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We thank the editors and reviewers for their constructive comments on the prior draft of our manuscript and have made the following major changes to clarify the contribution, address comments, and improve the manuscript:

1. We now emphasize one contribution of the work is to synergistically recommend water and vegetation management to improve habitat and have added text in the abstract, introduction, results, discussion, and conclusions and Figures 6 and 10 to emphasize this contribution. Prior systems modeling work has focused on the water management component. Managing vegetation – planting area for native floodplain vegetation and vegetation cover variables – was a part of the original model but we never showed or discussed results.
2. Explain more clearly in Section 3.3 when the suitable habitat area objective function is first introduced the overarching assumption that suitable areas are dynamic through time. Specifically, the suitable area in one time period for one species and life stage is considered separately than suitable area for a different life stage in a different time period. Suitable habitat area simply measures the capability of the habitat at that time to support a particular species and life stage. New text in Section 3 now explains that this assumption is permissible because although different bird species require different water depths, they use impounded wetland units in different seasons. Also, native floodplain vegetation require water at a particular time of the year and vegetation growth over time is tracked separately with planting area and cover variables (see major change #1). And while adult fish require water depths to spawn in winter months that are different than water depths needed by fry in summer months, new text in Section 4 (Results) now emphasizes that the model increases or sustains suitable habitat area across all habitat types, species, and life stages compared to modeled historical conditions. New text in the Section 5 (Discussion) notes limits of this approach and identifies important further work to collect field data on fish growth, in-migration, out-migration, predators, natural die off, and other factors and couple models of these species distribution processes to the WASH model.
3. Edited to improve readability. We have also moved some figures and tables to the appendix to make room for the new figures that show results for the vegetation component.

Below, bullet pointed text in blue are editor/reviewer comments and our responses are in black plain text.

* The manuscript titled “Systems Modeling to Improve River, Riparian, and Wetland Habitat Quality and Area” has improved in clarity and focus since the original submission. The paper has potential, particularly in the use of a web-based tool for accessibility and engaging with stakeholders. That said, a number of the reviewer comments provided for the original submission have not been addressed, and further work is needed to justify the novelty of the work; adequately assess results and model performance; as well as improve readability. It is often difficult to follow the logic of what has been undertaken, with a number of inconsistencies and contradictions present.

Thank you. We address these and the other comments as described below.

**General**

* The analysis of results is at times unconvincing, particularly with respect to the seasonality of habitat suitability. This was also raised in previous reviewer comments, but has not been addressed. Habitat suitability encompasses intra- and inter-annual variability in flow conditions, hence it is unclear how it can vary each month.

We interpret the reviewer's comment about seasonality to mean that habitat suitability is a meta concept that connects multiple physical places across time. For example, a habitat is suitable when it is suitable in all months (or all the months that the species needs to complete its multiple life stages). We, like prior research (e.g. Steinschneider et al. (2014), Higgins et al. (2011), Alminagorta et al. (2016)), rather define habitat suitability dynamically on a month-by-month basis. We use this definition to answer questions like: are the conditions in a particular month suitable for the life stage and function that the species will undergo at that point in time? How does the suitable area at one point in time compare across management scenarios? In the WASH model, suitability simply measures the capability of the habitat at that time to support a particular species and life stage and is not based on species population distribution or counts.

We have added text in Sections 3, 4, and 5 as described in Major Change #2 above to more clearly define use of suitable habitat area in the model and the assumptions associated with that use. Text also justifies that the assumptions are appropriate for the wetland migratory birds, native floodplain vegetation, and aquatic fish species and their life stages used in the model. For example, tundra swans, stilts, and avocets require different water depths but use impounded wetlands at different times of the year. Only one life stage is considered for cottonwood trees and further vegetation cover and growth are tracked with separate constraints. Importantly, model results show potential to increase the suitable habitat area for each habitat type, species, and species life stage. For example, suitable aquatic habitat increases in all months for all fish life stages compared to modeled historic conditions. New text in the discussion section points out the need for future work to collect additional field data that describe fish growth, in-migration, out-migration, predators, natural die off, and other factors, and couple models of these species distribution processes to the WASH model. For example, such work could add a constraint or module for fish mass balance similar to the existing constraint for vegetation growth and cover.

* The authors argue that the model demonstrates increased habitat area, which appears to result from an increase in reservoir releases. It is unclear where this additional water is coming from, and what the impacts are elsewhere in the system.

There is no additional water, the model-recommended reservoir operations simply shift water in time from spring to late Fall and Winter. The increased suitable habitat area is a result of recommended changes to reservoir monthly storage and release operations. The recommended operations, depicted in Figure 5, release more water during winter months and create additional storage space during the winter and early spring. That storage space fills with spring runoff and helps reduce reservoir spills during May and June. Reservoir spills in May and June have low marginal ecological and water supply benefits. The model shifts those releases to winter months. Historical release are very small in winter months and the additional modeled recommended releases increase the low prior-existing base flows and have large ecological benefits.

We verified mass balance at each reservoir. We substituted in Figure 9 a time series of river flow at an environmental reach closer to the reservoir to better show the mass balance on the reservoir -- inputs, change in storage, and outflows. We also substituted traces for upstream Porcupine reservoir to show that the water mass balance and main findings also apply there.

* The authors present a simulation during an observed period, but do not compare this with observed habitat data. Reference is made to the use of satellite imagery for assessing vegetation, which could be used to verify results.

The simulation of model results was done by using known and measured flows across the watershed. While very little satellite imagery and fish sighting data were available for the year under study (2003), we could not use them to measure habitat suitability. Instead, we worked with a group of stakeholders to identify priority species and help us assess the feasibility and ecological benefits of our model recommendations. All the improvements that we suggested in the manuscript were verified by the project stakeholders. To clear some of that confusion, we removed all references in the manuscript to creating “a measurable and observable metric”. We also added text in several sections to emphasize that model results are compared against modeled historic conditions.

* Reference is made to the role of planting vegetation in the introduction and discussion, but it is not shown as part of the results.

