updates in 2020. Using rainfall runoff models calibrated before this update but with updated SILO data as inputs, resulted in magnified differences in streamflow between –17.3% and 7.2%. Nguyen et al. (2023) further showed that extending the old timeseries with 3 years of the new data led to lower streamflow differences within –0.5% to +1.3%. This issue poses questions regarding hydrological models established before the major SILO updates and requires reassessment of their performance. While extending the old timeseries with updated SILO data might be valuable short-term, a more robust long-term solution is yet to be decided.

The present study builds on the work of Nguyen et al. (2023) and expands the analysis to two coastal catchments on the North Coast of NSW. The following questions are addressed within this study:

i. What is the impact of the latest SILO updates on rainfall and potential evapotranspiration in two coastal catchments?
ii. What is the effect of the updated climate inputs on rainfall runoff model performance?
iii. What is the effect of the updated inputs (incl. inflows) on the entire river system model?

2. CASE STUDY AREAS

The selected case study areas on the NSW North Coast, the Richmond River and Manning River basins, are shown in Figure 1 including the analysed headwater catchments and associated climate and streamflow gauging stations.

The Richmond River basin is located on the far-north coast of NSW on the land of the Bundjalung Nation. Its drainage area of approximately 7,000 km^2 is characterized by forested uplands reaching elevations of around 1,100 m AHD (Border Ranges) and cleared plains for agriculture towards the coast. Around 150,000 people live within the area (Australian Bureau of Statistics, 2021). There are three major storages indicated in Figure 1, with Rocky Creek Dam (capacity of 14 GL) providing the bulk water supply for the region. Most of the system is unregulated except the regulated reach downstream of Toonumbar Dam and the total of all entitlements according to the 2023 water sharing plan is 105.5 GL. The latest Richmond River system model was developed in 2019 using SILO climate data downloaded prior to the three recent major updates as inputs for the calibration and simulations.

The slightly larger Manning River basin on the lower-north coast covers an area of about 8,420 km^2 from 1,500 m AHD in the west to the Pacific Ocean in the east. It is located on the land of the Biripi Nation. Besides the drinking water supply of the population of around 60,000 (Australian Bureau of Statistics, 2021), main water usages in the region are related to agriculture (livestock, irrigation). There are no major dams in this unregulated catchment and the total entitlement according to the 2022 water sharing plan is 84.1 GL. The Manning River system model was built in 2021 using SILO climate data from the same year. This is prior to the two most recent major SILO updates.

