nature portfolio

Peer Review File

Where Does the Colorado River’s Water Go?

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

9th Nov 23

Dear Mr Richter,

Your manuscript titled "Where Does the Colorado River's Water Go?" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

In particular, please ensure that the revised manuscript meets the following editorial thresholds:

******

** Provide full justification for your methods and assumptions made for calculating the water budget estimates (including the variability of the consumption estimates).

** Communicate the limitations and uncertainties in your research and expand your discussion accordingly.

*****

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
[link redacted]
** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Carolina Ortiz Guerrero
Associate Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements (Download the link to your computer as a PDF.)

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
- Accession codes where appropriate
- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

My full, signed report will be submitted as in pdf form.

Reviewer #2 (Remarks to the Author):

I believe that the results from this manuscript are novel and of broad interest to the field and to decision-makers. I think the data compiled in this study will be widely used, particularly in the future interest of Colorado River water uses. It appears that access to the data and ability to reproduce the work would be fairly straightforward. Please see attached file for specific comments and broad comments.

Review of “Where Does the Colorado River’s Water Go?” Manuscript COMMSENV-23-1567-T

30 October, 2023

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New York, U.S.A.
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The authors provide a useful water budget which contributes to a more comprehensive understanding of the system-wide impacts which would occur under the expected reduced future inflows to the Colorado River Basin. The paper identifies its major contribution as “a full sectoral and crop-specific accounting of where all [the Basin] water goes.” This may be technically correct at the level of detail given for irrigated crops, and the tables are certainly helpful by transparently including exports, uses in Mexico, and the Gila River Basin in the accounting. Their aggregate figures are credible, and the underlying details are for the most part sound.

There are several shortcomings in the current manuscript which should be addressed. First, only point estimates are provided, but work by some of the same authors using the same sources shows, for example, that upper basin agricultural consumptive use estimates vary by as much as a one million acre feet (about 40%) from year to year. Somewhat related to this, the discussion of data quality is limited, and does not extend to discussion of other reasonable estimates of aggregate consumptive use over the authors’ time frame or others. Third, there appear to be limitations in allocating exports to different uses. Fourth, as the authors note, water stocks in the Basin vary over time. While their budget implicitly assumes no change in surface or groundwater water stocks over time, the paper states that there was “an average annual overdraft of 14% [over reservoir stocks] during [the 2000-2020] period.” Of equal importance, changes in groundwater stocks do not explicitly appear in their budget and are in one case allocated to annual use. Fifth, the authors should be clear about whether this is meant to be a scientific estimate of actual consumptive use versus a compilation of Bureau of Reclamation (USBR) and state reported usage over time.

I do want to spend some time with what is really good here. The framing of the paper in defining categories as irrigated agricultural, municipal-commercial-industrial (MCI), reservoir evaporation, and riparian/wetland ET provides a very useful perspective. The attention to institutional accounting conventions (e.g. Upper and Lower Basins) which are crucial to policy discussions is important and commendable. Presenting the key tables in both SI units and using the volume measurement most used for policy work (acre-feet) is essential. The calculations allocating irrigation to a variety of crops appear reasonable and are sufficiently disaggregated as to inspire some confidence. Limiting the scope of the paper is also highly desirable, though I will argue below that some broadening to include discussion of accuracy and inter-annual variability, and to address changes in stocks is warranted. This would also go in the direction of clarifying the additional contributions here compared to the Richter (2020) paper.

Let me now address my major concerns:

1. Variability and Consumptive Use Estimates

Some consumptive water use in the Basin varies little from year to year, while other uses may vary greatly. Some of this results from an interplay of physical conditions and state water rights and priorities. This is likely most important in the Upper Basin, where Fleck, Kuhn, and Schmidt (2022) show that the same data used here results in highly variable consumptive use at the annual time scale (Figure 1 below).

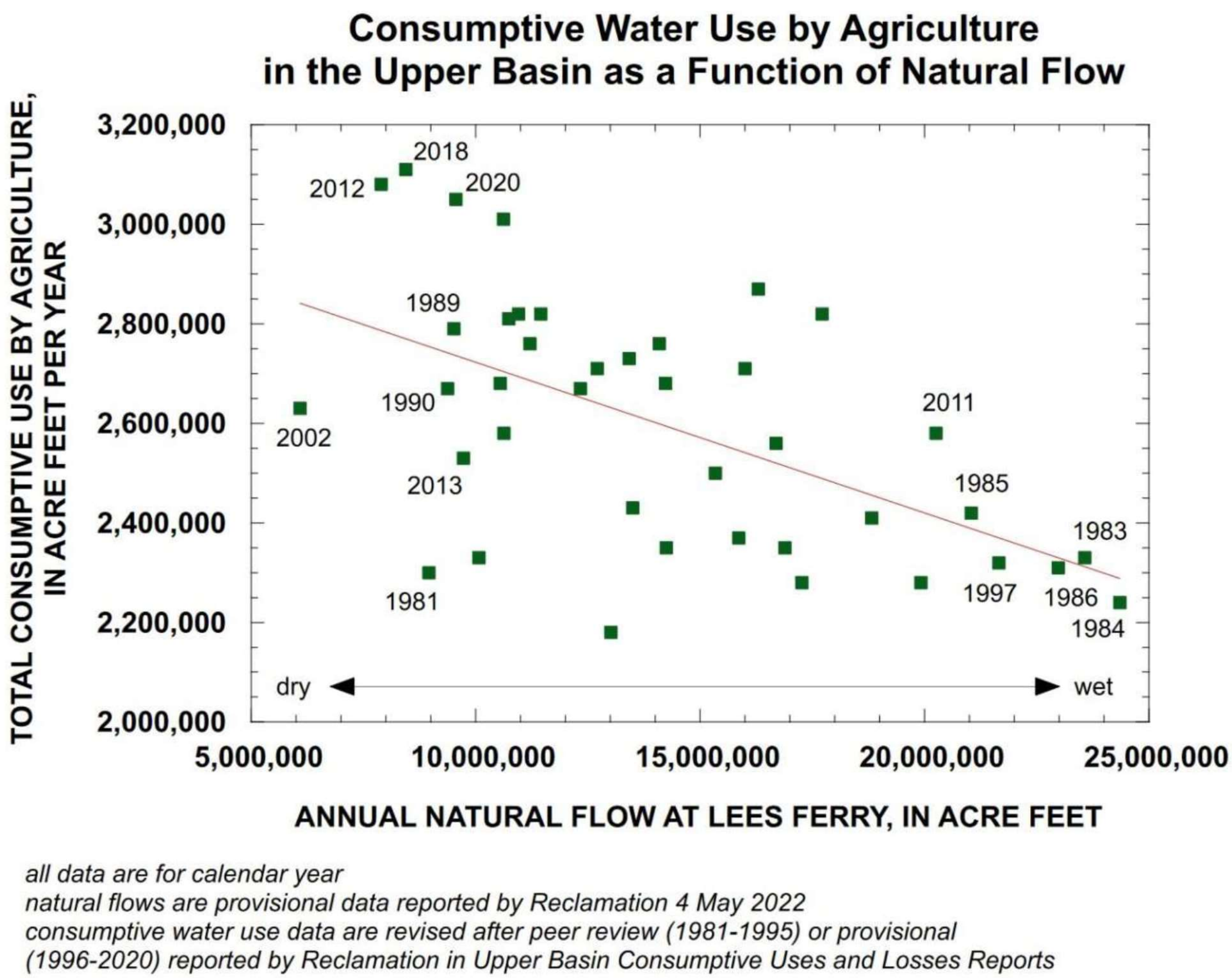

Figure 1. Annual variation in consumptive use. Reproduced from Fleck, Kuhn, and Schmidt (2022).