Thank you for this comment. We now emphasize co-management of water and vegetation as a major contribution of this manuscript (see Major Change #1). While prior systems models have focused on water management efforts to improve floodplain connectivity, our model formulation considers both water management and vegetation cover. Water management is controlled by managing reservoirs and diversion canals and vegetation cover is improved by planting native and desirable plants, such as cottonwoods in our case study. Our approach allows managers to take more proactive role in concurrently improving floodplain connectivity and habitat conditions for riparian plants.

We have added Figures 6 and 10 and new text in Sections 4 (Results) and 5 (Discussion) describe model recommended water and vegetation management including timing, locations, and interactions. We have also added text throughout the manuscript that emphasizes the coordinated management of water and vegetation. Thanks again for this comment.

* The description of the analysis is in areas confusing and contradictory, such as stating that a single year is used for analysis, then introducing an additional wet and dry year, and finally showing results for a five year period. The authors also indicate that spring flows and connectivity is important for cottonwood trees, yet recommends reducing spring spills and increasing winter flows.

Thank you for your comment. The model was developed and applied for one year as the base case for comparison against existing water management practices. We included additional years to test the model’s sensitivity to changes in boundary flow conditions and to test the multi-year affect on the model performance and results.

To address the reviewer’s comments, we significantly shortened text in Section 3.5 and added Table 3 to summarize the scenarios.

The model recommends reducing spring spills as a method to manage reservoir flows and control releases. Reducing reservoir spills requires releasing more water in early spring which significantly helps maintaining floodplain connectivity. Controlled and gradual releases also prevent large spills (i.e. spikes in Figure 5) which can be harmful to cottonwood seedlings and brown trout eggs. These sentences are added to the second paragraph of the results (Section 4) that also explains how model recommended reservoir releases shift water in time (see prior comment).

* The results show an increased reservoir release during high flow periods which are reduced in the recommendations made by the authors. However, it is possible that these high releases are for flood mitigation, yet this is not discussed. Contradictory to their results, the authors also suggest in the discussion that managers need to consider increasing flood flows, despite their results suggesting a decrease.

The model recommends to reduce late spring reservoir releases; this reduction could help mitigate flooding impacts during the runoff season. The model formulation (Eq. 15) accounts for reservoir capacity and associated flood operations as a constraint on reservoir storage. All additional water beyond reservoir capacity is currently spilled, which increases flooding risks. The WASH –recommended reservoir operations to release water in winter and vacate space to capture spring runoff flows is a classic reservoir operation to reduce flood damages. This operation is often called a seasonal guide curve and is in use in numerous reservoirs across the country including nearly every large reservoir in Sacramento and San Juaquin basins, California, Bear Lake, Utah, among others. WASH recommendation attempt to capture and store spilled volumes.

To address the reviewer’s comment, we have added text in the second paragraph of the Discussion (Section 5) to describe the synergistic benefits to improve aquatic and floodplain habitat and reduce flooding. Again thank you for this comment, it helped us see the synergistic habitat-flood damage reduction benefits.

* It would have been very helpful to see a summary of how earlier reviewer comments have been addressed.

We are not sure what happened here. We submitted a response letter with our resubmission. For your benefit, we have attached our previous response letter to this letter (appendix A).

**Abstract**

* The novel contribution is unconvincing, other models have also adopted species specific approaches, such as that developed by Szemis et al. already referenced in the paper.

It is correct that other models have adopted species specific approaches to manage flow. However, these approaches set target flows that are based on minimum instream flow requirements or natural flow regimes. Optimization algorithms in these approaches were either constrained by flow targets or formulated to minimize the deviation from those targets. The contribution of our approach here is that our algorithm maximizes habitat area in the watershed between competing species which allows managers to compare potential improvements across time and sites. Also, to maximize habitat area, our model simultaneously manages water and vegetation (through planting native vegetation and vegetation mass balance) to improve habitat. Prior work has focused on water management. Please see major change #1 (above) for numerous changes we made to address this comment.

* Line 30 – ‘constrain instream flow’ is unclear – it suggests that flows are actually being constrained, whereas I think what is meant is that minimum flows are ensured using constraints.

Thank you for the suggestion. We rephrased this line to clarify that minimum flows are often used as a constraint on flow in system models.

* Line 51 – see comment above regarding contradictory information on snowmelt

We added table 3 to clarify the confusion regarding different scenarios.

**Introduction**

* Line 64 – ‘opportunities to improve habitat’ – the regulation of rivers isn’t done to improve habitat, but existing regulation can be potentially modified to improve habitat.

We use the term “regulated rivers” here to refer to rivers where the flow is controlled with dams and reservoirs. We agree that regulations are often not enacted to improve habitat, but having some control over flow can provide opportunities to manage the flow to benefit different users.

We rephrased this sentence in line XX to read: “controlling flows in regulated rivers provide opportunities..”

* Line 72 – typo – “They species”

Corrected to “These species…”

* Paragraph starting line 68 needs re-working, it is unclear and misleading

We have removed several vague sentences and provided more specifics in the other sentences. If the text is still unclear, please explain what is unclear and misleading.

* Line 77 – change ‘define’ to ‘estimate’ or similar

Thank you. We changed ‘define’ to ‘estimate’.

* Line 80 – ‘create desired ecosystem functions’ is unclear

Reworded to “..support ecosystem functions”.

* Line 82 – typo ‘dervatives’

Corrected. Thank you

* Lines 89-92 – There is a mismatch in the examples given to justify the approach – examples are for estimating suitability, which need to be coupled with a hydrologic model to compare locations, timing etc. The model developed here also needs to couple the ecological response component with a hydrologic model. Other models have also considered such questions, e.g. Szemis et al.

The examples provided use water mass balance to compare locations, timings, and magnitudes. We use similar equations in Eqs. 6 and 8 in our model formulation. While we see a value in coupling our model with a hydrologic model to improve our estimates of inflows and losses in the system, this will make the model a lot more complicated and will require significant more data and computing time. We included the reviewer’s comment as a model limitation and a suggestion in the Discussion (Section 5):

“A finer spatial resolution or coupling our model with a hydrologic model could improve our findings”

* Line 93 – ‘can include..’

