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Independent Peer Review of the State Water Project – Delivery Capability Report

An individual letter review for the Delta Science Program

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Delta Science Program

DELTA STEWARDSHIP COUNCIL

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General comments

This report describes the efforts undertaken by a multi-agency workgroup including experts from California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) in hydrology, climate, operations, and model development to review and develop methods to adjust the historical hydrology data to better reflect the current and near future conditions. The adjusted data provides the baseline historical conditions upon which future projections can be developed following the historical sequence of events.

The workgroup evaluated previous approaches to adjusting the historical hydrology data, which focus on removing the long-term trends in the historical temperature record and running hydrology models with and without adjustment of the temperature to produce time series of historical runoff. Precipitation is not adjusted as there have not been statistically significant long-term trends. Comparison of the hydrologic simulations with and without adjustment of the temperature input shows large biases of the hydrologic simulations and uncertainties in the hydrologic simulations depending on how temperature is adjusted to account for the observed long-term trends. This comparison led the workgroup to decide on developing a new approach to adjust the historical hydrology data.

The workgroup finalized on an approach that directly adjusts the historical runoff data based on the Full Natural Flow (FNF) rather than performing hydrologic simulations using adjusted meteorological data. Through analysis of the FNF data, the workgroup determined the long-term changes in FNF during the historical period that should be accounted for to better reflect the current and near future FNF conditions. Details of the FNF adjustment method as well as some results are included in the report.

Overall, the report provided good rationales for why historical hydrologic data should be adjusted to better reflect the current and near future conditions. For example, historical hydrologic data are used as input to water resources planning models, so they need to be accurate enough to support such modeling and reflect important aspects of historical hydrologic changes that affect water resources planning. The steps undertaken by the workgroup to evaluate the previous adjustment approaches are solid and the reasoning for why directly adjusting the historical FNF rather than using hydrologic modeling combined with adjustment of the meteorological forcing is well explained (p. 12). The new approach adopted by the workgroup to adjust the historical FNF is scientifically sound and well described, except for some typos and editorial errors in the relevant sections and Appendix B. The results show that the adjusted historical FNF (1922-2015) reasonably matches the statistics of the FNF in the contemporary reference period (1992-2021).

While the new approach to adjust the FNF historical data is an improvement over previous approaches, some factors may be considered in future efforts to re-evaluate and improve the adjustment approaches, particularly as more data become available in the next few years to decade. These factors are discussed in more details in the response to the charge questions and briefly summarized here:

(1) The temperature and precipitation in California are strongly modulated by multi-decadal modes of variability, namely the Interdecadal Pacific Oscillation (IPO). The 30-year rolling average of historical precipitation (Figure 7) and temperature (Figure A-1) carries to some degree the signature of the IPO (see more details under charge question 2). The influence of the IPO on California's temperature, precipitation, and runoff should be discussed in this report and considered in future efforts to update/improve the adjustment of historical hydrology data.

(2) Hydrologic modeling is important as it is needed to project future changes in runoff, and it is useful for interpreting the historical and future hydrologic changes. While it is out of the scope of the workgroup to address various challenges in hydrologic modeling, it is important for DWR and USBR to invest resources to address uncertainty and biases in hydrologic modeling, as exemplified by the analysis performed by the workgroup on the previous adjustment approach in which hydrologic modeling plays an important role.

(3) Some specific details such as assumptions used in the new method could be further investigated in future studies for potential improvements in the adjustment methodology (see more details under charge question 3).

Figures 17-22 provide important evaluation of the new adjustment approach. It would be useful to develop additional metrics that can be used to further support the value of the new adjustment method, particularly regarding hydrologic extremes, and to support potential future efforts to compare different adjustment approaches.

Specific comments

Charge question 1

Is this method an improvement over the use of unadjusted historical data (i.e., an assumption that the historical timeseries is stationary) for representing current conditions? Why or why not?