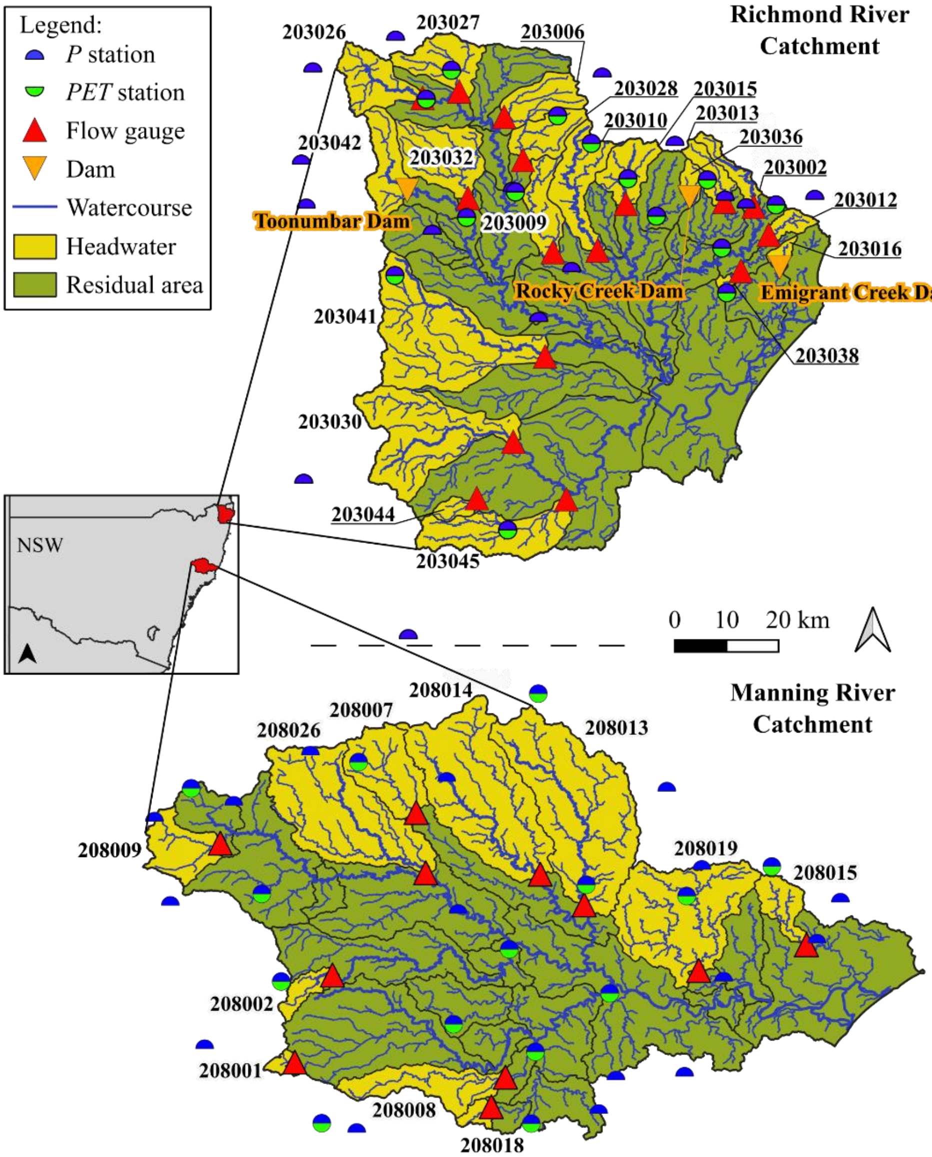

Figure 1 Overview of case study areas.

3. METHODS

3.1. Climate data analysis

The difference between the old (x_{old}) and the updated SILO timeseries variables ($x_{updated}$) was assessed as the percentage difference (*pd*) defined in equation 1:

$$pd = \left(\frac{\sum_i^n x_{updated,i}}{\sum_i^n x_{old,i}} - 1\right) \times 100\% \qquad \text{(equation 1)}$$

As the changes in SILO data mainly affect interpolated values in the timeseries, the percentage difference may change depending on which subperiod is analysed. For the calibration of hydrological models, a subperiod during which streamflow data are available as a reference (objective function) needs to be selected. Although the SILO updates impact the simulation of streamflow in the model over the whole period, only the changes within the calibration period will affect the optimal parameters of the model. The *pd* values are therefore calculated for both the long-term period up to the end of x_{old} and for the selected calibration period of the respective headwater catchments.

3.2. Effects on rainfall-runoff model outputs

During the development of the two river system models, several Sacramento rainfall-runoff models (Burnash et al, 1973) were calibrated to simulate the inflows from the headwater catchments shown in Figure 1 (indicated with 6-digit catchment-ID). This was done using the up-to-date SILO data at that time. The changes of SILO climate data that have occurred since then, have impacted model performance. The magnitude of impact depends on the percentage difference between the old and updated versions of the dataset for the period of interest (here the calibration period). Note that the calibration periods of the headwater catchments vary between catchments, which are based on the period with best-quality observed streamflow data. The total flow percentage bias *pb* defined in equation 2 was used to assess the model performance for both the Manning River and Richmond River headwaters.

$$pb = \left(\frac{\sum_i^n Q_{sim,i}}{\sum_i^n Q_{obs,i}} - 1\right) \times 100\% \qquad \text{(equation 2)}$$