Corrected. Thank you

* Line 100 – sentences cannot begin with ‘Or’

Replaced with “Alternatively,..”

* Lines 108- 112 – the authors discuss the limitations of using indices, yet that is what they develop

The suitable habitat area metric we use in the model objective function has units of area. The argument here is that minimizing indices and deviations from a target are useful but do not help managers identify opportunities to improve habitat across habitat types, time, and space. Also the indices make it difficult for managers to quantity what they will gain.

We rephrased line XX to read: “Using indices and deviation objectives in minimization problems makes it difficult for…”

* Line 117 – delete ‘measured in acres’ – this is not significant to the main message

Deleted.

* Line 122 – the focus on planting is unclear and seems out of place here

We have revised this use throughout (see Major Change #1). As explained earlier, while prior systems models have focused on water management efforts to improve floodplain connectivity, our model formulation considers both water and vegetation management. Vegetation management includes planting native floodplain vegetation (cottonwoods) and associated vegetation cover. We included a better description of the role of planting riparian trees across the manuscript to highlight this contribution.

* Line 123 – it is stated that stakeholders help define objectives yet in Line 120 it is suggested that an objective is developed to support managers

Reworded to be more specific. It now reads: “…stakeholder to help define indicator species …

**Study Area**

* Line 141 – what is meant by distributed flow regimes?

This is a typo. We corrected the word to “disturbed”

**Model development**

* Figure 2 – why planting area?
* Line 220 – how is plant cover important for aquatic habitat?

As explained earlier, while prior systems models have focused on water management efforts to improve floodplain connectivity, our model formulation considers both water and vegetation management. Again, we have revised this use across the manuscript and please see Major Change #1.

* Line 227 – this isn’t an assumption in many other models

This use follows Szemis et. al (2012; 2014). We have rewritten this paragraph to better describe the approach and assumptions.

* Lines 237 – 242 – species are described without clearly stating that they have been selected as indicator species

Prior paragraphs (3.1 Select indicator species) explain why we selected indicator species in table 1 to represent habitat quality.

* Line 279 – how does determining the proximity of plants help restore connectivity?
* Line 300 – summation across plant species is discussed but only a single species is used

The summation is provided in the model formulation to provide an adaptable model that can be applied at other basins with multiple plant species. The same code allows multiple fish species.

The reviewer is correct. We only use cottonwood for floodplain habitat. The other example (willows) is provided an example to explain how the assumption of lateral distance might differ between species.

We rewrote this paragraph in line 349 to read:

“*The summation across plant species in eq. [3] allows one or multiple plant species to coexist at different lateral distances from the riverbank and these different lateral distances require different flood magnitudes to establish connectivity. Here, we only use cottonwood trees, which live adjacent to river banks and require flood recurrence of 2-year for lateral connectivity”*

* Lines 330 – 342 – it isn’t clear how this work extends the work by Alminagorta et al, the current description suggests model inputs and outputs are plotted against each other, rather than changing the model

That’s correct. We didn’t change Alminagorta et al’s model. Rather, we related his model inputs and outputs and used the relationship in our model (Eq. 4). The text now clarifies.

* Line 378 – what flow limits are relaxed?

We deleted this paragraph and summarized it in table 2.

* Line 385 – why introduce a new species here?

We have removed mention of bluehead sucker in the manuscript to focus on the contribution of synergistic management of water and vegetation (Major Change #1).

**Results**

* Line 418 – how do results compare with observations?

As mentioned above, we do not have on-the-ground, in-the-field observational results. Instead, we validated model results and recommendations with the project stakeholders as discussed in the Discussion Section.

* Figure 6 – what is the meaning of the total area lines?

The total areas in Figure 4 are the maximum physical areas of aquatic, floodplain, and wetland habitats in the watershed combined for every reach in the watershed. The bars represent the amount of that area, every month, that is considered suitable to support the livelihood of its respective indicator species.

* What would a ‘without development’ scenario look like?

Thank you for your question. We discussed this alternative with our project stakeholders at the early stages of the model development. They indicated that such scenario is extremely unlikely given that flow in the Bear River has been altered and managed for nearly a century now. Natural flow regimes along the River during the pre-development era are unknown. Therefore, this scenario was not considered. We have added text in Section 2 to explain and better justify the use of systems modeling to identify improvements over current conditions.

* Line 450 – isn’t the model infeasible because constraints were set to limit demands?

The model constraints required meeting full urban and agricultural demand. The model becomes infeasible in 2003 base case scenario because there is insufficient water to meet 110 percent urban and agricultural demand, i.e., the water supply system is nearly at capacity. The effect of this limit was relaxed in figure 7 to test the tradeoff between human demand and the objective function.

* Line 471 – the comparison of improvement for different locations is interesting but needs further explanation. For example, why would East Fork have the largest shadow value?

Thank you for your question. We added the following line to the manuscript to answer your question: “*The East and South Forks in addition to Blacksmith Fork had the largest shadow values in the system because both active reservoirs (Hyrum and Porcupine) are located on these reaches*.”

**Discussion**

* Line 483 – how does the model help manage plants? This isn’t demonstrated.

One of the model’s main decision variables is planting area (RVj,k,t,n), which is described for every reach (j,k), time step (t) and species (n). Model recommendations show managers the locations and times to plant riparian trees to increase plan cover, which helps improve floodplain habitat suitability. The emphasis of water and plant management is now a major thrust of the paper (see Major Change #1) and we have added two figures to show planting results.

* Line 489 – as above, planting seems out of place in the analysis

We hope that our prior explanations above address this question.

* Line 492 – why are spring flows reduced when these are supposed to support Cottonwood?

As explained before, spring flows are managed to reduced reservoir spills. This is beneficial to both cottonwood and help seedlings to survive large runoff events.

* Line 504 – the suggestion that ‘managers should try to acquire…’ is a large, sweeping statement that needs further support.