Second, the part of the "Law of the River" which allocates water between Lower Basin states gives low priority to Central Arizona Project deliveries. This is presumably reflected in the agreements discussed in lines 97-113 for relatively near-term river operations, and institutionally introduces variability in the water budgets with changes in river flows (and especially storage conditions.) Figure 2 illustrates some of this variability since 2000 using USBR diversion data for the Basin's Lower Basin states. This illustrates California's weaning itself from use of "excess" water and reductions in CAP use in 2022 due to low basin storage. But importantly, it's also suggestive of a time trend: the mean Lower Basin use for 2000-2019 in MCI and irrigated agriculture (reported as over 7 million acre-feet) is larger than that reported for 2020 and 2022. There is no "right" answer here, but there is nuance which the paper should introduce and briefly address, given that it devotes a full page to agreements supporting drought contingency planning.

2. Accuracy of Consumptive Use Estimates

The authors have not provided any comparisons with independent estimates of consumptive use or other losses in the basin independent of what they present. There are good reasons to base their budgets on the USBR data: these are the canonical figures used for Basin modeling and studies, and are certainly the most widely recognized estimates. Other approaches would be less accepted and useful in the policy world and would detract from the main purpose of this paper. That said, other approaches are certainly possible. In fact, the authors developed and used one such approach through their method of allocating irrigation consumptive use across crops. The authors do not say anything about the how those estimates compare to the USBR estimates. They should address this.

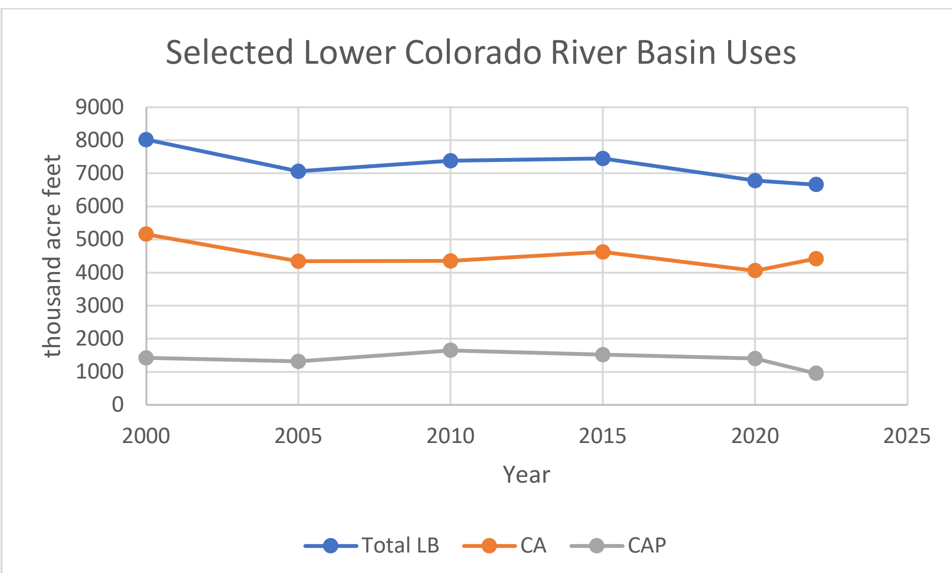

Figure 2. Annual variations in consumptive use. Data from USBR, Colorado River Accounting and Water Use Report (various years).

2. Accuracy of Consumptive Use Estimates

The authors have not provided any comparisons with independent estimates of consumptive use or other losses in the basin independent of what they present. There are good reasons to base their budgets on the USBR data: these are the canonical figures used for Basin modeling and studies, and are certainly the most widely recognized estimates. Other approaches would be less accepted and useful in the policy world and would detract from the main purpose of this paper. That said, other approaches are certainly possible. In fact, the authors developed and used one such approach through their method of

allocating irrigation consumptive use across crops. The authors do not say anything about the how those estimates compare to the USBR estimates. They should address this.

My discussion of variability and reliability of these estimates is not meant to distract from the central theme of the authors' work: a simple and authoritative budget of annual use. The authors simply need to address the limitations of single budget and, through text or a supplementary table or two, provide the context needed to understand limitations. This theme extends through the remainder of my comments, though in some cases I will suggest that some calculations might reasonably be revised.

3. Allocation of Exports

The authors state that "All uses of exported water are considered to be consumptive uses." It makes little sense to exclude return flows from MCI use when wastewater flows clearly contribute to downstream use. This is largest in magnitude along the Colorado Front range, clearest for Albuquerque which now uses exports through the Azotea tunnel, and whose wastewater has been described as the largest tributary to the upper Rio Grande. A very rough rule of thumb is that at least half of MCI use is non-consumptive; with mostly downstream agriculture this means that the MCI percentage of MCI use may be double what actually occurs. This seriously impacts the accuracy of the sectoral use proportions, and continues the regrettable practice of consistently overestimating MCI use when details of the disposition of diversions and return flows are not available.

Related to this issue:

a. In many cases a municipally led export project leases supplies for agricultural uses. To what degree has that been captured by the accounting?

b. Return flows from CAP MCI use will also not be properly allocated to downstream agriculture given the methods described in the paper.

4. Flows and stocks.

While peripheral to the main point of the paper, this should be addressed in some way. I see several issues to consider here:

a. Nontrivial quantities of CAP water are physically banked as groundwater. The authors say they painstakingly allocated subcontracts to the "final end use" including groundwater basin storage for later use. What portion is actually being stored and not consumed? This seems inconsistent with the idea of a budget for pure flows.

Given the complexity of the subcontracts, the pressures on municipal entities to secure future supplies, and the subsidies required for agricultural subcontracts there must be uncertainties here. It would be good to have a qualitative sense of a plausible range of estimates here. 10% greater or less on the MCI? 50%?

b. Groundwater use in the Gila River Basin is often mined groundwater. To what extent does the budget include unsustainable groundwater use, perhaps as return flows delivered through Gila River surface or alluvia? Do the AMA reports help in understanding this?

c. Across the 20 year historical period used for the budget the authors suggest there was a substantial change in surface water storage. Perhaps this could be added as a final line in the budget? Groundwater storage changes should also be noted here. More ambitiously a balance sheet reflecting changes from 2000 to 2019, in addition to the annual budgets could be added. This would then be akin to standard accounting practices for tracking finances.

d. There is evidence that there are substantial groundwater flows associated with Lake Powell/Glen Canyon Dam in particular (Myers, 2013). These are potentially large enough to affect the basin water budget in a nontrivial way. This should be addressed qualitatively.

5. The authors have produced a relatively simple annual budget for the full Colorado River Basin along with several sub-basins. The choice on what to present and how to define the sub-basins are spot-on. The data sources are widely known, and with that the budgets are something of a known quantity. This is all the start of an important contribution for the intended purpose to "aid design of strategies and plans for bringing water use into balance with available supplies."