Furthermore, the percentage difference *pd* as defined in equation 1 was used to compare the old and new simulated flows among each other. This was done over the entire long-term period as well as split into the low, mid and high flow range (low: <=25%-percentile; mid: >25% and <80%-percentile; high: >=80%-percentile)

3.3. Effects on river system model

The changes in headwater inflows and climate variables will have a combined effect on the entire system. Urban demand and irrigation models used within the river system models are also driven water availability and climate data such as evaporation deficit and crop water evapotranspiration. This alteration of climate and usage can have implications on water restrictions and water availability in storages, impacting also the operation of the dams. To showcase the magnitude of impact on the river system model, the previously established Richmond River model (2019 - eWater Source v.5.0) was run with all updated climate data and rainfall-runoff inflows and compared to the original results. As Rocky Creek Dam is the most important drinking water source of the region, the effect on water availability of this dam was investigated, by looking at the storage volume over time and on the related fluxes. Furthermore, the percentage change of an irrigator demand was analysed.

4. RESULTS AND DISCUSSION

4.1. Climate data analysis

For all climate timeseries used in the headwater rainfall-runoff models of the Richmond and Manning River systems, the percentage difference due to the major SILO updates described in Section 1 were calculated (equation 1). Figure 2 shows this percentage difference (*y*-axis) categorised into the headwater catchments (*x*-axis) and into two periods: the overlapping period of the two downloads (referred to as the long-term period) and the calibration period of the respective headwater rainfall-runoff models (periods with reasonable observed streamflow data available; note most streamflow gauging stations opened after 1950). The comparison for the Richmond River basin (Figure 2a) is between downloads in 2019 and 2024. The one for the Manning River basin (Figure 2b) between 2021 and 2024.

The percentage difference *pd* of the climate timeseries for the Richmond range from –16.5% to +0.6% for rainfall *P* and from –4.3% to +4.2% for potential evapotranspiration *PET* in the long-term period of 1889-2018. In terms of *P*, this is a massive overall reduction of water input to the system. In terms of *PET*, no overall tendency is revealed by the data and the *pd* varies significantly between headwater catchments. Changes in *P* in the calibration period are generally milder, because they are recent periods with higher availability of observed values. *PET* as a derived variable was subject to change over the entire period.

Unlike for the Richmond, the comparison within the Manning basin only involves two of the four SILO updates. Generally, changes are much less significant with –0.1% to +0.2% change in *P* and –1.0% to +0.2% for *PET* in the long-term period. Noticeable is the higher *pd* of *PET* during the calibration periods attributed to the SILO update in 2023 of solar radiation to satellite for data after 1990.

The comparison between the results of the two river systems suggests that the SILO update in 2020 lead to more significant changes than the updates in 2022 and 2023.