We rephrased this statement to read:

*“*Acquiring upstream storage rights would allow Refuge managers to store winter flows and release in summer to beneficially improve summer bird habitat. Storage rights would also help managers plan for droughts.

* Lines 506 onward – these results seem to indicate an overall increase in flows – where is this water coming from? At what cost?

There is not additional flow, just shifting water in time from Spring spills to larger late Fall and winter releases. Larger winter releases vacate reservoir storage space that can capture (rather than spill) spring runoff. Please also see prior responses to this comment.

* Line 524 – the suggestion to increase flood flows is contradictory to the results presented

As explained earlier, the model recommends releasing more water between Dec. to Mar. while reducing reservoir spills in Apr. and May. Again, please see prior responses to this comment.

* Line546 – if the model has been validated, this would be useful to show

As explained earlier, the model was validated using stakeholders’ input and feedback on the model formulation and results. We are not sure how to show this validation.

* Line 551 onward – can the authors provide an indication of which of these uncertainties they think are most important? Those listed seem to vary from general to very specific.

We didn’t test many of these uncertainties here in this manuscript. In a separate manuscript, we found that the model is more sensitive to input parameters (e.g. budget, available water, human demand) than structural uncertainties that are related to model ecological formulations (e.g. shape of suitability curves). These uncertainty results are available in Chapter 3 of Dr. Alafifi’s PhdD dissertation (2018; https://digitalcommons.usu.edu/etd/6970/) which was submitted in July 2018 to the *Journal of Water Resources Planning and Management* and currently in revision in response to reviewer comments.

**Conclusions**

* As previously indicated, the novelty described here is not convincing

We hope that revisions that emphasize the synergistic management of water and vegetation to improve habitat (Major Change #1) now constitute a novelty. Prior work has focused on only water management. The text here has been expanded to emphasize.

* How did stakeholders receive this tool? Has it been adopted?

The web tool was used in discussions to guide the selection of indicator species, breakdown the river network into nodes and links, and share temporal and spatial results and focus discussions on system limitations and potential interventions. Currently, the Cache Water District, which was formed by ballot initiative in 2016 and whose mandate area is Cache County, Utah (half of the model domain) is investigating ways to amend current Utah instream flow laws so they can pursue model recommendations to improve habitat. The work has also been shared with a Utah legislator who suggested additional people to speak with and educate about the need to amend Utah water rights law to allow more entities (individuals, conservancy districts, water providers, canal companies, etc.) to hold instream flows. The discussion has been expanded to describe these responses.

Appendix A: Pervious Response Letter to Reviewer’s Comments



April 04, 2018

Dear Dr. Dan Ames,

# Enclosed is a revised manuscript of Paper #ENVSOFT\_2017\_528, titled “*Systems Modeling to Improve River, Riparian, and Wetland Habitat Quality and Area”* that we are resubmitting for publication in the *Journal of Environmental Modeling and Software.*

We appreciate the numerous comments and constructive feedback the reviewers provided on the original manuscript. The main changes in this manuscript include:

* Improve the literature review and clearly identify contributions of the manuscript.
* Reorganize the paper to introduce the study area earlier and build the methods and model formulation sections around it.
* Shorten paper length and improve sentence structure and grammar throughout the manuscript.

Below, we list the suggestions, questions, and comments of the reviewers in *italics* and provide our responses in plain blue text to describe changes we have made in the manuscript. We reference lines in the manuscript.

We look forward to hearing from you.

Sincerely,

Ayman H. Alafifi and Dr. David E. Rosenberg

***Reviewer 1***

*The manuscript titled “Systems Modeling to Improve River, Riparian, and Wetland Habitat Quality and Area” presents an interesting analysis using optimisation to improve ecological condition in a river basin, particularly in terms of the comparative value of increased flow for different locations. However, the paper needs substantial re-writing to improve readability and justification of the analysis. The novel contribution of the work needs to be emphad, demonstrating how it fills gaps in previous literature.*

*Further general and specific comments are as follows:*

***General***

1. *The paper needs significant editing to improve grammar and sentence structure. The paper is lengthy and could benefit from being more concise.*

Thank you for pointing this out. We have reviewed the paper to improve grammar and sentence structure. We introduced the study area earlier and moved the constraints to an appendix which reduced the paper length from 718 to 627 lines.

1. *The paper refers to using a systems approach, but it does not explain in what way it adopts such an approach.*

We revised the literature review in the manuscript (lines 91-96) to explain the shortcomings of using species-, time-, and site-specific suitability metrics to make decisions on when, where, and how to allocate water between species and habitats across a watershed. Embedding suitability indices in a systems optimization model helps determine flow regimes that can improve overall habitat quality. The systems approach also helps identify feasible flow regimes.

1. *The terms habitat quality and area aren’t clearly distinguished in the analysis, it is unclear how quality is actually defined.*

We added this sentence in the model description in line 120 to show how quality and area are related: ‘Suitable habitat area represents the combination of habitat quality and area, is measured in acres, and indicates the area of good quality habitat with physical characteristics that can support the life needs of priority species.’

1. *The analysis appears to need further refining or at least explaining – for example how can habitat suitability increase and then decrease on a monthly basis? This appears to not account for the seasonality needed for habitat suitability. Similarly, referring to an increase in the two year recurrence flow does not account for this seasonality.*

The model assumes that each of the three habitat components (aquatic, floodplains, and wetlands) and their indicator species have independent ranges of flow-related attributes that define their suitable habitat. While the model attempts to maximize the suitable area for each indicator species by timely- and spatially-allocating available water, it does not consider the least-available area for a species through its life cycle as a limiting habitat factor. Rather, it sums monthly suitable areas in the objective function. Other methods to aggregate multiple measurable metrics use arithmetic or geometric averages assume that good habitat for one species compensates for poor condition for another species ([Ahmadi-Nedushan et al., 2006](#_ENREF_1)). We added a sentence in line 229 to better articulate this assumption.