But the authors promise more – "a full accounting of where all that water goes *en route* …." This suggests scientifically defensible choices at each stage, and here the paper does not reach its full potential. Most simply, the limitations of this work in particular and this type of highly aggregated product in general should be explored. There is almost a complete lack of attention to limitations at present. And where existing data sources fail to make reasonable allocation choices the authors have not made appropriate adjustments.

Minor items:

a. The authors might consider presenting an additional alternative in the ag / MCI proportions: allocating reservoir evaporation to each sector in proportion to its consumptive use. This would seem reasonable, as the purpose for much of the Basin storage is specifically to support irrigated agriculture. Variations on the theme are also reasonable: to the extent that MCI demand is more inelastic than irrigation for agriculture, then its storage demands will be greater.

b. There are other loss sources which are not mentioned by the authors. While I believe the categories for the accounts are a very good choice, several other depletions or situations should be mentioned:

> i. Return flows from IID to the Salton Sea are not discussed. I expect these are "consumptive use" given the data source used by the author. Note how this differs from the described treatment of Wellton-Mohawk return flows. Consistency would be desirable here, or at least description of assumptions and magnitudes.
>
> ii. How are non-ET evaporative losses allocated? Simple evaporation (other than from reservoirs) is rarely discussed, but may in some cases be important. How large are they? 1%? 5%?

iii. The use of “export” is inconsistent within the paper. In some cases it refers only to the Upper Basin and MWD, and in other cases it seems to include IID, Coachella, and CAP. IID and Coachella are arguably outside or inside (and treated inconsistently on the maps). All of this is institutional of course, so writing clearly about it while maintaining consistency with the common terminology is challenging. But to someone who doesn’t know the Basin, the current paper could be confusing in this area!

iv. Because irrigated agriculture is the largest user, and its consumptive use is difficult to estimate, the uncertainties in its estimate really need to be discussed. In the method section what is the use of efficiency data all about?? Looking at the USBR Excel sheet tab on efficiency makes me wonder if the data is any good at all. It seems to be largely about canal losses.

v. Riparian: the authors state that these are not given because “No estimates of riparian vegetation evapotranspiration for the Upper Basin or the Gila River exist.” This is problematic because, in contrast to the Lower Basin, upper tributaries of each of these sub-basins likely have substantial evapotranspiration. Also: no evaporation losses are given for exported water, despite reservoirs supporting distribution. These missions, with other notes about return flows for exports, that the claim of a complete water budget for the Basin is somewhat overstated.

c. Upper Basin advocates will be quick to point out that the Compact appears to allow much more use than is shown in the authors budget. There should be some sort of general disclaimer: the budget is an estimate of actual historical use, and makes no attempt to represent any past or future water rights.

<u>References</u>

Fleck, J., E. Kuhn, and J. Schmidt (2022). “Does the Upper Colorado River Basin Routinely Take Shortages in Dry Years?” url: www.inkstain.net/2022/07/does-the-upper-colorado-river-basin-routinely-take-shortages-in-dry-years/ (retrieved 11 October, 2023).

Myers, Tom. "Loss rates from Lake Powell and their impact on management of the Colorado River." *JAWRA Journal of the American Water Resources Association* 49.5 (2013): 1213-1224.

USBR*, Colorado River Accounting and Water Use Report (various years).*

Where Does the Colorado River's Water Go?
Reviewer Comments

This manuscript details a complete accounting of water use throughout the entire Colorado River Basin. This is a particularly important contribution to the existing literature because it includes components that are often neglected, such as trans-basin diversions and evaporative losses, and the additional inclusion of Gila River uses. I have a few minor comments of specific things to fix, and a few "bigger" comments that I think would help improve this manuscript. With these changes made (or adequately addressed), I would recommend approval for publication.

Specific Comments:

Page 3, line 47: Gila River accounts for 24% of the CRB?
Page 6, line 80: Water exported or to Mexico accounts for 24% of CRB
Page 6, line 88: would be appropriate to mention tribes here as they are now a part of the dialogue that they weren't previously in.
Page 6, line 89: "four legal agreements" but six are listed below.
Page 8, line 124: are the return flows from Arizona to Mexico being double counted?
Figure 2: the legend doesn't have any colors
Figure 3 is a really nice and informative graphic.
Figure 3: seems like reservoir depletion should be larger. Did you calculate this in some way, or take data from Powell and Mead? I'm assuming about 30mAF lost over the 20 years (just a guess) which would be 1.5mAF per year. Is that around what you have?
Figure 4: typo, change 2919 to 2019
Page 12, lines 186-194: this is an important thing to highlight, that it's not so easy to just grow something different.
Page 12, line 204: would be interested to see a time series of contributions for each year. Also, how different is the answer if you do cumulative totals for the 20 years, as opposed to an average?
Table 1: do some double checking to make sure all your columns and rows add up. I found a couple possible errors – first, total Mexico doesn't seem to include the riparian and wetland ET. Also, when I add the total upper basin, total lower basin, Gila, and total Mexico, it does not equal 19252, it's 19411 (which seems to be neglecting the Mexico exports column).
Table 2: double check your math on this one too. I'm assuming that I could take the totals from Table 1, remove the reservoir evaporation and riparian and wetland ET and get the same number that is the total for Table 2.

Broad Comments:

Interesting that the methodology comes after the discussion. When reading through the discussion, I kept wondering about measurements and where data was from. Which I think is why I'm more used to reading papers where the methodology comes first, and results and discussion come last. Not a change that is required, but thought it was worth a mention.

What about error bars, or range of uncertainty? What numbers are more certain and which ones may have large error bars on them? I think this should be a point of discussion.

The data in Tables 1 and 2 are very informative. I really like how you put it together in Figure 3. I would recommend considering additional ways to visualize the data to help tell your story, that way readers do not have to spend so much time squinting at a table.

I think more value could be added to this manuscript by highlighting how these numbers compare to expected deliveries (7.5mAF for Upper and Lower each, 1.5mAF for Mexico in the compacts). If we neglect evaporative losses from reservoirs, it looks as though the Lower Basin is taking exactly its allotted amount. But when you account for evaporation, they are overusing. From what I know, Upper Basin states account for evaporative losses for their budgeting (managed by the Upper Colorado River Commission), but the Lower Basin states do not, even though they lose more than 1.5mAF per year from that. Combine this information with the fact that, even including evaporation, the Upper Basin does not use even close to what they're allotted (because of their required deliveries to LB), and the Lower Basin continues to use more, there are clear implications here of where continued cuts need to be made. Based on your calculations, would you consider "extrapolating", assuming no changes to current practices, how long the basin would have before it runs out of water (basically to Mead and Powell deadpool)? Additionally of interest, would be to address specific numbers in the Tables that need to be considered for long-term sustainability of the basin and its reservoirs (e.g., including reservoir evaporation and ET in allotments, or CAP taking water between Powell and Mead for groundwater storage).

A year-to-year analysis that shows total use compared to actual naturalized runoff would be helpful, in the spirit of providing information to help with planning and strategy. Basically, each year, total use is 15.7mAF and total basin runoff (supply) has been closer to 13mAF, but ranging between 10mAF in drought years and 17mAF in a few wetter years (not sure on exact numbers that include both upper basin flows and lower basin flows-with Gila included). Basically, this is your budget analysis and including what's in the account (supply) to see exactly how much the basin is overspending.

COMMSENV-23-1567-T "Where Does the Colorado River's Water Go?"