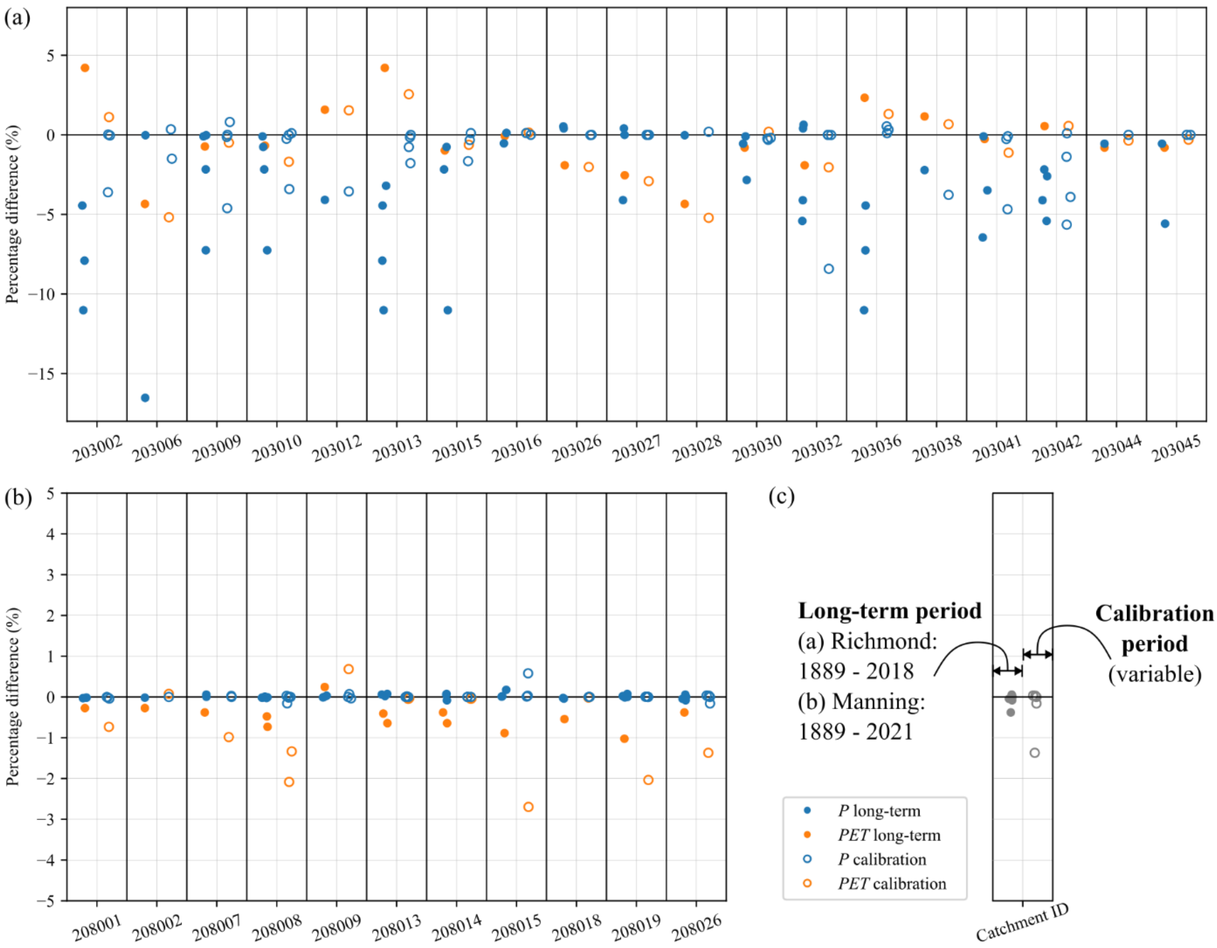

Figure 2 Percentage difference (equation 1) between SILO climate timeseries (Precipitation *P* and potential Evapotranspiration *PET*) before and after major SILO updates used for the headwater rainfall-runoff models. (a) Richmond River basin, comparison of downloads in 2019 and 2024. (b) Manning River basin, comparison of downloads in 2021 and 2024. (c) Legend.

4.2. Effect on rainfall-runoff model outputs

Table 1 shows the impact of the SILO updates on headwater rainfall-runoff models (6-digit ID) that were calibrated using the earlier download of the climate data for the two case study areas. The direction of change to drier or wetter conditions is highlighted in a colour scale (blue: wetter; orange: drier).

The left part of Table 1 represents the calibration period and shows (table header from left to right): (i) the percentage difference in modelled rainfall *pd P*. (ii) percentage of infilled data in the period (Interp.). (iii) percentage difference of potential evapotranspiration *pd PET*. (iv) observed mean annual flow (*Q* obs). (v) flow bias (sim. vs. obs.) using 2019 data (*pb* 19). (vi) flow bias using 2024 data (*pb* 24). Several of the initially well performing models deteriorated to an unacceptable degree using the updated climate inputs (flow bias of –12% to +5.7% for the Richmond and –1.3 to 3.0% for the Manning). The rain data in the Richmond, further show a tendency of timeseries with higher percentage interpolated data showing a higher *pd* value.