Seasonal variability for priority species were considered as part of defining suitable ranges for different species at different life stages (Table 1). For example, adult and fry brown trout are abundant in the basin at different seasons and require different ranges of water depths at those times of the year. The model considers seasonal variability on a monthly basis where it attempts to allocate available water for species when and where they need it to improve habitat conditions. We added a sentence in line 181 to emphasize how the model accounts for seasonal variability.

1. *The paper appears to build on previous work which develops the WASH model, yet this is not clearly stated. The paper needs to identify what components already exist, and what the additional contributions are.*

You are correct. We developed a new metric to measure watershed habitat suitability for aquatic, floodplains, and wetlands. In the case study, we used a wetlands metric that was developed by [Alminagorta et al. (2016](#_ENREF_2)) to measure suitability of wetland habitat to changes in flow regimes. Alminagorta’s work was applied at the Bear River Migratory Bird Refuge which is the most downstream node in our model just before the Great Salt Lake, Utah. We clarified that part of the work and explained it in more detail in lines 338-351.

***Abstract***

1. *The abstract provides results but does not make a clear case for how the work is novel and addresses existing gaps in the literature.*

We revised the abstract and added a sentence in line 32 to address gaps in the literature.

1. *Instead of focusing on case study specific results, it would also be preferable to provide new insights gained from the analysis.*

We shortened the case study results and added a sentence at the end of the abstract to provide new insights from our analysis.

1. *Line 66 – managers don’t ‘need’ to define priority species – this is one approach which ‘can’ be used.*

Deleted and rephrased the sentence.

1. *Line 66 – first sentence needs restructuring to avoid multiple use of ‘and’*

Rephrased the sentence.

1. *Line 72 – sentence unclear, suggest rewording to ‘..and wetland area, thereby enabling measurement in observable units’.*

Thank you. We reworded this sentence.

1. *Line 74 – suggest deleting ‘as an objective to maximise’.*

Thank you. We removed this sentence.

1. *Line 78 – what is meant by ‘habitat performance’? How can it mainly increase only during certain months?*

We reworded this sentence following the suggestion below for shadow values. The analysis allowed us to quantify the expected increase in habitat area for each additional unit of water flow at every headwater tributary location in every month. The Little Bear River had the greatest returns for the months August through December because there are reaches within the Little Bear with aquatic and floodplain habitat that need just a little more water to improve to good habitat condition. Also, there are reaches downstream that will similarly benefit with just a little more water. Other locations will require a lot more water. We added more discussion to the text in line 517 to emphasize this finding.

1. *Line 81 – change to “reservoirs’”*

Corrected. Thank you.

1. *Line 83 – what is meant by ‘harming human users’? Later in the analysis it is mentioned that indeed increased flooding may require buyback of land – this is an impact.*

We mean here fully satisfying urban and agricultural water demands in the basin. We reworded this sentence to read: ‘..while meeting urban and agricultural water demands’

***Highlights***

1. *Poorly worded and does not adequately summarise the paper.*

We rephrased the highlights to better summarize the paper and its contributions.

***Introduction***

1. *Line 188 – ‘planting efforts to advance…’ – suggest rewording or deleting.*

We reworded this paragraph and improved its readability.

1. *Line 195 – why must a choice be made as to which to target? Ideally all would be considered, although in reality this is often impractical.*

We agree. We reworded this sentence to “identify and locate the aquatic, floodplain, and wetland habitats in the basin that need improvement”

1. *Line 197 – As per pervious comment, it is incorrect to suggest ‘managers must select indicator species’ – this is just one approach.*

Thank you. We reworded these sentences to address the comment.

1. *Line 200 – state why species must be directly impacted by flow conditions.*

We define the characteristics of ‘indicator species’ here as species ‘whose presence denotes a healthy ecosystem, that can be monitored for abundance, and are impacted by flow conditions’. We reworded the first part of sentence to show that. It now reads: ‘Second, would be to select indicator species from among the numerous species available in each habitat. Indicators are species whose presence…’

1. *Line 202 – only if being modelled are mathematical equations needed, they are not required in general for managing ecosystems.*

Yes we agree. We changed the sentence to read: ‘Third, managers may use models to mathematically quantify..’

1. *Line 204 – would avoid using ‘must’ for collaborating with stakeholders – this is seen to be a desirable and useful approach but isn’t a ‘must’.*

Changed ‘must’ to ‘may’.

1. *Line 206 – habitat only needs improving if observed conditions are in a poor state.*

We agree. We mean here to ‘identify when, where, and how’ habitat can be improved over observed conditions. Adding an ‘if needed’ at the end of the sentence might be redundant.

1. *Line 229 – avoid using ‘etc’*

Removed. Thank you.

1. *Line 232 – sentence starting ‘For example, the Habitat Suitability..’ needs rewording as* *different models are being described, yet the sentence structure suggests it is a single model.*

Thank you. We reworded this sentence following your suggestions below.

1. *Line 247 – above the authors describe different models but without critiquing them – what are the actual limitations? The need for additional tools equally applies to the ecological model framework used in the paper.*

We removed the IFIM, HEC-EFM, or ELOHA models from the manuscript because the intent was not to review these models. Rather, we’re reviewing their underlying assumption of using the Habitat Suitability Index (HSI) to measure habitat quality. HSI, as a unitless index, cannot help managers decide when and where to allocate water and money to improve multiple habitats across the watershed.

1. *Line 255 – minor comment – I prefer ‘indices’ instead of indexes, but both are correct.*

Thank you for your suggestion. For consistency with similar literature, such as ([Ahmadi-Nedushan et al., 2006](#_ENREF_1); [Burgman et al., 2001](#_ENREF_3); [Moir et al., 2005](#_ENREF_5)), we changed ‘indexes’ to ‘indices’ in the manuscript.