Responses to Reviewer Comments

Reviewer #1

Comment: The authors provide a useful water budget which contributes to a more comprehensive understanding of the system-wide impacts which would occur under the expected reduced future inflows to the Colorado River Basin. The paper identifies its major contribution as "a full sectoral and crop-specific accounting of where all [the Basin] water goes." This may be technically correct at the level of detail given for irrigated crops, and the tables are certainly helpful by transparently including exports, uses in Mexico, and the Gila River Basin in the accounting. Their aggregate figures are credible, and the underlying details are for the most part sound.

Response: We very much appreciate this reviewer's careful and constructive review, and we appreciate acknowledgement of the paper's contributions.

Comment: There are several shortcomings in the current manuscript which should be addressed. First, only point estimates are provided, but work by some of the same authors using the same sources shows, for example, that upper basin agricultural consumptive use estimates vary by as much as a one million acre feet (about 40%) from year to year. Somewhat related to this, the discussion of data quality is limited, and does not extend to discussion of other reasonable estimates of aggregate consumptive use over the authors' time frame or others. Third, there appear to be limitations in allocating exports to different uses. Fourth, as the authors note, water stocks in the Basin vary over time. While their budget implicitly assumes no change in surface or groundwater water stocks over time, the paper states that there was "an average annual overdraft of 14% [over reservoir stocks] during [the 2000-2020] period." Of equal importance, changes in groundwater stocks do not explicitly appear in their budget and are in one case allocated to annual use. Fifth, the authors should be clear about whether this is meant to be a scientific estimate of actual consumptive use versus a compilation of Bureau of Reclamation (USBR) and state reported usage over time.

Response: Each of these comments is addressed below.

Comment: I do want to spend some time with what is really good here. The framing of the paper in defining categories as irrigated agricultural, municipal-commercial-industrial (MCI), reservoir evaporation, and riparian/wetland ET provides a very useful perspective. The attention to institutional accounting conventions (e.g. Upper and Lower Basins) which are crucial to policy discussions is important and commendable. Presenting the key tables in both SI units and using the volume measurement most used for policy work (acre-feet) is essential. The calculations allocating irrigation to a variety of crops appear reasonable and are sufficiently disaggregated as to inspire some confidence. Limiting the scope of the paper is also highly desirable, though I will argue below that some broadening to include discussion of accuracy and inter-annual variability, and to address changes in stocks is warranted. This would also go in the direction of clarifying the additional contributions here compared to the Richter (2020) paper.

Response: We very much appreciate this reviewer's careful and constructive review, and we are grateful for his mention of the paper's strengths. We address comments about accuracy, inter-annual variability, and changes in stocks below.

Comment: Variability and Consumptive Use Estimates
Some consumptive water use in the Basin varies little from year to year, while other uses may vary greatly. Some of this results from an interplay of physical conditions and state water rights and priorities. This is likely most important in the Upper Basin, where Fleck, Kuhn, and Schmidt (2022) show that the same data used here results in highly variable consumptive use at the annual time scale. Second, the part of the "Law of the River" which allocates water between Lower Basin states gives low priority to Central Arizona Project deliveries. This is presumably reflected in the agreements discussed in lines 97-113 for relatively near-term river operations, and institutionally introduces variability in the water budgets with changes in river flows (and especially storage conditions.) Figure 2 illustrates some of this variability since 2000 using USBR diversion data for the Basin's Lower Basin states. This illustrates California's weaning itself from use of "excess" water and reductions in CAP use in 2022 due to low basin storage. But importantly, it's also suggestive of a time trend: the mean Lower Basin use for 2000-2019 in MCI and irrigated agriculture (reported as over 7 million acre-feet) is larger than that reported for 2020 and 2022. There is no "right" answer here, but there is nuance which the paper should introduce and briefly address, given that it devotes a full page to agreements supporting drought contingency planning.

Response: The purpose of this paper is to provide an accurate and complete accounting for "Where the Colorado River's Water Goes." It makes no attempt to explain why water use levels changed other than describing key basin agreements that directly affect the volume of water consumed. We have not discussed prior appropriation water rights or the Law of the River and their influence on water use because those issues have been thoroughly explained in a plethora of other papers and media articles; instead, this paper simply describes how much water was consumed in each sub-basin and sector; as we explain in our paper, we feel that this is a unique and important contribution. Our estimates are based on 20-year (2000-2019) average values for each of our water budget components; use of multi-year averages is standard hydrologic practice in the preparation of a water budget. However, we do agree that some depiction of the variability in the water budget components would be an important addition to our averaged water budget; we have added Figure 5 and associated text to illustrate this variation and we thank this reviewer for this suggestion.

Comment: Accuracy of Consumptive Use Estimates
The authors have not provided any comparisons with independent estimates of consumptive use or other losses in the basin independent of what they present. There are good reasons to base their budgets on the USBR data: these are the canonical figures used for Basin modeling and studies, and are certainly the most widely recognized estimates. Other approaches would be less accepted and useful in the policy world and would detract from the main purpose of this paper. That said, other approaches are certainly possible. In fact, the authors developed and used one such approach through their method of allocating irrigation consumptive use across crops. The

authors do not say anything about the how those estimates compare to the USBR estimates. They should address this.

Response: This reviewer has raised an important issue concerning the accuracy of data included in our water budget. In response, we have added text in our Methods section to further explain the specific source(s) for each of our datasets and we describe how the data were collected/measured or how estimates were calculated. This elaboration should give readers a better sense for potential inaccuracies or uncertainties. We have also explicitly acknowledged potential inaccuracies in the first paragraph of our Methods section. We hope that these additions satisfy this reviewer's concerns and recommendations about data quality.

We are unaware of any other efforts to compile a detailed water budget for the entire Colorado River Basin. The Bureau of Reclamation has prepared water budgets for the Upper and Lower Basins (excluding the Gila River Basin), but they used the same datasets that we have used; unsurprisingly, our estimates for those sub-basins match theirs. Additionally, the USGS described water uses and trends for the Colorado River Basin over the 1985-2010 period, but their summary has the same shortcomings as our 2020 Nature Sustainability paper because it does not include exported water nor Mexico; also, because they use water withdrawal data instead of water consumption data, we cannot directly compare our results with theirs. The USGS published a very useful comparison of their data estimation methods with those used by Reclamation, and we now reference that publication in our paper.

We have compared our current study with the water budget we included in our 2020 Nature Sustainability paper and explain those differences in our Discussion section. Importantly, we explain differences in our estimation of crop-specific water consumption. Given that the estimates from our Nature Sustainability paper are frequently cited in the media, we felt that this comparison and its explanation were important to communicate.

Comment: My discussion of variability and reliability of these estimates is not meant to distract from the central theme of the authors' work: a simple and authoritative budget of annual use. The authors simply need to address the limitations of single budget and, through text or a supplementary table or two, provide the context needed to understand limitations. This theme extends through the remainder of my comments, though in some cases I will suggest that some calculations might reasonably be revised.

Response: We have added text and a new Figure 5 describing inter-annual variability in water consumption in the Colorado River Basin. Our water budget is based upon multi-year averages, as is standard hydrologic practice. Our water budget has been compiled using both Reclamation data sources as well as additional sources as described in our Methods. We have added clarifying text in our Methods section to better elaborate the data measurement or estimation procedures used by each data source, and we have added an acknowledgement in our Methods section that data inaccuracies and uncertainties exist.