The right part of Table 1 represents the long-term period (2019 vs. 2024) and shows (table header from left to right): (i) simulated mean annual flow using 2019 data (*Q* 19). (ii) simulated mean annual flow using 2024 data (*Q* 24). (iii) percentage difference *pd* of simulated rainfall (*pd P)*. (iv) *pd* of potential evapotranspiration (*pd PET*). (v) *pd* of simulated mean streamflow (*pd Q*). (vi) *pd lQ* for the low-range (<=25%-percentile). (vii) *pd mQ* for the mid-range (>25% and <80%-percentile). (viii) *pd hQ* high-range (>=80%-percentile). The impact on the different flow ranges varies significantly within headwater catchments in some cases even showing changes in opposing directions (e.g. colours of 203006, 203016 and 208015). This can lead to apparent low overall difference *pd Q* due to compensation among the different flow ranges (e.g. 203016). While the Manning tended towards wetter conditions for almost all catchments and flow ranges, the Richmond mostly changed towards drier conditions except three catchments.

Table 1: Comparison of rainfall-runoff model outputs using climate input data pre and post SILO updates. All models were calibrated using the climate data before the SILO updates. (a) Richmond River basin. (b) Manning River basin. Orange: change to drier conditions; Blue: change to wetter conditions.

(a)	Calibration period (var)						Long-term period (1889-2018)							
ID 203	*pd P* %	Int-erp. %	*pd PET* %	*Q* obs GL/yr	*pb* 19 %	*pb* 24 %	*Q* 19 GL/yr	*Q* 24 GL/yr	*pd P* %	*pd PET* %	*pd Q* %	*pd lQ* %	*pd mQ* %	*pd hQ* %
002	–1.2	12	1.1	64.4	–0.7	–3.8	67.0	56.1	–7.7	4.2	–16.3	–21.7	–18.5	–15.8
006	0.1	31	–5.2	117.1	2.8	–0.2	99.4	98.0	–2.3	–4.3	–1.4	–1.3	–1.0	–1.5
009	–1.2	23	–0.5	119.2	0.0	–1.8	43.4	40.8	–2.5	–0.7	–6.0	–8.1	–6.1	–6.0
010	–0.4	17	–1.7	86.8	–1.4	0.2	92.0	88.3	–1.9	–0.7	–4.1	–5.3	–4.6	–4.0
012	–3.6	55	1.5	36.0	–0.7	–8.1	40.5	37.2	–4.1	1.6	–8.0	–9.2	–7.9	–8.1
013	–0.5	9	–0.1	75.3	–1.4	–2.1	55.9	49.9	–6.1	–0.6	–10.8	–11.8	–10.9	–10.8
015	–0.7	8	–0.6	107.4	0.0	0.9	95.5	86.1	–5.7	–1.0	–9.8	–13.8	–9.6	–9.8
016	0.1	17	0.2	22.2	–0.2	0.0	21.1	20.9	–0.3	–0.1	–0.9	9.6	14.0	–6.8
026	0.0	3	–2.0	31.8	0.0	3.8	27.8	29.0	0.5	–1.9	4.2	8.1	4.7	4.2
027	0.0	1	–2.9	42.0	0.0	4.9	31.3	32.6	–0.2	–2.5	4.0	3.2	3.2	4.2
028	0.2	21	–5.2	86.5	–1.4	5.7	64.3	68.2	0.0	–4.3	6.0	9.5	5.8	6.0
030	–0.3	15	0.2	52.4	0.0	–2.3	65.9	62.8	–1.6	–0.8	–4.7	–12.8	–8.7	–4.3
032	–1.3	16	–2.0	102.9	0.0	–1.1	63.6	62.2	–1.6	–1.9	–2.4	–3.2	–2.9	–2.2
036	0.4	1	1.0	32.4	–0.5	0.0	31.3	28.6	–5.1	2.3	–8.7	–18.6	–9.9	–7.7
038	–3.8	100	0.7	10.1	–0.1	–7.4	10.2	9.7	–2.2	1.1	–5.5	–6.4	–5.6	–5.4
041	–2.1	29	–1.1	83.4	0.0	–4.4	98.8	88.8	–3.3	–0.3	–10.1	–32.1	–13.2	–9.6
042	–2.9	25	0.6	29.7	0.0	–12.0	36.1	31.4	–3.5	0.5	–12.9	–17.0	–14.4	–12.5
044	0.0	0	–0.4	7.7	0.0	0.3	6.6	6.6	–0.6	–0.8	–0.5	–2.7	–1.4	–0.3
045	0.0	0	–0.3	50.0	0.0	–0.2	47.9	46.4	–1.5	–0.8	–3.1	–8.4	–5.0	–2.9