1. *Line 255 – ‘…flow to satisfy’ – satisfy what?*

Removed and changed the sentence to ‘… such as meeting minimum required instream flow’

1. *Line 288 – suggest rewording to ‘subjectively define an appropriate target’ and deleting ‘as a natural or species required flow’. This is confusing.*

Thank you. We think providing examples of what a target means here is important for the reader. We clarified this sentence and changed it to: ‘…need to subjectively define an appropriate target, such as natural flow regime or species-required flow, and identify an acceptable deviation level’

1. *Line 290 – deviations and indices can also have physical meaning depending on how they are defined.*

We reworded this sentence to clarify that we mean the deviations and indices used in the objective functions of the reviewed models only. We also further clarified limitations of reviewed models and approaches in lines 112-117.

1. *Line 297 – have the authors considered the Weighted Usable Area approach? It is worth contrasting with this approach. As for earlier comment, the novelty of this particular habitat approach needs drawing out.*

Thank you for the suggestion. We have included a more thorough review of WUA on lines 90-94. The Weighted Usable Area (WUA) offers a similar measurable metric but only provides a description of habitat quality for a single species at a particular site in a specific time period. Making water allocation decisions between multiple species and habitats requires embedding a measurable metric for each species in a systems model.

1. *Line 297 – I wouldn’t have thought habitat area was necessarily easy to measure – what species are being considered here? How are the habitat boundaries being defined?*

Yes, we agree that habitat areas are not easy to measure. We used field work to measure physical aquatic habitat area and remote sensing imagery with ground-truthing for floodplain and wetland areas. Suitable area for each habitat type is then calculated as a fraction of the actual physical area of that habitat. The fraction is an aggregate index that measures suitability of habitat attributes to support ecosystem functions of priority species. This approach allows us to quantify habitat conditions in units of area and also allows for a meaningful description of ecological benefits of model recommendations over observed conditions.

We added the three types of habitat that we considered here: aquatic, floodplain, and wetland in line 123. We introduced key species for each habitat later in the methods section.

1. *Line 299 – it is unclear from this wording whether the current study develops both the metric and the model or just the metric. If just the metric, appropriate references are needed for the model. Also note that WASH in hydrology typically stands for water, sanitation and hygiene.*

Thank you. Yes, we contribute both the metric and a model that uses the metric. We reworded lines 119-121 to clarify that we developed a new metric and a new systems model that uses this metric as an objective to maximize.

1. *Line* 305 *– need to make it clear what species are being considered. Is only vegetation considered? Otherwise planting wouldn’t make sens*e.

As mentioned above, we added the habitat types that we consider in our model in line 123. In terms of species, we consider fish for aquatic habitat, plants for floodplain, and birds for wetlands. We introduce these species later in the methods and the case study.

***Methods***

1. *This section needs some rewriting to improve clarity.*

We rewrote and reorganized many parts of this section to improve clarity. We also introduced management goals in the case study earlier in this section to help readers appreciate the collaborative modeling approach of our work.

1. *Line 323 – what is a ‘network of ecosystem’?*

We removed this phrase.

1. *Line 344 – what is ‘inventory existing information?’*

Changed to :’ inventory available hydrologic, hydraulic, and ecological information’

1. *Line 357 – why impounded wetlands? Explained later, but needs to be introduced here.*

Re-organizing the paper and starting with the study area should improve readability. We stated in the study area that the Bear River Migratory Bird Refuge is composed of 300 km2 of impounded wetlands.

1. *Line 361 – what is an ‘affected area’?*

We added a sentence in line 227 to define affected areas: ‘Affected areas are the reach-specific habitat areas in the watershed at which each suitability index applies (Figure 2)’

1. *Line 363 – delete ‘e.g. m2’*

Deleted. Thank you

1. *Line 441 – stating that fish spawning etc happen at a monthly time scale seems odd – are there any references to support this?*

Thank you. We corrected that to: ‘fish spawning, seed recruitment,’ …., ‘occur during particular months’.

1. *Line 570 – sentence starting ‘Bankfull discharge..’ needs rewording.*

Shortened to: ‘Bankfull discharge is often associated with the 2 year flood recurrence interval’.

1. *Line 580 – is land ownership public or private? Surely increasing flooding would have an impact if privately owned.*

Thank you for your comment. You’re correct, most land adjacent to the Bear River is privately owned by private individuals or PacifiCorp, which manages run-of-river hydroelectric plants. Improving floodplain habitat while mitigating for adverse impacts of flooding requires managing for multiple objectives. Recent conservation easements made by PacifiCorp illustrate one way to co-manage for multiple objectives. We added lines 528- 536 to explain potential risks of floods on private land and how this applies to the study area.

1. *Line 591 – This is confusing – connectively refers to long term connectivity accounting for seasonal variations. Having just more frequent high intensity flows is not necessarily a good thing.*

Here, we define successful lateral connectivity as to when flood events are large enough to exceed bankfull discharge during seed germination season for target riparian plants. Such flooding helps in plant recruitment. Bringing up the case study here should help clarify how we account for seasonal variation for cottonwood as an example indicator species.

1. *Line 598-599 – It isn’t clear to me how plants at different distances is accounted for in equation 3.*

Thank you for pointing this out. The floodplain connectivity index is a function of lateral distance from the streambanks. Successful connectivity means that streamflow exceeds bankfull discharge and inundates target indicator plants during their seed germination period. Cottonwood, for example, lives adjacent to streambanks and require less low flood recurrence level to inundate its trees. Pacific willow is found more upland in the floodplain area which mean it will need a larger flood recurrence value to get inundated.

We added a sentence in line 308–313 to explain.

1. *Line 624 – As above, why only impounded?*

Answered above.

1. *Line 634 – define what the WSI actually is*

We added a sentence to define wsi in line 345.

1. *Line 644 –Section 2.3 – the constraints section can be summarised and condensed. Much of the text is self-evident from the equations, and just a summary of the intent is needed (unless where central to the main message of the paper).*

Thank you for your suggestion. We moved the constraint equations into appendix II and only provided a summary to describe the model physical, natural, and management constraints.

1. *Line 710 – how is ‘natural growth or death’ defined/calculated?*

We define it here as the natural increase or decrease in riparian plant cover without any interference from river managers. This change in riparian cover is measured using either USDA NAIP imagery or field measurements. In our case study at the Bear River, we assumed this value to be zero because we do not expect to see significant natural change in cottonwood cover along the river within 1 year. We added a sentence in line 857 to define ‘natural growth or death’.