Comment: Allocation of Exports
The authors state that "All uses of exported water are considered to be consumptive uses." It makes little sense to exclude return flows from MCI use when wastewater flows clearly contribute to downstream use. This is largest in magnitude along the Colorado Front range, clearest for Albuquerque which now uses exports through the Azotea tunnel, and whose

wastewater has been described as the largest tributary to the upper Rio Grande. A very rough rule of thumb is that at least half of MCI use is nonconsumptive; with mostly downstream agriculture this means that the MCI percentage of MCI use may be double what actually occurs. This seriously impacts the accuracy of the sectoral use proportions, and continues the regrettable practice of consistently overestimating MCI use when details of the disposition of diversions and return flows are not available. Related to this issue:
a. In many cases a municipally led export project leases supplies for agricultural uses. To what degree has that been captured by the accounting?
b. Return flows from CAP MCI use will also not be properly allocated to downstream agriculture given the methods described in the paper.

Response: It is standard practice in water budget accounting to consider all water exported from the basin of interest as being fully consumptively used because none of that water is returned to the basin of origin. For example, USGS Special Investigations Report 2018-5021[1] on the Colorado River includes this statement: "The term 'consumption' as used in this report means that the water is removed from the system and is no longer available for other uses within the hydrologic Colorado River basin" and in its Glossary defines consumptive use as: "A depletion of surface water or groundwater due to human-caused activity, including interbasin transfers." In a hydrology textbook being used by many universities, one of our authors (Richter) states the following in "Chasing Water": "After withdrawn water is used on a farm or in a city or industry, some portion of that water runs off the farm or down the drain and reenters the original water source as 'return flow.' The portion of used water that is not returned to the original source is considered a "consumptive use," that is, it is lost or depleted from the water account. When constructing a water budget for a particular water source, it is very important to pay attention to water being moved between water sources. Many cities withdraw their water from one freshwater source but return it to another freshwater source or to the ocean. All of the water that is not returned to the original source is considered to be consumptively used (depleted) with respect to the original source."

We have added text in our Methods to better explain this concept. As discussed above and in our Methods, we carefully differentiated the end uses of water exported from the basin for all diversions greater than 2,000 AF/year (30 of 47 structures) using websites, publications, and direct personal communications with the operators of each diversion structure. We have also explained how we allocated end uses to the 17 other very small diversion structures (all located in the Upper Basin), which in aggregate amount to 1% of all water exported from the Upper Basin.

Regarding MCI water use from the Central Arizona Project, the vast majority of urban water use dependent upon the CAP is recycled and used within the urban area itself. For instance, Phoenix recycles every gallon of wastewater generated, and uses the recycled water for power plant cooling or irrigating golf courses and other landscape areas. Less than 1% of this recycled water goes to agricultural irrigation. Regardless of how recycled water is used, we fully account for all agricultural water use – regardless of the source of the water – using the methods described in this paper.

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[1] Maupin, M.A., Ivahnenko, T. & Bruce, B. *Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010.* USGS Special Investigations Report 2018-5021.

Comment: Flows and stocks.
While peripheral to the main point of the paper, this should be addressed in some way. I see several issues to consider here:
a. Nontrivial quantities of CAP water are physically banked as groundwater. The authors say they painstakingly allocated subcontracts to the "final end use" including groundwater basin storage for later use. What portion is actually being stored and not consumed? This seems inconsistent with the idea of a budget for pure flows. Given the complexity of the subcontracts, the pressures on municipal entities to secure future supplies, and the subsidies required for agricultural subcontracts there must be uncertainties here. It would be good to have a qualitative sense of a plausible range of estimates here. 10% greater or less on the MCI? 50%?

Response: We have assumed that the small (~11%) portion of CAP water that is (temporarily) stored in a groundwater bank in any given year is subsequently extracted and consumed in following years. Because we are using a fairly long period of years in our averaging, we have accounted for the ultimate end use of any banked water in our estimates of MCI and agricultural uses.

Comment: b. Groundwater use in the Gila River Basin is often mined groundwater. To what extent does the budget include unsustainable groundwater use, perhaps as return flows delivered through Gila River surface or alluvia? Do the AMA reports help in understanding this?

Response: As the title of our paper implies, we have focused our water budget analysis on the consumption of the waters of the Colorado River hydrologic system, including its surface water tributaries and shallow alluvial groundwater. We have not attempted to account for deep groundwater pumping that is not hydrologically connected to surface water features. The AMA datasets used in this study for the Gila River Basin categorize each type of water source used; we have used only water consumed from surface water in the Gila River system. The dataset used for the upper Gila River basin was provided by the University of Arizona, and it does include some shallow alluvial groundwater use but this groundwater is presumed to be hydrologically connected to surface water that is regularly replenished by river infiltration. Similarly, Reclamation estimates of water use throughout the Upper and Lower Basins does include some alluvial groundwater consumption that is quickly replenished by river flow. We have added clarifying text in our Methods section to address this shallow alluvial groundwater use.

Comment: c. Across the 20 year historical period used for the budget the authors suggest there was a substantial change in surface water storage. Perhaps this could be added as a final line in the budget? Groundwater storage changes should also be noted here. More ambitiously a balance sheet reflecting changes from 2000 to 2019, in addition to the annual budgets could be added. This would then be akin to standard accounting practices for tracking finances.

Response: Our water budget focuses only on consumptive uses of water and not water supplies. However, as indicated in Figure 3, reservoir depletion during 2000-2019 has served as a source of water, not a consumptive use. As discussed above, the only groundwater consumption included in our Tables 1 & 2 is groundwater sourced from shallow alluvial aquifers that are regularly replenished with river infiltration.

Comment: d. There is evidence that there are substantial groundwater flows associated with Lake Powell/Glen Canyon Dam in particular (Myers, 2013). These are potentially large enough to affect the basin water budget in a nontrivial way. This should be addressed qualitatively.

Response: We thank this reviewer for raising this issue because we agree that it is non-trivial. The seepage of reservoir water into surrounding terrain can function both as a consumptive loss of water if the direction of flow is from a reservoir into bank storage, and as a source of water when bank storage drains back into a reservoir. For example, Myers estimates that ~200,000 acre-feet per year drained back into Lake Powell as lake levels dropped in the early 2000s, boosting available water supplies. We have added mention of this phenomenon in our Methods section on "Reservoir evaporation," but we are unable to include these alternating changes in bank storage in our water budget due to inadequate measurement certainty at all of the basin's reservoirs. We hope that these reservoir/bank storage exchanges will be better monitored or estimated in the future.

Comment: The authors have produced a relatively simple annual budget for the full Colorado River Basin along with several sub-basins. The choice on what to present and how to define the sub-basins are spot-on. The data sources are widely known, and with that the budgets are something of a known quantity. This is all the start of an important contribution for the intended purpose to "aid design of strategies and plans for bringing water use into balance with available supplies." But the authors promise more – "a full accounting of where all that water goes en route …." This suggests scientifically defensible choices at each stage, and here the paper does not reach its full potential. Most simply, the limitations of this work in particular and this type of highly aggregated product in general should be explored. There is almost a complete lack of attention to limitations at present. And where existing data sources fail to make reasonable allocation choices the authors have not made appropriate adjustments.