The new adjustment approach represents an improvement over the use of unadjusted historical data, which assumes the historical timeseries is stationary. Streamflow in California is affected by both temperature and precipitation. While the long-term trend in precipitation is small and not statistically significant in many watersheds, long-term temperature trend alone (which has been detected) can have important effect in changing the moisture content of the air and evaporative demand, which may change the precipitation variability. The temperature trend combined with changes in precipitation variability may further translate to changes in the seasonality and interannual variability of streamflow (which have been detected). Hence adjusting historical data may provide an overall historical trace that better reflects the current/near future hydrologic conditions. For example, Figure 19 shows that the adjusted FNF better matches the seasonal runoff of the reference period, which features higher and earlier peaks at the American River, Feather River, and Shasta Lake relative to the unadjusted historical data. This difference in runoff seasonality has important implications for water resources management.

Charge question 2

How well does the new method account for statistically significant trends to represent a quasi-stationary current climate while avoiding bias or trends that are artifacts?

The new method begins by analyzing the historical FNF (1922-2021) to identify statistically significant long-term trends. The workgroup looked at long-term trends in not only the annual FNF but also trends in interannual variability and seasonality, as these are important considerations for water management, and changes in variability and seasonality of streamflow have been well discussed in the climate change literature with supporting mechanisms. Long-term trends could not be established for annual FNF except for Tuolumne and San Joaquin. This result is not surprising because the temperature and precipitation in California are strongly modulated by the Interdecadal Pacific Oscillation (IPO). The IPO is a multi-decadal mode of variability featuring fluctuations in sea surface temperatures across the entire Pacific basin including both the North and South Pacific (Deser et al. 2004). The IPO, with a rough period of 15-30 years, is depicted by the IPO index as shown in Figure R1, with positive (negative) phases characterized by warmer (cooler) than average tropical Pacific and cooler (warmer) than average northern Pacific. Decadal precipitation variations are found to follow closely the evolution of the IPO over much of the western and central U.S. (Dai 2013).

By modulating the eastward extension of the North Pacific jet and the blocking high pressure over the North Pacific, the IPO modulates precipitation and temperature in California. Dong et al. (2021) found that the positive-to-negative phase transition of the IPO between 1979-2019 may have contributed to the California drought by inducing a westward retreat of the North Pacific jet and increasing the persistence of high pressure, both reducing the advection of moisture towards California and contributing to the drying in California. These processes are similar to the modulation of California precipitation by El Niño-Southern Oscillation (ENSO) on an interannual timescale. Thus the influence of the IPO on California precipitation may be viewed as the multi-decadal modulations of the IPO on the frequency, intensity, and duration of El Niño and La Niña events, which influence the weather patterns and California precipitation (Gershunov and Barnett 1998).

Comparing the IPO index (Figure R1) with the annual runoff (Figure R2), the correspondence between the transition of the IPO phases with the wetting and drying trends in California is discernible. For example, there is a hint of reducing runoff before 1950, consistent with the transition from a positive to negative phase of IPO during that period. Similarly, the increasing trend in runoff between roughly 1950 and 1980 corresponds to the transition from a negative to positive IPO phase during that period, and the reducing trend in runoff between 1980 and 2010 corresponds to the transition from a positive to negative IPO phase during that period. Similar correspondence between the decadal temperature trends (Figure R3) and the IPO index (Figure R1) can also be found. Generally, California displays warming and drying trends during the transition from a positive to a negative IPO phase, and vice versa. Note the hint of a return from a negative to a positive IPO phase since 2011, which could modulate the temperature and precipitation trends in the coming years to decades. Recognizing the influence of the IPO on California temperature and precipitation provides an important context for interpreting the decadal variability and long-term trends.