1. *Line 736 – how can stage-flow be linear but width-flow not linear? This seems contradictory.*

You are correct. Width-flow was actually modeled as linear and we changed the model formulation accordingly.

1. *Line 769 – how were these costs derived? How do they influence the analysis?*

We show this in more details in the case study. Unit costs and total budget are input parameters. Later in the discussion, we present the shadow value of the budget (30 acres per additional 10,000 dollars available to plant cottonwoods) and compare it with the shadow value for additional water in the system.

***Case Study***

1. *Line 815 – delete ‘and individual families’*

Removed.

1. *Line 828 – what is a ‘junior’ water right?*

We clarified this sentence by adding: ‘According to the western U.S. prior appropriation doctrine, the Refuge..’. We also now define key senior and junior water rights concepts in the Case Study section.

1. *Line 848 – reword ‘regulated flow hydraulics’*

Changed to flow regime.

1. *Line* *883 – what ‘model results’ are these?*

We removed this sentence for brevity. Table 2 summarizes model input data and their sources.

1. *Line 988 – change to ‘representative’ of an average year based on the last 15 years. A single year in itself can’t be representative.*

Thank you. Corrected.

1. *Line 1126 – how were temperature and area combined for the index?*

Water depth is the primary abiotic habitat attribute that we use here to define habitat suitability for fish because managers can control and relate depth and instream flow. Water temperature is also critical to the survival of many cold water fish species. Water temperature is influenced by variations in atmospheric condition and elevation. Therefore, we use temperature to adjust suitable water depth ranges. At sites where water temperature does not exceed the temperature fish can tolerate, suitable depth ranges are defined based on empirical data, literature review, or expert opinion. At sites where water temperature exceeds fish tolerance for temperature, the minimum water depth is identified from temperature observations as the water depth observed at these reaches at the warmest time of the year under study.

We added these sentences in lines 251-258 to explain how temperature affected our selection of indicator species for this study: ‘The lower elevation Bear River main stem has warm summer water temperatures that reach 26o C. The higher elevation Little Bear and Blacksmith Fork rivers have cooler water temperatures that do not exceed 22.5o C ([Watershed Sciences, 2007](#_ENREF_7)). [Johnstone and Rahel (2003](#_ENREF_4)) report that water temperature at or above 25o C could be lethal for BCT, while [Raleigh et al. (1984](#_ENREF_6)) reported that brown trout can tolerate water temperature up to 27.2o C. Currently, cutthroat trout is only abundant in the headwaters of the Blacksmith and Little Bear rivers (DeRito, pers. comm., 2016). Thus, we assigned BCT as the indicator fish species in colder headwater reaches and brown trout in remaining warmer reaches.’

1. *Figure 3 – why a limit of 1m? Does water go higher?*

Yes water can go higher but the value of the suitability index will continue to be 1 past a suitability water depth threshold.

1. *Figure 5 – is there a point at which habitat starts deteriorating? Correct spelling of wetland on axis.*

The results of Alminagorta et al. (2016; Figure 1 below) were used to construct monthly relationships between wetlands suitability index and instream flow. We ran Alminagorta et al. model to obtain the monthly weighted usable areas (WU) from the annual water availability scenarios in Figure 1 and divided these areas by the total Refuge area. Alminagorta et al. results show that WU increases with additional water, particularly with low invasive vegetation cover.

Spelling on axis is corrected. Thank you.



Figure 1: Weighted usable area for wetlands as a function of annual water availability (x-axis) and initial invasive vegetation cover (traces). From: Alminagorta et al. (2016)

***Results***

1. *Line 1360 – can this result be verified using observed data?*

Verifying the modeled water area of suitable habitat using observed field data (fish and bird counts, vegetation cover, and aquatic and wetland wetted areas) is an ongoing research activity. In this study, we verified model assumptions and results as part of the participatory modeling process with river managers and stakeholders (some of whom collect that primary data).

1. *Line 1364 – how was this additional area achieved? Through planting?*

Additional suitable area was achieved by two management actions: (1) timely-releases of water from reservoirs to coincide with priority species life stage-specific needs for water at the reaches where they live, and (2) planting more riparian trees to increase cover.

1. *Line 1370 - how does habitat increase occur in a particular month or months? e.g. planting decisions would occur once only - not then decrease.*

As above, habitat areas are functions of both water availability and planting decisions. Therefore, habitat area increases in particular months over modeled historic conditions when water becomes available in the system to allocate for species to support ecological functions.

1. *Figure 7 – more flow isn’t always a good thing, need to consider seasonality. Is there any natural or historical flow data demonstrating that the modelled version is actually better?*

That is a very valid argument, especially for wetlands. In our case study, we compared our findings with the Refuge suitable areas that were modeled by Alminagorta et al (2015) for the same Refuge. One of the years that they modeled (2008) experienced flow patterns that are similar to our model recommend flows at the Refuge. Alminagorta et al. found that flows in 2008 created 715 km2/yr of usable area for wetlands, which compares to 870 km2/yr that were created by WASH model in 2005. The difference between the two areas were mainly because of the additional water that WASH was able to allocate to the Refuge in summer months to support resting, breeding, and feeding for over 200 migratory bird species. Figure 7b shows that the Bird Refuge does not receive its allocated water right during summer months because of human consumptive use upstream. Here, we proposed that managing reservoir releases to reduce spring runoff spills can help better allocate water to meet human demands while providing more water to improve habitat quality at the Refuge.

1. *Figure 8 - Presumably the peak release in the observed data is for providing flood storage – what are the implications of releasing more water during this period?*

Actually, the model recommended strategy will release less water during the spring runoff season. Currently, the spring snowmelt runoff fills the reservoirs and managers must spill additional runoff to prevent overtopping the dam (currently, there is a small amount of reserved flood storage in these reservoirs). This situation is exacerbated because managers store all inflow and precipitation through the winter and do not release water. In contrast, the model recommends gradual releases of water during winter and early spring for the benefit of environmental users. This creates a win-win case because spring runoff can now be captured in the reservoirs for multiple summer users.

