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I have been asked to review "Scientific *Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflow, Cold Water Habitat, and Interior Delta Flows*"

And specifically this first conclusion of the report-
"**1. Significant changes have occurred to the hydrology and hydrodynamics of the Sacramento River and its tributaries, Delta eastside tributaries, and the Delta.**
The Science Report focuses on the flow characteristics of the main stem Sacramento River, its tributaries, the three eastside tributaries to the Delta and the interior Delta. These flows are critical to supporting ecological processes and the species that depend on those processes, including native anadromous and estuarine species. The magnitude, duration, timing and frequency of flow in all these waterbodies were evaluated to assess the types of change in the flow regime that have occurred over time. This information is provided as background and supporting information for subsequent chapters. Diversions and exports have reduced average annual outflow, reduced winter and spring outflow and reduced seasonal variability (Figures 2.4-7 and 8 and Table 2.4-3) over time. Water development in regulated tributaries, such as the Sacramento River at Freeport, has resulted in reduced annual flows, a reduction and shift in spring inflow, an increase in summer inflow, and a decrease in hydraulic variability (Figure 2.2-5 and Table 2.2-2). Tributaries without large reservoirs generally have lower flows in summer and part or all of the fall. Project pumping in the south Delta has increased (Figures 2.4-4 and -5) and this has resulted in an increase in the magnitude and frequency of reverse (upstream) flows on Old and Middle rivers (Figure 2.4-5). This information is included in Chapter 2 of the Science Report."

The structure of my review will provide an overall brief summary of the report to communicate what lessons evidence and conclusions I drew from reading the report. Next I will assess each of the factual claims of the conclusion and then assess whether the overall conclusion is supported by the document and relevant science. Following that I will make general and specific comments about aspects of the report that the writers can take into account at their discretion.

General description of what I read in the report-

The scale of work involved in putting together this report as a whole and the Chapter 2 on hydrologic changes is truly impressive. The diverse systems represented and the author's careful explication of the hydrologic variety of the system is very well done (Pages 2-3-2-12)

I very much appreciate the careful distinction the authors make between natural and unimpaired flows. As they note knowing what the natural flows in this system would be without human influence is a difficult if not unknowable system attribute. The authors thus rightly, in my opinion, focus on unimpaired flows to investigate the impact of human water resources management on the hydrology of the Delta and its tributary rivers.

The authors then proceed to show that the differences between natural and unimpaired flows are small and then proceed to investigate the departure of actual flows from the unimpaired flows over time. Showing that the hydrology of inflows and outflows of the Delta has continued to become more strongly differentiated from the unimpaired flows (Figures 2.1-1-2.1-3).

Figure 2.1-10 starts building the evidence to support this conclusion and shows the profound changes in river system hydrology in the historical record compared to un-impaired flow estimates. Importantly the results also show differential river system responses to wet and dry years. The authors also provide the well prepared Table 2.1-1 to permit an easy view of how their assumptions and the SAC-WAM model might influence the results displayed in Figure 2.1-10. The SAC-WAM model is key to the estimates of unimpaired flows and while all modelling comes with uncertainty SAC-WAM is assigned a fairly basic task here to simulate the unimpaired flows of the system as compared to the observed flows. Additionally SAC-WAM is built upon the foundation of the established and well regarded WEAP model.

The authors then step through a discussion of the hydrology of the Sacramento and other major tributary rivers. In each system the authors carefully walk through the shift in hydrology due to water resources management in the system and show a typical shift of decreased spring streamflow and increased summer streamflow in response to management. Some tributaries to the Sacramento have little shift in hydrology due to few dams and reservoirs or other diversions in their watersheds. As might be suspected rivers with large reservoirs and significant water diversions have the greatest difference between observed and unimpaired flows.

After discussing the impacts of hydrologic alterations on inflows to the Delta the authors shift focus to the flood basins with the River systems as these can influence the water flow through the coupled river-Delta system. Of note in this section the authors do not provide a figure showing the locations and scales of these basins. Such a figure would assist the reader in understanding the nature and importance of the systems and where they fit in the overall hydrologic system. These flood basins are important since they can impact the magnitude timing and duration of flood flows in the tributary river systems to the Delta. Changes in these hydrograph characteristics then have an effect on the ultimate hydrologic flows in, within, and out of the Delta.

The authors finally move in section 2.4 to the Delta itself and show that the cumulative change in inflows to the Delta from the various tributaries results in a much drier system overall particularly during the spring snowmelt season and to a lesser degree an increase in observed inflow compared to unimpaired flows during the late summer.

Flow in the Delta is of course further complicated by the human infrastructure that is used to wheel water through the Delta to the Bay Area, the southern Central Valley, and the urban centers of southern California. This pumping further interacts with tidal processes to make for a very complicated set of hydrodynamics. The authors clearly show that change in management can result in significant shifts in hydrology in the Delta (evidenced by changes in south Delta exports in figure 2.4-4). Figure 2.4-5 also documents a significant shift in Delta flows with the OMR region seeing significant upstream flow much of the time compares to the unimpaired and pre-1968 series which show much less frequent upstream flows.