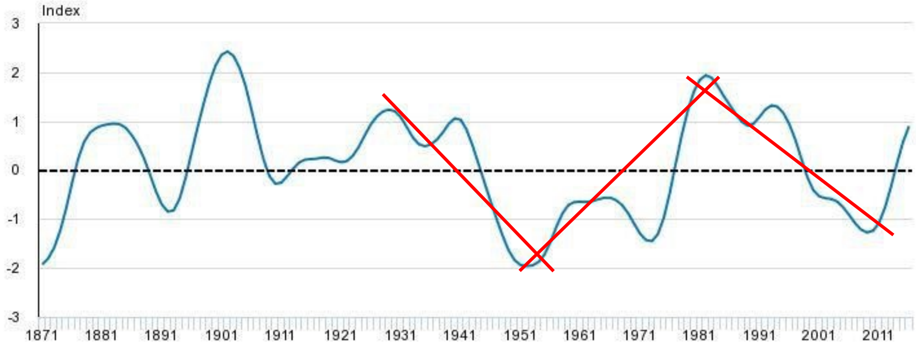

Figure R1: Evolution of the IPO index showing periods of transition between positive and negative phases, as roughly depicted visually by the linear fit lines shown in red for three transition periods. (Source: https://en.wikipedia.org/wiki/Interdecadal_Pacific_oscillation#References, adapted from Henley et al. 2015).

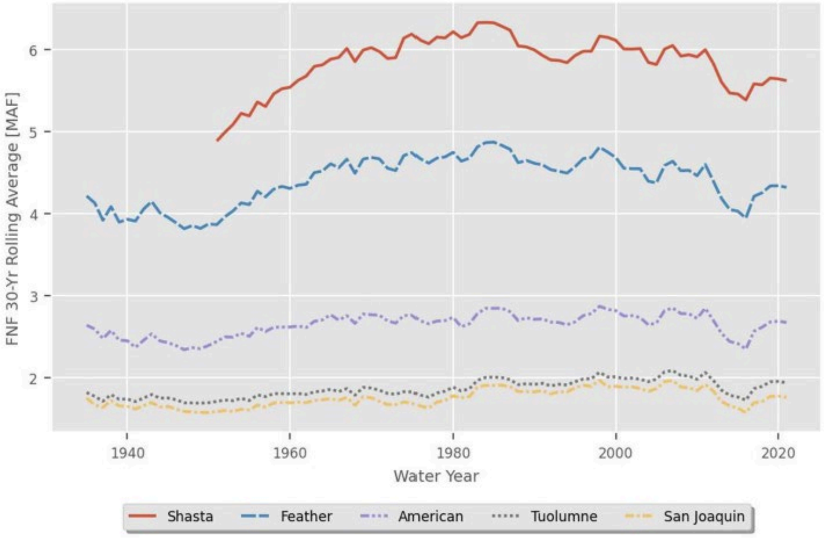

Figure R2: Reproduction of Figure 7 of the report showing the 30-year rolling average of annual runoff.