1. *Line 1545 – why does the model become infeasible?*

Existing human urban and agricultural water demands in the basin are large and nearly equal to available supply. The optimization model becomes infeasible when we increased total human demand by 10%. In this case, demand exceeded available water and the model was infeasible. We added a sentence in line 454 to explain this.

1. *Figure 10 – how is habitat quality measured?*

Thank you. We corrected the y-axis on the second panel to read: Aquatic Suitability index (unitless)

1. *Line 1683 – this statement is misleading – the calculation shows the greatest return for each unit of flow, it does not state which location has highest ecological value. That said, the analysis itself is interesting, being able to demonstrate the value of increased flow for different locations.*

Thank you for your suggestion. We rephrased the sentence to: ‘To identify when and where a unit of flow will most increase habitat area throughout the basin,...’

***Discussion***

1. *Line 1721 – I would be very surprised if there are no impacts – what about flooding? Cost of planting? There must be others.*

While we considered human demands and available budget as constraints on management actions, there are definitely many other natural or management constraints that our model does not account for. For instance, increasing flood recurrence could depreciate land value and increase the costs of property flood insurance.. We deleted the sentence: ‘harm human users’ throughout the manuscript and replaced it with more meaningful sentences to describe model constraints such as: ‘satisfying urban and agricultural demands’.

***Conclusions***

1. *Need to clearly state what the novel contribution of this work is, and how it fills gaps in the literature rather than re-stating the results.*

Thank you. We improved the conclusions and added 3 sentences starting at lines 603 to state the novel contribution of the manuscript and how its advancing the literature.

***Reviewer 2***

*This paper describes a modeling system to optimize water management operations for maximizing ecological benefits expressed as aquatic, floodplain, and wetland habitat area. The manuscript has its merits for publication.  However, it cannot be accepted at the current form.  The following comments are provided for the authors.*

1. *Current organization of the manuscript is confusing: While authors may intend to introduce the model as a generic tool, it is really site specific and requires the Little Bear River as the background for the reader to understand the model formulation better.  I suggest that the authors introduce the site condition before describing the model.*

Thank you for your suggestion. We changed the organization of the manuscript to introduce the study area earlier and build the methods and results around it. Later in the discussion, starting at line 595, we show how our work can benefit other regulated river system managers and the steps required to apply our approach to other rivers.

1. *Ecological objectives may not be able to capture all the competing needs of today’s water management:  The model focuses on competition need for environmental users (as aquatic, floodplain, and wetland) while treating the irrigation demands and budget as the constraints.  The tool would be more convincing to include water supply and cost as items for optimization.  You can sell it better to the stakeholders for meeting the competing needs among users while saving money.  How is flood control is factored into the scheme?*

We agree that ecological objectives are not designed to capture all competing water needs in the basin. Rather, they intend to propose management actions to improve habitat conditions over observed conditions.

We also explored the tradeoff between habitat area and human water demand objectives in Figure 9 where we showed that reducing urban and agricultural demand by 10% increased suitable habitat area by approximately 4,000 acres. Note, this exploration adopted the constraint method (adjusting the right hand side value of the water demand constraint numerous times) to identify the tradeoff between habitat area and water demand objectives. The constraint method is one method to identify the tradeoffs between competing needs that the reviewer requests.

Flood control is factored in the equations describing reservoir operations [eqs. 5, 6, and 15] where the minimum and maximum reservoir storage volumes reflect the sizes of the dead pool and flood control pool.

We also further explored and thoroughly analyzed the effects of revegetation costs, budget, and 10 other model parameters. This uncertainty analysis is presented in {Alafifi, 2018 #697}.

1. *Using habitat area of aquatic, floodplain, and wetland components for optimization requires clarification of seasonal requirements:  How the seasonality is factored in the optimization scheme is not clear to the reader.  If the goal is to maximize the area, one may end up to excess release of water in the dry season when flow should be mostly confined in the channel.   In addition, how should stakeholders assign the proper weight to each component so the area is not dominated by a single component?  For example, if the wetland area is much larger than that of the channel and floodplain, the benefit of the smaller ones may not necessarily be less in spite of their small areas.*

We hope that reorganizing the manuscript to introduce the case study earlier per an earlier suggestion, will help clarify the seasonal requirements for priority species. Table 1 shows suitable ranges for different species at different life stages. Each life stage has a different timing (season) through the year. For example, adult trout are abundant in the fall and spring and fry brown trout are abundant in the summer and have different suitable ranges of water depths. The model considers seasonal variability on monthly basis where it attempts to allocate available water for species when and where they need it to improve habitat conditions.

Weights in this model were assigned using a participatory approach with stakeholders. This approach allowed us to be flexible in the mathematical model to try a set of weights to define habitat types, important reaches, and months, then, examine results, and revise based on stakeholder feedback.

It is true that impounded wetland area in the Lower Bear River basin are larger than both aquatic and floodplain areas. We intentionally used equal weights of 1 for all habitats indicators to avoid favoring a location, species, or months. Therefore, we dissected the total objective function into its three habitat components and provided managers with a comparison between habitat areas in both model recommended and historic conditions in Figure 6. The figure illustrates that although floodplain habitat area is the smallest in the system, it experienced the largest (10-fold) increase over historic conditions.

1. *Editorial:  SI unit should be converted.  Assistance from a technical editor is needed to correct many grammar errors present in the manuscript.   The manuscript is lengthy and that impacts its readability.*

Thank you for your suggestions. We reviewed the manuscript and corrected many grammar errors. Thank you. We kept the model results in U.S. Customary Units because our river managers and stakeholders are more familiar with these units and can easily draw comparisons to existing operations. We have added a sentence to the manuscript to explain the use of customary units.

We shortened the manuscript by introducing the case study earlier, succinctly describing the objective function and its components, and moving the descriptions of model constraints to an appendix. This has shortened the manuscript from 718 to 627 lines

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