Response: We respectfully disagree with this reviewer's assessment. We believe that we have used the most accurate datasets available for each sub-basin and sector in our water budget, and now that we have added riparian & wetland evapotranspiration throughout the CRB (see below) we believe that our water budget now represents the entirety of water consumed from the Colorado River hydrologic system in a scientifically credible manner. We have added much clarifying text to describe each data source, along with the methods used to measure or estimate each component of our water budget. We have also added text acknowledging the potential inaccuracies of these data. We hope that this reviewer might elaborate on any other 'limitations' that we have not addressed.

Comment: The authors might consider presenting an additional alternative in the ag /MCI proportions: allocating reservoir evaporation to each sector in proportion to its consumptive use. This would seem reasonable, as the purpose for much of the Basin storage is specifically to support irrigated agriculture. Variations on the theme are also reasonable: to the extent that MCI demand is more inelastic than irrigation for agriculture, then its storage demands will be greater.

Response: This is an interesting suggestion, but we believe that it is important to track reservoir evaporation as a separate water budget component so that the manner in which water is consumed throughout the basin is clearly revealed.

Comment: There are other loss sources which are not mentioned by the authors. While I believe the categories for the accounts are a very good choice, several other depletions or situations should be mentioned:

a. Return flows from IID to the Salton Sea are not discussed. I expect these are "consumptive use" given the data source used by the author. Note how this differs from the described treatment of Wellton-Mohawk return flows. Consistency would be desirable here, or at least description of assumptions and magnitudes.

Response: We agree that it would be inconsistent to account for agricultural return flows into the Cienega de Santa Clara in Mexico while not similarly accounting for agricultural return flows into the Salton Sea. We have now included Salton Sea inflows in the"Riparian and Wetland ET" component of our water budget, and reduced agricultural water use in the Lower Basin (which includes the Imperial Irrigation District) accordingly. We thank this reviewer for this helpful suggestion.

Comment: b. How are non-ET evaporative losses allocated? Simple evaporation (other than from reservoirs) is rarely discussed, but may in some cases be important. How large are they? 1%? 5%?

Response: The only evaporation or evapotranspiration relevant to this water budget occurs either within reservoirs (evaporation) or along the river corridors in the basin. This reviewer's comment motivated us to invest considerable additional time in estimating riparian & wetland evapotranspiration throughout the entire CRB, increasing our total consumptive use by 12%.

Comment: c. The use of "export" is inconsistent within the paper. In some cases it refers only to the Upper Basin and MWD, and in other cases it seems to include IID, Coachella, and CAP. IID and Coachella are arguably outside or inside (and treated inconsistently on the maps). All of this is institutional of course, so writing clearly about it while maintaining consistency with the common terminology is challenging. But to someone who doesn't know the Basin, the current paper could be confusing in this area!

Response: We respectfully disagree that our definition of exports is inconsistent within our paper, and we are confused as to why this reviewer has made these assertions given our detailed mapping and accounting for exported water. The areas receiving exported water (inter-basin transfers) are clearly delineated in Figures 1 & 2 and defined within the paper as any water exported outside of the Colorado River Basin's physical boundary. We have also listed the major recipients of exported water in our Methods section on "Exported water consumption." We meticulously assembled data for 47 individual inter-basin transfer structures and allocated the annual volumes of water moving through each of those structures to their respective end uses. We have added elaboration of our approach in the Methods section.

Comment: d. Because irrigated agriculture is the largest user, and its consumptive use is difficult to estimate, the uncertainties in its estimate really need to be discussed. In the method section what is the use of efficiency data all about?? Looking at the USBR Excel sheet tab on efficiency makes me wonder if the data is any good at all. It seems to be largely about canal losses.

Response: We thank this reviewer for catching the reference to "efficiency" at the end of our Methods section on "Crop-specific water consumption." There was no need to include the last two sentences in this Methods section because those sentences are not relevant to this study. Embarrassingly, they were carried over from the Methods section of another recently published paper that used a computerized hydrology model that required water withdrawals as inputs. We have removed those two sentences from this paper and apologize for the confusion. Our methods for estimating crop ET (agricultural consumption) are detailed in our Methods section.

Comment: e. Riparian: the authors state that these are not given because "No estimates of riparian vegetation evapotranspiration for the Upper Basin or the Gila River exist." This is problematic because, in contrast to the Lower Basin, upper tributaries of each of these sub-basins likely have substantial evapotranspiration.

Response: Yes this is true! We thank this reviewer for this comment because it motivated us to develop estimates of riparian & wetland evapotranspiration throughout the CRB. Our data sources and approach are now detailed in our Methods section.

Comment: f. Also: no evaporation losses are given for exported water, despite reservoirs supporting distribution. These missions, with other notes about return flows for exports, that the claim of a complete water budget for the Basin is somewhat overstated

Response: As discussed above, we do not include reservoir evaporation or return flows in our accounting for exported water because all exported water is fully consumptively used with respect to the Colorado River basin. Evaporation from reservoirs within the CRB is included in our water budgets.

Comment: Upper Basin advocates will be quick to point out that the Compact appears to allow much more use than is shown in the authors budget. There should be some sort of general disclaimer: the budget is an estimate of actual historical use, and makes no attempt to represent any past or future water rights.

Response: We have added text in the introduction section and results to explain that we are reporting averaged annual water consumption during the period 2000-2019. The simple reason the Lower and Upper Basins are using less than allocated by the Colorado River Compact is due to the reality that the river system does not produce the volume of water assumed by the Compact.

Reviewer #2

Comment: Page 3, line 47: Gila River accounts for 24% of the CRB?

Response: The area of the Colorado River Basin in its entirety is 246,000 square miles, the area of the Gila River Basin is estimated at 60,000 square miles or 24% of the CRB. We have added text clarifying that 24% refers to drainage area, not water contributed!

Comment: Page 6, line 80: Water exported or to Mexico accounts for 24% of CRB

Response: The total volume of water consumed in the entire Colorado River Basin sums to 19,253,642. The volume of water that is either exported outside of the CRB or is consumed in Mexico sums to 3,634,537 acre-feet per year, or 19% of the entire CRB. (note that we have modified our estimate to 19% instead of 24%).

Comment: Page 6, line 88: would be appropriate to mention tribes here as they are now a part of the dialogue that they weren't previously in.

Response: We agree! We have added mention of the 30 tribal nations within the CRB.

Comment: Page 6, line 89: "four legal agreements" but six are listed below.

Response: We thank this reviewer for catching this mistake and we have corrected it.

Comment: Page 8, line 124: are the return flows from Arizona to Mexico being double counted?

Response: No because the volume of water flowing through the Wellton-Mohawk canal into the Cienega de Santa Clara is accounted for separately from other uses in Reclamation's datasets. All other data used in this study is consumptive use, so no other return flows are counted in our water budget.

Comment: Figure 2: the legend doesn't have any colors

Response: We're not sure what happened to the version of the paper you reviewed. Our pdf submission includes colors in Figure 2's legend.

Comment: Figure 3 is a really nice and informative graphic.

Response: We thank this reviewer for this compliment, and we agree that it is a nice addition to the paper that we added just before submitting.

Comment: Figure 3: seems like reservoir depletion should be larger. Did you calculate this in some way, or take data from Powell and Mead? I'm assuming about 30mAF lost over the 20 years (just a guess) which would be 1.5mAF per year. Is that around what you have?

Response: The average annual reservoir depletion in Lake Mead + Lake Powell from 2000-2021 was 1.4 MAF but from 2000-2019 it was 'only' 1.15 MAF (the reservoirs lost a lot more water in 2020 and 2021)

Comment: Figure 4: typo, change 2919 to 2019

Response: We thank this reviewer for catching this mistake and we have corrected it.