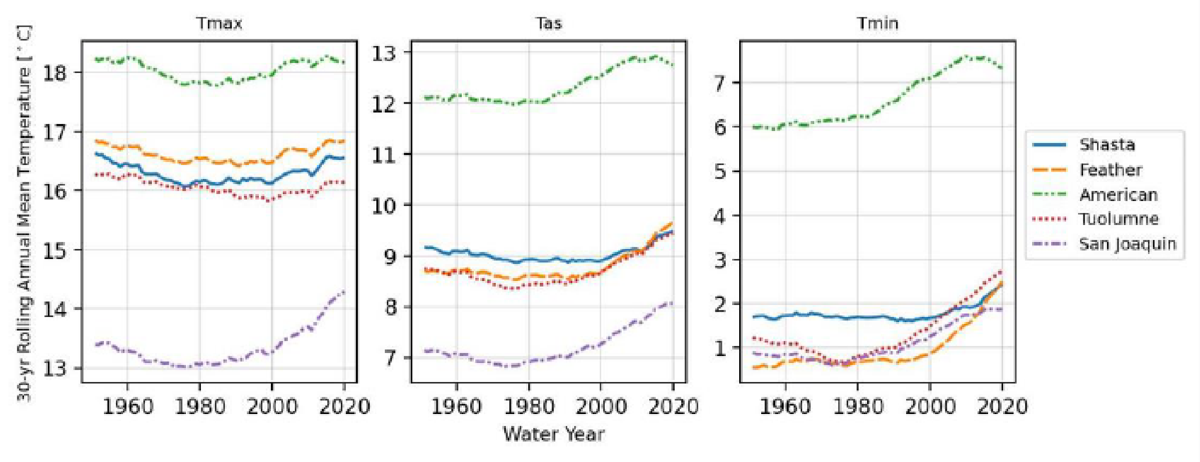

Figure R3: Reproduction of Figure A-1 of the report showing the 30-year rolling averages of maximum, minimum, and average temperature.

Reviewing Figures 7, 8, and 11 of the report through the lens of the IPO, a notable imprint of the IPO phase transitions on the various multi-decadal trends emerges. The relationship between the IPO phase transition and the multi-decadal annual precipitation trend may be explained by the aforementioned impacts of the IPO on the North Pacific jet and high pressure. The increase in interannual variability of runoff (standard deviation of annual runoff), which is more obvious between 1970 and 2010 in Figure 8, could be partly explained by the warming temperature during that period (Figure R3) that increases volatility by increasing atmospheric moisture content, which amplifies precipitation variability. The warming temperature since ~1970 or 1980 could reflect both the impact of the IPO phase transition and anthropogenic warming.

Modulation of the IPO on California's temperature and precipitation suggests more careful analysis is needed in the future to separate the long-term anthropogenic trends from the multi-decadal variability to avoid biasing the adjustment by the multi-decadal variability. Large ensemble climate simulations may be helpful for such analysis. Importantly, because of the IPO impact, choosing the contemporary reference period of 30 years requires some thought, and continued monitoring of the temperature, precipitation, and runoff over the near few years to decades is important for assessing the need to re-evaluate the approaches used to adjust the historical hydrologic data.

Charge question 3

What specific investigations or improvements should be considered in future updates of this dataset?

As elaborated in the comments on charge question 2 above, the role of the IPO in the multi-decadal variability of temperature, precipitation, and runoff may confound the determination of long-term trends. This should be investigated in the future using observed historical data in combination with multi-model and large ensemble climate simulations to provide insights on the role of external (anthropogenic) forcing and internal variability (IPO) in the historical record.

In addition to issues related to the IPO, further investigations regarding the previous and new adjustment approach should also be considered:

1. Previous adjustment methods only adjust temperature but not precipitation, as there is not a clear long-term trend in precipitation (partly because of the influence of the IPO). However, with a focus on FNF, the workgroup identified changes in interannual variability and seasonality of FNF and developed a new approach that adjusts the interannual variability of both precipitation and FNF. It would be useful to revisit the previous adjustment methods by combining the adjusted precipitation from the new approach and the adjusted temperature from the previous approaches that remove the long-term trend as input to hydrology models for comparison with the adjusted FNF based on the new approach. Such comparison may provide some insights on the relative contributions of temperature and precipitation changes to the increasing interannual variability and changing seasonality of runoff. Such insights are important to support an implicit assumption used in the new approach that changes in runoff are only driven by changes in precipitation, although changes in temperature (Figure R3) may affect runoff through changes in evapotranspiration that are not directly connected to precipitation.
2. The new approach implicitly assumes that the changing seasonality of runoff is driven by the changing seasonality of precipitation. Therefore, the Year-to-Month adjustment method first adjusts the monthly precipitation based on the precipitation water year types of the reference period and adjusts the monthly runoff based on the mean runoff associated with the precipitation water year types. However, warmer temperatures are likely to have

important contributions to the changing seasonality of runoff (e.g., Marvel et al. 2021), which may not be captured by the precipitation water year types. A potential way to capture the impacts of temperature on runoff seasonality is to further divide the precipitation water year types by including temperature information (e.g., wet/warm, dry/cold). While it is possible that the correlation between precipitation types and temperature types is strong enough that precipitation types alone would also capture the temperature effects (e.g., both ENSO and IPO are characterized by correlated precipitation and temperature anomalies (e.g., Mo 2010)), it would be useful to confirm through analysis of the historical records.