(b)	Calibration period (var)						Long-term period (1889-2021)							
ID 208	*pd P* %	Int-erp. %	*pd PET* %	*Q* Obs GL/yr	*pb* 19 %	*pb* 24 %	*Q* 19 GL/yr	*Q* 24 GL/yr	*pd P* %	*pd PET* %	*pd Q* %	*pd lQ* %	*pd mQ* %	*pd hQ* %
001	–0.01	64	–0.73	30.1	0	0.6	26	26	–0.02	–0.28	0.2	1.0	0.6	0.0
002	0.00	63	0.07	36.5	0	–0.1	38	38	–0.02	–0.28	0.5	0.4	0.6	0.5
007	0.01	54	–0.98	52.2	0	1.1	47	48	0.03	–0.38	3.2	2.7	1.5	3.9
008	0.00	59	–1.34	69.9	0	0.5	62	63	–0.02	–0.48	2.8	0.7	1.4	3.4
009	0.03	51	0.68	34.6	0	–1.3	42	43	0.01	0.24	1.3	3.7	0.9	1.4
013	0.01	54	–0.03	178.1	0	0.1	173	178	0.08	–0.65	2.9	2.5	0.8	3.5
014	0.00	50	–0.05	157.0	0	0.0	112	117	–0.09	–0.65	4.3	3.4	2.2	4.9
015	0.08	54	–2.7	48.6	0	3.0	46	47	0.03	–0.89	2.4	–2.7	1.3	2.5
018	0.00	62	–0.01	8.7	0	0.0	9	9	–0.03	–0.54	2.8	0.3	1.4	2.9
019	0.00	40	–2.04	203.3	0	2.9	223	229	0.02	–1.02	2.8	0.2	0.5	3.1
026	–0.03	59	–1.37	96.9	0	1.4	94	98	0.00	–0.38	4.1	3.2	2.4	4.7

4.3. Effect on downstream river system

To investigate the impact on the downstream of a river system, the existing Richmond River eWater Source (v5.0) model was used to simulate the river system. This was done once using climate and rainfall-runoff inputs downloaded/simulated in 2019 and once in 2024. Three example results are compared between the two model runs in Figure 3. For each investigated variable, the timeseries of annual totals are provided on the left and the percentage difference *pd* of the corresponding SILO station data and the *pd* of the investigated variable itself are shown on the right. Graph (a) illustrates a part of the Rocky Creek Dam RCD storage balance determined by inflow *Q*, rainfall volume *P* and evaporation volume *PET*. On the long-term average, the net inflow to RCD (excl. spills, extractions) decreased by almost 10%. This decrease in net inflow is attributed to the period earlier than 1975. Graph (b) illustrates the demand from a local water utility (LWU) node in the system. Despite less rainfall and more evapotranspiration, the urban water demand model shows a low change on the long-term average due to compensation of periods with higher and lower demand comparing the two model runs. Graph (c) shows the demand at a lumped irrigator (IRRI) node. The reduced *PET* for this node lead to a reduction of the long-term average demand. While the demand mostly was reduced before 1950, the more recent period after 1990 shows higher demands using the 2024 SILO data. The changes after 1990 are attributed to the change of solar radiation to satellite data in the most recent update of the SILO database. Altogether this shows that the change in SILO climate data has impact in various modelled parts of the river system.