Comment: Page 12, lines 186-194: this is an important thing to highlight, that it's not so easy to just grow something different.

Response: We agree and discuss this in greater detail in another recently published paper that we cite here.[2]

Comment: Page 12, line 204: would be interested to see a time series of contributions for each year. Also, how different is the answer if you do cumulative totals for the 20 years, as opposed to an average?

Response: As mentioned above in our responses to Reviewer #1's comments, it is standard hydrologic practice to use multi-year averages when compiling a water budget for a basin of interest. However, we have added a new Figure 5 that illustrates the inter-annual variability in MCI and agricultural water consumption during 2000-2019. Use of cumulative totals for each sector and sub-basin would result in the same proportions of water consumed by each sector and crop because all of those calculations would be using the same time period (2000-2019).

Comment: Table 1: do some double checking to make sure all your columns and rows add up. I found a couple possible errors – first, total Mexico doesn't seem to include the riparian and wetland ET. Also, when I add the total upper basin, total lower basin, Gila, and total Mexico, it does not equal 19252, it's 19411 (which seems to be neglecting the Mexico exports column).

Response: We very much appreciate the careful attention to detail provided by this reviewer, and we have corrected these errors.

Comment: Table 2: double check your math on this one too. I'm assuming that I could take the totals from Table 1, remove the reservoir evaporation and riparian and wetland ET and get the same number that is the total for Table 2.

Response: You are correct, and we have corrected these errors.

Broad Comments: Interesting that the methodology comes after the discussion. When reading through the discussion, I kept wondering about measurements and where data was from. Which I think is why I'm more used to reading papers where the methodology comes first, and results and discussion come last. Not a change that is required, but thought it was worth a mention.

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[2] Richter, B.D., Y. Ao, G. Lamsal, D. Wei, M. Amaya, L. Marston & Davis, K.F. Alleviating water scarcity by optimizing crop mixes. *Nature Water*. https://doi.org/10.1038/s44221-023-00155-9

Response: The sequencing of different sub-sections is set by the journal's guidelines.

Comment: What about error bars, or range of uncertainty? What numbers are more certain and which ones may have large error bars on them? I think this should be a point of discussion.

Response: We are unable to provide any quantitative error bars or ranges of uncertainty due to the manner in which these data have been measured or estimated. However, we have added discussion of the measurement and estimation procedures for each of the datasets we used, see revised Methods.

Comment: The data in Tables 1 and 2 are very informative. I really like how you put it together in Figure 3. I would recommend considering additional ways to visualize the data to help tell your story, that way readers do not have to spend so much time squinting at a table.

Response: We agree and have modified our Figure 4 to provide more insight into how water is being consumed in each of our four sub-basins. Note that we have also added a new Figure 5 to illustrate inter-annual variability in water consumption.

Comment: I think more value could be added to this manuscript by highlighting how these numbers compare to expected deliveries (7.5mAF for Upper and Lower each, 1.5mAF for Mexico in the compacts). If we neglect evaporative losses from reservoirs, it looks as though the Lower Basin is taking exactly its allotted amount. But when you account for evaporation, they are overusing. From what I know, Upper Basin states account for evaporative losses for their budgeting (managed by the Upper Colorado River Commission), but the Lower Basin states do not, even though they lose more than 1.5mAF per year from that. Combine this information with the fact that, even including evaporation, the Upper Basin does not use even close to what they're allotted (because of their required deliveries to LB), and the Lower Basin continues to use more, there are clear implications here of where continued cuts need to be made. Based on your calculations, would you consider "extrapolating", assuming no changes to current practices, how long the basin would have before it runs out of water (basically to Mead and Powell deadpool)? Additionally of interest, would be to address specific numbers in the Tables that need to be considered for long-term sustainability of the basin and its reservoirs (e.g., including reservoir evaporation and ET in allotments, or CAP taking water between Powell and Mead for groundwater storage).

Response: We're pretty sure that the Upper Basin gave up hope of using its full Compact allocation of 7.5 MAF a long time ago! We understand this reviewer's interest in hearing our forecasts of what may happen in the future, or our assessment of which components of our water budget need to be reduced to attain sustainability, but such prognostications are beyond the scope of this paper; we do not believe that we can make scientifically credible forecasts with the data we have because we would need to dive deeper into the ways that both cities and irrigation districts have already invested in water conservation measures and evaluate potential additional savings that could be attained. That said, we have added a paragraph near the end of our Discussion section that specifies the amount of overconsumption presently occurring, and the *volume of reduction that will be needed to stabilize the reservoirs and to adapt to a climate-warming future.*

Comment: A year-to-year analysis that shows total use compared to actual naturalized runoff would be helpful, in the spirit of providing information to help with planning and strategy. Basically, each year, total use is 15.7mAF and total basin runoff (supply) has been closer to 13mAF, but ranging between 10mAF in drought years and 17mAF in a few wetter years (not sure on exact numbers that include both upper basin flows and lower basin flows-with Gila included). Basically, this is your budget analysis and including what's in the account (supply) to see exactly how much the basin is overspending.

Response: We understand this reviewer's interest in portraying annual fluctuations in the supply-demand balance (or imbalance!). However, that dynamic has been discussed and graphed in many previous journal papers and media articles – see for example the graph below from Richter 2023.[3] The unique and important contribution of our paper is a substantial improvement in the accuracy of the accounting for water consumption in the Colorado River Basin. We do, however, address the supply-demand imbalance in our Discussion section.

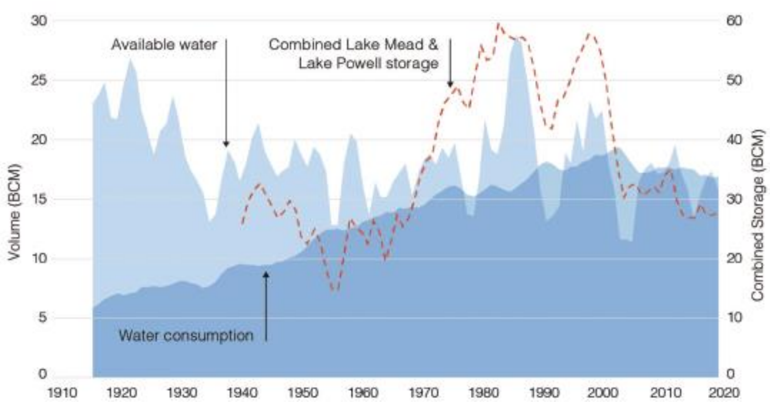

Fig. 2. (Color) Consumptive use of Colorado River water increased gradually over the last century, reaching a peak in 2000. River flow has decreased by ~20% since 2000, but total consumptive use has decreased by only 15% on average. With consumption regularly exceeding supply in recent decades, the water stored in Lake Mead and Lake Powell has been heavily depleted. The two reservoirs did not fill completely until the early 1980s. BCM = billion cubic meters. (Data from US Bureau of Reclamation 2022b, c, d.)