3. Since FNF is used as the basis of the new method for hydrologic adjustment, it would be useful to provide an evaluation of the FNF and sensitivity of the adjustment results to uncertainty in the FNF. For example, could the long-term trends in FNF interannual variability be contributed to in some ways by changes and/or variability of water use that is not well represented by the FNF?
4. Hydrologic extremes present specific challenges for water resources management. It would be important to further investigate ways to improve the adjustment approaches to better account for potential changes in hydrologic extremes and develop specific metrics to evaluate the adjustment methods based on hydrologic extremes. For example, extrapolation is needed to determine the adjustment of runoff based on the runoff curves (e.g., Figure B-1) for extreme wet and dry years. This may have effects on the tails of the cumulative distribution function (e.g., Figure 18). Some sensitivity analysis and specific metrics regarding hydrologic extremes could be useful to explore potential improvements of the adjustment methods and facilitate comparison of methods regarding the impact on the hydrologic extremes. Here hydrologic modeling could also provide some insights regarding the runoff curves at the extreme dry and wet ends.

While the runoff curves were determined through experimentation of different functional forms relating annual precipitation and annual runoff, it is worth comparing the empirically determined runoff curves with those derived from hydrologic modeling, particularly using a variety of hydrology models to inform uncertainty in estimating the runoff curves. Additionally, data available over many watersheds may be used to train machine learning algorithms to determine their potential for future use in estimating the runoff curves and extending the runoff curves as well as the Year-to-Month adjustment method to consider the relationship between runoff and both temperature and precipitation.

Charge question 4

How frequently should DWR consider updating this dataset?

The frequency with which DWR should consider updating the adjusted hydrologic data depends on advancement of new knowledge/techniques and availability of new data. A nominal 5-year frequency seems reasonable in reviewing more recent literature on the impacts of climate change and variability on hydrology, advancements in tools such as hydrology modeling and machine learning, and whether the expanded length of data recorded suggests the need to revise the analysis of variability and trends in the hydrologic data. Given the 15-30 years period of the IPO and its impact on hydrometeorology of California, 5-10 years of additional data may provide useful information on the transition of the IPO phases and inform the selection of the reference period.

Charge question 5

The draft Climate Adjusted Historical Hydrology dataset presented for review is adjusted to a 1992-2021 climate condition. This period is entirely retrospective. With a goal of more accurately simulating the range of hydrologic variability under current climate conditions, what are the pros and cons of taking a more prospective approach in future iterations by, for example, including modeling of potential future conditions to capture a 30-year climate period centered on the current year rather than concluding with the current year?

Dong et al. (2021) found that internal variability particularly related to the IPO contributes to more than 70% of uncertainty in model simulation and projection of precipitation changes in California. Accounting for uncertainty due to internal variability is especially important for the near future as the response to external forcing may still be modest (e.g., Lehner et al. 2020). Uncertainty in projecting the precipitation decadal trends of California may be constrained by the IPO phase transition (Dong et al. 2021). To more accurately simulate the range of hydrologic variability under current climate conditions, it would be advantageous to explore a more prospective approach in future iterations by incorporating information about the IPO phase transition in the recent past as well as decadal prediction of the IPO in the next decade or two. Decadal predictions differ from climate change projections in that decadal predictions are forecasts conditioned on the initial conditions of the climate system (Meehl et al. 2014) while climate change projections are free running simulations informed only by the socio-economic scenarios (e.g., SSP585). Large ensemble simulations and decadal predictions are available from multiple models in the Multi-Model Large Ensemble Archive (MMLEA) (https://www.cesm.ucar.edu/community-projects/mmlea) and CMIP6 archives, respectively, for analysis. Such research should be considered exploratory to inform a more prospective approach in future iterations.

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