The authors compile a compelling set of graphs comparing both unimpaired and current conditions of Delta inflow and outflow as well as historical changes in outflow (Figures 2.4-5, 2.4-7 and 2.4-8) that clearly demonstrate the hydrologic changes that water resources development and management has exerted on the inflow and outflow of water from the Delta. They further this argument in showing the X2 distance increasing for current conditions compared to unimpaired and also showing its movement upstream in more recent periods versus earlier observed periods (Figures 2.4-10, 2.4-11 and 2.4-12).

Part 1 – "Diversions and exports have reduced average annual outflow, reduced winter and spring outflow and reduced seasonal variability (Figures 2.4-7 and 8 and Table 2.4-3) over time."

The authors clearly demonstrate through the use of historical data and the SAC-WAM model that inflows and outflows from the Delta have changed significantly through the impact of water resources management on the Delta system. The authors further show clearly that the changes in hydrology in this system are focused on reduced seasonal variability that has resulted in reduced winter and spring inflows and outflows from the Delta and increased summer inflows and outflows. These changes have resulted in the salinity boundary called X2 moving farther up the Delta system.

Part 2 - "Water development in regulated tributaries, such as the Sacramento River at Freeport, has resulted in reduced annual flows, a reduction and shift in spring inflow, an increase in summer inflow, and a decrease in hydraulic variability (Figure 2.2-5 and Table 2.2-2)."

This result showing the shifting of spring snowmelt flows into the summer period is evident repeatedly on the river systems contributing to Delta inflows. The figure and table cited are certainly appropriate pointers to this large body of evidence. However I might use an e.g. in the parenthetical figure call so that readers understand this is not the only figure supporting the conclusion.

Part 3- "Tributaries without large reservoirs generally have lower flows in summer and part or all of the fall."

This conclusion is supported by the current condition versus unimpaired flows descriptions of several of the Sacramento River's tributaries (e.g. Figure 2.2-9). However the nature of the monthly flow figures and the arithmetic y-axis that the authors have chosen makes it somewhat difficult for a reader to assess how much low flow summer conditions have changed in these non-impounded tributary streams. While the decreased summer and fall flows is seen on a number of streams an alternative data presentation either focused on this season, using cumulative flow duration curves, or logarithmic y-axes would help the reader observe the evidence for this conclusion more clearly.

Part 4 – "Project pumping in the south Delta has increased (Figures 2.4-4 and -5) and this has resulted in an increase in the magnitude and frequency of reverse (upstream) flows on Old and Middle rivers (Figure 2.4-5)."

Figure 2.4-5 and the description of the Delta hydraulics clearly demonstrates that reverse (upstream) flow conditions now occur a greater fraction of the time than historically. The authors also provide convincing evidence that these hydrodynamic changes are due to increased pumping in the south Delta. It seems recent pumping has decreased and several scientific approaches to understanding the effect of this reduction on Delta flows and upstream flows have commenced. It would be nice to see some data showing what the effect of the reduced pumping has been on X2 or on Delta Outflow. I understand the impacts of the recent drought may confound such an analysis but the changes in pumping provide a useful real world test of the system and it would be valuable to see the impacts of those changes on Delta conditions.

Overall conclusion

Conclusion 1 of the report – "**1. Significant changes have occurred to the hydrology and hydrodynamics of the Sacramento River and its tributaries, Delta eastside tributaries, and the Delta."** Is supported by the evidence included in this report. The evidence for this conclusion is built up brick by brick by the authors. First they show that the tributaries have shifted significantly in their flow particularly in shift of spring snowmelt to summer flows on rivers with impoundments. This shift in river flows integrated across the Delta tributaries leads to overall decreases in inflow to the Delta particularly during the spring snowmelt season. These decreases in inflow combine with the exports form the Delta and the managed flow architecture of the Delta to reduce outflows. This reduction in outflows has in turn caused an eastward movement of the fresh saline water boundary and has caused reversed or upstream flows to become more common than downstream flows in portions of the Delta. Combined this evidence points to significant changes in the hydrology of the tributary rivers to the Delta and the hydraulic flows of the Delta itself. As noted above there a few places where clarification or additional data and analysis might be helpful in further increasing confidence in this conclusion but these slight changes would likely strengthen the evidence supporting this conclusion.

Minor Comments

Table 2.4-3 describes the unimpaired contributions to total Delta outflow from various locations. It is unclear why the percentages in each column sum to be greater than 100%. It could be either due to double counting on some reaches (both upstream and downstream locations are included) or it could be due to the hydrologic changes. The authors should explain the problem of sums greater than 100% in a footnote to the table or in the text of the document.