[3] Richter, B.D. 2023. Decoupling urban water use from population growth in the Colorado River Basin. Journal of Water Planning and Management 149(2) https://ascelibrary.org/doi/abs/10.1061/JWRMD5.WRENG-5887

19th Jan 24

Dear Mr Richter,

Your manuscript titled "Where Does the Colorado River’s Water Go?" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment, provided you comprehensively address the remaining discussion points from reviewer 1 in the manuscript. If appropriate, we will publish your manuscript under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Carolina Ortiz Guerrero
Associate Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors have addressed my concerns regarding variability and reliability of the water budget data presented in their initial submission. In addition, the resubmission more fully addresses limitations of the paper, including flows which cannot be reasonably quantified (bank storage and release), and provides clarity on treatment of tributary and non-tributary groundwater.

A major new effort in quantifying riparian and wetland uses has been undertaken by the authors and is introduced here. The methods appear technically sound (though I am not qualified to evaluate these in detail), but the results diverge from the estimates for the other sectors which are derived (accurately) from the "authoritative primary data sources."

These results qualitatively change our understanding of consumptive use for the Basin. Their estimate of riparian and wetland use increases from 4% (first submission, reflecting primarily the "authoritative" sources) to 19% of total Basin consumptive use (c.f. the MCI total of 18%). In the Upper Basin, where the Upper Colorado River Basin Consumptive Uses and Losses Report does not quantify "channel losses" and in which the authors did not previously report any consumptive use in their budget, the consumptive use is now reported as nearly double the municipal (MCI) uses. These may all be perfectly correct (and would be netted out in the USBR naturalized flow estimates and thus not really noticed for allocation purposes) but are <i>nonetheless extraordinary</i>.

This is a new and important contribution of the paper, but these extraordinary findings for the CRB and the potential implications justify (at least) a thoughtful standalone paragraph devoted to the topic. This would include discussion of how these results differ from the "authoritative" estimates (e.g. Table 1, first paper submission Lower Basin w/o Gila of 657 MCM vs. second submission of

1,752 MCM) and any other comparable findings from other basins or regions (e.g. California).

Remaining concerns of mine do not need to be reconciled, but I do wish to briefly summarize them:

a. Coachella Valley Irrigation District use is defined as an export which does not seem consistent with the Imperial Irrigation District being treated as within the basin. Both regions use water originating from the All-American Canal, drain to the Salton Sea, and are shown in Figure 1 as within basin. Adjacent municipal use (tiny in the scheme of things) is from recharged Colorado Aqueduct water; Figure 1 shows this as an export which seems questionable given drainage to the Salton Sea. (Also see lines 342-43 which has a typo.)

Alternatively, treat it all as an export, and then, helpfully, the Salton Sea returns flows are captured in Table 1 by the Lower Basin – Exports sector.

b. I remain concerned that the actual use (as opposed to permanent ownership) of Upper Basin exports may not be characterized accurately. Exports to Colorado's highly urbanized Front Range are two thirds of the total. Within that, the Colorado Big Thompson Project accounts for almost three quarters of imports, and actual use is at least half agricultural: "In 2018, though, municipal and industrial ownership of the 310,000 Colorado-Big Thompson water units…crept to 70 percent, leaving just 30 percent owned by agricultural users …. But more than half of the system's water still has been delivered to farmers in recent years, according to Northern Water data." (The Longmont Times, quoted by Northern at https://coyotegulch.blog/2019/01/29/). Denver Water imports account for most of the rest, but Denver has a relatively small proportion of reuse; the remainder of wastewater goes to downstream agricultural (and some riparian and wetland) use. It seems unlikely that, for Colorado at least, actual agricultural use of CRB exports is less than 50%.

Thank you to the authors for careful attention to a great amount of detail in their response to the first review.

Reviewer #2 (Remarks to the Author):

The authors satisfactorily addressed all of my comments in their revised manuscript. They also took the time to address all comments by the other reviewer. Based on the revisions, I recommend publication of this manuscript.

January 21, 2024

Dear Journal Editors,

We have prepared our final revision of our manuscript (COMMSENV-23-1567A) according to guidelines provided by the journal and its editors, see accompanying Editorial Requests Table.

We have also modified our final manuscript in response to reviewer comments as follows.

Reviewer #1 comments

Comment: This is a new and important contribution of the paper, but these extraordinary findings for the CRB and the potential implications justify (at least) a thoughtful standalone paragraph devoted to the topic. This would include discussion of how these results differ from the "authoritative" estimates (e.g. Table 1, first paper submission Lower Basin w/o Gila of 657 MCM vs. second submission of 1,752 MCM) and any other comparable findings from other basins or regions (e.g. California).

Response: We appreciate this reviewer's acknowledgement of the 'extraordinary' advancement we have been able to achieve in this latest revision of our paper, and we note that our efforts were motivated by this reviewer's comments on an earlier draft of our paper. We have added text in lines 157-167 that explains why these new estimates of riparian evapotranspiration differ so much from earlier estimates.

Comment: Coachella Valley Irrigation District use is defined as an export which does not seem consistent with the Imperial Irrigation District being treated as within the basin. Both regions use water originating from the All-American Canal, drain to the Salton Sea, and are shown in Figure 1 as within basin. Adjacent municipal use (tiny in the scheme of things) is from recharged Colorado Aqueduct water; Figure 1 shows this as an export which seems questionable given drainage to the Salton Sea. (Also see lines 342-43 which has a typo.)

Response: We have included the Imperial Irrigation District as being within the physical boundary of the Lower Basin following the rationale of Schmidt (2022).[1] However, the majority of the Coachella Valley Irrigation District lies at a higher elevation than the IID and is assumed to not have been inundated by the Colorado River Delta; we have therefore treated the CCID as a recipient of an inter-basin transfer (exported water) while including the IID as part of the Lower Basin.

[1] Schmidt, J.C. *Maps Matter: A few suggested changes to the Colorado River basin base map*. Center for Colorado River Studies, Utah State University (2022).

Comment: I remain concerned that the actual use (as opposed to permanent ownership) of Upper Basin exports may not be characterized accurately. Exports to Colorado's highly urbanized Front Range are two thirds of the total. Within that, the Colorado Big Thompson Project accounts for almost three quarters of imports, and actual use is at least half agricultural: "In 2018, though, municipal and industrial ownership of the 310,000 Colorado-Big Thompson water units…crept to 70 percent, leaving just 30 percent owned by agricultural users …. But more than half of the system's water still has been delivered to farmers in recent years, according to Northern Water data." (The Longmont Times, quoted by Northern at https://coyotegulch.blog/2019/01/29/). Denver Water imports account for most of the rest, but Denver has a relatively small proportion of reuse; the remainder of wastewater goes to downstream agricultural (and some riparian and wetland) use. It seems unlikely that, for Colorado at least, actual agricultural use of CRB exports is less than 50%.

Response: As this reviewer suggests, there are important differences between ownership and use of water exported through the Colorado-Big Thompson project to the Front Range of Colorado. These differences exist because a portion of this exported water was purchased and now owned by municipal interests but is leased back to the original agricultural users. To ensure that our differentiation among end users of water is accurate, we relied on data provided directly by the Northern Colorado Water Conservancy District (aka "Northern Water") for the Colorado-Big Thompson project, as noted in our Methods, which indicates that agricultural use is 54%. The remainder of water exported from the Upper Basin, including water exported to Colorado's Front Range and to the Central Utah Project, is strongly dominated by municipal uses, bringing the averaged municipal use of Upper Basin exports to 71%.

We thank you for the care and attention given to the two rounds of peer reviews provided.

Sincerely,

Brian D. Richter
Corresponding author