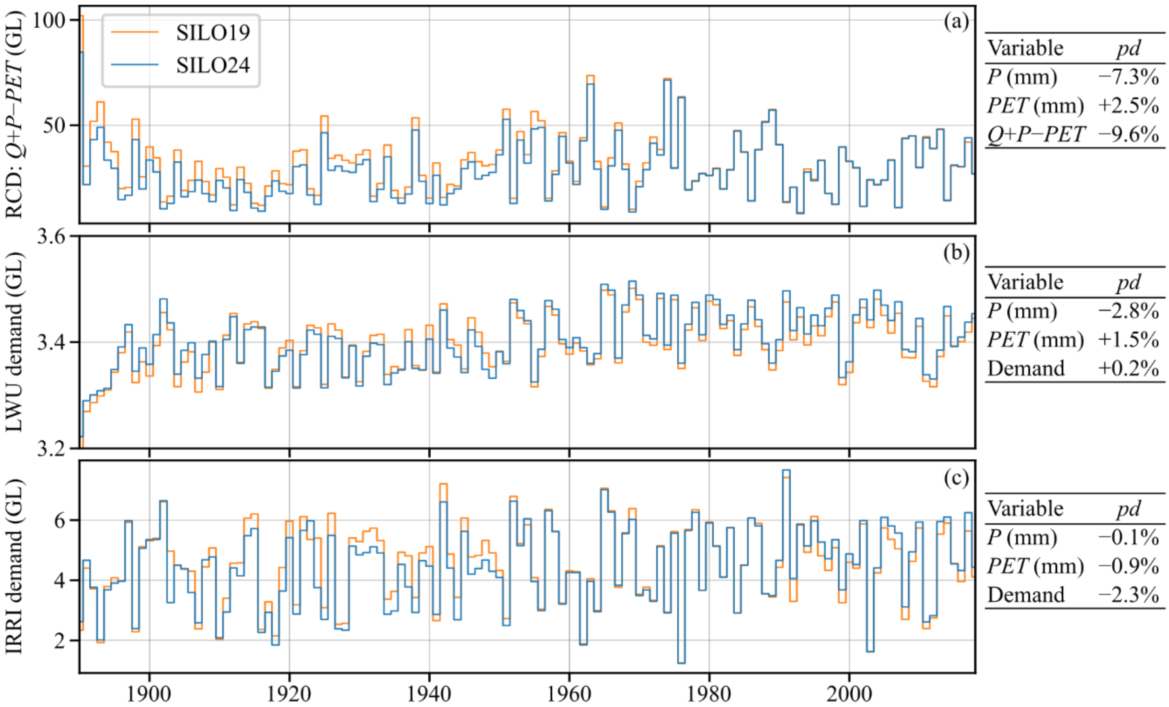

Figure 3 Simulated annual totals of (a) RCD storage's net inflow, (b) demand at a local water utility (LWU) node, (c) demand at an irrigator (IRRI) demand node based on SILO climate input data from 2019 and 2024 in the Richmond River system model.

5. CONCLUSION AND OUTLOOK

The presented case studies highlight the impact of recent major updates to the SILO database in two NSW coastal catchments. The latter two of those updates are reflected in the Manning River and all four in the Richmond River case study having one SILO update in common with the study by Nguyen et al. (2023). The overall percentage change of the timeseries due to the updates varies greatly between catchment, station, time horizon, percentage interpolated values, and variable. The percentage changes of climate data for the Richmond (–16.5 to +4.2%) were substantial compared to for the Manning catchment (–1% to +0.3%). These major changes in climate data in the past 5 years have affected the simulated water balance of various river system models calibrated prior to the data updates. Such river system models are used to assess compliance of water users with water sharing plans on a regular basis, to inform policymakers for long-term strategic planning and other applications. The change in water balance can cause complications for those applications as the initial model performance is not given any more and might be affected by future changes. Whether that is the case for a certain model will need to be assessed more frequently to see whether recent or future SILO updates affect model outcomes to an inacceptable degree. As (re-)calibration of an entire river system model is extremely time-consuming, it is not feasible to do that every time there is a slight change of the climate data, but rather a threshold or criterion is needed for when a model must be recalibrated. This should be based on both inputs and outputs, as the system might not be sensitive to all changes.

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